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EARL WARREN, Governor

DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO
OLAF P. JENKINS, Chief

SAN FRANCISCO] BULLETIN No. 118 [APRIL 1943

GEOLOGIC FORMATIONS

AND

ECONOMIC DEVELOPMENT OF THE OIL AND GAS FIELDS

OF

CALIFORNIA

(In Four Parts, Including Outline Geologic Map
Showing Oil and Gas Fields and Drilled Areas)

PREPARED UNDER THE DIRECTION OF
OLAF P. JENKINS

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LETTER OF TRANSMITTAL

To His Excellency, The Honorable Earl Warren,
Governor of the State of California

Sir: I have the honor to transmit herewith Bulletin 118 of the Division of Mines of the Department of Natural Resources on the "Geologic Formations and Economic Development of the Oil and Gas Fields of California."

The petroleum industry in California is outstanding among our diversified mineral resources of economic value and utilization both in normal peace-time activities and in the present war emergency. It has accounted in recent years for 65 percent to 80 percent of the total value, annually, of all mineral production in this State.

The assembling and supervision of the preparation of text and illustrations of this almost monumental volume have been handled by Olaf P. Jenkins, supervising geologist of the Division of Mines, with the assistanee of his editorial assistant, Elisabeth L. Egenhoff. One hundred twenty-six geologists have contributed articles for this bulletin, each on a subject or area well known to him. Without this cordial and freely given cooperation of the men and companies in the petroleum industry, it would have been impossible for the limited staff of the Division of Mines to have covered the field so authoritatively and effectively.

Walter W. Bradley,
State Mineralogist

San Franciseo, March 11, 1943.

PREFACE

The theme of Bulletin 118 is *geology*—the guiding science in exploration for oil and gas. For the petroleum industry of California, the greatest of all mineral developments in the State, it has been our aim to issue a useful, authentic, and up-to-date source book. This bulletin is also to serve as a companion to the Geologic Map of California, issued by the Division of Mines in 1938, and to treat of the long and eventful sedimentary record of the State, especially where it concerns the areas which have been drilled in the quest for oil and gas.

One hundred twenty-six geologists have contributed articles for this bulletin, each on a subject particularly well known to him. Maps, sections, charts, and pictures have been used freely to augment the text. Index maps, all reproduced on the scale of 1:500,000, the same as that of the Geologic Map of California, furnish graphic definitions of the oil fields and their productive acreage. Selected citations to literature, grouped according to the various names applied to the areas accompany these index maps; together they serve as a glossary and a ready reference to available published data on the geology of the individual fields. All published rock formation names are briefly defined and accompanied by selected citations in a glossary of geologic units. The citations throughout the bulletin refer to one master bibliography which is in itself a record of the accomplishments of the science and development of the petroleum industry. The bulletin has been indexed so that the reader may readily find not only the subjects discussed in the bulletin, but also the names of fields and their descriptions published elsewhere.

Finally, in a pocket, is an economic state map, showing the locations of the oil and gas fields and other drilled areas. The map shows the major geologic features and various data of significance in the exploration for oil and gas. It is one of a series of economic mineral maps now being issued by the Division of Mines.

Bulletin 118 has been arranged in four parts. The first, *Development of the Industry*, is of general economic, historic, and developmental concern. The second, *Geology of California and the Occurrence of Oil and Gas*, is of a fundamentally scientific nature, especially intended to cover the problems of geologic history, stratigraphy, and structure. It discusses where oil is found in the rock formations and how it happened to accumulate in such extraordinary amounts. The third part, *Descriptions of Individual Oil and Gas Fields* is intended to give brief and ready reference to the essential features of each area which has attracted attention from the standpoint of exploration. The fourth part is devoted to the glossary of geologic units, the master bibliography, and the general index to the entire bulletin.

As the gathering of data for this volume progressed, the undertaking was found to be too great to handle as one unit, and the information too timely to withhold from distribution until it was all in readiness for publication. For that reason, the bulletin was divided into four parts, and each part was printed as it was completed. An issue of 4,000 copies was made, 2,000 of which were bundled and stored for final binding, while the remaining 2,000 were made available through distribution as paper-covered *pre-prints*.

PART ONE:
- Title-page date of pre-print, April 1940; date when first made available, October 1940.

PART TWO:
- Title-page date of pre-print, August 1941; date when first made available September 11, 1941.

PARTS THREE AND FOUR (issued together):
- Title-page date of pre-print, March 1943.

FINAL BOUND ISSUE:
- Title-page date of bound volume, April 1943.

The individual reports for Bulletin 118 were prepared during a period of more than four years. The first manuscript was received December 30, 1937; the last was completed in the early part of 1943. The date when each manuscript was submitted for publication has been entered in a footnote at the beginning of each article, and the reader is cautioned always to consider this date, since new developments or discoveries may have taken place since that time.

For many years there has been a genuine need for a treatise on the oil and gas resources of California. Previous statewide reports on this subject have long been out of print.[1] *Geology of California*, by the late Ralph D. Reed,[2] which served magnificently the purpose of bringing order out of chaos, so far as interpretative geologic history of California is concerned, is now also out of print. Great strides have since been made in new discoveries and interpretations so that it is now essential that a volume such as this bulletin should be issued to bring together our present knowledge.

The success achieved in securing support from many authoritative agencies in the making of the Geologic Map of California, suggested the idea of employing the same method in preparation of this book. The result has been indeed gratifying. More contributions were received than anticipated, and the oil companies are to be congratulated for their generosity to science in releasing this vast wealth of information.

Since Bulletin 118 is a composite of many separate articles prepared especially for this volume, its authenticity may be relied upon. We have refrained from abstracting or copying earlier published works, or piecing together unpublished material. *Although some areas, therefore, are omitted from the descriptions, the reader is not left without a means of securing data, since all known references to published information are cited.*

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[1] Watts, W. L. Gas and petroleum yielding formations of central valley of California. Bulletin 3, 100 pages, 13 illustrations, 4 maps, 1894.

Watts, W. L. Oil and gas yielding formations of Los Angeles, Ventura, and Santa Barbara Counties. Bulletin 11, 94 pages, 6 maps, 31 illustrations, 1897.

Watts, W. L. Oil and gas yielding formations of California. Bulletin 19, 236 pages, 60 illustrations, 8 maps, 1900.

Prutzman, Paul W. Production and use of petroleum in California. Bulletin 32, 230 pages, 116 illustrations, 14 maps, 1904.

Prutzman, Paul W. Petroleum in southern California. Bulletin 63, 430 pages, 41 illustrations, 6 maps, 1912.

McLaughlin, R. P., and Waring, C. A. Petroleum industry of California, with folio of maps (18 x 22). Bulletin 69, 519 pages, 13 illustrations, 83 figures, 18 plates, 1914.

Vander Leck, Lawrence. Petroleum resources of California, with special reference to unproved areas. Bulletin 89, 186 pages, 12 figures, 6 photographs, 6 maps in pocket, 1921.

[2] Reed, Ralph D. Geology of California. American Association of Petroleum Geologists, 355 pages, 60 figures, 1933.

In addition to the long list of authors who have contributed reports for Bulletin 118, there are many other persons who have very kindly supported the work. These include the following: The Supervisor and Deputy Supervisors of the California State Division of Oil and Gas; the chief geologists and executives of the oil companies; members of geological departments of educational institutions; individuals, research workers, and consultants; and many other persons particularly interested in our success, such as the editors of the Petroleum World and of the Bulletin of the American Association of Petroleum Geologists. To all these persons and companies who have so generously contributed to make this bulletin a success, we wish to express our deep appreciation.

While this bulletin has been in press several noteworthy publications have appeared which are not listed in the Bibliography. They include general reports on exploration and development in California during 1941 [3]; reports on the natural gas reserves of the State [4] descriptions of the Paloma oil field,[5] the West Montebello oil field,[6] the Wilmington oil field,[7] the Edison oil field,[8] the Midway-Sunset oil field,[9] the Imperial carbon-dioxide gas field,[10] and Humboldt County [11]; a monograph on the Franciscan-Knoxville problem [12]; papers on Martinez formation,[13] and the Eocene in western Santa Ynez Mountains, with map [14]; a discussion of the Crocker Flat landslide area [15]; a description of dam sites in California [16]; a discussion and map of the Ventura region [17]; and a paper on Marysville Buttes.[18]

It is hoped that this volume will serve as a guide to a better understanding of the geology of California and of the ways of developing and conserving the vast mineral resources with which the state has been so generously endowed.

OLAF P. JENKINS,
Ferry Building, San Francisco.

March 10, 1943.

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Estimate of the natural gas reserves of the State of California as of January 1, 1941 and as of January 1, 1942. Case No. 4591, Special Study No. S-334. Railroad Commission of the State of California and Department of Natural Resources, Division of Oil and Gas, 29 pages, map. San Francisco, November 15, 1942.

[5] Geis, W. H. A plan for operation of the Paloma field. American Institute of Mining and Metallurgical Engineers, Petroleum Division Petroleum Development and Technology Transactions, volume 146, pages 83–88, 1942.
Wood, James T. Jr. Geology and development of the Paloma field, Kern County, California. American Institute of Mining and Metallurgical Engineers, Petroleum Development and Technology, Transactions, volume 146, pages 76-82, 1942.

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[12] Taliaferro, Nicholas L., Franciscan-Knoxville problem. American Association of Petroleum Geologists Bulletin, volume 27, no. 2, February, pages 109-219, 1943.

[13] Watson, Elizabeth A. Age of the Martinez formation of Pacheco syncline, Contra Costa County, California. The American Midland Naturalist, volume 28, no. 2, pages 451–456, September, 1942.

[14] Kelley, Frederic Richard. Eocene stratigraphy in western Santa Ynez Mountains, Santa Barbara County, California. American Association of Petroleum Geologists Bulletin, volume 27, no. 1, January, pages 1–19, 1943.

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(To accompany "Economic Mineral Map No. 2—Oil and Gas," in pocket, and "Citations to Selected References," in Part Three.)

GEOLOGIC FORMATIONS AND ECONOMIC DEVELOPMENT OF THE OIL AND GAS FIELDS OF CALIFORNIA

Part One

Development of the Industry

Editorial note:

PART ONE represents the first of four divisions of Bulletin 118, and is intended to review the phenomenal growth of the oil and gas industry in California by giving incontrovertible facts and figures, presented in such a manner that they are readily available. Emphasis is laid on why the industry has so rapidly developed. What may lie in the future, however, is left to the reader's own judgment.

The following chapters are included in PART ONE:

Chapter I

Development and Production

CONTENTS OF CHAPTER I

ECONOMICS OF THE OIL AND GAS INDUSTRY OF CALIFORNIA

By J. R. Pemberton*

OUTLINE OF REPORT

INTRODUCTION

The State of California did not by chance reach the phenomenal development which we now find. It came about primarily and perhaps entirely because of the natural resources with which this State is blessed.

The most important industry in California aside from agriculture is the petroleum industry. Modern civilization gives little thought to the petroleum industry's great responsibility of providing oil products of any desired specification at almost any spot in the world at a price satisfactory to the purchaser, but simply takes for granted that the oil will be provided. When it is realized that no wheel can turn within the State without lubricants, that nearly all transportation by modern civilization uses petroleum in some form or another as fuel, and that even our great electric plants could not operate without high specification mineral lubricants, then and then only can the importance of the petroleum industry be appreciated. When it is observed that to the end of the year 1938 the total value of the gold produced within the State was over $2,000,000,000 whereas the oil and gas that has been produced has sold for nearly $5,500,000,000 the particular effect of the oil and gas resources of the State upon its prosperity is at once apparent. It is comparatively a short time ago that Dana came around the Horn in a ship bound for California to take back a load of dried cow hides. At that time, that industry was the only one within the State engaged in any export business. When we perceive that in the span of our present lives, the search for, finding, and development of oil fields in California has resulted in uncovering 118 prolific oil fields and 10 gas fields, some of them lying at depths of 2, 2½, and nearly 3 miles below the surface, it is furthermore apparent that there must have been an enormous development of exploration technique, and in the actual drilling of holes and extraction of oil and gas from the crust of the earth. This history, with the necessary research in geology, physics, chemistry, hydraulics, and applied engineering, is a fascinating tale, and would occupy in space many, many shelves in a library. In this account, we shall concern ourselves only with the outstanding features of the growth of this enormous industry within our State, its effect upon the economics, and the probable trend of development during the next 100 years.

* Oil Umpire for California. Manuscript submitted for publication January 5, 1940.

COMPARATIVE VALUE OF OIL, GAS, AND GOLD IN CALIFORNIA

Year To and Incl.	Petroleum Barrels	Petroleum Value	Naturol Gas M. Cubic Feet	Naturol Gas Value	Gold Value
1875	175,000	$472,500	-----------	-----------	$956,102,174
1876	12,000	30,000	-----------	-----------	15,610,723
1877	13,000	29,250	-----------	-----------	16,501,268
1878	15,227	30,454	-----------	-----------	18,839,141
1879	19,858	39,716	-----------	-----------	19,626,654
1880	40,552	60,828	-----------	-----------	20,030,761
1881	99,862	124,828	-----------	-----------	19,223,155
1882	128,636	257,272	-----------	-----------	17,146,416
1883	142,857	285,714	-----------	-----------	24,316,873
1884	262,000	655,000	-----------	-----------	13,600,000
1885	325,000	750,750	-----------	-----------	12,661,044
1886	377,145	870,205	-----------	-----------	14,716,506
1887	678,572	1,357,144	-----------	-----------	13,588,614
1888	690,333	1,380,666	12,000	$10,000	12,750,000
1889	303,220	368,048	14,500	12,680	11,212,913
1890	307,360	384,200	41,250	33,000	12,309,793
1891	323,600	401,264	39,000	30,000	12,728,869
1892	385,049	561,333	75,000	55,000	12,571,900
1893	470,179	608,092	84,000	68,500	12,538,780
1894	783,078	1,064,521	85,080	79,072	13,863,282
1895	1,245,339	1,000,238	110,800	112,000	15,384,317
1896	1,257,780	1,180,793	131,100	111,457	17,181,562
1897	1,911,569	1,918,269	71,300	62,657	15,871,401
1898	2,249,088	2,376,420	111,165	74,424	15,906,478
1899	2,677,875	2,660,793	115,110	95,000	15,336,031
1900	4,329,950	4,152,928	40,566	34,578	15,863,355
1901	7,710,315	2,961,102	120,800	92,034	16,989,044
1902	14,356,910	4,692,189	120,968	99,443	16,910,320
1903	24,340,839	7,313,271	120,134	75,237	16,300,653
1904	29,736,003	8,317,809	144,437	91,035	18,633,676
1905	34,275,701	9,007,820	148,345	102,479	18,898,545
1906	32,624,000	9,238,020	168,175	109,489	18,732,452
1907	40,311,171	16,783,943	169,991	114,759	16,727,928
1908	48,306,910	26,566,181	842,883	474,584	18,761,559
1909	58,191,723	32,398,187	1,148,467	616,932	20,237,870
1910	77,697,568	37,689,542	10,579,933	1,676,367	19,715,440
1911	84,648,157	40,552,088	5,000,000	491,859	19,738,908
1912	89,689,250	41,868,344	12,600,000	940,076	19,713,478
1913	98,494,532	48,578,014	14,210,836	1,053,292	20,406,958
1914	102,881,907	47,487,109	16,529,963	1,049,470	20,653,496
1915	91,146,620	43,503,837	21,992,892	1,706,480	22,442,296
1916	90,262,557	57,421,334	28,134,365	2,871,751	21,410,741
1917	95,396,309	86,976,209	44,343,020	2,964,922	20,087,504
1918	99,731,177	127,459,221	46,373,052	3,289,524	16,528,953
1919	101,182,962	142,610,563	52,173,503	4,041,217	16,695,955
1920	103,377,361	178,394,937	58,567,772	3,898,286	14,311,043
1921	112,599,860	203,138,225	67,043,797	4,704,678	15,704,822
1922	138,468,222	173,381,265	103,628,027	6,990,030	14,670,346
1923	262,875,690	242,731,309	240,405,397	15,661,433	13,379,013
1924	228,933,471	274,652,874	209,021,596	15,153,140	13,150,175
1925	232,492,147	330,609,829	194,719,924	15,890,082	13,065,330
1926	224,673,281	345,546,677	214,549,477	19,465,347	11,923,481
1927	231,195,774	260,735,498	224,668,940	20,447,294	11,671,018
1928	231,811,465	229,998,680	260,887,116	22,260,947	10,785,315
1929	292,534,221	321,366,863	400,129,201	29,067,546	8,526,703
1930	227,328,988	271,699,046	315,513,952	24,559,840	9,451,162
1931	188,270,605	141,835,723	344,959,920	16,690,695	10,814,162
1932	177,745,286	142,890,247	284,168,872	16,272,061	11,765,726
1933	172,139,362	143,063,972	271,743,544	15,403,514	15,683,075
1934	174,721,282	159,529,671	263,207,517	14,408,761	25,131,284
1935	205,979,855	179,335,311	302,447,193	17,680,661	31,165,050
1936	214,773,315	211,667,185	298,922,708	18,585,970	37,710,470
1937	238,558,562	237,845,872	323,883,714	19,859,865	41,110,230
1938	249,395,763	258,354,343	332,358,439	22,310,755	45,889,515
1939	223,725,410				
Total	5,371,838,660	$5,121,223,533	4,967,596,761	$342,540,871	$2,060,925,706

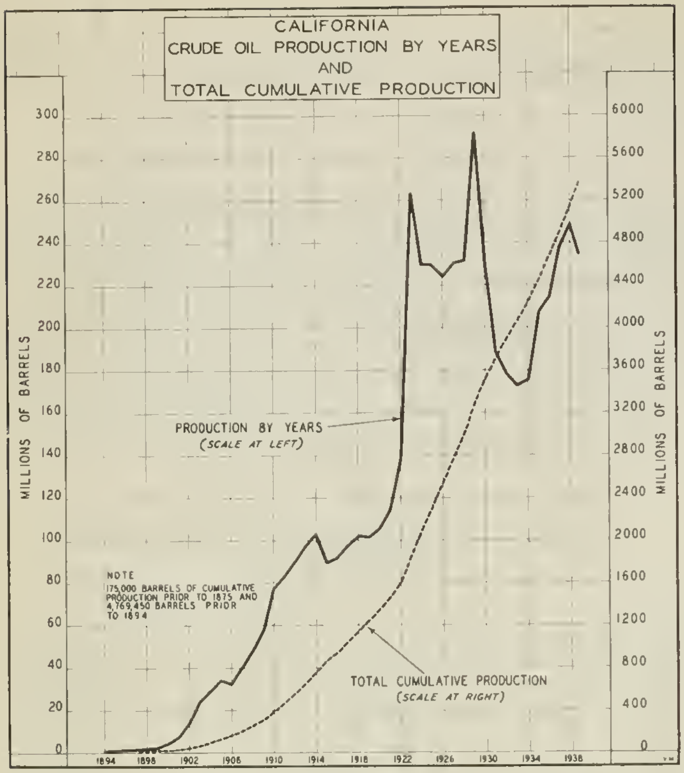

FIG. 1.

DEVELOPMENT OF THE INDUSTRY

FIRST PERIOD—NINETEENTH CENTURY

Oil apparently was used by the aborigines for many purposes. We find that asphalt was used to mend leaks in boats, as an exterior coating for certain utensils to be ornamented by pieces of shells and colored stone stuck into the asphalt. Medicine men and chiefs used some of the natural seepages of gas to evoke fire for tribal rites. Apparently the white man gave scant attention to the oil found in many of the great seepages until the late sixties and early seventies, although it is quite probable that the oily asphalt may have been used for greasing axles of the early day wagons. Following the discovery by Drake in Pennsylvania that wells could be drilled to tap strata saturated with oil, development in California commenced, the first well to be drilled being completed in 1865.* To the end of the nineteenth century, close to 3,000 wells had been drilled, less than 1,000 of which were on production at the end of the century. Cumulative total production of oil to the end of 1899 was less than 15,000,000 bbl., slightly less than 0.3% of the total cumulative production at the end of 1938. During this period, wells were comparatively shallow, and confined to the proximity of surface seepages of oil. Some small, rather short pipe lines had been built to get the oil from the wells to railroads, but no trunk pipe lines had been built, and certainly no large refineries at centers of consumption had been considered. Refining was conducted in the vicinity of the producing area. Twenty-two fields in all were found, of which only three may be classed as major discoveries—the great McKittrick oil field (1898), the Kern River oil field (1899), and the Brea Canyon oil field (1899). Fields discovered prior to 1897 were all of minor importance as we know the industry today, and the production that year of less than 2,000,000 bbl. from all of the fields of the State, which is an amount less than 5,500 bbl. per day, obviously did not indicate a very great demand for oil. The oil was used principally as fuel, although some refining for the manufacture of kerosene and lubricants was taking place. It was near the end of the century that oil used as fuel in locomotives began first to develop a demand, and in general, from this period to the present, development of oil fields, including their discovery, has been stimulated entirely by a rapidly increasing demand, a call for more oil, with the accompanying reward to the finder.

SECOND PERIOD—1900 TO 1929

The petroleum industry in California reached its peak of development during these 30 years, and its growth is parallel to the development of machinery utilizing oil as fuel or lubricant. The automobile had been invented and was being manufactured and sold in increasing numbers. There were several makes by 1904. Gasoline, a product of refining, which had been the bane of the kerosene makers lives in the past century, now came into its own. Development of electricity for lighting displaced kerosene in areas where electricity was available, and the vast multitude of new machines called for a rapidly increasing volume of lubricants. The large oil companies which we have with us today were well on their way at the opening of the century.

At the end of 1904, ten more fields had been discovered, four of which were of enormous importance—the East Coalinga oil field, West Coalinga oil field, Midway-Sunset oil field, and the Santa Maria (Orcutt, Lompoc) oil field. During the years 1905, 1906, and 1907, no fields were discovered.

With the discovery in 1904 of the Casmalia oil field, the thirty-second field discovered within the State, utilization of the first discovery tool was exhausted. All of the 32 oil fields producing prior to 1905 were discovered by drilling wells near surface seepages of oil or gas. This period of development may be likened to mining, and actually was conducted to a great extent by people who had been in the mining business. The reasoning was clear: if oil were coming out of the surface, and especially if it came out of a recognizable and easily traceable stratum, wells drilled to depths where that stratum could be encountered would produce oil. How-

* *An Economic Effect of the Rise of the American Petroleum Industry:* Whale oil, extensively employed in the manufacture of soft soap, in the preparation of leather and coarse woolen cloths, in the making of coarse varnishes and paints, and as a machinery lubricant, no longer ranks as an essential. In some English towns, about 1819, the streets were lighted with gas made from whale oil. Spermaceti, a neutral, inodorous fatty substance from the head of the Sperm Whale, was used in the manufacture of candles, unguents and ointments, and as a lamp fluid. In 1859, the discovery of petroleum in America sealed the fate of whale oil as an illuminant, for kerosene rapidly supplanted it. In the peak year 1846, the American whaling fleet numbered no less than 736 vessels with a total tonnage of 233,262 whose value exceeded $21,000,000; the total business interests connected with the whaling trade were estimated at $70,000,000 with a total employment of 70,000 persons. The financial slump of 1857 and the Civil War, together with the rapid growth of uses of mineral oils and the corresponding development of the petroleum industry all adversely affected whaling, which continued in a much more restricted fashion, the emphasis being placed on whalebone rather than whale oil. Perhaps the most important single factor in the decline of whaling, with the attendant economic effect and decline of an essential section of the American merchant marine of New England, may be ascribed to the development of the American petroleum industry. *Note supplied the editor by Robert F. Heizer.*

ever, with the discovery of Casmalia, apparently all seepages within the State had been tested, and the industry was at a loss for ways and means to discover other oil fields obviously needed because of the rapidly increasing demand for oil and the consequent reward for discovery.

During the late nineties and the early 1900's, study and research were devoted to the problem of why oil should occur in certain places in prolifically productive pools, while elsewhere in the same strata, nothing but salt water was encountered. The answer to the problem was the anticlinal theory of the accumulation of oil. This theory recognized only two fundamentals. First, that oil, being lighter than water, would float on water. Assuming a mixture of oil and water in strata, the oil would in time segregate itself from the water and occupy the higher portion of the strata, leaving the water in the lower portion. Second, that the strata should not lie in a horizontal position. Those who had been drilling for oil had found that the strata containing oil and the strata above the oil-bearing layer were seldom resting in a horizontal position, but were tilted and sometimes folded into all sorts of complicated structures; and it had been discovered that there were places where strata were actually folded into domes. The anticlinal theorists said that such a fold would be productive of oil because the oil in rising above the salt water could not get out of the fold and would be trapped there. Several minor requirements were also suggested: (1) that the anticline or dome should consist of beds of rocks overlying other layers of rocks known to carry oil elsewhere; (2) that the geological section of rocks in the anticline should include at the base a bed of porous sandstone, to serve as the reservoir rock; (3) that the reservoir rock should be overlain by an impermeable layer of shale or clay to act as a blanket, thus preventing the oil in the lower porous sandstone layers from rising upward to the ground surface. This theory was tested immediately, and there followed, beginning in the year 1908, a wave of drilling at sites selected by geologists. Oil companies were at first reluctant to drill upon recommendations made by newly graduated geologists, but noting the success attained by some of them, accepted the practice. During the 21-year period from 1908 to 1929, methods of applied geology resulted in the discovery of 53 oil fields. Furthermore, most of the greatest oil fields in California were tapped by the drill during this period.

The end of this second period of development saw the production of 292,000,000 bbl. of oil during 1929, which still stands as the peak year of oil production in California. The cumulative production to the end of that year was 3,308,368,000 bbl. This period was characterized by the development of the several great oil companies within the State; the enormous system of pipe lines which connects every field with trunk pipe lines from the San Francisco Bay region to the harbor at Los Angeles; and the large refineries and marine loading stations along the coast where oil is loaded into ships. There was likewise an enormous growth in the supply industry whereby manufacturers were pressed to design and construct equipment of the type needed to stand the increasing strains of drilling deeper into the earth's crust, and also to supply the enormous amounts of materials needed to complete the large number of oil wells drilled during the 21-year period.

THIRD PERIOD—1930 TO 1940

The technique of finding oil and getting it out of the ground reached such phenomenal success in the years from 1923 to 1929, not only in California but all over the United States, that the production of oil and oil products exceeded the market demand. The development had been stimulated by greatly increased market demand but the reward for discovery of oil and capturing it outstripped the demand, and by the end of the year 1929 the surplus of oil in tanks above ground, in reserve in the ground, and in daily production, literally swamped the industry. Towards the end of 1929 ways and means had to be devised to curb the excess flow of oil, and a program of production curtailment was begun. Thus, prior to 1930, it may be stated that the producer of oil generally had no other problems than to find a place to drill for oil, then to get the money, and finally to drill the well, because a ready market was always available for his oil. Beginning in 1930, however, he was confronted with a most important problem; that of finding a market. Curtailment of oil in California, starting in a feeble way in the last months of 1929, has passed through many stages, each stage being a successful improvement on the preceding one. It is now so thoroughly understood and accepted by all producers of oil as to constitute almost as fixed a necessity in business as taxes. Not only have the producers themselves been forced to curtail by failure to find markets, but they also have voluntarily curtailed in recognition of the surplus of oil. We find that many of the oil-producing states have passed laws forcing producers to curtail. No law in California has successfully passed through the vote of the people on referendum proceedings. The Federal Government during the period September, 1933, to June, 1935, had in effect a Code of Fair Competition for the Petroleum Industry, wherein regulation of production was accomplished, but on May 28, 1935, the United States Supreme Court held the Code to be unconstitutional. Thus, excepting that short period, oil production in California has been curtailed entirely by voluntary agreement among the producers themselves since 1929. During this period of 10 years, the State has at all times had the ability to produce an amount of oil several times as great as the actual production. Because of this ability to produce over and above the expected consumptive demand for oil products, curtailment of production of all wells other than the small strippers will have to continue for many years to come. The Federal Government has taken cognizance of the entire subject, and from the point of view of elimination of waste, particularly waste of underground energy, has proposed from time to time to pass national legislation for the purpose of regulating the extraction of petroleum from the ground. The whole subject of curtailment is complicated by the conflicting interests of the competitive units we find in the industry. There is competition between adjacent landowner lessors caused by their royalty interest in production; competition between producers desirous of obtaining as much as possible from their own wells; and competition between companies for all of the various and sundry reasons which we find in normal business activities. Curtailment is with the California oil industry to stay until such time as the current ability of all wells within the State to produce oil does not exceed the current market demand.

DISCOVERY OF CALIFORNIA OIL FIELDS

Year	Field	Methods of Discovery: Seepage	Geology	Geophysics
1875	PICO CANYON	×	--	--
1875	EX-MISSION	×	--	--
1880	PUENTE	×	--	--
1882	TAPO EUREKA	×	--	--
1885	SISAR-SILVERTHREAD	×	--	--
1886	HALF MOON BAY	×	--	--
1887	HOPPER CANYON	×	--	--
1887	SESPE	×	--	--
1887	WILEY CANYON	×	--	--
1889	ELSMERE CANYON	×	--	--
1889	NEWHALL	×	--	--
1889	RICE CANYON	×	--	--
1892	LOS ANGELES	×	--	--
1892	CONEJO	×	--	--
1894	SUMMERLAND	×	--	--
1894	BARDSDALE	×	--	--
1896	TORREY CANYON	×	--	--
1898	McKITTRICK	×	--	--
1898	WHITTIER	×	--	--
1898	MODELO	×	--	--
1899	KERN RIVER	×	--	--
1899	BREA CANYON	×	--	--
1900	EAST COALINGA	×	--	--
1900	TEMBLOR RANCH	×	--	--
1901	RIDEOUT HEIGHTS	×	--	--
1901	WEST MIDWAY	×	--	--
1901	WEST COALINGA	×	--	--
1902	SALT LAKE	×	--	--
1903	BEVERLY HILLS	--	×	--
1903	LOMPOC	--	×	--
1903	SANTA MARIA (ORCUTT)	×	--	--
1904	CASMALIA	×	--	--
1908	CAT CANYON	--	×	--
1909	BUENA VISTA HILLS	--	×	--
1909	WEST COYOTE	--	×	--
1910	LOST HILLS	--	×	--
1910	DEVIL'S DEN	--	×	--
1911	EAST COYOTE	--	×	--
1911	SHIELL'S CANYON	--	×	--
1911	SOUTH BELRIDGE	--	×	--
1912	SIMI	--	×	--
1912	NORTH BELRIDGE	--	×	--
1914	GATO RIDGE	--	×	--
1916	VENTURA AVENUE	--	×	--
1916	SOUTH MOUNTAIN	--	×	--
1917	MONTEBELLO	--	×	--
1918	TIPTOP—FRESNO	--	×	--
1918	KRAEMER	--	×	--
1919	RICHFIELD	--	×	--
1919	ELK HILLS	--	×	--
1920	HUNTINGTON BEACH	--	×	--
1921	SANTA FE SPRINGS	--	×	--
1921	LONG BEACH	--	×	--
1922	TORRANCE	--	×	--
1922	WHEELER RIDGE	--	×	--
1923	DOMINGUEZ	--	×	--
1923	MOUNT POSO	--	×	--
1924	TEMESCAL	--	×	--
1924	INGLEWOOD	--	×	--
1924	ROSECRANS	--	×	--
1925	NEWPORT	--	×	--
1925	KERN FRONT	--	×	--
1926	SEAL BEACH	--	×	--
1926	ALAMITOS HEIGHTS	--	×	--
1927	SULPHUR MOUNTAIN	--	×	--
1927	RINCON	--	×	--
1927	COFFEE CANYON	--	×	--
1927	ROUND MOUNTAIN	--	×	--
1927	ELWOOD	--	×	--
1927	POTRERO	--	×	--
1928	HUASNA	--	×	--
1928	LAWNDALE	--	×	--
1928	FRUITVALE	--	×	--
1928	KETTLEMAN HILLS	--	×	--
1928	DORSEY	--	×	--
1928	DOMINION	--	×	--
1929	PREMIER	--	×	--
1929	SANTA BARBARA (OLYMPIC)	--	×	--
1929	VENICE	--	×	--
1929	CAPITAN	--	×	--
1930	TERRA BELLA	--	×	--
1931	CHINO	--	×	--
1931	SANTA BARBARA (MESA)	--	×	--
1931	SAN MIGUELITO	--	×	--
1931	PYRAMID HILLS	--	×	--
1932	KETTLEMAN MIDDLE DOME	--	×	--
1932	McVAN	--	×	--
1933	S. E. MOUNTAIN VIEW	--	×	--
1934	EDISON	--	×	--
1934	DEL REY HILLS	--	×	--
1934	N. W. MOUNTAIN VIEW	--	×	--
1935	EARL FRUIT—MOUNTAIN VIEW	--	×	--
1935	LION MOUNTAIN	--	×	--
1935	EL SEGUNDO	--	×	--
1935	BARTOLO (WHITTIER)	--	×	--
1936	PADRE CANYON	--	×	--
1936	SANTA MARIA VALLEY	--	×	--
1936	GRAPE VINE (TEJON RANCH)	--	×	×
1936	WILMINGTON	--	--	×
1936	TEN SECTION	--	--	×
1936	GREELEY	--	--	×
1937	CANAL	--	--	×
1937	N. MOUNT POSO	--	×	--
1937	RIO BRAVO	--	--	×
1937	ARVIN	--	--	×
1937	YORBA LINDA	--	×	--
1937	NEWHALL RANCH	--	--	×
1938	CANFIELD RANCH	--	--	×
1938	PYRAMID (MOUNTAIN VIEW)	--	×	--
1938	ALISO CANYON	--	×	--
1938	COLES LEVEE	--	--	×
1938	TUPMAN	--	--	×
1938	COALINGA EOCENE POOL	--	×	--
1939	STRAND	--	--	×
1939	PALOMA	--	--	×
1939	N.E. COALINGA	--	×	--
1939	SOUTH MOUNTAIN VIEW	--	×	--
	Totals	30	75	13

NEW METHODS OF DISCOVERY—1936 TO 1940

GEOPHYSICS

During the period from the end of 1929 to 1940, applied geological methods accounted for the discovery of 23 oil fields. In 1922, a new tool was discovered. This method was applied geophysics, which involved the use of instruments operated on the surface of the ground. These, because of certain reactions within themselves, were able to analyze subsurface rock conditions and locate favorable structures within which oil might be found. No instrument has so far been devised and universally accepted which will locate oil as such, although many attempts have been made and many individuals are operating secret instruments of their own device with claims of success.

The Torsion Balance

The geophysical instruments employed successfully by the industry fall into three principal classes. First to be used was the torsion balance. This instrument registers the force of gravity at the point upon which the instrument is set and locates subsurface masses of either lesser or greater density than the surrounding area. In the case of the salt domes in Texas and Louisiana, the density of the salt is much less than the density of the rock in which the salt has been intruded. Therefore, the location by the instrument of a mass of a *lesser density* than that of the surrounding area is assumed to indicate the presence of a salt dome. Drilling subsequently determines whether the dome is present and whether oil exists. In areas where salt domes do not occur, the torsion balance, by the discovery of subsurface masses of *greater density* than that of the surrounding area, indicates a bulging upward of deep-seated, heavy beds closer to the surface at the point of discovery than in the surrounding area, thereby indicating an anticline or dome; subsequent drilling will discover the characteristics of the area and whether it contains any oil.

The torsion balance has been unsuccessful in California principally because of the great variation in character of sediments, the intrusive heavy volcanic rocks, and extremely broken up and complicated subsurface structure.

The Magnetometer

The second geophysical instrument successfully operated was the magnetometer, an instrument that records the direction of the magnetic lines of force in the earth's crust. By mapping the pattern of these lines the subsurface structure is determined. This is principally due to differences in electromagnetic characteristics of the different geological strata; and where there is a hidden anticline or dome, the magnetometer has been useful in determining this fact.

The Seismograph

The third instrument was the seismograph. The seismograph, using the *refraction method*, registers the time an elastic wave, caused by an explosion of dynamite, takes to travel from the point of explosion to a recorder. With the assumption that the velocity of such wave in any given stratum is known, after recording the time, the distance which the wave traveled can be calculated. Thus if strata lay horizontally between the point of explosion and the location of the instrument, a far less time interval would be occupied by the traveling of the wave than if the beds or the strata were to dip deeply into the earth and then return near the vicinity of the instrument. Later, the refraction method was discarded for a much better use of the seismograph by the *reflection method*. In the reflection method, an elastic wave initiated by an explosion of dynamite rebounds from each stratum and comes back to the surface as an echo. Dynamite is exploded in the bottom of a small hole drilled to the water table, and recording instruments are placed at previously surveyed points ranging all the way from a few hundred yards to a mile or more away from the point of explosion, and records from the explosion are obtained by each recorder. The records are studied and the attitude of any stratum with reference to a horizontal plane is determined and structure of that stratum is mapped. The reflection seismograph, because of the fact that the physical phenomena studied or recorded are man-made and therefore can be forced to function at any spot desired, has so far surpassed the torsion balance, magnetometer, and refraction seismograph as to cause it to be for all practical purposes the only successful geophysical instrument in use during the last few years. In California, both the torsion balance and magnetometer failed completely to locate any oil fields, whereas 12 extremely important fields have been discovered by means of the reflection seismograph since 1936, and a very large number of these instruments are now in continuous use in California.

GEOCHEMISTRY

It is generally assumed that more fields may yet be discovered by the use of the reflection seismograph, but with the thought that this tool involving geophysics may be incapable of locating all fields, a fourth method is just coming into use, which is called the geochemical method. In the use of geochemistry, which means the chemistry of the earth, it has been discovered that in the soil overlying some oil fields, through leakage of hydrocarbon gases during the millions of years in which the oil has been accumulated in the pool, slight traces of hydrocarbon substances may be detected. The geochemist samples the soil systematically and believes it possible to locate the presence of an underground oil pool when he obtains the necessary chemical indications in the soil. This method, like all the others which have been used, has its deficiencies, for the chemical indicators which are looked for in the soil may have been eroded away, altered, or rendered impossible of detection, or perhaps may never have existed. But in any case, it is looked on with great favor, and while as yet no oil field has been discovered in California by this method, fields impossible of location by any of the methods referred to previously may be discovered by this one.

RESULTS OF EXPLORATION

In future exploration for oil, all of the known methods will be utilized and the search will be conducted only in areas known to be geologically favorable. It definitely may be stated that oil in commercial quantities does not occur in areas where rocks favorable to the original existence of oil are not present. The favorable areas for exploration of oil actually comprise but a small part of the total area of the State.

As a result of the application of all these methods for the discovery of oil, California at the beginning of the year 1940 has seen the development of 118 oil fields and 10 gas fields. In many of these fields, several separate and distinct pools exist that really in themselves constitute the equivalent of other oil fields. There are 203 entirely distinct and separate oil pools in California, and doubtless deeper pools yet remain to be developed in several of the more important oil fields where the drilling has as yet not penetrated the entire thickness of sedimentary beds known to produce oil elsewhere.

In these oil fields there are 19,481 oil wells capable of production. Of these wells, 820 are not equipped with mechanical means of producing, having been shut in for curtailment purposes. Thus there are 18,661 wells capable of producing at a moment's notice. During the month of December, 1939, there were 107 new wells completed and thus there were 18,554 wells which were the effective wells actually producing as of December 1, 1939. A table is attached showing the classification of these 18,554 wells on that date, according to various arbitrary groupings as to size. Wells in California range in size from those capable of producing one barrel daily to the great gusher wells with indeterminate capacities that are certainly many thousands of barrels daily. The actual potential of large wells is never demonstrated because of lack of desire on the part of operators to subject wells to the possible damage resulting in a wide-open flow test. From the following table, it may be seen that over 55% of the wells are incapable of producing more than 20 bbl. daily and that 75% of them fall below 50 bbl. daily. Likewise, 55% of the wells of the State are able to produce but little more than 3% of the total potential of the State, while 290 wells, representing 1.5% of the State's wells, are capable of producing 41.5% of the total potential of the State.

POTENTIAL GROUPING OF CALIFORNIA WELLS ACCORDING TO SIZE

(All Wells in State December 1, 1939)

	Number of wells		Potential B/D		
			Each group		
Potential groups	Each group	Accumulated smallest to largest	Total	Average per well	Accumulated smallest to largest
0— 10 B/D (Inc.)	7,263	7,263	34,061	4.7	34,061
11— 15	1,747	9,010	22,881	13.1	56,942
16— 20	1,247	10,257	22,720	18.2	79,662
21— 25	939	11,196	21,940	23.4	101,602
26— 30	691	11,887	19,634	28.4	121,236
31— 40	1,039	12,926	37,419	36.0	158,655
41— 50	797	13,723	36,674	46.0	195,329
51— 75	1,166	14,889	72,625	62.3	267,954
76— 100	712	15,601	62,964	88.4	330,918
101— 150	758	16,359	94,588	124.8	425,506
151— 200	458	16,817	81,025	176.9	506,531
201— 300	443	17,260	109,080	246.2	615,611
301— 400	210	17,470	72,849	346.9	688,460
401— 500	144	17,614	66,268	460.2	754,728
501— 600	84	17,698	46,466	553.1	801,194
601— 700	80	17,778	52,806	660.1	854,000
701— 750	43	17,821	31,927	742.5	885,927
751— 800	25	17,846	19,696	787.8	905,623
801— 850	38	17,884	31,817	837.3	937,440
851— 900	26	17,910	22,920	881.5	960,360
901— 950	16	17,926	14,880	930.0	975,240
951—1000	16	17,942	15,803	987.7	991,043
1001—1500	170	18,112	211,078	1,241.6	1,202,121
1501—2000	152	18,264	272,907	1,795.4	1,475,028
2001 and up	290	18,554	1,048,004	3,613.8	2,523,032

CURTAILMENT

The principal object of curtailment is to preserve the oil of California in its natural resting place, the oil pool, until such time as it is needed. Obviously, the movement of all of the oil remaining in the ground from its natural reservoirs into surface tanks would be an inane and useless procedure, the proper course being to produce oil only as fast as it can be consumed; or in other words, as fast as the market calls for it. Oil can not be stored like gold, copper, iron, and other products of the earth because it is highly volatile and inflammable. Thus curtailment has been devised to stabilize the industry and prevent waste. In California, curtailment of oil has been accomplished solely by voluntary action among the producers themselves wherein a portion of the ability to produce of each well is assigned to that well as its quota of the market demand. The demand for products in crude oil during 1939 in California averaged 618,200 bbl. daily, or approximately one-quarter of the total producing capacity of the State. However, it would be unjust to ask a producer having a four-barrel well to limit his production to only one barrel daily and to him it would be equally unjust to permit a producer having a well capable of producing 10,000 bbl. daily to produce 2,500 bbl. daily. Curtailment is similar in some respects to taxes on income. The larger the ability of the well to produce, the larger is its ability to curtail; hence the curtailment program has always had as a fundamental basis the allowance first for a minimum allotment below which no well is asked to curtail. This exemption from curtailment has been proportionate to depth in recognition of the cumulative greater cost of pumping a deep well than a shallow one. Because of the large number of wells of great capacity to produce, it has been impossible to use the principle of applying a percentage to the remaining potential of a well after it has been given a minimum allotment for depth and a top allotment has been adopted, above which no well, regardless of size, shall be permitted to produce. This top allotment has fallen from its original high of 450 bbl. daily to 195 bbl. daily in January, 1940. Thus there is an exemption granted for small wells and a prohibitive top placed on all large wells and the remainder of the quota of the State has been obtained by applying a power factor to the remaining potential of the small and intermediate wells. The outstanding fact of all of this is that curtailment in California is now and has been for some time borne principally by the large wells, and furthermore that the allotment to large wells is continually falling. This has been caused by the great wave of drilling for the past several years in the development of the many new and extremely prolific deep fields within the State. That the necessary burden of curtailment will be borne by the large wells to a constantly increasing amount seems likely. However, the law of diminishing return may function and eventually the earnings of an expensive deep well may be so out of proportion to the capital cost as to cause it not to be drilled.

RECORD OF OPERATIONS IN CALIFORNIA OIL FIELDS

		Wells completed					Wells
Year	New rigs	Oil	Gas	Dry	Total	Wells abandoned	producing at end of year
1875-1899	*	2,295	---	629	2,924	---	945
1900	470	808	---	222	1,030	---	1,295
1901	*	935	---	221	1,156	---	2,152
1902	*	348	---	114	462	---	2,397
1903	159	383	---	134	517	39	2,575
1904	*	328	---	171	499	252	2,715
1905	*	244	---	8	252	257	2,734
1906	*	167	---	7	174	140	2,661
1907	*	296	2	11	309	62	2,559
1908	*	594	5	23	622	75	3,762
1909	*	578	7	60	645	71	4,282
1910	*	763	4	50	817	83	5,127
1911	*	970	8	104	1,082	246	5,947
1912	*	776	6	71	853	402	6,320
1913	*	789	9	67	865	293	6,817
1914	*	512	8	47	567	197	7,132
1915	170	272	8	20	300	175	7,311
1916	672	613	7	32	652	214	7,784
1917	766	686	10	48	744	162	8,362
1918	607	676	18	63	757	155	8,968
1919	692	547	10	51	608	211	9,229
1920	925	572	*	74	646	159	9,490
1921	1,082	704	*	47	751	162	9,980
1922	1,379	837	*	114	951	204	8,916
1923	1,327	980	*	347	1,327	293	9,396
1924	1,240	1,238	*	336	1,547	587	11,320
1925	1,262	948	*	338	1,286	479	11,069
1926	1,138	913	*	284	1,197	484	11,333
1927	1,160	901	*	281	1,182	543	11,284
1928	1,290	712	*	191	903	512	10,711
1929	1,306	910	*	314	1,224	526	10,515
1930	964	755	*	254	1,009	574	9,454
1931	259	243	3	238	484	177	8,612
1932	207	167	17	191	375	172	8,901
1933	354	243	5	163	411	215	10,158
1934	641	451	1	247	699	200	11,399
1935	1,035	729	34	347	1,110	203	12,778
1936	1,094	790	12	320	1,122	208	12,230
1937	1,484	1,147	17	314	1,478	273	13,463
1938	1,154	993	7	265	1,265	252	14,161[1]
1939	1,045	860	8	96	964	228	14,844[2]
Total	23,882	28,673	206	6,914	35,793	9,485	

[1] Excludes 4,665 shut-in wells.
[2] Excludes 4,593 shut-in wells.
* Not reported.

ESTIMATES OF RESERVES

In the early days of the California oil industry, no thought was given to the ultimate amount of oil a well would produce. The oil well was drilled and allowed to produce until it was uneconomical to operate, and the ultimate production was not known until then. In the compilation of the production records of thousands of oil wells very important data have been obtained which show that there is great variation in the amount of oil recovered per acre from an oil pool. This ranges from a few thousand barrels to more than half a million barrels per acre, and the average for the entire State is around 50,000 bbl. per acre. It has been found that the ultimate production of a well depends upon the thickness of the oil sand in which the oil is found; the porosity, or the proportion of the sand thickness that is pore space; the permeability, or the ease with which fluids move out of the pores into the hole, which is affected by the size of the pores and not the porosity; the viscosity of the oil; the gas-oil ratio; the temperature and pressure; and other factors of lesser importance. Suffice it to say that all of these factors are determinable from core samples of the oil sand and with a portion of the productive life of the well as a base, it is possible to calculate within reasonable limits the ultimate production of an oil well. In addition, the ultimate production of an oil well and even its daily capacity to produce may be determined from core samples before the well is actually placed on production. The modern practice is to sample the sand, and from the study of the sample calculate the ultimate productivity per acre of that particular sort of sand. This practice is the only way of estimating the ultimate recovery of most of the newly discovered fields in California, of which many are exceedingly important. For those fields in California which have been producing oil for many years, in some cases as much as 50 years, it is customary to plot graphically the annual production of not only each individual well in the field but the entire field; and by extending the curve expressed by the graphs into the future, the future production may be estimated. Using all methods of calculation, it has been determined that as of January 1, 1940, the known reserve of oil to be produced from the known oil fields, not only from existing wells but from those yet to be drilled, using *present methods of production,* is approximately 3,160,000,000 bbl., the State having already produced 5,391,000,000 bbl. of oil.

SECONDARY METHODS OF RECOVERY

The reserve of 3,160,000,000 bbl. is not indicative of the amount of oil known to exist in the ground in California, but is the amount of oil which the existing wells, and those yet to be drilled in areas considered proven, *will produce.* The actual or true reserve, by which must be meant all of the oil to be produced in the future from known producing areas, is probably vastly greater; and this additional oil over and above the 3,160,000,000 bbl. will be produced by secondary methods of recovery.

Research by chemists and physicists on the behavior of oils and gases in reservoirs and the histories of the productive life of oil wells indicates that the conventional method of producing oil through an oil well is at best only a high grade skimming operation, and that a great deal of oil is left in the ground when the well ceases to produce. To give an example: if a container were filled with absolutely clean, typical oil sand, and then oil were poured into the container until the pores of the sand were saturated, it would be found impossible to extract from the container all of the oil which was placed there. The part remaining would consist of a film of oil adhering to and surrounding each grain of sand. This volume of oil alone may amount to as much as 20 per cent of the total oil placed in the container. It is estimated that possibly as much as 50 per cent of the original oil is not recovered by oil wells.

Much study has been given to the problem of capturing this residual oil, and several so-called secondary methods of recovery have been devised.

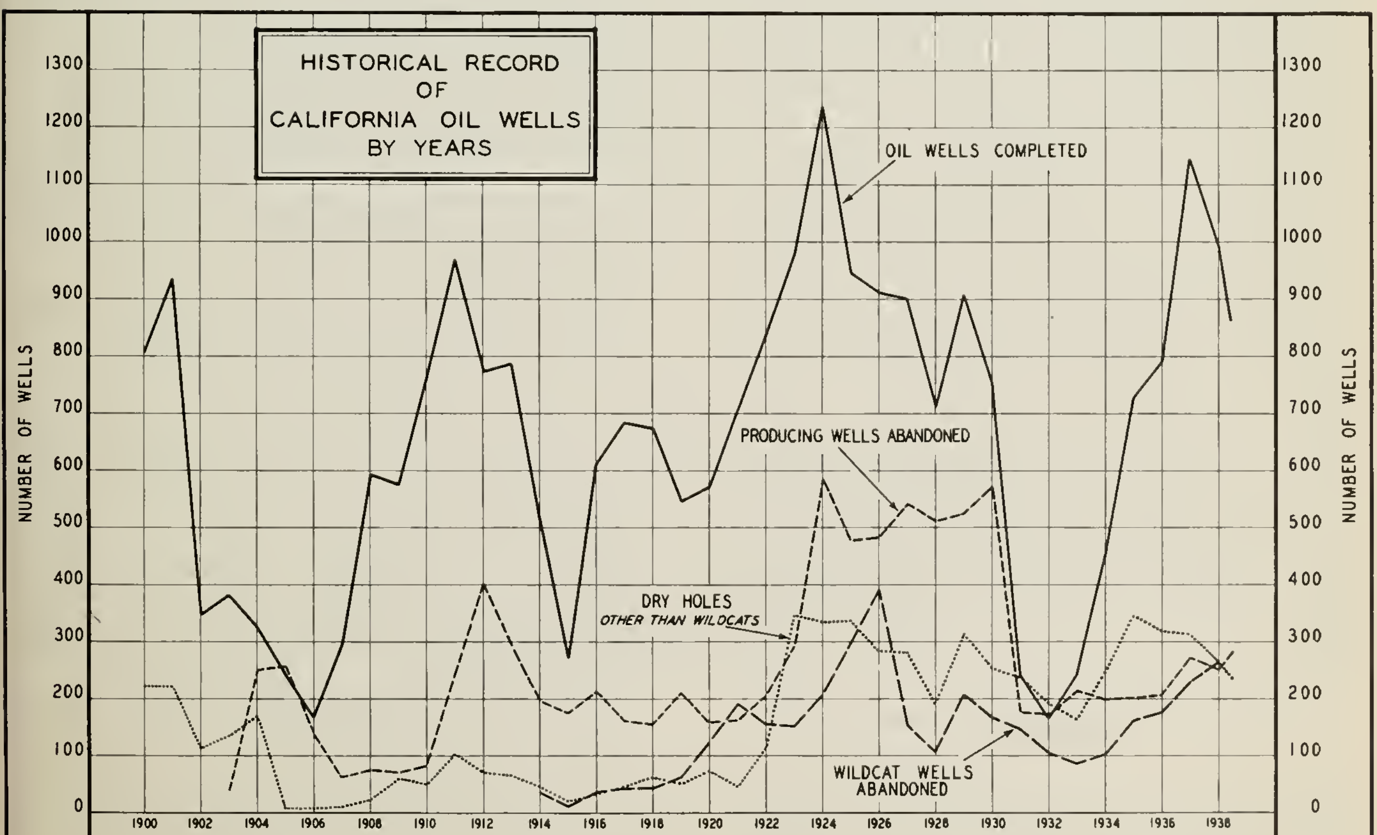

Fig. 2.

Secondary methods of recovering oil have been tried successfully elsewhere and it is assumed that they may be utilized in California. By far the most important of the methods so far adopted has been the *re-pressuring* method by which gas, injected in certain wells from the surface back into the oil sand, passes through the sand and forces the residual oil to other wells. This method has been very successfully carried out in some of the fields of eastern United States where uniform sand conditions exist and the injected gas permeates the entire thickness of oil-bearing strata. In California, because of the great variation in composition of our thick sandstone oil reservoirs, it has been found that injection of gas for re-pressuring purposes is unsuccessful because the gas will travel through the field in any layer of sand which is most permeable and thus by-pass the bulk of the sand containing the residual oil. The expense of the operation apparently so far has not been justified in California, and it is doubtful if in the far distant future this method will be used, because the gas itself may not be available.

The second method of secondary recovery is the *flooding* process, in which water carrying soda ash or other alkalies in solution is injected through wells in the edge of the field in amounts sufficient to wash the oil in the sand towards the wells highest on the structure. This method has been used with great success in the Appalachian and Mid-Continent fields of the United States, but so far has never been attempted in California. It seems probable that this method may function with great efficiency in certain fields and doubtless some day will be tried. It is possible that the method may be varied by injecting chemical solvents instead of water at the perimeter of the oil field and by extracting the oil from the chemical solution as it is pumped from the wells high in the structure. The chemical solvent process of course will be expensive and until such time as oil is very dear it is not likely to be attempted.

A third method of secondary recovery utilized with great efficiency in Germany during the world war of 1914-1918 was the *mining* method, wherein shafts were sunk and galleries run through the field directly beneath the oil sand, and short wells drilled from the roof of the galleries upward into the sand. The oil drained through the wells into the galleries and was then pumped to the surface. In the shallow oil fields in California there seems to be no reason to question that this method can be successfully applied.

The application of any or all of the secondary methods of recovery of residual oil in old oil fields will not occur until the search for new oil fields within the State meets with failure; until the production of the wells approaches the point where oil must be imported from other areas and the value or selling price of oil begins to increase. In other words, scarcity of oil and rising prices will bring about secondary methods of recovery.

RELATIONS BETWEEN LANDOWNERS AND OPERATORS

Assuming the operator has located a place where he desires to drill a well, the next step is either to purchase the land or, in case the purchase price of the land is prohibitive, to obtain a lease from the owner. A conventional lease between the landowner and the oil operator is essentially a partnership contract in which the landowner permits the operator to enter upon his land and use as much of the surface as is necessary for the purpose of drilling wells for oil. The term of the lease is conventionally 20 years and as long thereafter as oil or gas is produced in commercial quantities. It is customary that the landowner receive a fixed sum of money or other consideration for signing the lease and also that he receive a fixed part of the proceeds of production of oil, gas, and casinghead gasoline. The royalty rates usually are one-eighth in wildcat territory and one-sixth in more favorable localities. Almost any lawyer is acquainted with the necessary details embodied in a lease and should be consulted before signing with an oil operator. The operator agrees to start drilling the well on some definite date, and in case he is unable to do so, a sum of money must be paid to extend the time for the commencement of drilling. In case the landowner does not agree, it may be stipulated in the lease that drilling be commenced on a fixed date or the lease be terminated.

An oil pool is a unit, and inasmuch as the days of intense competition between individual operators and landowners holding rights covering the oil pool are ended, and curtailment is here to stay, the operation of an oil pool, including its development and production of oil and gas, should be with proportionate profit to all, and therefore for all of the best interests of the oil pool itself, the landowners and operators prior to the drilling of any wells and prior to the discovery of the exact producing limits of the field, often execute a unit-operation agreement. In unit operation, the landowners and operators pool their interests and each obtains his proportionate part of the production from the entire pool. In this way senseless competition between adjoining wells is avoided; rates of production of the pool are stabilized; and the greatest return in money over the longest period of time results. Many unnecessary wells will not be drilled and more profit will result from the entire operation. In other words, an oil pool under a unit system of operation is treated as if one operator owned the entire pool.

Oil, gas, and casinghead gasoline produced from wells are commonly sold to purchasing companies and the lessors' share is sold with that of the producer. Either the producer or the purchaser pays the lessor for his share. Prices paid for oil depend to a large extent upon the gravity of the oil and the gasoline content of the oil. Usually the heavier oils have less gasoline than do the lighter oils and hence the price paid for crude oil varies proportionately to the gravity. Dry gas is sold to public utility gas companies for an agreed price, there being no fixed gas market. Likewise, the market for casinghead gasoline fluctuates greatly and does not bear any constant relation to the price of crude oil, but usually is determined by location, proximity of market, and quality of gasoline.

Excepting in a few shallow fields producing heavy oil, crude oil as it comes from the ground usually is accompanied by natural gas. The natural gas is the principal propulsive agency which forces the oil from the reservoir rock into the well and up to the surface of the ground. The gas as it issues from the well with the oil carries with it gasoline in the vapor stage and it is customary in an oil field which produces gas to have installed a casinghead gasoline plant, through which the gas after it is separated from the oil is passed; and the gasoline, now called casinghead gasoline, is extracted, the dry gas going on to the public utility gas company pipe lines. Casinghead gasoline often produces a very considerable portion of the revenue derived from an oil well. Often the oil producer does not erect and maintain his own casinghead gasoline plant and the plant is installed by one in that business. If this eventuality occurs, it is customary for the casinghead plant owner to execute a contract with the operator and the landowner wherein the plant owner pays the operator a royalty portion of the gasoline manufactured and the landowner will therefore receive his royalty proportion of the oil operator's royalty.

In the early days of production of oil in California, gas was considered an undesirable product. Oil wells as soon as completed were permitted to flow wide open into large open earthern pits and the gas was permitted to escape to the air. Because most of the oil fields were relatively shallow in the early days and the reservoir rock in which the oil occurred consisted of unconsolidated and loose sand, a great quantity of sand commonly came out of the well with the oil and gas, and the sand often filled the earthen pit and another had to be constructed. The early operator looked with pleasure upon the great quantity of sand his well produced because it was his opinion that a great cavity was being created at the bottom of his well, with an increasingly large surface of oil sand exposed and would in the end develop into a great underground reservoir from which he could pump his oil as soon as the boisterous activity of the well, caused by the gas present with the oil, had ended. It was the desire of the early operator to get as much sand as possible out of his well and in addition to get rid of the gas as quickly as possible so his well could be placed on the pump. The fact that wells operated in this way in many cases produced large quantities of salt-water brine with the oil at about the time the gas was exhausted was of no concern to the operator because it was his belief that the salt water was the main motivating power; and the operator, finding that his well produced salt water, felt that it was the water that was forcing the oil to his well, and that it was not an undesirable factor.

Since those days, physicists and chemists have applied themselves to a study of what actually goes on in the ground in an oil pool and have ascertained the true story of the behavior of oil, gas, and water in underground reservoirs. Results of this study indicate that gas occurs not only in the form of gas as gas but also exists in a liquefied state dissolved in the oil. In the release of pressure in the bottom of an oil well, because of the fact that the well is an open hole to the surface, the highly compressed and liquefied gas commences to expand towards the hole and forces oil ahead of each expanding bubble and thence up the hole. An oil field, prior to its being drilled, contains a fixed quantity of oil and a fixed quantity of gas; and the theoretically perfect way of producing the oil and gas from a field would be to produce at such rate and under such conditions as to cause each barrel of oil as it issues from the well to carry with it the exact proportion of gas which originally the total gas of the field bore to the total oil of the field. Because of the fact that gas is much more mobile than is liquid petroleum, gas has a tendency to force itself through the oil in the reservoir and issue from the well with the oil in increasing proportions so that unless there is some form of control exercised over the production of gas with the oil many barrels of oil remaining in the ground will be robbed of the gas to produce the one barrel of oil which issues up the hole, and all of the gas of the field will be produced long before all of the oil is produced. In the operation of an oil well in such fashion that the original gas-oil ratio is maintained in the production of all of the oil from the field, the total energy existing in the compressed and liquefied gas is utilized. Because oil and gas are lighter than water, we find in California in all cases that the oil and gas pool is surrounded by water which saturates the same strata in which the oil and gas occur. The pressure in the bottom of the hole usually will vary close to 4 lb. per sq. in. to each 10 ft. of depth to the hole. Variations both under and over this pressure are caused to a great extent by the elevation of the well above sea level. The well which first taps an oil pool at a depth of 8,000 ft. encounters a pressure at the bottom of the hole of approximately 3,200 lb. per sq. in. This pressure could of course not exist at the bottom of the well unless a similar pressure existed in the water surrounding the oil pool. As the oil and gas are extracted from an oil pool, the water surrounding the pool moves up into the sand formerly occupied by the oil and gas because it has the inherent pressure to so move, but the most important point is that water can not encroach into the sand at a rate as fast as gas and light oils can leave the sand. Thus the pressure at the bottom of an oil well is seldom maintained at its original pressure during the life of a well but diminishes at an appreciable rate during the production of oil and gas from the field. This is not necessary, but is customarily the history of a normal oil and gas field, because the desire of the operators leads them to get the oil and gas as soon as they can rather than by the most efficient method. Thus unless the operation of an oil pool is controlled in such fashion as to cause the gas-oil ratio of the produced oil to be the same as that originally in the pool and at such rate as to maintain the original bottom-hole pressure, the gas-oil ratio decreases and finally diminishes to a negligible amount. The bottom-hole pressure falls to a trivial amount, the well will no longer flow, and pumping equipment must be purchased and placed in the well. Modern science teaches us that all of this is unnecessary and that all oil pools could be operated in such fashion that the last drop of oil in the sand would be produced at the surface at exactly the same pressure as is encountered by the first well. Because the pumping of an oil well is expensive and especially so in deep wells, deep pumping wells will be abandoned by the operator while still capable of producing oil when the daily income is less than the expense. Thus large quantities of oil will be abandoned and never produced by these wells in such fields. Each year sees much progress in the method of handling oil and gas wells but as long as it is impossible to curb the competitive spirit between operators and landowners separated by a fence, it will be impossible to operate an oil field as nature intended it to be operated. In Texas, where an enormous surplus of producing capacity exists over and above the consumptive market demand, may be found the best examples of scientific control of production of an oil field. In California we have few such examples.

SPECULATIONS AND INVESTMENTS

Many oil wells are drilled by promoters who finance themselves by selling stock or interests of some sort to the public. It is customary for such promoters to be extremely optimistic in regard to the future earnings of their venture, and the unscrupulous promoter is prone to cite facts and figures about the productivity of some of the greatest producing fields in California and paint a glowing picture of the probable earnings to be gained from an interest in his well. Let the prospective purchaser of such interests insist not upon comparisons with the known great producing fields in California but upon actual facts as to what is known of the particular ground in which the prospective well is to be drilled. Usually other wells exist near by and some data are available. Let the prospective purchaser of an interest in such a well not concern himself with statements of the initial production of nearby wells, because many wells have been drilled in California which, while producing nearly a 1,000 bbl. per day during the first few days of their life, are perhaps producing less than 100 bbl. daily in a few months, and the ultimate recovery of oil from the well after paying the drilling costs, expenses of operation and the royalty did not net the owners a profit, but actually a financial loss. There also are many wells in California which, although producing not more than 400 bbl. daily during their best days have produced many hundreds of thousands during their lives. Thus initial production or rate of production is not necessarily a barometer of the total amount of oil an oil well will produce. Generally speaking, the prospective investor in an oil well may discover for himself with what regard the area is held by the conservative element in the oil industry in California by ascertaining the names of the oil companies which actually are operating within the field. Let the prospective purchaser also know how many acres the conservative oil companies allow for each well they drill, realizing that if these companies find it necessary to space wells such that each drains 10 acres of land, it must be unprofitable for those same companies to drill 10 wells on 10 acres and if the seller of interests in a prospective well states that he has an acre of land upon which to drill his well, one should divide by 10 the productivity and ultimate expectancies of those other wells drilled within the same field which are given 10 acres of land to draw from.

To sum up: The actual value of an oil well is affected by the ultimate production of oil, gas, and gasoline from the well. This figure is subject to enormous variations in California and is affected by the acreage surrounding the well, the thickness of the sand, the character of the oil, the permeability of the sand and many other factors. No fields within the State are so similar as to warrant any other than very general comparisons, each field and even each well being a law unto itself. The drilling for oil is a highly speculative business and not an investment business. The odds against obtaining oil in a wildcat well are very great.

COSTS OF DRILLING AND PRODUCTION

It costs money to produce oil and gas in California. The United States Department of the Interior in the year 1935, following several years study of the cost of producing oil, determined that the average cost in California is $0.585 per barrel of oil. This does not include the original cost of the land or lease upon which the wells are located nor the income taxes paid by the operator upon his profits, nor the overhead and administrative expense, all of which would raise the cost considerably. When the cost of unsuccessful wildcat wells is added to the cost of an operator's development in the localities in which he got oil, the cost per barrel likewise increases considerably because records in California show that at least 37 wildcat wells are drilled before the discovery of an oil field, and also that a high percentage of wells drilled in oil fields themselves are dry holes, most of these being "edge" wells drilled in determining the extent of the field. Thus in drilling alone there are a great many losses which must be added to the total cost of being in the oil business. Again the administrative costs of operating an oil producing company, even though small, add to the total cost of producing oil. In going into the oil business, which one does when one buys stock in a new venture, it would be well to make some computations in which the total amount of oil expected to be produced is divided into all of the future expenses of the company to determine the actual cost of producing oil. This for round figures should never be more than 75¢ per barrel in California and there are some leases in existence in which the operator reserves the right to discontinue producing oil from the landowner's property if the selling price is less than 75¢ per barrel.

WILDCAT WELLS ABANDONED IN CALIFORNIA AND FIELDS DISCOVERED—1860-1938

Year	*Wildcat wells abandoned*	*Fields discovered*		*Average depth per well*	*Number wells abandoned per discovery*
		Oil	*Gas*		
1860–1913	834	55	1	2,200	15
1914	38	--	--	2,773	--
1915	11	--	--	2,773	--
1916	37	1	--	2,773	86
1917	44	3	--	2,773	15
1918	44	--	--	2,773	--
1919	62	3	--	2,773	35
1920	125	1	--	2,773	125
1921	193	2	--	2,773	97
1922	157	1	--	2,773	157
1923	152	2	--	2,773	76
1924	207	2	--	2,773	104
1925} 1926}	391	2	--	3,642	191
1927	153	5	1	3,578	26
1928	107	4	--	3,733	18
1929	209	3	2	4,134	42
1930	169	--	--	3,920	--
1931	147	2	--	4,039	158
1932	105	--	--	3,272	--
1933	87	1	--	3,104	192
1934	102	2	2	3,153	26
1935	162	1	3	3,457	41
1936	178	4	2	3,886	30
1937	231	3	--	3,798	77
1938	265	5	2	4,072	38
1939	96	4	--	4,890	37
Total	4,306	106	13		

Taxes on oil production are increasing annually. Apparently all governmental bodies are laboring under the misapprehension that an oil producer is rolling in profits and can be taxed accordingly. County taxes in most counties in California are now computed upon the basis of the future expected production and the prospective investor in an oil project may confer with the county assessor and determine the number of barrels per acre which for taxation purposes are expected to be produced in any portion of any oil field within a county, thereby obtaining a check on the promoter. Inasmuch as over 35,000 wells have been drilled in oil fields in California and in addition, over 4,200 wildcat wells have been drilled and abandoned, it is obvious that the difficulty of finding new fields in California must be very great. With all of the scientific talent available within the State and with the many wildcat wells drilled each year, only four oil fields were discovered in the State in the year 1939, six being discovered in the year 1938. The new fields discovered are found annually at greater depths, and deep drilling, in addition to the exploratory expense in locating a place to drill, causes the cost of exploratory drilling to be increasing annually. The deepest drilling so far has been to a depth of 15,004 ft., although that well is producing from a depth of over 13,000 ft. In the Rio Bravo field, all of the wells are over 11,000 ft. in depth and in several fields nearly all of the wells are over 8,000 ft. in depth; yet 20 years ago there were very few wells that even had been drilled to a depth of 6,000 ft.

The cost of drilling wells is approximately $10.00 per ft. in California, after preliminary wells have determined the most efficient way of drilling in each field. In the deep fields, that is those of 9,000 ft. or more, the cost is from $12.00 to $15.00 per ft. Some 211 wells in the world have already been drilled to depths greater than 10,000 ft. and 60 of these are in California.

REFINING

Those who are in the oil business are in that business solely because they believe that they can make more money in that industry than by occupying themselves with any other business. Oil is taken from the ground and converted through refining processes into all of the various components or products for which there is a demand. Thus the growth of the industry in California and its development to the point we see it now is due entirely to an actual demand for petroleum products totaling 225,000,000 bbl. in the year 1939. Because California is not a portion of any large oil producing area but is isolated, our State has a rather definite and fixed area within which to dispose of its oil products. This area consists of the five western States: California, Oregon, Washington, Nevada, and Arizona; and of what is known as the Pacific foreign market, which includes principally Alaska, Western Canada, Hawaiian Islands, Japan, Russia, China, and the Philippine Islands. To all of these markets petroleum products of definite and fixed specifications must be shipped, and each market has its own specifications. Gasoline of course is the product of most widespread, important demand and involves the most money. Fuel oil is second in importance, diesel oil next, and lubricants from the point of view of money, the item of least importance.

In view of the fact that crude oil is worthless as such and only products of crude oil are demanded, the oil refinery, next to the oil well, is the most important unit in the oil business. Crude oil is a physical mixture of a great series of hydrocarbons, each of which is chemically distinct from the other and recognized by the proportion of carbon to hydrogen in the molecule. Each separate hydrocarbon substance will vaporize or boil at a different temperature. Thus the simplest oil refinery, and the one used in the early days of the petroleum industry, was a simple still to which heat was applied and the crude petroleum boiled. At any given temperature all of the hydrocarbons have a boiling point, equal to that temperature or lower, and boil off and are condensed again into liquids; and with each increase in temperature to the still, other fractions would be vaporized and afterwards condensed. The first outstanding improvement over this simple topping still was the cracking plant. In the *cracking process* heavy fractions were subjected to a great pressure and exceedingly high temperatures, with the result that the molecule was torn apart and atoms of hydrogen and carbon re-united in a new combination. The result was a lighter product with coke as a residual by-product. By this process the yield of gasoline from any crude oil could be greatly increased over the yield from a simple topping plant. Beginning in 1934, research into refining methods has developed refining processes of breath-taking importance. Thus we have the method known as *catalytic cracking*, in which even larger quantities of higher quality gasoline are made than under the original cracking process. Yields of as high as 90% gasoline have been obtained from chargiug stocks from which no gasoline could be obtained by any other process. Another process of transcendental importance is the *polymerization process*. This process is the reverse of all other refining processes because instead of producing lighter and more valuable fractions from heavier oils, gases are charged into the still directly and then under mild heat and pressure in the presence of catalysts are converted into controlled liquid products within the range of normal motor fuel gasoline. The *alkylization process* is an improvement on the polymerization process in that gases are converted into extremely high octane anti-knock gasolines. The *hydrogenation process* is one in which hydrogen may be injected into the process of distillation and extremely valuable oil products of wide range are made from low-grade charging stocks. Many other processes of minor importance, variations of those mentioned, have been developed, all for the purpose of making more useful the products of the normal straight or topping process, and actually serving to make a barrel of crude oil go much farther. It can be stated confidently that a barrel of crude oil now is equivalent to perhaps four barrels of crude 30 years ago, and annual improvements in refining technique may be predicted to stretch the usefulness of a barrel of crude oil. Another extremely interesting development is a refining process which converts hydrocarbon gases into white powder which can then be converted into products from which such widely diversified items are made as women's hose; acid, heat, and corrosion resisting insulation for electric wires; transparent belts, straps, and ribbons with enormous tensile strength; paper of various colors which is not affected by acids, chemicals, or heat; and, in a word, a mass of synthetic products, every one of which is more durable and just as practical as the article imitated, the slightly increased price alone now preventing the widespread marketing of such products. In general, it may be said that the petroleum industry has not at any time sought to force a product into a market by endeavoring to create demand for something that can be made in refining processes; but the development of every product which is now sold, from medicinal oil, vaseline, insecticides, etc., down to coke, has been the result of a definite and fixed demand on the part of the public for the product. It is expected that the ingenuity of chemists and refiners is such that a great many additional petroleum products can be manufactured as soon as the demand exists. The aviation industry each year sees a demand for gasolines of higher octane rating and more power in order to drive high speed aeroplane engines at high altitudes under conditions previously known to be formidable to the old type fuels.

There are 81 refineries in California with a capacity of 974,000 bbl. daily. Of these, the capacity of the cracking plants alone is 114,785 bbl. daily. In addition, there are 109 casinghead gasoline extraction plants with an output capacity of 3,500,000 gal. daily. Of course neither the refineries nor the casinghead plants operate at capacity, the refinery through-put being about 500,000 bbl. daily and the casinghead gasoline production being about 40,000 bbl. or 1,680,000 gal. daily.

STORAGE AND TRANSPORTATION

Of great importance to the petroleum industry is the transportation and storage system. Generally speaking, trunk pipe lines connect every field in the State with refining centers, and oil can be pumped from one end of the State to the other, and likewise can be delivered to marine loading stations along the coast at many points where either refined products or crude oil can then be transported by tankers to any part of the world.

Oil is stored in either steel tanks or, in the case of extremely heavy non-gasoline bearing crude oils and refinery residues or fuel oils, in concrete-lined earthen reservoirs with wooden tops. The reservoirs range in size from 100,000 bbl. to 4,500,000 bbl. each, while steel storage ranges from small tanks up to tanks of 120,000 bbl. capacity. The total tank capacity for all types of oils in California is nearly 190,000,000 bbl. In California as of January 1, 1940, the total oil in storage was around 153,000,000 bbl. exclusive of approximately 4,000,000 bbl. located in lease tanks adjacent to wells and not shipped into pipe lines. At this writing detailed figures are not available, but the 153,000,000 bbl. in storage is approximately as follows:

	Bbl.
Gasoline Bearing Crude Oil	35,000,000
Non-Gasoline Bearing Crude Oil	14,000,000
Fuel Oil Residuum	69,000,000
Coke and Distillates	8,000,000
Finished Gasoline	14,000,000
Natural Gasoline	2,000,000
Gas Oil and Diesel Oil	10,000,000
Naphtha Distillates	1,000,000
Total	153,000,000

From this it may be seen that of the 153,000,000 bbl. only 49,000,000 bbl. is crude, the remaining 104,000,000 bbl. being refined products. This is because refinable grades of crude oil are not conveniently stored without excessive loss due to evaporation, and hence generally are put through the refinery as soon as received, and the products stored separately in appropriate and smaller sized containers. The carrying of such a large volume of oil in storage represents one form of frozen capital. Yet it would be impossible for the industry to carry on its normal business without adequate working stocks similar to those in any other business. Under present day conditions, wherein the movement of each grade of oil product is known fairly well, a convenient and workable limit for storage of all products in California would be close to 100,000,000 bbl. of oil. Thus the above-ground stocks are at least 50% too great, and the industry would be far more comfortable were stocks to be reduced to around 100,000,000 bbl. Due to the large volume of heavy oils produced in California, the stock of California fuel oils above ground is commonly out of proportion to the movement of this commodity in trade. With over 45% of all the above-ground stocks in California consisting of fuel oils and residuum, it can be seen that stocks of this one commodity are very top-heavy. Happily, nearly all of the recently discovered oil fields, and doubtless those to be discovered, produce very light, high-grade refinable crudes and in time this surplus of fuel-oil stock will be reduced to more favorable levels. Inasmuch as fuel-oil stocks are carried in concrete-lined reservoirs, and due to the fact that evaporation is very low on this type of oil, the carrying charges on fuel-oil stocks are lower per barrel per year than for any other oil product.

OUTLOOK FOR THE FUTURE

Some time in the future, whether it be 20, 50, or 100 years hence, all of the oil fields in California will have been located and the production of the State will be less than demand for the territory served. At this time methods of secondary recovery will have been commenced and enough oil imported into the State to bridge the gap. It is possible that the production of oil from shale likewise may be attempted, there being in California large deposits of shale saturated with oil to the extent in some cases of nearly one barrel of oil to the ton of shale. Shale may be mined, ground, and then retorted and the vaporized oil condensed. When the secondary methods of recovery and the production of oil from shale decline, substitutes for oil will be manufactured. Substitutes can now be made from coal, and motor fuel can be made from alcohol. The success of substitutes for petroleum will have a profound effect upon manufacturing of machinery which utilizes oil or oil substitutes and eventually, perhaps several generations ahead, we shall undoubtedly see a complete revolution in modes of transportation and the source of power.

TAXATION AND ITS RELATION TO DEVELOPMENT AND PRODUCTION

By Granville S. Borden*

The fruits of industry are divided between capital, labor and governments. Capital takes its redemption and remuneration through profits or dividends; labor takes its share through wages; governments take their share through taxes. Each must have a just share, and the question of what is a *just share* and the question of who shall make the allocation are vital current political and economic issues. Certain political philosophies contend that government should take all the fruits and that some dictator or politician should have irrevocable discretion and power to distribute the fruits. Under our democracy we adhere to the view that capital is entitled to redemption and fair remuneration; that labor shall have a fair wage; and that governments shall make equitable levies. But since all human beings are inherently selfish, there are many variable views in regard to the question of what ratios shall be applied in a division of the fruits and who shall have the power to fix these ratios.

Perhaps all parties should devote more energy to means of increasing the crop, and not so much time to quarreling over a division of the existing crop.

Moreover, all three parties must guard against killing the goose that lays the golden eggs. For example, if the tax burden becomes oppressive and the consumer refuses to carry it, then business stagnates, with consequent unemployment, a reduction of profits, and curtailment of government revenue. If the producer assumes the increased tax burden, marginal operations must be closed down, and again the consequences are increased unemployment and diminished government revenue. Quite often an increase in a rate of tax results in a reduction of government revenue.

Perhaps the worst detrimental feature of selfishness and greed on the part of any one of the three distributees of the fruits of industry is the retardation of expansion of the enterprise. Growth means new jobs, more government revenue, better trade, and better standards of living.

Explorations and discoveries of oil and gas fields in California have resulted in tremendous contributions to the wealth of the State and the Nation and the well being of its citizens. When a prospector discovers a new oil field, and new sources of wealth are created, new sources of values for taxation and new sources of income to be taxed are engendered; new sources of jobs come into being, new stimuli to trade are quickened; new sources of profits are discovered. Thus there is a real contribution to capital, to labor, and to governments. There are more fruits to divide than there were before the discovery. There is a new supply to conserve, a discovery to offset the depletion sustained; finally, a new source of revenue to aid in further exploration and discovery of new sources of wealth, to the end that there may be a compounding of the benefits.

The governments' (Federal and State) share in the revenues of the petroleum industry in 1939 was approximately $1,400,000,000. Part of this bill was paid by the consumer of gasoline and other petroleum products. Another part was paid by the ultimate consumer of other products, supplies and commodities, the cost of which included the tax on gasoline and other petroleum products. The balance of the tax was absorbed by the industry.

Statistics prepared by the American Petroleum Industries Committee are available for interested persons to substantiate the claim that the ratio of governments' (Federal and State) share to total revenue of the petroleum industry is substantially higher than the general average of similar ratios in other industries.

Every member of the industry who has contributed services or money as a means of meeting this annual tax bill of $1,400,000,000 has just grounds for a feeling of elation and pride. Every contributor has aided in the accumulation of a tremendous fund of $1,400,000,000 and in making it available for appropriations for public purposes. This achievement is a commendable one from every point of view, and a huge share of the credit should go to the courage and intelligence of those who prospected, explored, developed, and added new oil and gas fields to those previously known to exist.

At the present time the following taxes are imposed on a California corporate operator of an oil and gas property:

A. By the State of California and its political subdivisions:

1. Direct state, county and municipal taxes on real and personal property based on values of property as of the first Monday in March.
2. Tax on the sale or use of gasoline at the rate of 3¢ per gallon.
3. Corporation franchise tax of 4% of the net income derived from business done in California.
4. Sales tax on sale of all commodities other than gasoline based on 3% of selling price.
5. Use tax of 3% on cost of goods used or consumed which have not been taxed under the sales tax.
6. A use fuel tax of 3¢ per gallon on diesel oil and other fuels (other than gasoline) used.
7. Unemployment compensation tax based on 2.7% of wages.
8. Miscellaneous minor levies.

B. By the United States:

9. Federal income tax based on 18% of net income as defined.
10. Capital stock tax based on $1 per $1,000 of the adjusted declared value of the capital stock.
11. Excess profits tax based on 6% of the amount by which adjusted net income under the income tax law is in excess of 10% of the adjusted declared value for capital stock tax purposes, and 12% of the amount by which this income is in excess of 15% of such adjusted declared value.

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*Attorney, Standard Oil Company of California. Manuscript submitted for publication April 15, 1940.

12. Tax on sales or use of gasoline of 1¢ per gallon on gallons sold or used.
13. Tax on sales of lubricating oils of 4¢ per gallon.
14. Tax on transportation of petroleum by pipe line equal to 4% of the service charge or a fair charge for similar services if not a public carrier or no fixed rate.
15. Tax on tires of 2¼¢ per pound on total weight, and a tax on inner tubes for tires of 4¢ per pound.
16. Tax on parts of accessories added to tank trucks, and tax on batteries, of 2% of sales prices.
17. Unemployment compensation tax of 3% of wages paid with credit up to 90% for taxes paid under unemployment tax laws of a State.
18. Old age pension tax of 1% of wages paid.
19. Stamp taxes on stock and bond issues and transfers and also on conveyances of realty.

In addition, as an indirect tax, there is the expense of keeping records; preparing returns, forms, and schedules; and maintaining a staff of clerks, accountants, engineers, and attorneys.

The scope of this paper does not permit a discussion of the problems involved, but merely a few of the important ones are mentioned:

1. Problems relating to the valuations of oil and gas properties and leases as a basis for county assessments.

2. Problems relating to securing proof of rights to statutory exemptions from taxes on sales and use of gasoline and other products.

3. Problems relating to determining taxable net income under the California corporation franchise tax law and the Federal income tax law, especially problems relating to treatment of intangible and tangible development expenditures, determinations of depletion and depreciation, inventories, valuations in reorganizations, subsidiary losses, capital gains and losses, bad debts, interest, loss and tax deductions.

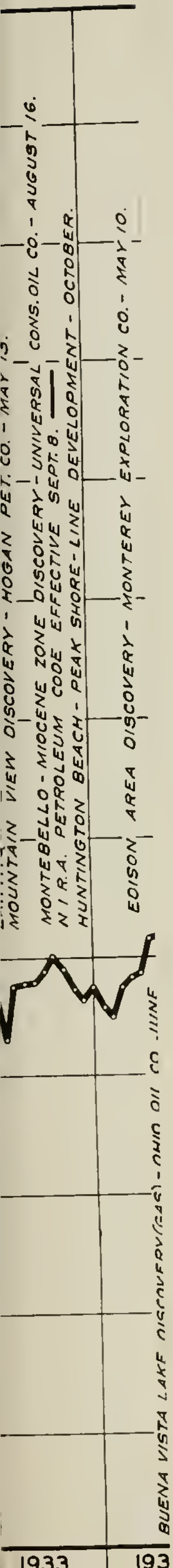
4. Problems relating to dividends for purpose of the dividend paid credit against income tax rates (under the 1936 and 1938 Revenue Acts), and the avoidance of a tax penalty on the accumulation of a surplus which may be needed in the business. (Section 102 of Internal Revenue Code.)

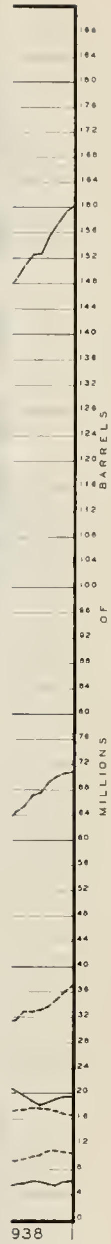
5. Problems relating to declaration of a proper capital stock tax value so as to minimize the capital stock taxes and at the same time avoid the excess profits taxes. (See items 10 and 11 above.)

6. Problems relating to the determination of fair charges for transportation of oil by pipe line in fixing the base for the 4% tax on transportation of oil by pipe line.

7. Problems relating to the definition of employee and wages under the laws imposing taxes on pay rolls.

This list is only a broad generalization of a few of the important problems confronting the industry as it tackles the problem of making an annual self-assessment of some $1,400,000,000.





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HISTORICAL PRODUCTION CHART

By H. L. Scarborough *

A chronological history of the petroleum industry in California from the beginning of the twentieth century to date is presented in the accompanying drawing. It lists the outstanding developments in the largest industry in the State of California together with other pertinent data associated with its growth from infancy to its present gigantic proportions, wherein it supports many allied industries and contributes millions of dollars in revenue to the State. The chart is intended as a ready reference for those within and without the industry. In a very convenient form, it offers the discovery dates of the various fields and their consequent development; other such important events as the oil workers' strike of 1921 and the following period of intensive development which sent production soaring to over 850,000 bbl. daily; consequent efforts at curtailment; another period of discoveries, including the discovery of Kettleman Hills in October, 1928, with a resulting output of nearly 880,000 bbl. daily in August, 1929—the highest point of output in the history of state production. It shows, more recently, the organization of the present curtailment body, followed by the inauguration of the NIRA Petroleum Code, which became effective September 8, 1933, and was terminated on May 27, 1935; and more recently still, the strenuous curtailment efforts in the early part of 1936, in which the Oil Producers Agency of California played a prominent part.

The compilation of the history outlined hereon in conjunction with the actual production curve affords the opportunity of obtaining at a glance the effect of the multitude of events upon the production of crude petroleum. It also offers a distinct picture of the effort put forth by the petroleum industry to keep the wheels of industry rolling with an assured supply of the petroleum products so necessary to the welfare of the modern business world.

Prior to 1903 production data were not available monthly so the daily average for the year is indicated. Data are from the Standard Oil Company of California (1900-1916), Independent Oil Producers Agency (1917-1921), and from the American Petroleum Institute and the California State Oil Umpire (1922 to date). All of the data have been checked by qualified persons in the industry, all of whom are satisfied as to their correctness.

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* Oil Producers Agency of California.
Manuscript submitted for publication April 3, 1939.

DIVISION OF MINES
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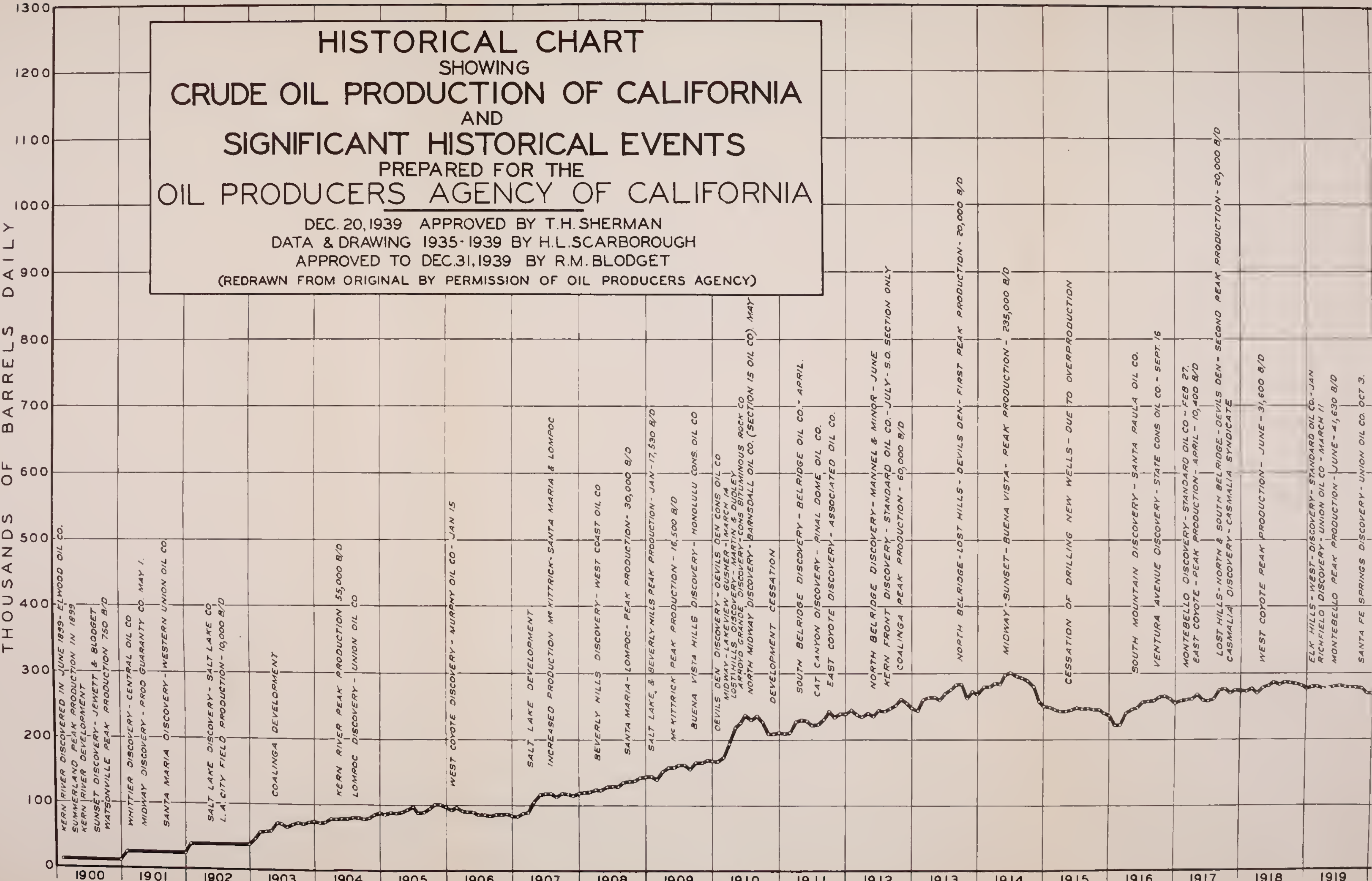
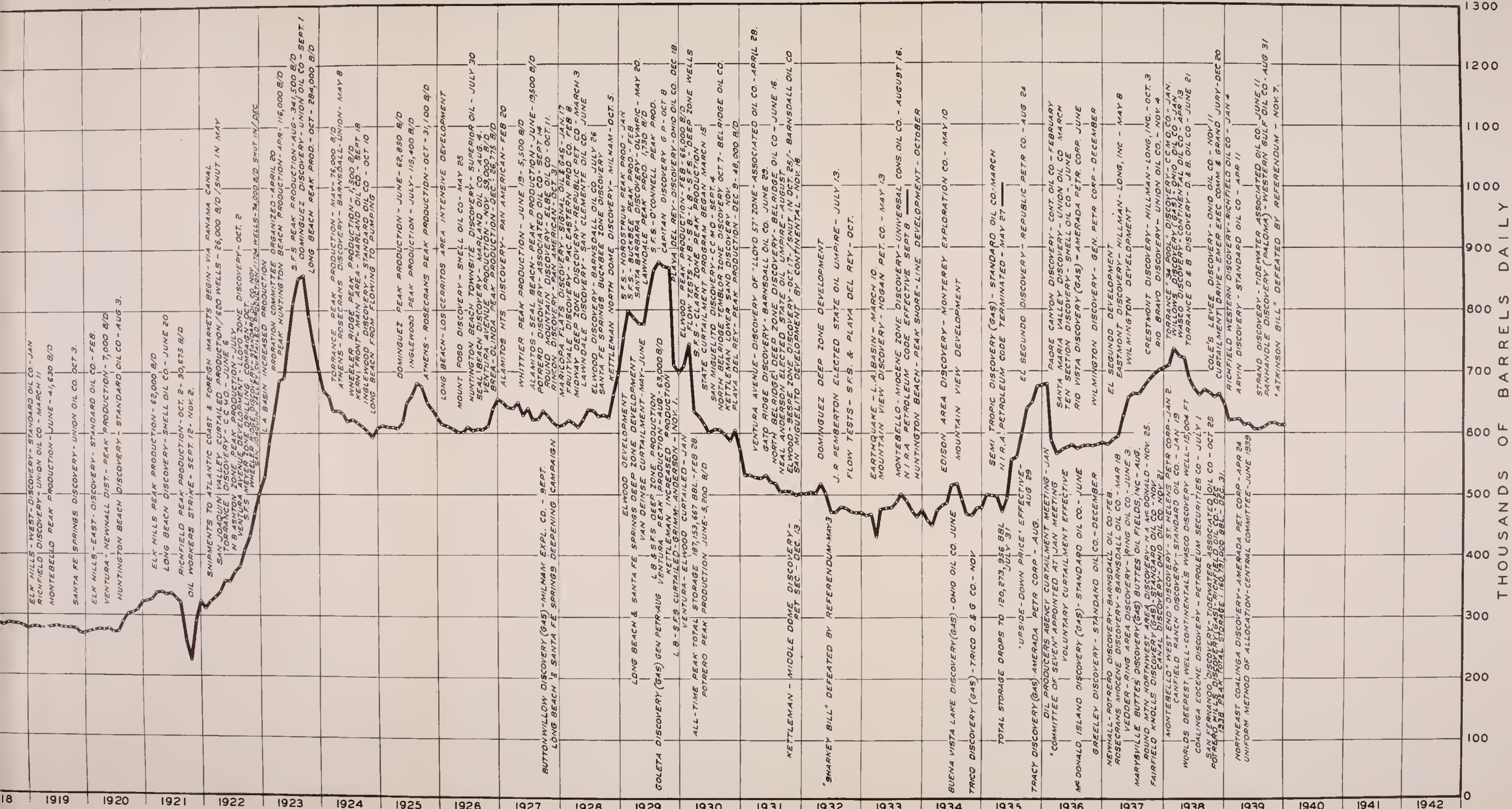


STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
RICHARD SACHSE, DIRECTOR

PLATE I



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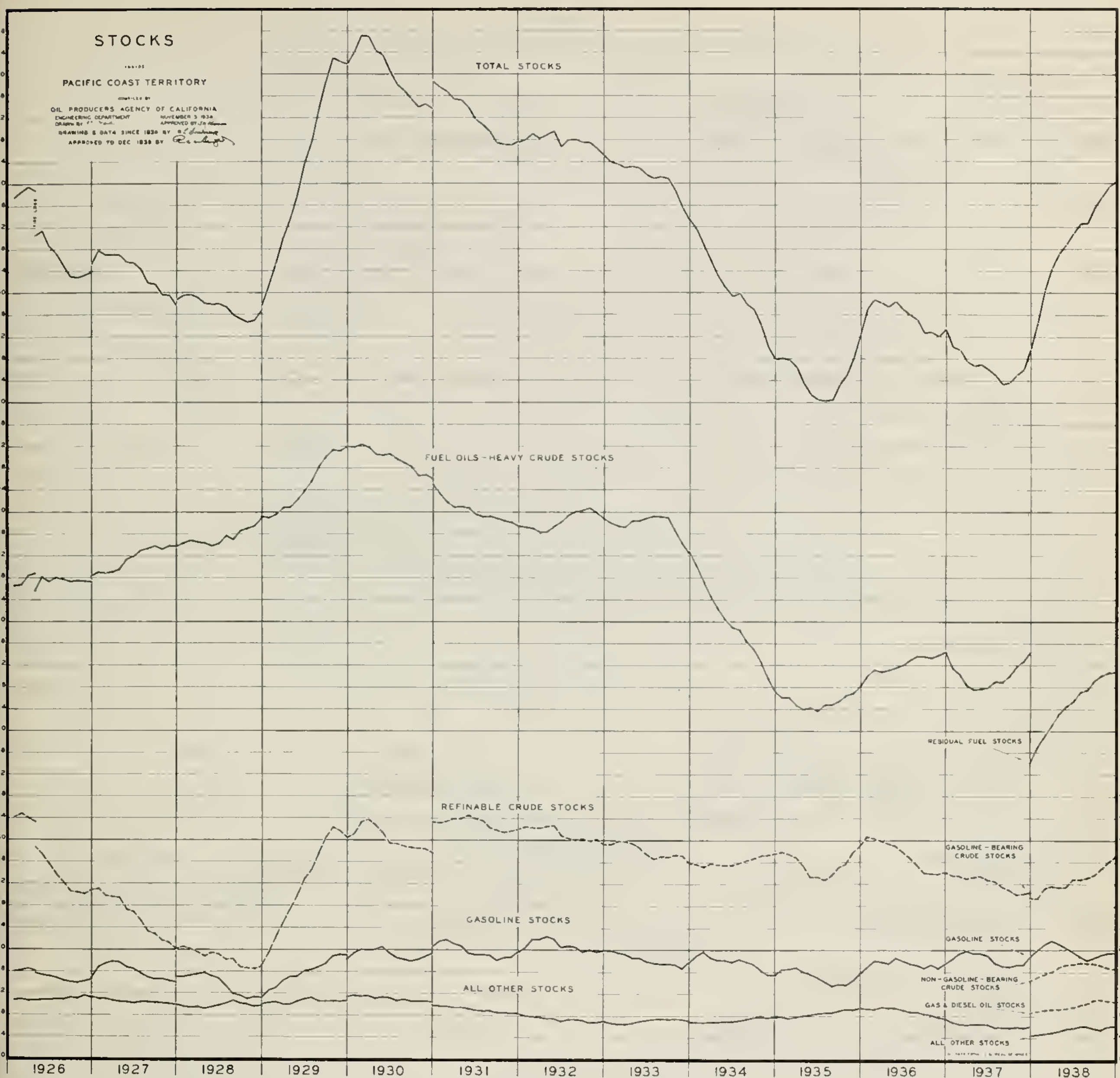


FIG. 3.

STOCKS CHART

BY H. L. SCARBOROUGH *

A graphic presentation of inventories of all petroleum products inside the Pacific Coast Territory (Arizona, California, Nevada, Oregon, and Washington) to and including December 31, 1938, is submitted through the medium of the above chart. Storage of all products on hand at the end of each month from January 31, 1926, to December 31, 1938, has been plotted to give the curves as shown. The "highs" and "lows" for each of the years depicted can very easily be ascertained from this record. In addition, it affords the student of petroleum economics a gauge of the general economic situation in the industry.

The chart is believed to be self-explanatory, with the exception of the revisions which were made at the beginning of the year 1938. Effective January 1938, the U. S. Bureau of Mines made several changes in its monthly report from which data for the chart are taken. Prior to that date, the Bureau had published consolidated figures for residual fuel oil and heavy crude stocks. For the month mentioned, however, the Bureau commenced the publication of data covering three new classifications: (1) gasoline-bearing crude petroleum; (2) non-gasoline-bearing crude petroleum; (3) residual fuel oil. Therefore, with this information available for the first time, the curve "fuel oils—heavy crude stocks," as previously carried on the chart, was split into three curves, namely: (1) non-gasoline-bearing crude stocks; (2) gas and diesel oil stocks; and (3) residual fuel stocks. (Stocks of "gas oil and diesel" were carried individually by the Bureau prior to 1938, but had been combined with "heavy crude and fuel oils" for brevity.) Adjustments in the storage data of the other products listed were due mainly to transfers which were made from "unfinished oils" in order that certain of these oils be classified according to their intended ultimate use.

* Oil Producers Agency of California. Manuscript submitted for publication April 3, 1939.

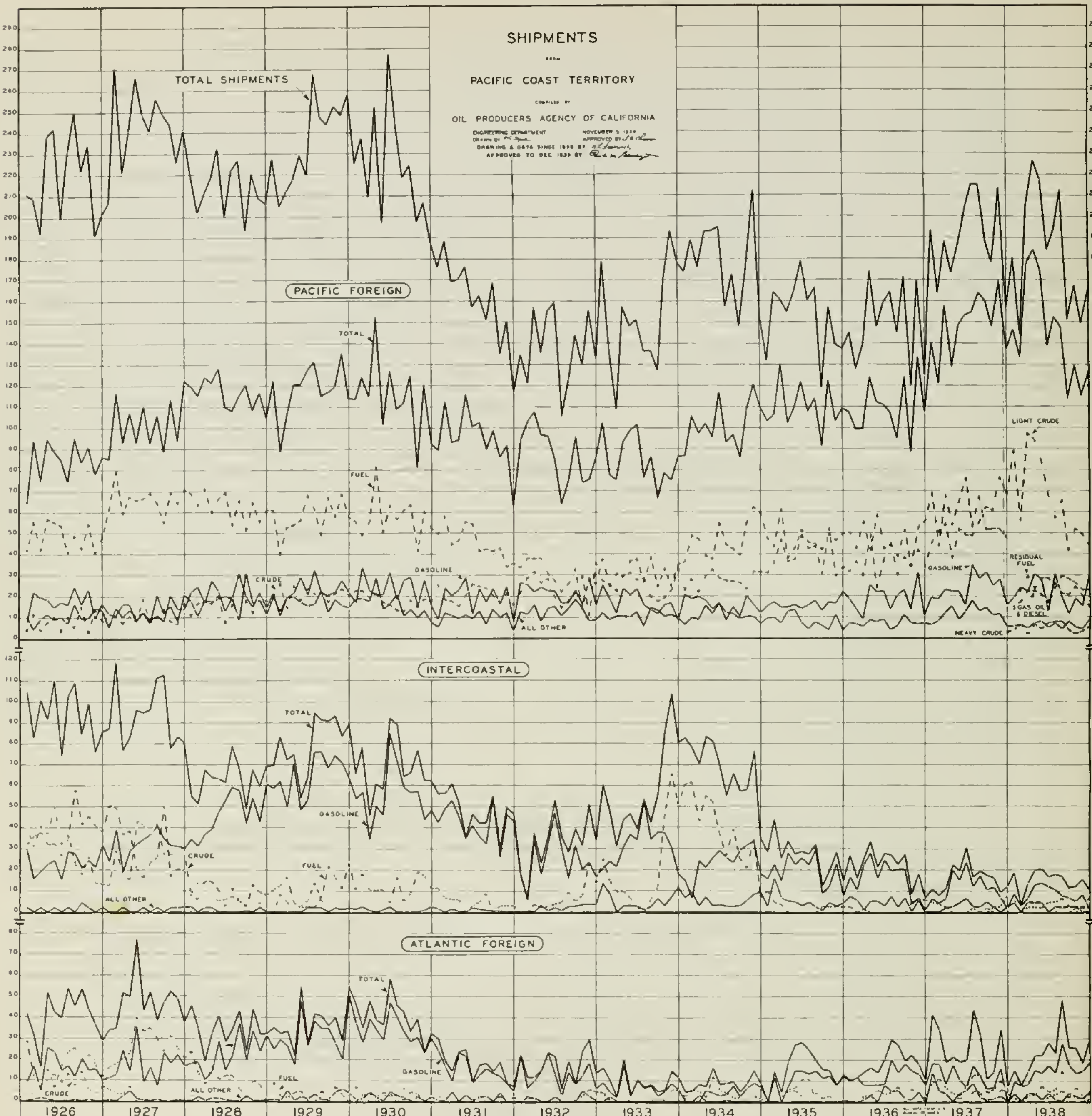


FIG. 4.

SHIPMENTS CHART

(January 31, 1926, to December 31, 1938)

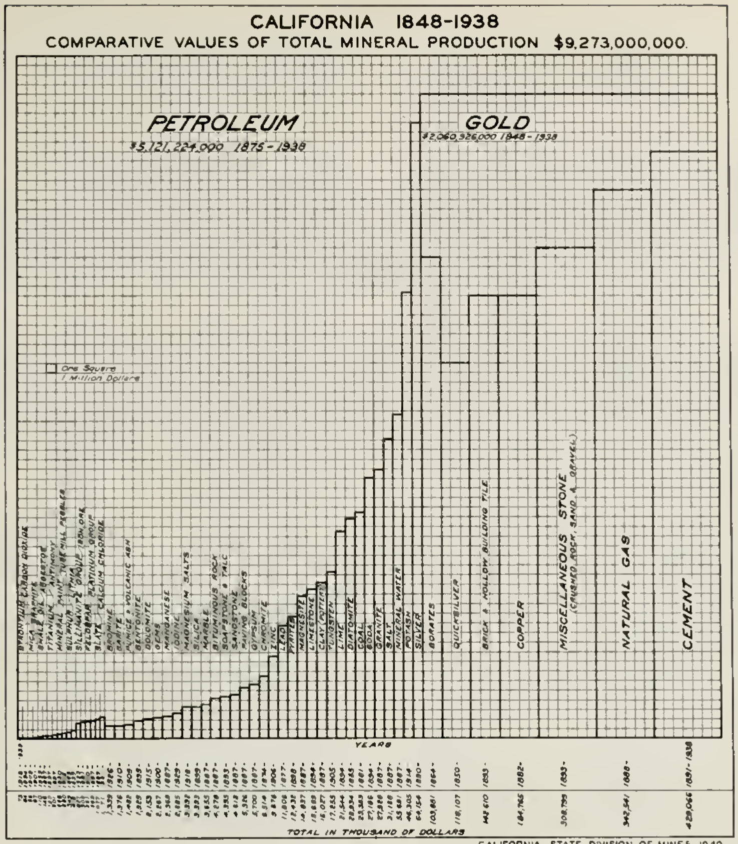
By H. L. SCARBOROUGH *

Shipments from the Pacific Coast Territory, as depicted in the above drawing, represent a considerable proportion of the total utilization of all California petroleum products. During 1938, foreign and east coast markets absorbed 28.35% of the total and in 1937 these same markets accounted for 26.75% of the total of petroleum and its products consumed during the year. Prior to the discovery and development of the Mid-Continent and Texas fields, California enjoyed considerable of the eastern demand for petroleum and also shipped large quantities of oil to Atlantic foreign destinations. Since Texas came into the picture with its great fields almost all of this business has been lost, as can be seen from the chart. In the last few years, however, new markets have been developed to the west, and the export business has shown considerable improvement over the low levels of 1931 and 1932.

The drawing is composed of three geographical divisions: Pacific Foreign, Intercoastal, and Atlantic Foreign. The first portrays shipments to all foreign countries on the Pacific side of North and South America, including the Canal Zone, and all countries westward from California to a line drawn from Suez to Capetown. The second includes all products shipped to ports on the Atlantic and Gulf Coasts of the United States. The last, Atlantic Foreign, is composed of all exports to countries on the Atlantic side of South America and all countries eastward to the line mentioned above. The highest curve on the chart is "total shipments," drawn in the Pacific Foreign division; this is the total of all products shipped to all countries in all divisions. (Shipments to Alaska and Hawaii were not included in the data used to compile this drawing.)

The revisions which were made commencing in January, 1938, were for the reasons outlined on the stocks chart. As the original of the above graph is in color, the new classifications were not "pointed" in any of the divisions except Pacific Foreign, due to lack of space. We realize that the 1938 curves are difficult to follow on this copy; therefore, anyone desiring the data from which the chart was compiled for the year 1938 may obtain them from the Oil Producers Agency of California.

* Oil Producers Agency of California. Manuscript submitted for publication April 3, 1939.


CALIFORNIA 1848-1938
COMPARATIVE VALUES OF TOTAL MINERAL PRODUCTION $9,273,000,000.
PETROLEUM
$5,121,224,000 1875-1938
GOLD
$2,060,326,000 1848-1938
One Square 1 Million Dollars
QUICKSILVER
BRICK & HOLLOW BUILDING TILE
COPPER
MISCELLANEOUS STONE
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YEARS
TOTAL IN THOUSAND OF DOLLARS
CALIFORNIA STATE DIVISION OF MINES, 1940

Fig. 4A

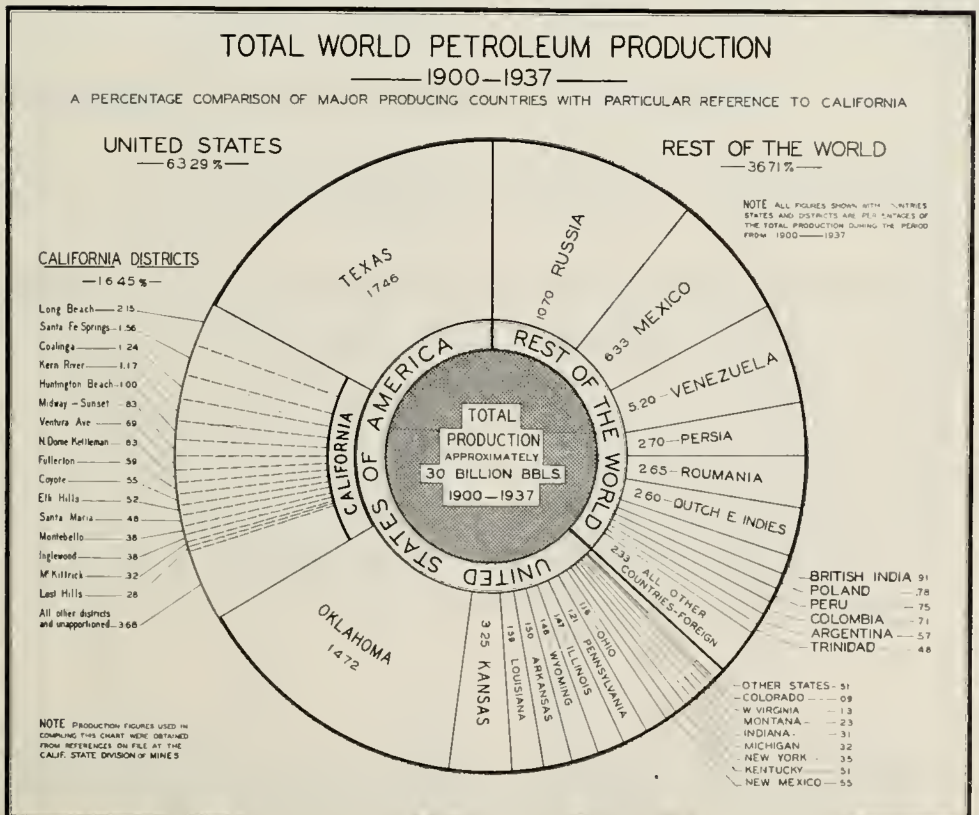
TOTAL WORLD PETROLEUM PRODUCTION
1900—1937
A PERCENTAGE COMPARISON OF MAJOR PRODUCING COUNTRIES WITH PARTICULAR REFERENCE TO CALIFORNIA
UNITED STATES
63 29 %
REST OF THE WORLD
36 71 %
CALIFORNIA DISTRICTS
16 45 %
Long Beach 2 15
Santa Fe Springs 1.56
Coalinga 1 24
Kern River 1.17
Huntington Beach 1 00
Midway – Sunset 83
Ventura Ave 69
N. Dome Kettleman 63
Fullerton 59
Coyote 55
Elk Hills 52
Santa Maria 48
Montebello 38
Inglewood 38
McKittrick 32
Lost Hills 28
All other districts and unapportioned 3 68
TEXAS 17 46
RUSSIA 10 70
6 33 MEXICO
5 20 VENEZUELA
2 70 PERSIA
2 65 ROUMANIA
2 60 DUTCH E. INDIES
2 33 ALL OTHER COUNTRIES-FOREIGN
BRITISH INDIA 91
POLAND 78
PERU 75
COLOMBIA 71
ARGENTINA 57
TRINIDAD 48
CALIFORNIA
UNITED STATES OF AMERICA
REST OF THE WORLD
TOTAL PRODUCTION APPROXIMATELY 30 BILLION BBLS 1900—1937
OKLAHOMA 14 72
3 25 KANSAS
1 59 LOUISIANA
1 50 ARKANSAS
1 48 WYOMING
1 47 ILLINOIS
1 21 PENNSYLVANIA
1 16 OHIO
OTHER STATES 51
COLORADO 09
W VIRGINIA 13
MONTANA 23
INDIANA 31
MICHIGAN 32
NEW YORK 35
KENTUCKY 51
NEW MEXICO 55
NOTE PRODUCTION FIGURES USED IN COMPILING THIS CHART WERE OBTAINED FROM REFERENCES ON FILE AT THE CALIF. STATE DIVISION OF MINES

Fig. 4B

SIGNIFICANT STATISTICS CHARACTERISTIC OF CRUDE OIL PRODUCTION OF CALIFORNIA

LOS ANGELES BASIN

AS OF JANUARY 1, 1939 PREPARED BY WM. R. WARONER

DISTRICT FIELD AND POOL	DATE OF DISCOVERY	AGE YEARS TO JAN.1,1939	NO. OF* WELLS	PROVEN AREA-ACRES	TOTAL OIL PRODUCTION THOUSANDS BARRELS: YEAR 1938	TOTAL OIL PRODUCTION THOUSANDS BARRELS: CUMULATIVE TO JAN.1,1939	AVERAGE OIL RECOVERY: PER WELL* BARRELS	AVERAGE OIL RECOVERY: PER PROVEN* ACRE BBLS.	AVERAGE* NUMBER OF ACRES PER WELL	WELL DEPTH: AVERAGE DEPTH FEET	WELL DEPTH: DEPTH TESTED	GRAVITY OF OIL: RANGE	GRAVITY OF OIL: WEIGHTED AVERAGE	PEAK PRODUCTION: MONTH & YEAR	PEAK PRODUCTION: PRODUCTION B/D
LOS ANGELES BASIN															
ALAMITOS HEIGHTS															
All Pools	June 1931	7 yrs. 7 mos.	47	110	602	22,715	483,298	206,500	2.3	5,810	9,054	16.0-27.8	26.8	Sept. 1927	40,158
BREA-OLINDA DISTRICT			415	1,380	2,100	161,774	389,817	117,228	3.3		8,201			Dec. 1926	26,776
BREA	1899	39 yrs.	115	450	1,356				3.9	3,867		16.6-26.0	24.5		
OLINDA	May 1897	41 yrs. 8 mos.	266	650	744				2.4	2,579		14.0-31.5	20.0		
TONNER	May 1920	18 yrs. 8 mos.	34	280					8.2	2,608					
COYOTE EAST			109	780	1,243	78,783	722,780	101,004	7.2		9,084				
Graham-Loftus-Hualde	May 1911	27 yrs. 10 mos.	90	580	577	77,199	857,767	133,102	6.4	3,343		18.0-26.5	20.6		
Mathis	Aug. 1927	11 yrs. 5 mos.	18	180	646	1,407	78,167	7,817	10.0	4,707		18.4-25.6	24.3		
Stern	Aug. 1929	9 yrs. 5 mos.	1	20	20	177	177,000	8,850	20.0	6,910		26.5-26.5	26.5		
COYOTE WEST			146	900	3,093	77,773	632,692	86,414	6.2		8,144	24.0-31.4	28.9		
Murphy	Apr. 1909	29 yrs. 9 mos.	90		1,460					3,988					
Ninety-nino	May 1924	14 yrs. 8 mos.	22		1,090					4,307					
Emery	Mar. 1930	8 yrs. 10 mos.	34		543					5,905					
DOMINGUEZ			221	810	9,742	106,989	484,113	132,085	3.7		10,435			Jan. 1925	56,982
Pliocene	Sept.1923	15 yrs. 4 mos.	180		6,841	98,240	545,778			4,694		28.0-31.5	30.3		
Miocene	May 1934	4 yrs. 8 mos.	41		2,901	8,749	213,390			7,247		27.7-35.3	30.6		
EL SEGUNDO															
All Pools	Aug. 1936	3 yrs. 5 mos.	56	700	3,869	7,681	137,161	10,973	12.5	7,316	8,009	16.5-28.7	21.8	Oct. 1937	21,889
HUNTINGTON BEACH NEW			273	570	6,485	71,515	261,960	126,465	2.1		9,054				
East Area															
Tar	July 1926	12 yrs. 6 mos.	43	60	185					2,182		11.0-19.0	17.4		
Main			168)		4,116					4,408		14.8-26.8	24.6		
West Area	Sept.1926	12 yrs. 4 mos	)	510											
Main			62)		2,184					4,395		19.8-26.0	23.9		
Tideland			73	190	4,379	35,641								Nov. 1933	35,327
HUNTINGTON BEACH OLD			395	1,700	5,412	199,362	504,714	117,272	4.3					Apr. 1923	112,000
Tar-Bolsa	Aug. 1920	18 yrs. 5 mos.	63	350	686				5.6	2,738		12.6-26.1	20.5		
Ashton	Apr. 1921	17 yrs. 9 mos.	332	1,350	4,726				4.1	4,222		14.5-26.3	23.5		
INGLEWOOD			291	860	5,336	111,841	384,333	130,048	3.0		6,508			Aug. 1925	104,212
Vickers-Machado	Sept.1924	14 yrs. 4 mos.	238	860	2,064	100,361	421,686	116,699	3.6	2,382		16.0-29.8	19.3	Aug. 1925	104,212
Rindge	July 1925	13 yrs. 6 mos.	30	150	1,564	6,266	208,867	41,773	5.0	3,280		13.7-38.0	27.7	May 1937	5,844
Rubel	Aug. 1934	4 yrs. 5 mos.	22	135	1,704	5,188	235,818	38,430	6.1	3,832		14.1-35.6	31.7	Dec. 1937	5,565
Moynier	Feb. 1932	6 yrs. 11 mos.	1	10	4	26	26,000	2,600	10.0	6,466		17.0-17.0	17.0		
LONG BEACH			1,266	1,310	20,485	616,552	487,008	470,650	1.0		10,157			Oct. 1923	244,527
Old Area	June 1921	17 yrs. 7 mos.	1,242	1,260	19,290	615,357	495,457	488,379	1.0	5,278		12.0-32.1	25.2	Oct. 1923	244,527
Northwest Extension Area	July 1937	1 yr. 6 mos.	24	50	1,196	1,195	49,792	23,900	2.1	4,416		22.6-25.0	23.3	July 1938	4,342
LOS ANGELES DISTRICT			107	400	180	65,482	-	-			5,084				
BEVERLY HILLS	July 1900	29 yrs. 6 mos.	4		42		-	-		2,840		14.6-17.6	15.9		
LOS ANGELES	1892	46 yrs.	95		53		-	-		894		15.0-15.0	15.0		
SALT LAKE	1902	36 yrs.	8		85		-	-		1,960		13.3-14.5	13.6		
MONTEBELLO			266	1,240	4,169	107,759	405,109	86,902	4.7		8,265			June 1919	38,051
Main Area			214	980	2,155	103,643	484,313	105,758	4.6					June 1919	38,051
Baldwin One-Two	Feb. 1917	21 yrs. 11 mos.	201		1,918					3,202		12.6-36.0	23.6		
Baldwin Three	Dec. 1924	14 yrs. 1 mo.	13		237					3,878		22.0-32.0	26.5		
Montebello Extension Area			20	90	333	2,435	121,750	27,056	4.5						
Cruz	Sept.1933	5 yrs. 4 mos.	2		10	157	78,500			7,043		37.0-37.0	37.0		
Nutt	Feb. 1935	3 yrs. 11 mos.	18		323	2,278	126,556			5,887		30.0-39.0	36.7	July 1936	4,461
West End Area	Dec. 1937	1 yr. 1 mo.	32	200	1,681	1,681	52,531	8,405	6.3	6,091		35.0-38.0	36.4	Dec. 1938	9,962 x
PLAYA DEL REY			204	640	2,275	42,996	210,765	67,181	3.1		7,048			Nov. 1930	40,347
Del Rey Hills Area	Nov. 1934	4 yrs. 2 mos.	53	200	841	7,009	132,245	35,045	3.8	6,335		18.0-24.0	22.0	June 1935	14,694
Venice Area			151	440	1,434	35,987	238,325	81,789	2.9					Nov. 1930	40,347
Upper	July 1930	8 yrs. 6 mos.	93		872					4,501)					
Lower	Dec. 1929	9 yrs. 1 mo.	58		562					5,979)		10.9-24.4	20.1		
POTRERO															
All Pools	Apr. 1928	10 yrs. 9 mos.	13	110	225	2,486	191,231	22,600	8.5	5,592	8,376	33.0-47.8	43.9	June 1930	3,981

LOS ANGELES BASIN—CONTINUED

RICHFIELD	Mar. 1919	19 yrs. 10 mos.	301	1,202	3,133	83,741	278,209	69,668	4.0		10,496			Oct. 1921	27,939
East Area			227		1,468										
Chapman			88		592					3,287		14.1-25.6	18.7		
Kraemer			139		876					4,512		15.7-28.8	21.4		
West Area			74		1,665										
Chapman			32		539					3,656		15.0-25.5	19.5		
Kraemer			42		1,126					4,496		13.0-25.5	21.2		
ROSECRANS-ATHENS			125	295	3,737	36,096	288,768	122,359	2.4		10,389			Oct. 1925	25,437
Rosecrans Area			86	236	3,525				2.7						
Maxwell-Hoge	Aug. 1924	14 yrs. 5 mos.	28		349					4,848		31.5-42.0	38.8		
Zinns	Nov. 1927	11 yrs. 2 mos.	22		466					6,156		31.3-36.3	33.8		
Miocene	Mar. 1937	1 yr. 10 mos.	36	120	2,710	3,116	86,556	25,967	3.3	7,723		30.9-33.7	33.1	Nov. 1938	12,980 x
Athens Area			39	60	212				1.6						
Upper	Feb. 1925	13 yrs. 11 mos.	16		88					4,495)					
Lower	May 1924	14 yrs. 8 mos.	23		124					5,197)		32.0-40.0	36.2		
SANTA FE SPRINGS			676	1,240	12,617	449,153	664,428	362,220	1.8	5,371	11,314	9.0-38.0	32.5	Aug. 1923	322,522
Foix	May 1922	16 yrs. 8 mos.	7	70		2,875	410,714	41,071	10.0					Dec. 1922	6,434
Bell	Oct. 1921	17 yrs. 3 mos.	88	320	1,662	48,254	548,341	150,794	3.6					Nov. 1922	50,586
Meyer	Oct. 1919	19 yrs. 3 mos.	357	1,240	5,322	214,236	600,100	172,771	3.6					Aug. 1923	306,071
Nordstrom	Nov. 1926	10 yrs. 2 mos.	41	150	1,194	29,510	719,756	196,733	3.7					Jan. 1929	54,343
Buckbee	July 1928	10 yrs. 6 mos.	66	260	1,257	36,079	555,062	128,864	4.3					Feb. 1929	113,947
O'Connell	Feb. 1929	9 yrs. 11 mos.	57	350	1,922	70,871	1,243,351	202,489	6.1					July 1929	203,762
Clark-Hathaway	June 1929	9 yrs. 7 mos.	60	480	1,218	47,286	788,100	98,513	8.0					Jan. 1930	114,379
Deep Zone			1		42	42	42,000							Nov. 1938	176
SEAL BEACH			93	320	2,599	59,508	639,871	185,963	3.4		9,054			July 1929	43,646
Bixby-Selover	Aug. 1926	12 yrs. 5 mos.	20	285	508	21,961	1,098,050	77,056	14.3	4,793		10.0-25.0∅	16.6∅		
Wasem	June 1927	11 yrs. 7 mos.	51	320	1,495	31,947	626,412	99,834	6.3	5,286		11.0-28.2∅	28.5∅		
McGrath	Feb. 1928	10 yrs. 11 mos.	22	235	596	5,600	254,545	23,830	10.7	6,428		16.0-28.9∅	26.4∅		
TORRANCE-HERMOSA			722	4,060	5,176	90,805	125,769	22,366	5.6		6,597			May 1924	57,538
Hermosa Area			6	40	36	392	65,333	9,800	6.7	3,171		14.0-16.0	15.1		
Torrance Area			683		4,769										
Main	June 1922	16 yrs. 7 mos.	461	3,600	1,850	86,079	186,722	23,911		3,527		13.3-25.2	19.3	May 1924	57,538
Flint			14		75	204	14,571			4,475		19.6-24.0	22.4		
Thirty-four)	June 1938	7 mos.	168	350	2,420	2,420	14,405	6,914		4,976		15.0-27.0	25.6)	Oct. 1938	13,750 x
D & B)			40	235	424	424	10,600			5,261			)		
Torrance Extension Area	Mar. 1936	2 yrs. 10 mos.	33		371	1,286	38,970			3,659		13.0-20.8	16.9	Aug. 1936	2,086
WHITTIER			176	540	344	17,702	100,580	32,762	3.1		5,040				
Bartolo Area	July 1935	3 yrs. 6 mos.	3	15	8					3,200		27.0-27.1	27.1	Dec. 1935	82
Central Area	1898	40 yrs.	162	485	291					2,054		14.3-22.5	16.9)		
Rideout-Heights Area	1901	37 yrs.	11	40	45					2,621		14.0-29.5	21.7)	Year 1917	3,170
WILMINGTON			594	4,025	34,044	40,284	81,286	11,981	6.8		6,814			Feb. 1938	100,770
Long Beach Harbor Area			186	1,239	15,620	15,620	83,978	12,607	6.7					Nov. 1938	51,676
Ranger Zone	Jan. 1938	1 yr.	79		3,448	3,448	43,646			3,097		15.0-27.3	20.1	Nov. 1938	11,356
Terminal Zone	Jan. 1938	1 yr.	107		12,172	12,172	113,757			3,873		20.0-26.0	26.1	Nov. 1938	40,319
Wilmington Area			408	2,786	18,424	32,664	80,059	11,724	6.8						
Terminal	Dec. 1936	2 yrs. 1 mo.	119	1,220	9,979	16,718	140,487		10.3	3,558		16.2-24.2	22.5	May 1937	36,293
Town Lot	Jan. 1935	4 yrs.	289	1,566	8,445	15,946	55,176		5.4	3,617		12.7-30.3	16.3	Oct. 1937	35,246
OTHER FIELDS			81	370	302	3,384	41,778	9,146	4.6						
ALISO CANYON	Oct. 1938	3 mos.	1	20	23	23	23,000	1,150	20.0	5,359	5,392			Nov. 1938	346x
CHINO	Apr. 1931	7 yrs. 9 mos.	2	20		-	-			2,260					
KRAEMER	Sept. 1918	20 yrs. 4 mos.	11	60	41	1,378	125,273	22,967	5.5	2,950		18.2-19.5	19.4		
LAWNDALE	Dec. 1928	10 yrs. 1 mo.	6	30	26	1,030	171,667	34,333	5.0	5,841	7,406	23.0-29.0	25.9	June 1929	1,729
NEWPORT						129									
PUENTE HILLS	About 1880	58 yrs.	42	120	21	610	14,524	5,083	2.9	2,500		25.2-25.2	25.2		
YORBA LINDA	July 1937	1 yr. 6 mos.	19	120	191	214	11,263	1,783	6.3					July 1938	690
Shell			1	20		2	2,000	100	20.0	2,325					
Smith			18	100		212	11,778	2,120	5.5	1,815					
LOS ANGELES BASIN TOTAL:			6,577	23,562	127,168	2,462,381	374,393	104,506	3.6						
STATE TOTAL:			18,826	139,489	249,123	5,156,223	273,888	36,965	7.4						

* Based on number of wells capable of production January 1, 1939. (Abandonments not available).
∅ Based on Wet Gravities
a Nominal acreage
x Apparent peak production not reached as of January 1, 1939.

SIGNIFICANT STATISTICS CHARACTERISTIC OF CRUDE OIL PRODUCTION OF CALIFORNIA

COAST AND TRANSVERSE RANGES

AS OF JANUARY 1, 1939 PREPARED BY WM R WARONER

DISTRICT FIELD AND POOL	DATE OF DISCOVERY	AGE YEARS TO JAN.1,1939	NO. OF WELLS*	PROVEN AREA-ACRES	TOTAL OIL PRODUCTION THOUSANDS BARRELS YEAR 1938	CUMULATIVE TO JAN.1,1939	AVERAGE OIL RECOVERY PER WELL* BARRELS	PER PROVEN ACRE BBLS.	AVERAGE* NUMBER OF ACRES PER WELL	WELL DEPTH AVERAGE DEPTH FEET	DEPTH TESTED	GRAVITY OF OIL RANGE	WEIGHTED AVERAGE	PEAK PRODUCTION MONTH & YEAR	PRODUCTION B/D
COASTAL															
SANTA BARBARA DISTRICT															
CAPITAN			55	260	1,067	3,380	61,454	13,000	4.7		4,071			Mar. 1938	3,116
Vaqueros	Oct. 1929	9 yrs. 3 mos.	31	190	816	1,860				1,399		16.0-21.7	21.2	May 1938	2,477
Sespe	Jan. 1931	8 yrs.	24	260	251	1,520				2,734		34.9-43.0	42.1	Nov. 1935	2,000
ELWOOD			82	520	2,248	64,424	785,658	123,892	6.3		7,157			May 1930	46,983
Vaqueros	July 1928	10 yrs. 6 mos	66	520	2,027	62,375				3,128		21.6-36.3	33.7	May 1930	46,983
Sespe	Oct. 1931	7 yrs. 3 mos.	16	210	221	2,049				3,904		28.1-41.1	32.6	May 1936	3,542
SANTA BARBARA															
Vaqueros	May 1929	9 yrs. 8 mos.	35	102	159	3,095	86,429	30,343	2.9	2,026	4,730	13.7-18.9	17.0	Jan. 1935	4,422
SUMMERLAND															
All Pools	1894	44 yrs.	9	40	11	3,136	348,444	78,400	4.4	876	5,041	17.3-18.9	18.0	1899	570
SANTA MARIA DISTRICT			561	12,975	6,052	144,433	257,456	11,132	23.1						
CASMALIA															
All Pools	1904	34 yrs.	71	1,010	.91				14.2	1,679	3,900	8.5-20.7	10.3		
CAT CANYON			71	865	135				12.2						
East)	1908	30 yrs.	27		5					3,352)		10.0-14.0	12.0		
West)			43		112					2,844)	7,199	14.6-15.5	14.6		
Las Flores	Aug. 1938	5 mos.	1		18					6,440	6,556				
GATO RIDGE															
Tognazzini	June 1931	7 yrs. 7 mos.	14	600	1,508	2,403	171,643	4,005	42.9	3,174	6,510	13.6-14.0	13.9	Aug. 1938	9,279 x
LOMPOC															
All Pools	Feb. 1903	35 yrs. 11 mos.	36	2,700	85				75.0	2,711	4,310	20.0-21.0	20.5		
ORCUTT															
All Poole	1903	35 yrs.	231	3,300	867				14.3	3,175	5,815	18.0-26.0	22.6		
SANTA MARIA VALLEY															
Moretti	Sept.1934	4 yrs. 4 mos.	138	4,500	3,311	5,002	36,246	1,112	32.6	4,477	8,133	13.0-17.0	16.9	Sept. 1938	11,863 x
VENTURA DISTRICT															
PADRE CANYON															
All Pools	Feb. 1936	2 yrs. 11 mos.	9	100	290	775	86,111	7,750	11.1	5,929	7,291	28.1-31.0	29.1	June 1937	1,235
RINCON															
Hobson-Tomson-Miley	Dec. 1927	11 yrs. 1 mo.	53	495	1,394	9,728	163,547	19,653	9.3	3,812	7,449	26.8-30.6	30.0	Oct. 1928	4,764
SAN MIGUELITO			10	300	753	3,230	323,000	10,767	30.0		10,030			Feb. 1938	3,108
Hobson	Sept.1931	7 yrs. 4 mos.	1		25	179				7,825		29.6-29.6	29.6		
Grubb One	Nov. 1931	7 yrs. 2 mos.	8		680	2,773				6,822		30.0-34.0	32.0		
Grubb Two	July 1933	5 yrs. 6 mos.	1		48	278				7,926		30.0-30.0	30.0		
VENTURA AVENUE			346	1,905	12,917	200,331	560,090	105,161	5.5		11,070			Aug. 1929	62,040
Gosnell-Lloyd	Sept.1916	22 yrs. 4 mos.	272		7,360)					6,246		12.4-50.0	27.8		
Edison	Oct. 1926	12 yrs. 3 mos.	47		1,084)	187,173	586,749			7,188		25.5-31.8	30.1		
Fifty-seven	Apr. 1931	7 yrs. 9 mos.	27		4,453	13,158	487,333			9,216		26.0-32.0	30.7	Aug. 1938	14,215 x

COAST AND TRANSVERSE RANGES—CONTINUED

BALANCE OF VENTURA COUNTY			629	3,705	1,608	53,777	65,496	14,515	5.9						
VENTURA-OJAI			18	110	20				6.1						
LION MOUNTAIN	May 1935	3 yrs. 8 mos.	4	60	16				15.0	1,744		20.0-20.0	20.0		
TIPTOP-FRESNO CANYON	1918	23 yrs.	14	50	4				3.6	844		22.0-23.0	22.8		
FILLMORE			198	1,055	536				5.3						
BARDSDALE	1894	44 yrs.	34	140	57				4.1	888	6,604	22.4-33.1	32.1		
SESPE	1887	51 yrs.	37	505	95				13.6	1,661	3,595	18.6-32.2	20.6		
SHIELLS CANYON	Apr.1911	27 yrs. 9 mos.	126	350	377				2.8	1,927	7,423	28.0-36.0	35.1		
TOPA-TOPA			1	60	7				60.0	3,244		33.3-33.3	33.3		
PIRU			101	735	374				7.3						
HOPPER CANYON	1887	51 yrs.	12	80	38				6.7	1,745	2,200	17.9-31.1	29.0		
MODELO	1898	40 yrs.	14	60	4				4.3	2,050		26.1-26.1	26.1		
TAPO-EUREKA	1893	45 yrs.	22	170	11				7.7	995	2,956	21.0-23.5	22.4		
TEMESCAL	Nov.1924	14 yrs. 2 mos.	12	235	271				19.6	2,411	4,584	21.4-23.8	22.0	Aug. 1937	990
TORREY CANYON	1896	42 yrs.	41	190	50				4.6	1,363	2,500	27.5-27.5	27.5		
SANTA PAULA			199	1,335	598				6.7						
EX-MISSION	1875	63 yrs.	25	130	12				5.2	1,585		18.0-28.0	25.2		
SISAR-SILVERTHREAD	1885	53 yrs.	73	330	47				4.5	663	3,934	15.0-24.0	18.5		
SOUTH MOUNTAIN	Apr.1916	22 yrs. 9 mos.	92	725	526				7.9	3,361	6,702	19.7-26.7	23.9		
SULPHUR MOUNTAIN	Nov.1927	11 yrs. 2 mos.	1	40	4				40.0	2,500		15.5-15.5	15.5		
TIMBER CANYON	1885	53 yrs.	8	110	9				13.8	2,605	3,300	24.9-34.0	28.7		
SIMI-CONEJO-OXNARD			113	470	80				4.2						
CONEJO	1892	46 yrs.	53	40					.8	100)	4,285				
OXNARD	June 1937	1 yr. 7 mos.	3	100	43				33.3	3,393)		8.0- 9.0	8.0		
SIMI	1912	26 yrs.	57	330	37				5.8	1,213		16.5-31.8	28.1		
NEWHALL			86	533	308	6,008	69,860	11,272	6.2						
ELSMERE CANYON	1889	49 yrs	9	60					6.7		2,117				
NEWHALL	1889	49 yrs.	23	160	38				7.0	1,496	1,468)	14.2-21.5	20.8		
											3,504)				
NEWHALL-POTRERO	May 1937	1 yr. 8 mos.	4	150	242	278			37.5	6,787		33.0-33.0	33.0	Aug. 1938	963 x
PICO CANYON	1875	63 yrs.	36	95	22				2.6	1,613	3,445	35.4-38.0	37.3		
RICE CANYON	1889	49 yrs.		40											
WILEY-TOWSLEY CANYON	1887-1900	51 yrs.	14	28	6				2.0	606	3,835	20.0-27.2	23.6		
OTHER COASTAL COUNTIES															
SAN LUIS OBISPO			22	300	32	783	35,591	2,610	13.6						
EDNA	1911	27 yrs.	17	200	21	714			11.8	1,151	4,424	13.0-14.0	13.3		
HUASNA	July 1928	10 yrs. 6 mos.	2	60	11				30.0						
PISMO	May 1935	3 yrs. 9 mos.	3	40		69			13.3	2,942		22.0-22.0	22.0	May 1936	285
SAN MATEO															
HALF MOON BAY	1886	52 yrs.	13	80	2	36	2,769	450	6.2	2,065					
SANTA CLARA			22	60	8	341	15,500	5,683	2.7						
LOS GATOS			13			51									
SARGENT			9	60	8	290			6.7	1,335		13.0-13.0	13.0		
COASTAL TOTAL:			1,932	21,375	26,849	493,477	255,423	23,087	11.1						

SIGNIFICANT STATISTICS CHARACTERISTIC OF CRUDE OIL PRODUCTION OF CALIFORNIA

SAN JOAQUIN VALLEY

AS OF JANUARY 1, 1939 PREPARED BY WM R. WARDNER

DISTRICT FIELD AND POOL	DATE OF DISCOVERY	AGE YEARS TO JAN.1,1939	NO. OF WELLS*	PROVEN AREA-ACRES	TOTAL OIL PRODUCTION THOUSANDS BARRELS: YEAR 1938	TOTAL OIL PRODUCTION THOUSANDS BARRELS: CUMULATIVE TO JAN.1,1939	AVERAGE OIL RECOVERY: PER WELL* BARRELS	AVERAGE OIL RECOVERY: PER PROVEN ACRE BBLS.	AVERAGE* NUMBER OF ACRES PER WELL	WELL DEPTH: AVERAGE DEPTH FEET	WELL DEPTH: DEPTH TESTED	GRAVITY OF OIL: RANGE	GRAVITY OF OIL: WEIGHTED AVERAGE	PEAK PRODUCTION: MONTH & YEAR	PEAK PRODUCTION: PRODUCTION B/D
SAN JOAQUIN VALLEY															
BELRIDGE NORTH			92	1,570	4,838	32,039	328,686	20,407	17.1		9,492				
Shallow	June 1912	26 yrs. 7 mos.	18	200	9	4,610	256,111	23,050	11.1	2,412		13.7	13.7		
Temblor	Oct. 1930	8 yrs. 3 mos.	18	550	586	15,810	878,333	28,746	30.6	5,457		36.2-41.7	41.1	Dec. 1932	8,448
Wagon Wheel	June 1932	6 yrs. 7 mos.	56	1,570	4,243	11,619	207,482	7,401	28.0	8,346		30.8-38.0	35.9	Nov. 1937	12,863
BELRIDGE SOUTH															
Shallow	Apr. 1911	27 yrs. 9 mos.	258	1,600	429	21,172	82,062	13,233	6.2	874		13.8-26.3	24.0	See Lost Hills - Main	
BUENA VISTA			891	11,700	6,418	265,153	297,590	22,663	13.1						
Buena Vista Front			221	3,500	1,754				15.8	4,020		24.0-27.0	26.7	See Midway	
Buena Vista Hills	1909	29 yrs.	670	8,200	4,664				12.2	3,043		22.5-28.7	26.5		
CANAL															
All Pools	Nov. 1937	1 yr. 2 mos.	15	800	847	879	58,600	1,099	53.3	8,291		36.2-38.5	37.5	Dec. 1938	3,837 x
COALINGA EAST			608	5,300	1,967	215,655	354,696	66,924	8.7	2,097		19.1-21.6	21.0		
Temblor	1900	38 yrs.	609	4,100	1,721	215,409	359,614	52,539	6.8	2,105				(Inc.West)1912	53,500
Eocene	July 1938	6 mos.	9	1,200	246	246	27,333	205	133.3	7,450	8,108			Dec. 1938	2,850 x
Cretaceous										1,200					
COALINGA WEST															
Main	1901	37 yrs.	719	4,200	1,882	140,725	195,723	33,506	5.8	1,583	4,833	12.7-23.0	15.8	See Coalinga East Temblor	
COFFEE CANYON			65	430	1,356	7,605	117,000	17,686	6.6						
New Area	Apr. 1935	3 yrs. 9 mos.	34	215	1,078	2,554	75,118	11,879	6.3	1,630		14.5-17.0	16.5	Apr. 1937	4,494
Old Area	May 1927	11 yrs. 8 mos.	31	215	278	5,051	162,935	23,493	6.9	1,670		14.2-16.0	15.3	Apr. 1933	2,900
EDISON			88	1,250	1,092	5,640	64,091	4,512	14.2					Aug. 1936	6,022
First Duff	July 1934	5 yrs.	61		746	3,836	62,885			1,671		15.0-26.0	17.9	Aug. 1936	4,501
Second Duff	May 1934	4 yrs. 8 mos.	27		346	1,804	66,815			3,290		16.0-25.4	21.1	June 1936	1,668
ELK HILLS			251	7,647	3,878	146,000	581,673	19,093	30.6		8,404			May 1921	60,823
Tupman Area	Feb. 1920	18 yrs. 11 mos.	215	7,007	3,878				32.6	3,118		15.0-25.0	22.1		
Hay-Carmen Area	Jan. 1919	20 yrs.	36	640	-				17.8	3,093					
FRUITVALE															
Martin-Kernco	Feb. 1928	10 yrs. 11 mos.	179	1,710	3,027	17,919	100,106	10,479	9.6	3,685	6,879	14.5-24.5	19.8	June 1937	9,241
GREELEY			18	1,600	1,164	1,695	94,167	1,059	88.9		12,504	32.1-60.1	38.6	June 1938	4,140
Greeley	Dec. 1936	2 yrs. 1 mo.	17	1,600	1,147	1,678	98,706	1,049	94.1	7,789				June 1938	4,140
11-2	June 1938	7 mos.	1	20	17	17	17,000	850	20.0	11,520				Nov. 1938	284 x
KERN FRONT															
All Pools	Aug. 1925	13 yrs. 5 mos.	447	2,540	3,046	40,823	91,327	16,072	5.7	2,175	2,650	12.3-15.5	14.4	Feb. 1928	20,763
KERN RIVER															
All Pools	June 1899	39 yrs. 7 mos.	2,131	7,000	931	273,343	128,270	39,049	3.3	838	4,852	12.0-14.6	13.3	1903	44,800
KETTLEMAN MIDDLE DOME															
Temblor	June 1932	6 yrs. 7 mos.	3	200	20	625	175,000	2,625	66.7	7,824	9,138	48.3-58.5	55.1		
KETTLEMAN NORTH DOME			240	16,500	25,587	201,962	841,508	12,240	68.8		11,746			Nov. 1935	110,614
Temblor	Oct. 1928	10 yrs. 3 mos.	235	16,500	25,041	201,416	857,089	12,207	70.2	8,266		34.1-37.2	36.5	Nov. 1935	110,614
Eocene	July 1937	1 yr. 6 mos.	5		546	546	109,200			10,848				Sept.1938	2,106 x
LOST HILLS			406	2,380	1,279	47,464	117,195	19,943	5.9		7,858				
Main Area	1910	28 yrs.	377	2.240	851	46,602	123,613	20,804	5.9	1,185		15.0-36.2	24.9	(Inc. Belridge South)1917	17,400
Williamson Area	June 1936	2 yrs. 7 mos.	28	140	428	862	30,786	6,157	5.0	1,441		13.2-14.1	13.7	Nov. 1937	1,846
McKITTRICK DISTRICT			316	1,565	1,270	88,359	279,617	56,459	5.0		6,664				
CYMRIC	Unknown		20		87					1,423		11.5-22.0	12.2	Nov. 1935	280
McKITTRICK	1887	51 yrs.	262		995					1,057		13.0-18.0	14.2	(See Midway)	
McKITTRICK FRONT	Unknown		24		180							11.0-16.2	15.2	Aug. 1937	780
Upper										910					
Lower										2,467					
TEMBLOR RANCH	1900	36 yrs.	10		8					343		14.0-14.0	14.0		

SAN JOAQUIN VALLEY—CONTINUED

MIDWAY-MARICOPA DISTRICT			2,703	17,500	16,444	592,540	219,216	33,859	6.5		9,735				
Gibson	Mar. 1936	2 yrs. 10 mos.	13		191					3,502		21.0-25.0	21.6	June 1936	2,926
Lake View	Mar. 1910	28 yrs. 10 mos.	67		4,290					2,912		20.5-24.0	21.3	(Excluding Lake View Gusher)	
Maricopa Flat	Sept.1928	10 yrs. 4 mos.	55		583					3,342		17.6-26.0)		Sept.1937	18,600
Midway East			581		3,025					2,564		12.0-28.0)	17.0	Mar. 1930	14,749
Midway West	May 1901	37 yrs. 8 mos.	1,914		6,719					1,344		11.0-25.0)		(Inc.Buena Vista & McKittrick)1914	137,000
Quality	May 1936	2 yrs. 8 mos.	53		1,187					2,096		14.0-16.9	15.4	June 1937	6,243
Republic	Mar. 1928	10 yrs. 10 mos.	20		449					2,985		16.0-22.0	19.2		
MOUNT POSO DISTRICT			317	2,140	6,183	42,793	134,994	19,997	6.8		3,130			Jan. 1936	22,157
BAKER	July 1935	3 yrs. 6 mos.	17	80	341	940	55,294	11,750	4.7	1,769		15.0-15.6	15.2	Nov. 1937	1,503
DOMINION	Dec. 1928	10 yrs. 1 mo.	22	150	172	1,132	51,455	7,547	6.8	1,538		14.0-15.6	15.1		
DORSEY	Sept.1928	10 yrs. 4 mos.	13	120	102	290	22,308	2,417	9.2	1,527		15.0-15.7	15.5		
MOUNT POSO			236	1,525	4,429	38,796	164,390	25,440	6.5						
Upper Vedder	July 1926	12 yrs. 6 mos.	163		2,504					1,761		15.0-16.0)	15.2	Dec. 1936	10,000
Lower Vedder	Jan. 1923	16 yrs.	73		1,925					1,827		)		Jan. 1936	12,250
NORTH MOUNT POSO															
Vedder	June 1937	1 yrs. 7 mos.	26	240	1,131	1,622	62,385	6,758	9.2	1,734		15.0-15.8	15.2	Dec. 1937	4,624
SUNSET	July 1935	3 yrs. 6 mos.	3	30	8	13	4,333	433	10.0	1,467		15.0-15.0	15.7		
MOUNTAIN VIEW			186	1,650	3,972	31,864	171,312	19,312	8.9		8,419			Sept. 1935	39,737
Northwest Area			75	745	975	9,845	131,267	13,215	9.9						
Hood	Apr. 1934	4 yrs. 9 mos.	40		460					5,062		21.2-26.6	25.1	Jan. 1937	2,657
Wharton	Mar. 1934	4 yrs. 10 mos.	35		515					5,234		23.1-28.6	26.5	Aug. 1935	14,275
Southeast Area			102	850	2,779	21,405	209,853	25,162	8.3						
Hood	Oct. 1933	5 yrs. 3 mos.	29		609					5,540		20.3-30.0	26.6	Jan. 1935	9,130
Nichols	July 1934	4 yrs. 6 mos.	22		349					5,258		21.0-28.5	26.4	Dec. 1938	1,992 x
Wharton	May 1933	5 yrs. 8 mos.	51		1,821					5,912		24.9-30.1	27.3	Nov. 1935	23,989
Earl Fruit Area															
Hood	Aug. 1936	2 yrs. 5 mos.	9	55	218	614	68,222	11,164	6.1	5,463		22.5-28.5	26.0	Sept.1937	3,361
POSO CREEK DISTRICT			85	810	626	2,437	28,671	3,009	9.5		6,070				
McVAN	Mar. 1932	6 yrs. 10 mos.	14	120	44	119	8,500	992	8.6	1,232		12.4-13.0	13.0	Feb. 1937	210
PREMIER	Apr. 1929	9 yrs. 9 mos	71	690	582	2,318	32,648	3,359	9.7	2,775		12.0-15.2	14.3	Apr. 1937	3,072
RIO BRAVO															
All Pools	Nov. 1937	1 yrs. 2 mos.	24	1,200	1,944	2,072	66,333	1,727	50.0	11,491	14,108	37.0-40.0	38.5	Nov. 1938	9,699 x
ROUND MOUNTAIN DISTRICT			160	1,170	4,055	14,202	88,763	12,138	7.3		3,763			Jan. 1938	13,324
Main Area			117	870	2,814	12,850	109,629	14,770	7.4				16.8		
Jewett	Apr. 1928	10 yrs. 9 mos.	34		367	2,272	66,824			1,712		16.2-17.2		Oct. 1937	1,763
Vedder	May 1927	11 yrs. 8 mos.	83		2,447	10,578	127,440			2,017		13.2-17.2		Jan. 1938	6,554
Northwest Area															
Vedder	1937	1 yr.	28	200	962	962	34,357	4,810	7.1	1,920		13.0-14.7	14.-	Apr. 1938	4,327
Pyramid Area															
Vedder	May 1937	1 yr. 8 mos.	15	100	279	390	26,000	3,900	6.7	1,786		16.3-16.8	16.6	Feb. 1938	952
TEN SECTION															
Stevens	June 1936	2 yrs. 7 mos.	34	1,500	2,473	3,594	105,706	2,396	44.1	8,219	8,964	35.4-35.4	35.4	Nov. 1938	8,796 x
WASCO															
Vedder	Apr. 1938	9 Mos.	3	200	125	125	41,667	625	66.7	11,968	15,004	37.7-37.7	37.7	Dec. 1938	633 x
WHEELER RIDGE															
All Pools (Upper)	Nov. 1922	16 yrs. 2 mos.	34	260	113	3,579	105,265	13,765	7.6	2,717	9,272	23.3-23.5	23.5	Sept.1924	1,173
OTHER FIELDS			45	130	140	201	4,467	1,546	2.9						
ARVIN	Dec. 1937	1 yr. 1 mo.	2	40	22	24	12,000	600	20.0	7,288		28.3-28.3	28.3	Jan. 1938	87
BLACKWELL'S CORNER														Sept.1937	21
CANFIELD RANCH	Jan. 1938	1 yr.	1	20	35	35	35,000	1,750	20.0	8,070		29.5-29.5	29.5	Mar. 1938	160
CHICO MARTINEZ			3		8	8	2,667			1,025		14.0-14.0	14.0	Oct. 1938	56
COLE'S LEVEE	Nov. 1938	2 mos.	1	20	11	11	11,000	550	20.0	9,365					x
DEVIL'S DEN	1910	28 yrs.	23		1	12	522			2,000		12.0-12.0	12.0		
GRAPEVINE	June 1935	3 yrs. 7 mos.	3	30	50	53	17,667	1,767	10.0	4,479	6,980	20.4-22.0	21.6	June 1938	212
MISCELLANEOUS			3		5	5	1,667			1,441		20.9-20.9	20.9	Aug. 1938	27
PYRAMID HILLS	June 1931	7 yrs. 7 mos.	2		6	34	17,000			2,096		17.0-17.0	17.0		
TERRA BELLA	June 1930	8 yrs. 7 mos.	6		1	18	3,000			1,000					
RICHFIELD WESTERN	Nov. 1938	2 mos.	1	20	1	1	1,000	50	20.0	8,676					x
SAN JOAQUIN VALLEY TOTAL:			10,317	94,552	95,106	2,200,365	213,276	23,271	9.2						

ANALYSIS OF CALIFORNIA PETROLEUM RESERVES AND THEIR RELATION TO DEMAND AND CURTAILMENT

By WM. R. WARDNER, JR.*

OUTLINE OF REPORT

GENERAL STATEMENT

Curtailment of crude production in California below the capacity to produce will be necessary for at least eight more years. This conclusion is evident from a study of California's petroleum reserves in relation to the rate of withdrawal. This minimum expectation for continued restriction of output is based upon the assumption that no new fields will be discovered during the period, and is determined without giving consideration to probable future additions to petroleum reserves.

A reasonable expectation with respect to future discoveries might include the bringing-in of additional fields and deeper pools with new reserves of one-half our present known reserves. Such an eventuality would lengthen the period during which curtailment must be practiced. If new reserves discovered during the period are as much as 1,500,000,000 bbl., curtailment of production will be extended over a longer period—14 to 19 years—depending upon requirements. Thus the required extension of time for restricted production may be as much as 2½ times the first-mentioned expectation. In this connection it might be pointed out that predictions have been circulated for many years calling attention to a shortage of oil just around the corner. However, today the State's reserves are greater than they were 15 years ago.

New discoveries generally contribute a large portion of the reserve supply needed to insure against a future oil shortage. It is now apparent that more efficient recovery methods constantly being developed are causing changes in estimates of recoverable oil, and promise to permit a substantial increase of present figures. Technical minds in the industry envisage that any scarcity of crude will promote the development of improved production technique and that as new processes yet untried are brought into play, a higher percentage of recovery will be realized, to the extent that ultimate yield in some instances may be doubled.

The study of petroleum reserves as a part of petroleum engineering has been carried on for many years, and while not an exact science insofar as accuracy of results is concerned, serves a very practical use in the industry's administration. Evaluating an oil property requires a study of the amount of recoverable oil, the expected rate of its withdrawal, and the time required for its production. Such an appraisal sets up values which may be used in establishing a price for a transfer of ownership, and in determining the most economic plan for the development and operation of a property. Such estimates are based on the available facts, together with reasonable assumptions. The assumed factors may include acreage, average sand thickness, average porosity, saturation, and location of edgewater.

As the property or field under study is developed and establishes an historical background, more and more data become available. The production record and the data on sub-surface pressure will then indicate a trend of decline, permitting more exact estimates to be determined. Revisions of former estimates then become necessary. As a field approaches the depleted state, assumptions become fewer and more of the factors become known, and the accuracy of appraisals is enhanced. Since information is now available in much greater detail on newly discovered fields, more accurate estimates of crude reserves are permitted than in the past. Some of the more significant studies include bottom-hole pressures, the analysis of core samples, measurement of the pressure, volume, temperature relationship of the oil and gas. Such studies were unknown a comparatively few years ago. Constant improvement in reserve estimates is a natural outgrowth of the studies of well production performance, and characteristics of reservoir behavior.

Past experience shows that estimates of underground reserves are generally conservative. In the figures set forth herein, only the proven acreage has been considered. Any statements relative to possible discoveries of new fields or deeper zones are mere conjecture. Weight has been given, however, to proven areas not yet developed; in several of the newer fields where structural features have not been fully defined, it is probable that a production area larger than that used in this estimate will later be proven. The proportion of the estimated recoverable reserve to the total oil contained in the reservoir has been based on the assumption that present-day facilities and equipment will be used. As already stated, however, more complete recovery will undoubtedly be realized in the future through improved productive methods. The present expectation of the total ultimate recovery varies widely, and in general may average from 25 to 40% of the original oil in place. The cost of producing oil and the economic limit of production based on crude prices in recent years places a limit on the total oil recovery. As a general average, the limit for economic operation for shallow wells has been taken as 5 bbl. per day; for wells of medium depth, 15 bbl. per day; and for wells of 7,000 ft. or more, 20 to 50 bbl. per day. These economic production limits cover lifting and operating expense only,

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and do not include the return of invested capital. They vary widely depending on particular conditions. A higher future price, if not consumed by higher overhead and taxes, may reduce this economic limit and provide revenue for utilizing more costly methods in obtaining the last barrel, so to speak, or exhausting the reservoir within the limits of physical laws.

ESTIMATION OF RESERVES

Methods of estimating reserves in general use may be classified briefly as follows: (1) the decline curve method; (2) the volumetric or oil in place method; (3) the material balance method.

DECLINE CURVE METHOD

The decline curve method is best suited to the study of production records under constant producing conditions. Field totals or production averages of groups of wells may be used, or a composite curve made up from data of several similar wells in the same sand. The curve thus established is projected into the future by making use of the observed slope. This is most readily accomplished by plotting the data on a logarithmic graph paper in such a manner that they will present a straight line which may be projected into the future. This method is less accurate when curtailment is being practiced; the higher the degree of curtailment, the less the value of the decline curve method. A thorough knowledge of the local conditions is necessary even where the production record shows a decline. The method is usually based on average production of groups of wells. and care must be taken in applying a generalized curve to a particular well. The greatest inaccuracies are found in the projection at the lower and more settled rates of production.

VOLUMETRIC, OR OIL IN PLACE METHOD

The second method involves the calculation of the actual volume of oil in the reservoir. The factors used are: (1) thickness of the oil-bearing sand; (2) average percent of pore space; (3) percentage of oil saturation; (4) percent of connate water present in the pore space; (5) free gas in the sand, as well as gas held in solution in the oil. These factors are determined from actual laboratory tests of the cores. Averages for each sand body may be used. The acreage of the field is worked out from sub-surface structure data. Knowing the total area and the volume of oil contained per acre, the total quantity of oil in the reservoir may be approximately determined. In these calculations, the greater the number of wells from which cores have been taken and analyzed, and the better their distribution through the productive zone and over the productive acreage, the greater is the accuracy of the reserve estimate. This total quantity of oil must then be modified by a recovery factor, which may be based on the measured permeability of the oil sands under consideration, compared to the same or other similar depleted oil sands where cores have been taken, and the oil remaining has been found by core analysis. Since very little information is available on this subject, experience and judgment generally must be used to supply or supplement this factor.

MATERIAL BALANCE METHOD

The material balance method of estimated reserves is based on the decline of reservoir pressure as related to the production of oil and gas. In general, the method requires a knowledge of the relationship between reservoir pressure, quantities of oil and gas produced, physical properties of the reservoir fluids, and oil and gas content of the reservoir.

When a reservoir has been drilled and oil and gas are produced, the reservoir pressure is lowered. Because of the reduced pressure, the remaining oil and gas expand. If, at the same time, the pressure is reduced below the critical point, the gas vaporizes from the oil, filling the space vacated by the oil and gas already produced. The pressure decline of the reservoir is thus retarded. The amount which the formation pressure has declined is dependent upon the volume of oil and gas remaining in the reservoir. With the same amount of production, a large volume of oil and gas remaining in the reservoir will result in a small pressure decline, and conversely, a small volume of oil and gas remaining will result in a large pressure decline.

The pressure-volume relationships of the oil and gas mixture under reservoir conditions are determined by testing samples in the laboratory. An assumption is made that complete equilibrium is attained in the reservoir at all times; this condition, however, is practically never realized. Knowing (a) the pressure-volume relationship of the oil and gas mixture, (b) the quantity of oil and gas produced, and (c) the decline of reservoir pressure, the total volume of the oil and gas contained in the reservoir can be calculated. In water-drive fields, the reduction in productive acreage caused by advancing edgewater should also be taken into account.

TABLE I***

	Crude reserves developed during year	*Crude production for year*	*Crude reserves end of year*	*Cumulative total production end of year*	*Indicated ultimate production of existing fields end of year*	*Crude utilized Total*	*Crude utilized **Domestic*
1925	--------	--------	2,889,265	--------	--------	------	------
1926	131,524	224,117	2,796,672	2,548,129	5,344,801	236,362	143,430
1927	159,958	230,751	2,725,879	2,778,880	5,504,759	237,244	156,343
1928	1,046,919	231,983	3,540,815	3,010,863	6,551,678	232,480	163,667
1929	229,935	292,037	3,478,713	3,302,900	6,781,613	246,688	175,705
1930	95,596	228,100	3,316,209	3,531,000	6,877,209	236,442	169,067
1931	254,769	188,829	3,412,149	3,719,829	7,131,978	194,057	*154,000
1932	--------	178,128	3,234,021	3,897,957	7,131,978	179,855	136,900
1933	158,944	173,083	3,219,882	4,071,040	7,290,922	185,860	137,279
1934	91,141	175,509	3,135,514	4,246,549	7,382,063	200,778	142,447
1935	28,393	207,832	2,956,075	4,454,381	7,410,456	202,642	154,214
1936	358,081	214,773	3,099,383	4,669,154	7,768,537	213,346	166,548
1937	195,840	238,520	3,056,703	4,907,674	7,964,377	241,706	181,301
1938	492,422	249,125	3,300,000	5,156,799	8,456,799	223,815	169,623
Total	3,243,522	2,832,787					

*Last six months average
**Crude demand in five western states, Alaska and Hawaii
***All figures in thousands of barrels

TOTAL RESERVES

To present a picture of California reserves it is necessary to review briefly the past record.

Figs. 5, 6, and 7 and Table I show the total reserves of California. A survey of individual fields has been made as of January 1, 1939, and from the data collected, initial reserve or ultimate recovery, has been computed by adding the present reserve to the total oil produced. This method introduces a minimum of error, and in presenting a picture of the previous years, is more accurate than an attempt to make use of earlier estimates.

Fig. 5 shows the cumulative yearly production, 1918 to 1938, inclusive. From 1922 to 1938, there has been a nearly constant rate of increase in cumulative production, with a maximum deviation in 1928 and 1929.

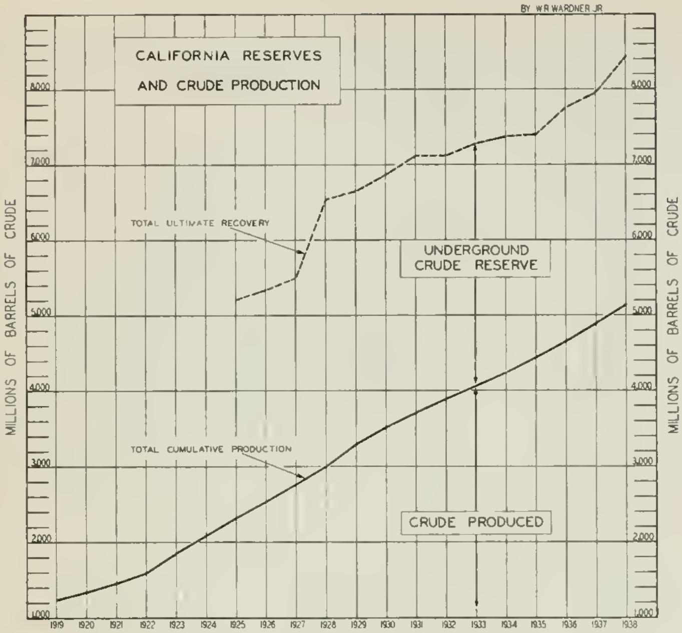

FIG. 5.

Known underground reserves at the end of each year from 1925 to the end of 1938 are shown in the area between production and ultimate production curves. The ultimate production at the end of any year is the sum of production and the known reserves at that time.

Fig. 6 shows the known underground reserves at the end of each year, together with the portion discovered during that particular year. The outstanding feature is the enormous increase in reserves during the year 1928 resulting in a peak of 3,540,000,000 bbl., and the gradual reduction to a low of 2,956,000,000 bbl. in 1935. The combined discoveries of 1936, 1937, and 1938 were substantially equal to those of 1928, and resulted in an increase to 3,300,000,000 bbl. in reserve at the end of 1938. It is also noteworthy that new discoveries exceeded production during this three-year period by 345,000,000 bbl.

Fig. 7 shows the depletion or exhaustion of reserves by years since 1925. The reserves of the existing fields at the end of a given year have been reduced annually by the production of these particular fields, resulting in a reserve depletion curve brought down to the end of 1938. The total quantity of crude remaining in reserve at the end of each succeeding year in those same fields that made up the reserve of the initial year may be read from Fig. 7. For example, the fields making up the 1925 reserve of 2,889,000,000 bbl. have, during the 13 years to the end of 1938, produced 1,839,000,000 bbl. and have at the end of 1938 a remainder of 1,050,000,000 bbl. in reserve. Likewise, the fields making up the 1928 reserves of 3,540,000,000 bbl. which, of course, include all fields discovered prior to 1928 and none afterward, had in the 10 years up to 1938 produced 1,741,000,000 bbl. of their 1928 reserves; at the end of 1938 the reserves remaining were 1,800,000,000 bbl.

Some of the data from which these charts have been constructed are given in Table I, and in addition the total yearly crude demand (crude utilized) is shown, together with the annual domestic utilization.

RESERVES PROVIDED BY NEW DISCOVERIES

1925-1938

A list of the fields and pools discovered each year since 1925 follows. These fields make up the total reserves developed during the year of their discovery. The total reserve at the end of 1938 for each field plus its cumulative production has been assigned to the year of its discovery.

NEW DISCOVERIES

1926

Mount Poso (Main)
Seal Beach (Bixby-Selover)
Ventura Avenue (Edison)

1927

Seal Beach (Wasem)
Potrero
Round Mountain
Dominguez (3, 4, 5)

1928

Seal Beach (McGrath)
Fruitvale
Elwood (Vaqueros)
Santa Fe (Buckbee, Nordstrom)
Maricopa Flat
Kettleman North Dome (Temblor)
Lawndale
Long Beach (Deep Zones)

1929

Santa Fe (Clark, O'Connell)
Santa Barbara Mesa
Poso Creek
Capitan (Vaqueros)
Playa del Rey (Venice Upper and Lower)

1930

West Coyote (Emery)
North Belridge (Temblor)

1931

Ventura Avenue ("57")
Gato Ridge
Elwood (Sespe)
San Miguelito
Kettleman Middle Dome
North Belridge (Wagon Wheel)

1932

None

1933

Coffee Canyon (Old)
Mountain View (Nichols, Hood, Wharton)
Montebello (Nutt, Cruz)
Huntington Beach (Tideland)

1934

Edison
Dominguez (Miocene)
Inglewood (Rindge, Rubel)
Playa del Rey (Hills)

1935

Coffee Canyon (New)
Mount Poso (Baker)
Mountain View (Earl Fruit)
El Segundo

1936

Ten Section
Greeley (Stevens)
Wilmington (Town Lot, Terminal)
Santa Maria Valley
Padre Canyon
Lost Hills (Williamson)

1937

Arvin
Canal
North Mount Poso
Rio Bravo
Yorba Linda
Kettleman North Dome (Eocene)
Montebello (West End)
Rosecrans (Miocene)
Newhall—Potrero

1938

Torrance ("34," D and B)
Wasco
Greeley (Vedder)
Coalinga Nose (Eocene)
Long Beach (Northwest Extension)
Wilmington (Harbor)

While there is an ever present threat that production may exceed demand, nevertheless it is necessary to carry

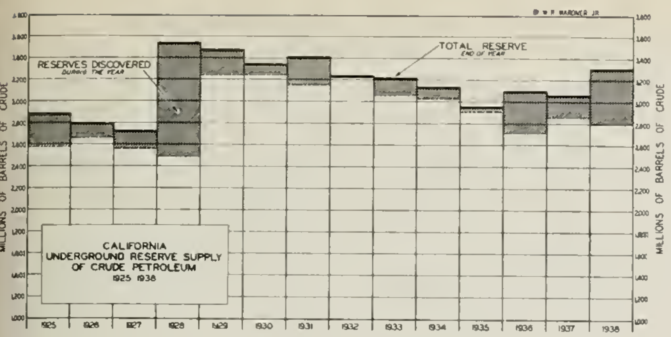

FIG. 6.

on a constant exploratory program to develop new reserves and provide a backlog for future requirements. History shows that whenever the reserve supply seems to be inadequate, even though existing producing capacity is far greater than market requirements, wildcat activity is stimulated. These eras of exploration have seldom failed to uncover substantial new reserves.

In California there have been three periods of discovery. In the first period (1920 to 1924), the discovery of Santa Fe, Huntington Beach, and Long Beach was brought about largely because of increased geological knowledge. In the second period (1926 to 1929), discoveries of Kettleman, Elwood, Dominguez, Seal Beach, Santa Fe-Deep Zones, Ventura-Edison Zone, and others were the result of improved technique, which made drilling to greater depths possible. The third period (1930 to 1935) was without many discoveries, because of the general business depression, high inventories, low demand, and lack of capital available for exploratory purposes. With the use of geophysical methods, a new era of discovery began in California with the discovery of Ten Section in the San Joaquin Valley. There followed a series of important discoveries during the next three years, which included Rio Bravo, Greeley, Canal, Wilmington, and Coalinga Nose. It is likely that additional fields will be found by this method, especially in the San Joaquin Valley. More obscure structural traps, such as overlaps, buttress sands and fault accumulations, which require precise and thorough geophysical surveys and study, are expected to be found in the future. Since the past search for oil fields in California has been highly successful, it is reasonable to assume that new fields will be found by use of the new geophysical methods of exploration which are under development.

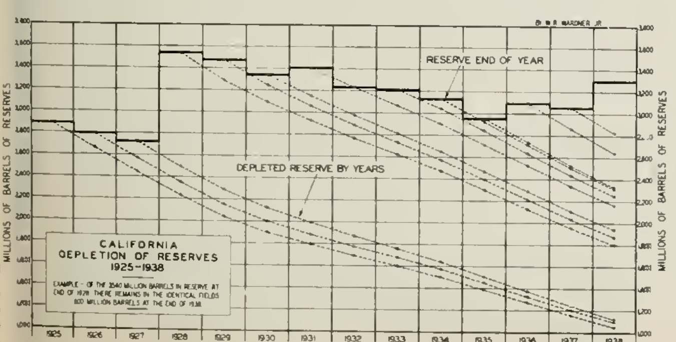

FIG. 7.

TABLE II—YEARS OF FUTURE SUPPLY AT VARIOUS RATES OF DISCOVERY AND VARYING DEMAND

Annual rate of discovery (millions)	*Years before shortage in supply (n)*	*Reserves as of Jan. 1, 1939*	*Reserve discovered in (n) years*	*Total production during (n) years (demand)*	*Reserves at end of nth year*	*Demand at end of period B/D*
		In Thousands of Barrels				
A—When demand increases at annual rate of 1½% of present (+9,000 B/D)						
0	8.2	3,300	---	1,850	1,450	674,000
25	8.9	3,300	223	2,058	1,465	680,000
50	9.7	3,300	485	2,305	1,480	687,300
75	11.0	3,300	825	2,625	1,500	699,000
100	12.5	3,300	1,250	3,015	1,535	712,500
125	14.5	3,300	1,813	3,543	1,570	730,500
150	17.0	3,300	2,550	4,230	1,620	753,000
200	24.8	3,300	4,960	6,490	1,770	823,000
B—When demand increases at annual rate of 1% of present (+6,000 B/D)						
0	8.3	3,300	---	1,903	1,397	649,800
25	9.2	3,300	230	2,121	1,409	655,200
50	10.3	3,300	515	2,392	1,423	661,800
75	11.9	3,300	893	2,749	1,444	671,400
100	13.8	3,300	1,380	3,212	1,468	682,700
125	16.1	3,300	2,013	3,815	1,498	696,500
150	19.3	3,300	2,895	4,656	1,539	715,800
200	30.4	3,300	6,080	7,698	1,682	782,200
C—When demand is constant						
0	9.2	3,300	---	2,010	1,290	600,000
25	10.6	3,300	265	2,275	1,290	600,000
50	12.2	3,300	610	2,620	1,290	600,000
75	14.2	3,300	1,065	3,075	1,290	600,000
100	17.3	3,300	1,730	3,740	1,290	600,000
125	22.0	3,300	2,750	4,760	1,290	600,000
150	29.8	3,300	4,470	6,480	1,290	600,000
D—When demand decreases at annual rate of 1% of present (−6,000 B/D)						
0	10.6	3,300	---	2,150	1,150	536,500
25	11.9	3,300	298	2,458	1,140	528,500
50	14.6	3,300	730	2,930	1,100	512,500
75	18.3	3,300	1,373	3,618	1,055	490,000
100	26.5	3,300	2,650	5,000	950	441,000
E—When demand decreases at annual rate of 1½% of present (−9,000 B/D)						
0	11.3	3,300	---	2,228	1,072	497,500
25	13.2	3,300	330	2,595	1,035	481,500
50	16.8	3,300	840	3,175	965	449,000
75	24.1	3,300	1,808	4,285	823	384,000

FUTURE PRODUCTION EXPECTANCY

It is the purpose to show here the reasonable future production expectancy under present and possible future conditions. Various conditions of discovery rates and market demand are shown together with the length of time which will elapse before a shortage in supply

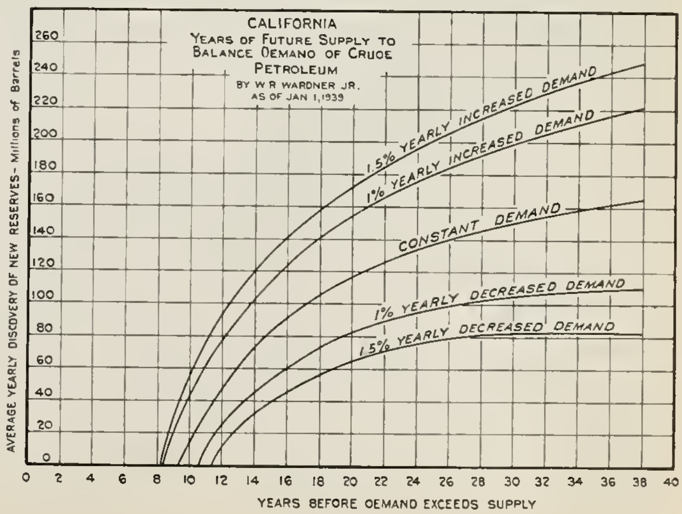

FIG. 8.

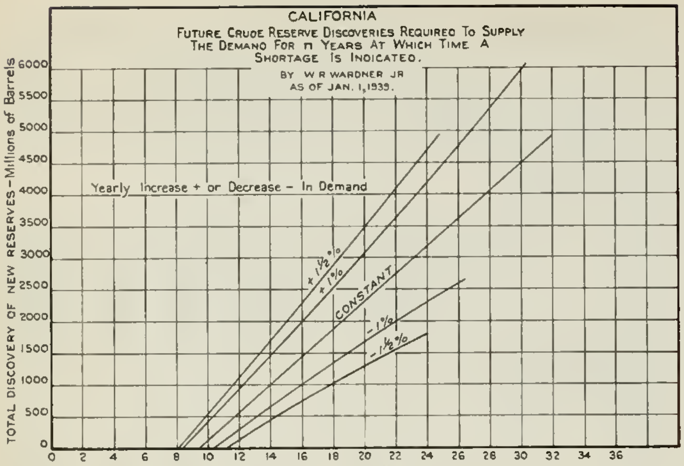

FIG. 9.

would occur under each circumstance. No predictions of the future are made here. The number of years before market requirements will exceed production at varying rates of discovery and demand are, however, shown. There has been no attempt to project the rate of production to the time of complete exhaustion of the reserves, but only to indicate the time which will elapse before an actual shortage in supply will occur. In the analysis of this subject, several charts have been prepared.

Fig. 8 shows the number of years before a shortage in supply would be reached under the condition of annual rates of discovery varying from 0 to 250,000,000 bbl. This relationship is shown under several conditions of demand: (1) with an annual increase of 1½% of the present demand; (2) with an annual increase of 1% of the present demand; (3) with a constant demand equal to 600,000 bbl. per day; (4) when demand decreases annually at the rate of 1% of the present demand; (5) when demand decreases annually at the rate of 1½% of the present demand.

Fig. 9 shows the total barrels of future crude reserves discoveries which would be required to supply the demand for n years, at which time a shortage would occur. In this chart, the same conditions of demand are shown as in Fig. 8.

Fig. 10 shows the total reserves which will remain unproduced at the end of n years under the conditions of demand shown in Figs. 8 and 9.

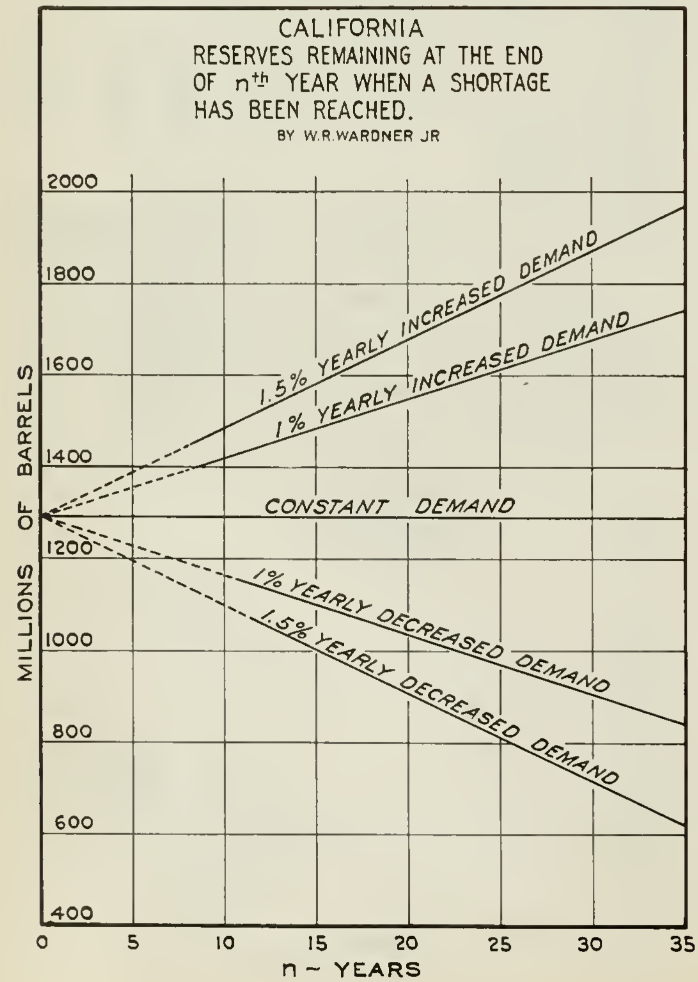

FIG. 10.

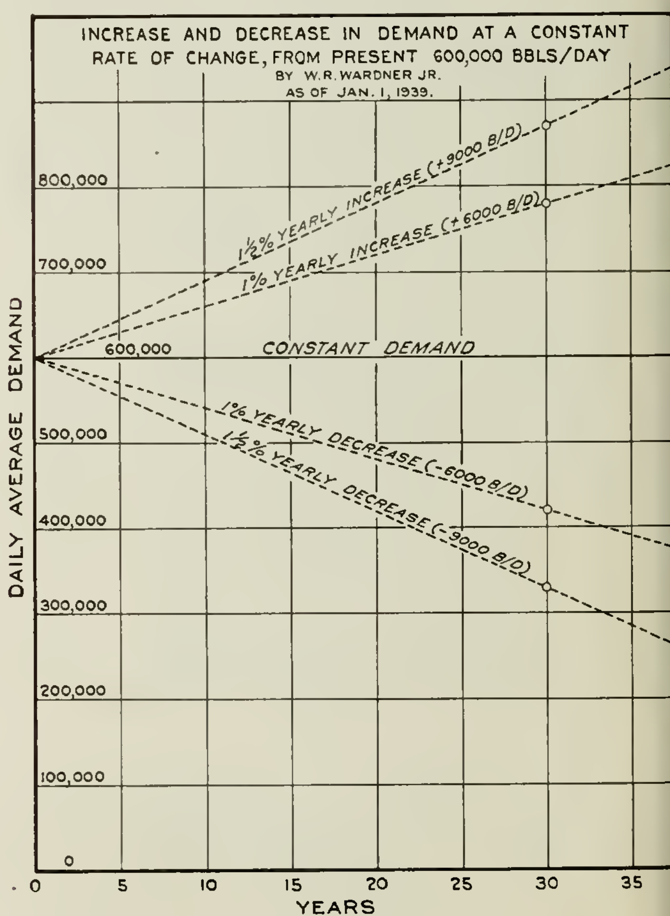

FIG. 11.

Fig. 11 shows the demand which will exist in barrels per day at the end of n years.

The data presented in these charts are also given in tabular form in Table II.

DEMAND FOR CALIFORNIA PETROLEUM PRODUCTS

The subject of demand for California petroleum is susceptible to considerable variation in interpretation. The elements of the cost of crude petroleum and the available supply regulate manufacturing processes applied in refinery operations and in recovering products. For example, in California the gascline demand is comparatively low in relation to the available refinable crude production, and the greater portion of the gasoline refinery through-put is straight-run gasoline. Cracking of the heavier crudes and fuel oils has not as yet been developed in California to the extent that it has in the Mid-Continent; however, equipment with much additional cracking capacity is now being installed. Along this line, it may be noted that the average refinery yield for the United States including California is 45%. The California average, however, is approximately 32%. It is quite obvious that if the total supply of crude petroleum diminishes, a higher refinery yield must be realized in order to supply the demand for gasoline.

The off-shore demand is subject to wide variation and is dependent upon world conditions and price, California price, and transportation costs. Practically all of the Atlantic seaboard demand for California petroleum products has been lost. Atlantic foreign demand is also being met by other domestic and foreign sources of supply. This may be illustrated by the fact that for the four-year period 1926 to 1929 inclusive, the average Atlantic shipments, domestic and foreign, amounted to 122,000 bbl. per day, whereas the average for 1935 to 1938 inclusive was 40,000 bbl. per day This represents a drop of 82,000 bbl. per day. It may also be noted that the total California demand for crude petroleum was 654,000 bbls. per day for the period 1926 to 1929 inclusive, while the average for the four years ending 1938 was 600,000 bbl. per day. There has, however, been a substantial increase in the Pacific foreign demand, which has had a tendency to offset to some extent the loss in Atlantic business. The off-shore demand has for recent years approximated 25% of the total demand for California crude. Because of this off-shore outlet, it has been possible to hold California crude stocks at a reasonable level, and the petroleum industry generally has been able to operate at a profit and support the exploration and development programs which are so essential.

POSSIBLE FUTURE CONDITIONS

The present demand for petroleum products from all markets now being served is considered in this study as 600,000 bbl. per day, exclusive of natural gasoline. Two assumptions must be made in any prediction of the future: (1) the actual demand which is to be expected, and (2) the rate of future discovery.

It is not possible to predict the future requirements from a study of the demand for the past 20 years. The statistics do not indicate any definite upward trend in demand over a long period. It seems more likely that if the available supply diminishes, improved refining methods and greater utilization of crude will tend to reduce the total demand; or, at least, the same volume of crude will satisfy any normal increase in gasoline demand.

During the past 20 years domestic fuel oil demand has been considerably reduced by the increased use of natural gas for household and industrial fuel. Natural gas has largely replaced artificial gas manufactured from fuel oil. Whereas for the period 1921 to 1930 inclusive the amount of gas wasted was 39% of the total amount produced, during the 8-year period 1931 to 1938 inclusive this waste was reduced to less than 7% of the total gas produced. The conservation brought about by this change will be of untold benefit in increased oil recovery and in storing gas reserves in the natural underground reservoirs for future needs. It might also be noted that diesel fuel has been replacing fuel oil; this process has not yet been concluded and a still greater use will undoubtedly be made of the heavy crudes which are now used for fuel.

The second assumption concerns the rate of discovery of crude reserves. All that can be done here is to consider a reasonable range of the annual rate of discovery. For the past 13 years the average discovery rate has been 250,000,000 bbl. per year, and the low point of 106,000,000 bbl. per year was reached during the depression from 1931 to 1935, when drilling and prospecting were at their lowest level. Thus the range for anticipated reserve discoveries would be between 0 and 250,000,000 bbl. per year; a reasonable expectation would be 100,000,000 bbl. per year. Because of the constant decline or depletion of developed fields, and the necessity of providing for a constant or increasing demand, new sources of supply continually must be discovered and drilled. It is estimated that the quantity of crude petroleum in sight for future needs as of January 1, 1939 is 3,300,000,000 bbl. This is $\frac{3}{8}$ of the indicated ultimate production for California, defined as the total production to date plus the present known underground reserve supply.

If the production rate in California were increased to the capacity of 1,400,000 bbl. per day, it is estimated that the decline would reduce production to the present demand of 600,000 bbl. per day within a period of six years, provided that no additional reserves were discovered. Under maximum producing conditions there is a wide variation in the decline rate of wells. Small settled producers have been observed to decline as little as 2% per year, and at the other extreme, new wells have been found that decline as much as 90% in a year's time. Although there is a wide difference between wells and fields in the State, for the purpose of this study, an average decline factor has been used. The rate of decline of the productive capacity of California oil fields has been computed to average 14.5% per year, taking wells of all classes.

At a curtailed production rate of 600,000 bbl. per day, equal to present demand, the decline would be considerably reduced, thus extending the time before the supply was less than the demand to 9.2 years. This period of years, however, is calculated upon the assumption that no new fields will be discovered. Realizing that such a condition is quite improbable because of the recent widespread wildcat activity and the continued successful discoveries, the assumption is not considered reasonable. The problem becomes more involved because of the continued discovery of new fields and the impossibility of predicting the frequency of discovery or the magnitude of the new fields. Since it is not possible to weigh the many factors affecting future production, and since the past cannot be regarded as a criterion, all we can hope to show is what the condition would be under given circumstances. The rate of future discovery is one of the unknown factors, and for the purpose of this review, a range of values is taken. A relation is made showing the number of years which will elapse before the demand is exceeded by the supply, at varying annual average rates of discovery. Several changing rates of demand and a constant demand are also compared and illustrated in Figs. 8, 9, 10, and 11.

The time that will elapse before the exhaustion of the reserves remaining unproduced at the end of *n* years is not predictable. This supply will continue over a long period of time because of the settled state of production and the low rate of decline. Reserves which are now estimated as unrecoverable, and are therefore not included in the present reserve estimate, may be made available by continued improvement in the methods of recovery. These methods, such as repressuring, and gas and water drive operations, are now being developed and should provide additional supply in declining years.

CURTAILMENT

For the past 10 years California oil fields have had the ability to produce under maximum conditions two to three times the market demand. During this time it has been necessary to restrict production not only to the demand but to an even lower level. This was for the purpose of reducing excessive inventories accumulated in 1928 to 1929 from the high flush production of Long Beach and Santa Fe Springs. A voluntary conservation program was inaugurated in November, 1929, to accomplish this end. Since that time curtailment has been operative. The oil producers of California have curtailed on the average to within 5% of the quotas set for the State.

The capacity of California oil fields to produce at a steady and sustained rate with all wells operating simultaneously has been computed to be 2.3 times the present requirements. Production at this rate, however, if continued for many months, would destroy the present relative stability of the oil industry and bring about financial ruin and chaos generally. The development of new fields greatly expands the potential production of the State. New wells are generally large and in the initial stage are capable of the maximum production of their life. Under wide-open conditions, wells may produce from 30% to 90% of their ultimate production during the first year. Under curtailment, however, these large flush new wells, which in some cases have potentials as high as 5,000 bbl. per day, are pinched back to as little as 200 bbl. per day, which represents only a small part of their capacity. In this manner the natural flowing life of a large number of wells will be extended for many years after the time they would otherwise have ceased to flow, and would have been put on the pump. As wells are produced normally, the rate of production is constantly declining; and likewise if they are curtailed their potential will still decline, although the actual restricted production may be more or less constant.

CONCLUSION

In conclusion it might be pointed out that the study of reserves is not an exact science and in the calculation of reserves many variable factors are taken into account. Therefore, a constant revision of estimates is necessary. Present California crude reserves are adequate to provide for requirements for at least 10 years. Improved production methods and a continuation of discoveries, at a normal rate, will provide for the bulk of California's future demand 20 to 25 years hence, although existing wells will still be producing substantial quantities at that time. More specifically, the discovery of 1,500,000,000 bbl. of new reserves during the entire period will necessitate a restricted output for 14 to 19 years.

In present fields, increased recovery resulting from improved production practices can be anticipated as a source of additional supply. The likelihood of discovering substantial additional reserves is enhanced by the new scientific methods of exploration. The vast acreage of the San Joaquin Valley and the Coastal Plains offers fertile ground for the application of these methods. Curtailment of output should be energetically promoted and adhered to if economic stability in the industry is to be maintained. The assurance of stable conditions is essential to provide for a vigorous exploration and development program necessary to insure a continuous future supply for the industry.

Bibliography: Hoots, H. W. 39a; Hubbard, W. E. 37; Katz, D. L. 36; Minshall, F. E. 37; Pyle, H. C. 39; Schilthuis, R. J. 36; Sherborne, J. E. 39; Wilhelm, V. H. 39a.

NATURAL GAS FIELDS OF CALIFORNIA*

By Roy M. Bauer** and John F. Dodge***

OUTLINE OF REPORT

MODES OF OCCURRENCE

Natural gas occurs in two ways: (1) as a separate and distinct product, not associated with petroleum deposits; this is called dry gas, or marsh gas; (2) in oil sands and associated with petroleum; in this case the gas is produced with the oil, and separated mechanically from it at the surface or casing head of the well, and is known as casinghead gas.

EARLY HISTORY

California's first natural gas production, a dry gas or marsh gas, was developed from an artesian well drilled at Stockton in 1864. A number of additional wells were drilled over a period of years, not only at Stockton, but also at Sacramento. All of the wells were small producers, yielding from 5,000 to 120,000 cu. ft. of gas per day. The heating value was rather low—650 to 800 B.t.u. per ft. as compared with the 1,000 to 1,150 B.t.u. per ft. for the average casinghead gas. The production was never sufficient for the needs of the community. At the present time, no gas is being produced commercially from these wells.

The first productive oil and gas well was completed in Pico Canyon near Newhall in Los Angeles County in 1870. Large oil production was developed in the San Joaquin Valley in the Coalinga, McKittrick, and Kern River fields at the turn of the century, but it was not until 1909, when the large-volume high-pressure gas wells were drilled in the Buena Vista Hills, Kern County, that attention was focused on natural gas obtained from oil fields. Because of the absence of proper high-pressure separators or gas traps and the inability to handle the high-pressure wells with the equipment then available, great wastage of dry gas from the upper sands, as well as casinghead gas, prevailed for a number of years. Since 1909, however, the proportion of gas utilized has gradually changed, from almost complete wastage to practically complete utilization. (See Tables I and II.)

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TABLE I—CALIFORNIA: DRY GAS PRODUCTION

(Cumulative to January 1, 1940)

	M. cu. ft.
Buena Vista Hills	107,487,732
Buttonwillow	16,741,600
Dudley Ridge	2,053,500
Elk Hills	75,912,805
Fairfield Knolls	14,333
La Goleta	14,886,887
Long Beach	1,475,876
Marysville Buttes	1,332,349
McDonald Island	18,004,747
McKittrick	1,032,953
North Midway	1,826,381
Paloma (formerly Buena Vista Lake)	2,589,418
Potrero Hills	———
Rio Vista	11,899,908
Rosecrans	29,453
Santa Fe Springs	7,919,799
Seal Beach	610,334
Semitropic	2,818,434
Tracy	8,068,238
Trico	4,184,624
Grand total	278,889,371

The total dry gas production of California represents only 3.9% of the total natural gas produced in the State.

TABLE II—CALIFORNIA: NATURAL GAS PRODUCTION AND UTILIZATION

Year	*M. cu. ft. net production from formation* Casinghead	Dry	Total	*Total Utilization*	*Unconserved gas* M. cu. ft.	Per cent
Prior	65,314,000	———	65,314,000	457,200	64,856,800	99.3
1906	20,465,000	———	20,465,000	153,000	20,312,000	99.2
1907	28,570,000	———	28,570,000	230,000	28,340,000	99.2
1908	33,920,000	———	33,920,000	479,000	33,441,000	98.6
1909	39,290,000	1,305,000	40,595,000	2,324,000	38,271,000	94.3
1910	57,094,000	7,866,200	64,960,200	2,764,000	62,196,200	95.7
1911	66,475,000	7,017,389	73,492,389	6,390,000	67,102,389	91.3
1912	70,989,000	5,387,581	76,376,581	9,355,000	67,021,581	87.8
1913	80,271,000	6,541,485	86,812,485	11,035,000	75,777,485	87.3
1914	89,435,000	7,011,996	96,446,996	17,829,000	78,617,996	81.5
1915	74,475,000	4,487,847	78,962,847	21,891,000	57,071,847	72.3
1916	74,819,000	5,286,684	80,105,684	31,643,000	48,462,684	60.5
1917	82,740,000	10,589,401	93,329,401	49,427,000	43,902,401	47.0
1918	91,225,000	11,453,908	102,678,908	39,719,000	62,959,908	61.3
1919	89,970,000	26,326,253	116,296,253	55,607,000	60,689,253	52.2
1920	95,948,000	22,743,444	118,691,444	66,041,000	52,650,444	44.4
1921	115,212,000	13,151,472	128,363,472	75,942,000	52,421,472	40.8
1922	144,544,000	14,145,830	158,689,830	84,580,000	74,109,830	46.7
1923	321,694,742	11,670,988	333,365,730	131,434,000	201,931,730	60.6
1924	259,707,978	14,850,207	274,558,185	189,692,000	84,866,185	30.9
1925	218,877,358	5,197,777	224,075,135	187,789,000	36,286,135	16.2
1926	221,872,505	7,319,608	229,192,113	204,915,000	24,277,113	10.6
1927	261,316,836	4,566,263	265,883,099	212,897,000	52,986,099	19 9
1928	311,020,653	2,435,219	313,455,872	251,252,929	62,202,943	19.8
1929	561,221,542	2,323,265	563,544,807	355,531,160	208,013,647	36.9
1930	547,985,826	6,131,075	554,116,901	322,149,891	231,967,010	41.9
1931	385,509,561	1,750,252	387,259,813	312,663,259	74,596,554	19.3
1932	280,333,931	1,742,170	282,076,101	262,013,774	20,062,327	7.1
1933	271,382,043	2,472,302	273,854,345	259,360,995	14,493,350	5.3
1934	283,142,012	4,957,292	288,099,304	269,524,394	18,574,910	6.4
1935	307,283,874	11,831,258	319,115,132	296,045,463	23,069,669	7.2
1936	338,079,684	5,784,611	343,864,295	319,403,271	24,461,024	7.1
1937	343,142,734	11,621,318	354,764,052	335,800,628	18,963,424	5.3
1938	362,043,223	13,792,266	375,835,489	337,601,673	38,233,816	10.2
1939	348,721,616	27,129,010	375,850,626	342,545,260	33,305,366	8.9
Totals (cumulative)	6,944,092,118	278,889,371	7,222,981,489	5,066,485,897	2,156,495,592	

Production data for years prior to 1923 were prepared from records of oil companies and gas companies and from gas-oil ratio computations; for years 1923 to 1929, inclusive, from gas company records; subsequent to 1929, from records of State Division of Oil and Gas.

Although the West Coyote field was discovered in 1906, it was not until 1914-1917 that the fields in the eastern portion of the Los Angeles Basin showed promise of developing large-volume gas production. The considerable increase in production that accompanied the successive completion of the Montebello and later Basin fields is clearly shown on Fig. 12.

In the San Joaquin Valley, the Elk Hills field (Kern County) was discovered in 1919. As is the case in the

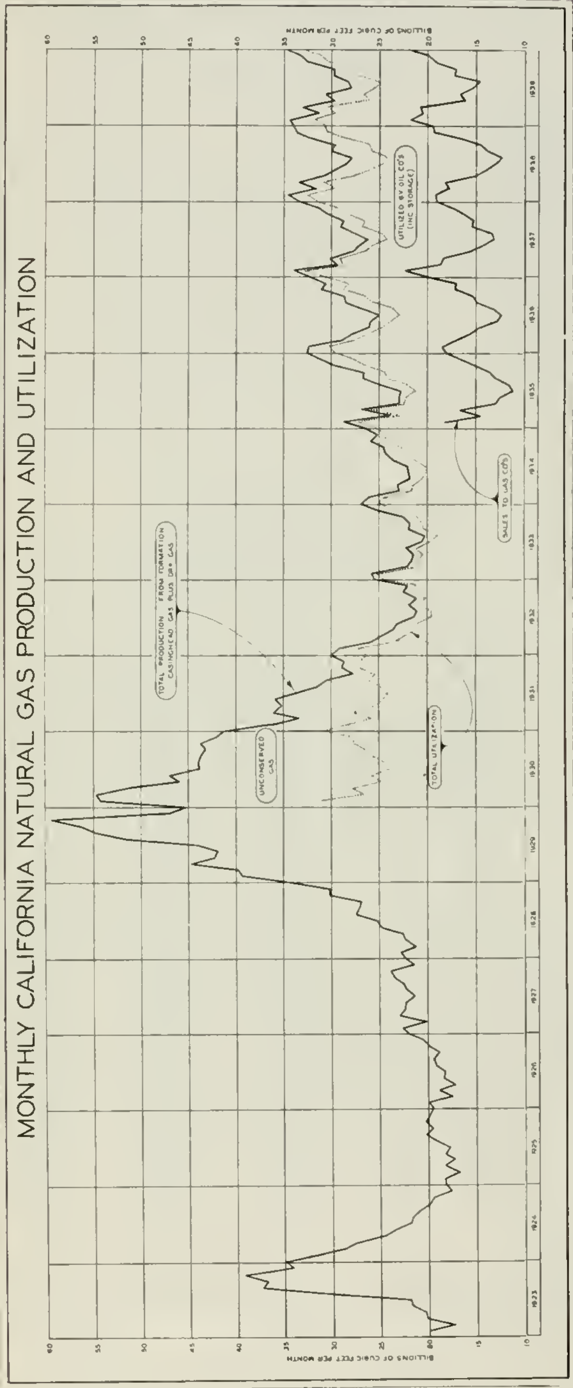

Fig. 12. Graph showing monthly production of natural gas in California (1923-1939), unconserved gas, and sales to gas companies. Illustrating seasonal fluctuations in utilization; showing in particular, since 1932, the efforts to adapt production to the resale requirements of the gas companies.

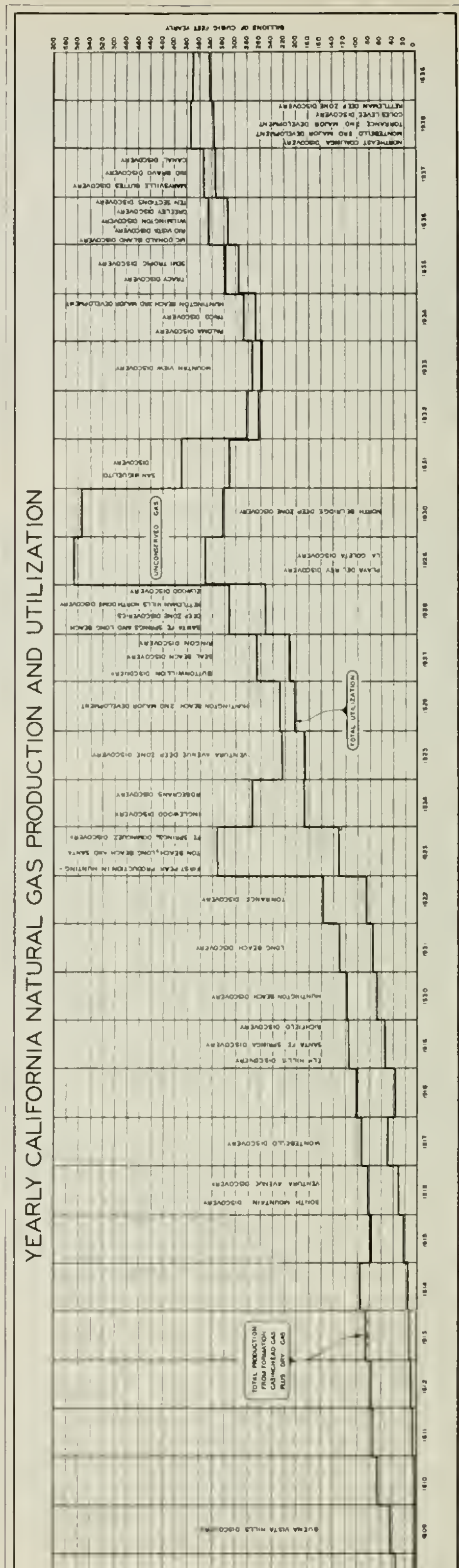

Fig. 13. Historical chart, showing significant discoveries and yearly production of natural gas in California; total utilization of natural gas; and unconserved gas.

Buena Vista Hills, a dry gas zone exists here, lying above the oil zone. Standard Oil Company's Hay No. 7 (Sec. 36, T. 30 S., R. 23 E., M. D.), a dry gas well producing from a depth of approximately 2,100 ft. from sands in the San Joaquin clay (Pliocene), has produced more gas than any other single well in the country. This section now forms a part of U. S. Naval Reserve No. 1, and no production is being taken from the gas zone at the present time.

Turning again to the Los Angeles Basin, reference to Fig. 12 will show the effect on production of the development of the "town-lot fields" in 1922-1924; Fig. 13 shows the resulting rapid increase in production and enormous wastage of gas in the Huntington Beach, Long Beach, and Santa Fe Springs fields. A prolific dry gas sand was developed in the Santa Fe Springs field, but unsatisfactory protection of the producing horizon resulted in the dissipation of the gas in a short time.

The rapid decline which follows every unrestricted town-lot development, caused increased activity in other areas. Four additional fields were developed in the Basin, but the most important discovery of this period was that of the deeper sands in the Ventura Avenue field in 1925.

In 1927 dry gas was found at Buttonwillow, Kern County. This was the first production of dry gas, not associated structurally with an oil field, to be discovered in the San Joaquin Valley, and the first of any importance in the State. This discovery was soon overshadowed by the completion of the first well in Kettleman Hills in 1928. Kettleman Hills proved to be a field of the first magnitude, and ushered in a new era of utilization of natural gas throughout the State.

The second mad scramble for production in the Long Beach and Santa Fe Springs fields took place in the latter part of 1928 and extended through 1929 and 1930. It was the result of the discovery of deeper zones in the existing fields. The greatest gas wastage in the State's history took place during these years.

DEVELOPMENTS IN THE PAST DECADE

In 1930 a deep zone was discovered in the North Belridge field. It has considerable importance from a gas standpoint as the gas cap associated with oil is extensive and under very high pressure.

The accompanying figures and Table I show the effect of the production decline in many fields, and of the curtailment and efforts at conservation which followed the enactment by the Legislature of the Gas Conservation Act of 1929. Since that time, the amounts of unconserved gas have been relatively small in spite of additional discoveries and some town-lot development in Huntington Beach (1934-1935), Wilmington (1938-1939), and Montebello (1939-1940).

FURTHER DRY GAS DISCOVERIES

The two most important dry gas fields in the State, not associated structurally with oil production, are McDonald Island and Rio Vista, in central California. These fields, which lie in the so-called river delta region, were discovered in 1936. A number of minor dry gas fields—including Semitropic, Trico, Tulare Lake, and Chowchilla—were also discovered about this time in the San Joaquin Valley. These latter fields have proven to be of no great importance because of limited productive area or low heating value of the gas.

RECENT DEEP FIELDS IN SAN JOAQUIN VALLEY

The year 1937 marked the first successful attempt for production at depths much in excess of 10,000 ft. in the San Joaquin Valley. The Rio Bravo field was the first of such developments, and discoveries at even greater depths are continuing today. Deeper drilling in the Kettleman Hills in 1938 encountered production in the Eocene and helped to strengthen that field's claim to first position among California's oil and gas fields.

DEVELOPMENT OF UTILIZATION

To the Santa Maria Gas Company goes the honor of being the first gas utility company in California to serve straight natural gas to its customers (1907). In 1910 a line 40 miles in length was laid from Taft in the Buena Vista Hills to Bakersfield; in 1912 and 1913 a line from the same place was laid to Glendale and Los Angeles. April 28, 1913, marked a new era in southern California history as the day of the first delivery of natural gas from the San Joaquin Valley.

During 1914 the cities adjacent to the eastern fields of the Los Angeles Basin were served with natural gas, and in December, 1915, the first Los Angeles Basin gas was delivered to Los Angeles. In these earlier years, however, domestic consumers were not served straight natural gas, the gas from the fields being reformed or blended with artificial gas to a B.t.u. value of 600 to 850 per cu. ft.

By January, 1927, all of the Los Angeles Basin area was served with 100% natural gas. Industrial utilization which had started in 1922 and 1923 with the large volumes of gas then available, continued to increase.

During August, 1929, natural gas reached San Francisco Bay area from Kettleman Hills; later service was extended to Stockton and Sacramento. January, 1940, nearly every important community in California was served with natural gas. This embraces 99% of the total number of gas consumers.

TABLE III—CALIFORNIA: NATURAL GAS UTILIZATION*

	*By Gas Companies***				
Year	*Central and Northern California*	*Southern California****	*Sub-total*	*By oil companies*	*Total*
1930	26,507,468	107,641,117	134,148,585	188,001,306	322,149,891
1931	52,083,555	106,469,578	158,553,133	154,110,126	312,663,259
1932	46,474,415	83,282,280	129,756,695	132,257,079	262,013,774
1933	51,643,562	92,085,170	143,728,732	115,632,263	259,360,995
1934	56,493,462	104,104,666	160,598,128	108,926,266	269,524,394
1935	63,537,829	110,453,608	173,991,437	122,054,026	296,045,463
1936	69,969,346	118,975,530	188,944,876	130,458,395	319,403,271
1937	76,726,384	123,714,721	200,441,105	135,359,523	335,800,628
1938	78,045,090	115,626,782	193,671,872	143,929,801	337,601,673
1939	94,598,185	124,573,252	219,171,437	123,373,823	342,545,260

* All data in M.cu.ft.
** For resale, company use and unaccounted for.
*** South of Fresno and Paso Robles.

SIGNIFICANCE OF THE INDUSTRY

The natural gas industry in California has developed steadily. During the past three years, natural gas has stood third in value among the mineral products of the State, being exceeded only by oil and gold. Since 1907, a growth in yearly revenues from nothing to over $80,-000,000 per year has taken place. The number of customers served has likewise increased, until California now holds top place among the States of the Union; it has held this place for the past five years. At the end of 1939, more than 1,700,000 domestic and commercial customers and 4,600 industrial and pumping plants were using natural gas. Total population in the area served is 5,600,000. During a corresponding period, pipe lines have been extended from a few miles to over 23,500 miles. The investment in lines, plants, and facilities exceeded $285,000,000 by the end of 1939.

RELATIONSHIP BETWEEN GAS AND OIL PRODUCTION

The supply of casinghead gas from an oil field is dependent almost entirely upon the amount of oil being produced from that field. The gas-oil ratio is defined as the number of cubic feet of gas (measured under standard surface conditions) produced with each barrel of oil. It can be varied somewhat for individual wells, but in the ordinary field (taken as a whole) the production of gas is directly dependent upon the oil production. Certain exceptional fields exist, such as Kettleman Hills and North Belridge, where (under present conditions of curtailment) the allowable oil production can be obtained from low gas-oil ratio wells. At times of greater gas demand, however, these low ratio wells can be closed in, and an equivalent oil production obtained from gas cap wells, greatly increasing the amount of gas available to the gas companies. Such changes are necessary to adapt the gas production to the load fluctuations. These fluctuations occur seasonally; even over the week-ends, with the cessation of industrial activity on Saturdays, a sudden and serious decrease in gas utilization takes place, and continues until the following Monday.

In certain other fields, injection of the surplus gas into partially or wholly depleted sands is resorted to during periods of low demand. These surpluses, together with such withdrawals from storage as can be handled, are then made available to the gas companies in time of cold weather or other periods of heavy demand.

Fig. 12 illustrates the seasonal variation in load, or utilization, on a monthly basis. If such a diagram were prepared on a daily basis, an equally wide variation would be shown between the days of the week.

IMPORTANCE OF DRY GAS FIELDS

The dry gas fields of California form a valuable reserve which may be drawn upon in time of heavy demand, and up to the present time they have served the industry in this manner. Where such fields lie close to a large metropolitan market, use of dry gas may supplant the use of casinghead gas from the oil fields, particularly if the oil field is at a considerable distance from the market. Normally, however, since the dry gas is commonly of a lower heating value than the casinghead gas, it may best be utilized by blending with the higher B.t.u. oil field gas. Dry gas deposits can be conserved in place indefinitely, while casinghead gas, for the most part, must be utilized as produced. Ultimately, as the gas associated with oil is exhausted, dry gas fields will assume a major importance in California; but up to the present time they have been relatively insignificant as illustrated by the statistics shown in Table I.

TABLE V—SUMMARY OF CALIFORNIA FIELDS HAVING IMPORTANT GAS RESERVES*

Central California	*Year of discovery*	*Zones containing gas or oil and gas*	*Approx. minimum depth to top of zone (feet)*	*Approx. thickness (feet)***	*Geologic age*
McDonald Island	1936	dry gas zone	5,200	250	Eocene
Rio Vista	1936	dry gas zone	3,800	350	Eocene
San Joaquin Valley					
Coalinga Extension North	1939	oil and gas	7,900	300±	Eocene
Coalinga Extension South	1938	oil and gas	6,600	800±	Eocene
Kettleman Hills N. Dome	1928	oil and gas	6,000	1,600	Miocene
	1938	oil and gas	10,500	600±	Eocene
North Belridge	1930	oil and gas	5,000	300	Miocene
	1935	oil and gas	7,400	350	Oligocene?
Buena Vista Hills	1909	dry gas zone	1,100±	500±	
		oil and gas	2,200±	600±	Lower Pliocene
Elk Hills	1919	dry gas zone	1,400±	500±	
		oil and gas	2,400±	800±	Lower Pliocene
Rio Bravo	1937	oil and gas	11,200	200	Miocene
Greeley	1936	oil and gas	7,600	100	Miocene
			11,250	200	Miocene
Coles Levee	1938	oil and gas	8,250	900	Miocene
Ten Sections	1936	oil and gas	7,800	600	Miocene
Coastal					
La Goleta	1929	dry gas zone	4,100	150	Miocene
Ventura Avenue	1916	oil and gas	1,000	7,000±	Pliocene
Los Angeles Basin					
Inglewood	1925	oil and gas	1,100	2,500±	Pliocene
Dominguez	1923	oil and gas	1,000±	3,000±	Pliocene
Wilmington	1936	oil and gas	2,100	2,400±	Pliocene / Upper Miocene
Long Beach	1921	oil and gas	2,300	6,400±	Pliocene / Miocene?
Huntington Beach	1920	oil and gas	2,000	2,700±	Pliocene / Upper Miocene
Montebello	1917	oil and gas	1,750	3,400±	Pliocene
Santa Fe Springs	1919	oil and gas	2,000±	3,600±	Pliocene
West Coyote	1908	oil and gas	3,300	2,000±	Lower Pliocene
Brea Olinda	1897	oil and gas	200	3,200±	Pliocene

* This summary includes the fields having the most important gas reserves. Such fields as Buttonwilluw, Santa Maria, Elwood, Rosecrans, South Mountain, Seal Beach, Playa del Rey, Torrance, Richfield, Tracy, Trico, and Marysville Buttes all produce gas but in relatively small quantities and the sum of the reserves in all of these fields is a relatively small percentage of the total reserves in the State. The fields shown in the summary are those which have substantial reserves to be produced at some future period.
** From top to bottom of entire producing interval.

POSITION OF GAS IN STRATIGRAPHIC COLUMN

Commercial deposits of natural gas occur in strata ranging in age from Cretaceous to Pleistocene, but by far the greatest part of the production obtained to date has come from the Pliocene and upper Miocene.

The gas obtained from the shallow wells near Stockton, though historically the earliest production developed, came from geological formations most recent in age, namely Pleistocene. Some of the latest fields discovered, such as Coalinga Extensions and the Avenal zone of Kettleman Hills, are producing from strata of Eocene age or older. In the Sacramento Valley, as at Marysville Buttes, gas is obtained from rocks of Cretaceous age.

Bibliography: Boone, A. R. 37; Davis, R. E. 38; Hoots, H. W. 39a; Uren, L. C. 37; Wall Street Journal 40.

TABLE IV—ANALYSES OF TYPICAL GAS SAMPLES FROM CALIFORNIA FIELDS*

Sample from / *Kind of gas*	*North Dome Kettleman Hills C.H. (Temblor)*	*North Belridge C.H. (Wagon-wheel)*	*Ten Sections C.H.*	*Rio Bravo C.H.*	*Semi-Tropic Dry*	*Rio Visto Dry*	*Coyote Hills C.H.*	*Dominguez C.H.*	*Long Beach C.H.*	*Santa Fe Springs C.H.*	*Wilmington C.H.*	*Ventura Avenue C.H.*
CO_2	---%	1.30%	0.50%	0.50%	0.1%	---%	---%	0.91%	0.50%	0.40%	3.00%	0.40%
CH_4	85.36	91.21	87.97	83.32	98.7	94.79	85.4	89.42	86.76	85.09	88.92	89.13
C_2H_6	8.62	3.61	8.05	10.31	0.0	2.82	8.0	6.05	7.19	10.23	4.27	4.90
C_3H_8	5.10	1.94	3.14	5.41	---	0.72	5.5	2.95	4.28	4.15	3.42	4.63
Iso-C_4H_{10}	0.48	0.36	0.16	0.36	---	0.17	0.6	0.36	0.66	0.08	0.25	0.51
N-C_4H_{10}	0.44	0.69	0.16	0.10	---	---	0.5	0.28	0.61	0.05	0.14	0.43
C_5H_{12}+	---	0.89	0.02	---	---	---	---	0.03	---	---	---	---
N_2	---	---	---	---	1.2	1.50	---	---	---	---	---	---
Calc. B.t.u.	1,173	1,089	1,118	1,174	992	1,030	1,178	1,105	1,152	1,187	1,057	1,134

*Reproduced from Bauer, R. M. 39, p. 103, Table No. 5.
It should be noted that the examples of dry gas analysis shown are of unusually high heating value, much higher than the values obtaining for such dry gas areas as Stockton, Chowchilla, and other minor San Joaquin Valley gas fields. The lower heating value of such gases is due to the complete absence of the heavier hydrocarbons and the presence of varying amounts of nitrogen and carbon dioxide.

Chapter II

Exploration

CONTENTS OF CHAPTER II

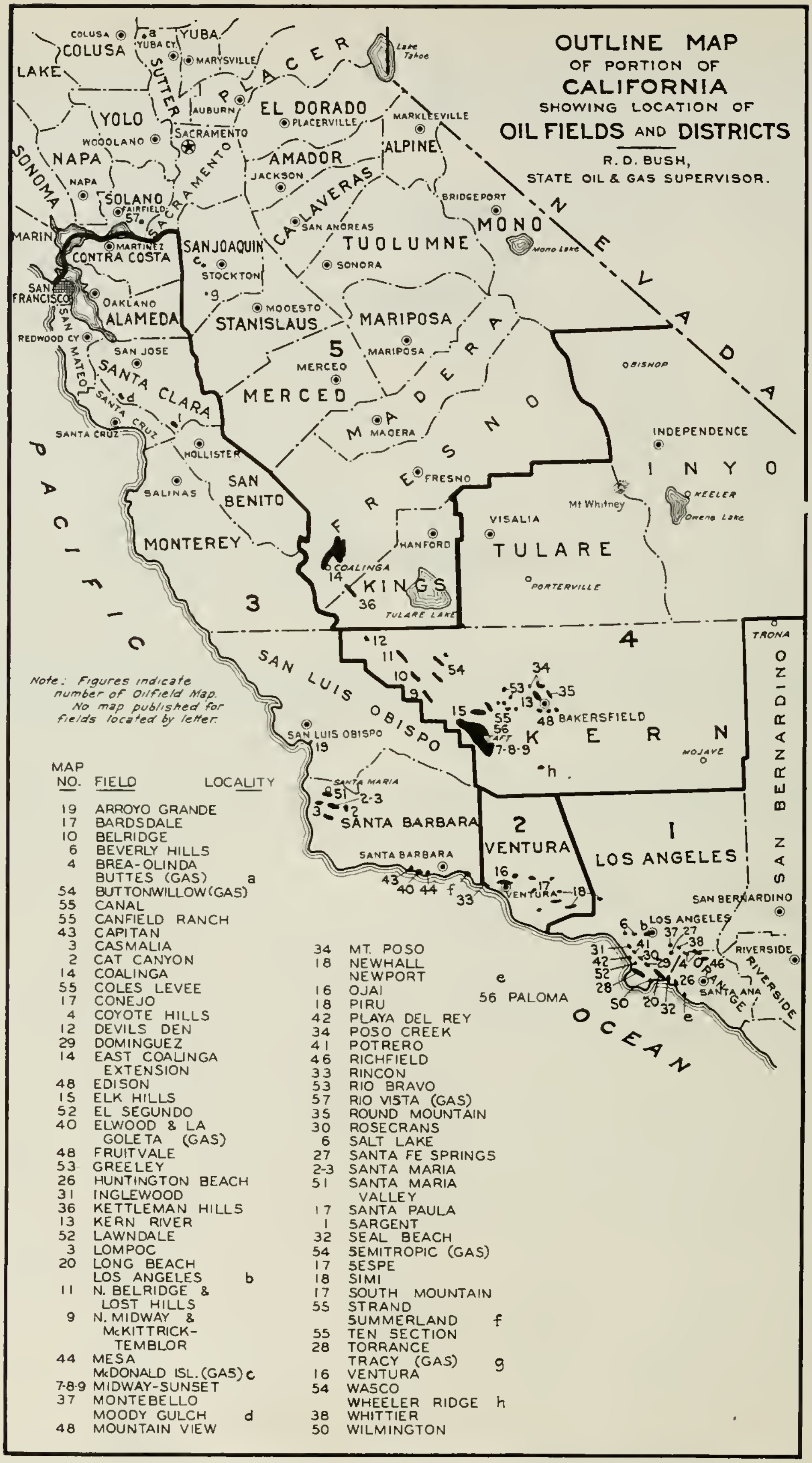

FIG. 13 A. Index map, prepared by the State Division of Oil and Gas, to show locations of oil fields and districts in California. The numbers correspond to maps, which may be obtained from the Division of Oil and Gas.

DEVELOPMENT OF ENGINEERING TECHNIQUE AND ITS EFFECT UPON EXPLORATION FOR OIL AND GAS IN CALIFORNIA

By Lester C. Uren*

OUTLINE OF REPORT

INTRODUCTION

The story of the search for petroleum in California and of the development of her many oil and gas producing fields, is the story of the petroleum industry itself. Almost from the inception of the industry in the United States, California has been recognized as a region offering great promise as a potential producer of oil and gas. The full gamut of methods and equipment, from the most primitive to the most modern, has found application here. Indeed, it would appear that during the last three decades, the California fields have been the proving ground for most of the innovations that characterize the highly scientific petroleum industry of today. Likewise, the California industry has been the training ground for many of the technical men who have been largely responsible for the development of the industry to its present high plane of efficiency.

In the present chapter, an effort will be made to trace briefly the development of methods of petroleum exploration and oil-field development, from the early days of the California industry to the present time, with particular emphasis upon the more modern methods and equipment utilized in the present-day industry. The period is one which extends from the early '60's when the first primitive efforts were made to develop commercial production in California, through the subsequent seventy-odd years of gradual improvement in engineering technique.

EARLY DISCOVERIES AND EXPLOITATION

The early years of the petroleum industry in California require little comment, as they were productive of no innovations that seem important in retrospect. The methods employed were those that had been found effective in development of the Pennsylvania fields. Little was known of the geology of the region, or of the influence of geologic structure on oil accumulation. The wells were located in the vicinity of outcrops that gave evidence of the presence of petroleum and, being shallow, primitive cable-tool equipment proved adequate in drilling them. California was a region isolated from populous sections of the country by long stretches of desert or by many days of ocean travel, and the market demand for petroleum products in the region served by the California industry was small. At most times, a surplus of oil existed; prices were low and there was little incentive for active search for new reserves.

Prior to 1894, all commercial production of crude petroleum in California was secured from Ventura County, particularly in the vicinity of Newhall and Ojai, where production was found in several shallow pools. It is probably a fair statement that the operators in these early pools had little understanding of the intricate geology of this region, and new pools were located primarily along trends from well marked outcrops and existing producers.

An interesting development of the early '60's in Ventura County, was the driving of a number of tunnels for oil drainage. With portals in the ravine below the precipitous slopes of Sulphur Mountain, these tunnels, though less than a thousand feet long, were so situated that they penetrated oil sands well below the surface. For many years they continued to produce small quantities of oil. Drainage of oil through mine openings had previously been practiced in a primitive way in other parts of the world, but the Sulphur Mountain tunnels are of interest as the first successful enterprise of the kind in the western hemisphere, and there have been few since.

In 1894, the Los Angeles and Salt Lake fields were discovered in what are now thickly populated portions of

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the City of Los Angeles. Interest was attracted to these areas by nearby brea pits and surface outcrops that gave promise of oil production from shallow horizons. Also, in the same year, successful wells were drilled on the coast, near Summerland in Ventura County, and a portion of this field, extending out from shore under tidelands, was later exploited by shallow wells drilled from piers—probably the first successful underwater development of an oil field. First production in the San Joaquin Valley was in the Coalinga field in 1896, this being the first California field to attain an annual rate of production in excess of a million barrels per year. Again, bituminous outcrops in the vicinity attracted attention and the early wells were located on monoclinal structures that obviously had yielded some of their oil to the outcrops. The early wells in these fields were but a few hundred feet deep, but down-dip exploration soon disclosed deeper, more prolific sands.

Discovery of the McKittrick and Midway-Sunset fields, situated much like the Coalinga field, on the eastward flanks of the Coast Range, and presenting a very similar geological and lithological picture, followed in 1898 and 1900. Across the Valley, east of Bakersfield, obvious surface indications led to the discovery of the Kern River field, also in 1900. Again, the early wells were less than a thousand feet deep. Likewise, the Brea-Olinda district in the Los Angeles Basin, and the Santa Maria field, near the coast in northern Santa Barbara County, were developments of the few years preceding and following the "turn of the century," which might well be regarded as the end of the first epoch of petroleum development in California. Gross production of all California fields, up to and including the year 1900, was 14,378,875 barrels and the maximum annual production of the period, attained in the year 1900, was only 4,324,000 barrels.

While geological knowledge played little part in the discovery of these early California fields, geologists were not without knowledge of the role of structure and its influence on oil and gas accumulation. The anticlinal theory of oil accumulation had been proposed and by 1900 was rather generally accepted, but it had not as yet become the custom for would-be producers of petroleum to seek geological advice.

DEVELOPMENT OF MODERN EXPLORATION METHODS

After the more obvious surface seepages had been noted and the localities about them explored with test wells, it came to be recognized among the larger and better informed oil producers that further progress in the finding of new pools was to be made only by application of the geological sciences (Lahee, F. H. 31). Accordingly, many producers began to employ geologists to advise in the selection of well sites and eventually most of the larger oil companies organized geological departments to engage in widespread reconnaissance and detailed geologic studies of the more promising areas.

It was early observed that most of the California oil deposits were confined to rocks of Pliocene and Miocene age and that accumulations were customarily found in dome or anticlinal structures or in "buttress" formations on the flanks of folds or against unconformities or fault planes and in definite relation to certain shale bodies that were likely "source rocks." Accordingly, early interest centered on these geologic horizons, and test wells were located in areas where they were within reach of the drill and where structural traps were observed to exist. Once these more favorable areas were selected, the work of the geologist in the field resolved itself largely into detailed studies of dip and strike of strata and the gathering of information helpful in forming an accurate picture of subsurface structure (Cox, G. H. 21). Surface locations for test wells were then selected at points that would permit them to intersect the prospective oil reservoir rock at or near its structural crest.

The science of paleontology was found to be a useful tool of the geologist in determining the approximate geologic age of formations exposed at the surface, as well as those penetrated by the wells. Certain fossil markers came to be recognized as characteristic of different geologic intervals and broad correlations of formations in different locations became possible. Out of this knowledge grew the science of correlation by identification of micro-fossils.

GEOPHYSICAL EXPLORATION

The conventional methods of the geologists, based largely upon surface areal studies, served well enough in the foothill regions where outcrops were plentiful and the broad structural features were fairly apparent. Eventually, however, as these more obvious structures were explored and tested, it became necessary to extend the search for new fields into areas where nature had been less generous in providing surface indicators. Geologists had long held the theory that oil-bearing structures might be found buried beneath the horizontally disposed sediments of the San Joaquin Valley, in areas where surface studies disclose little or nothing of deep-seated structural conditions. Particularly was this likely to be true where stratigraphic unconformities existed.

Development and application of geophysical methods of exploration during the last two decades have aided greatly in identifying structural features in localities where surface exposures were inadequate. Early efforts to apply geophysical methods in California were not successful, and, for a time, it was thought by many geologists that they would not be found helpful under the conditions presented in this region. It was considered that the strata overlying the oil measures were too much alike in density, elasticity, and other physical and lithologic characteristics to afford satisfactory reference horizons upon which to make observations. Torsion balance surveys were made in the California fields during the early '20's by some of the more forward-looking oil companies. Some companies made extensive magnetometer surveys; others seismic surveys. While the early efforts to apply these methods were not successful in discovering any new producing fields in California, gradual perfection of equipment and methods eventually began to produce more encouraging results. Particularly was this true of the reflection seismic method, now widely employed.

Within the last few years, many new California oil and gas fields have been discovered as a direct result of geophysical surveys. Notable among these are a highly prolific group of oil and gas fields situated in the area to the west and northwest of Bakersfield (i.e., Ten Sec-

FIG. 14. Aerial photographic map of an oil field made by combining vertical air views into a mosaic. Township and section lines, together with structural contours have been drawn on the mosaic. *(Courtesy of McGraw-Hill Book Co., Inc., and S. C. Herold.)*

tions, Wasco, Greeley, Cole's Levee) and several structures producing dry gas in the delta region of central California (Tracy, Rio Vista, McDonald Island).

Some authorities believe that we may have already exhausted the opportunities for application of geophysical methods in the finding of new oil and gas fields in California, but it seems more reasonable to believe that with further improvements in design of geophysical instruments and with better understanding and interpretations of the results of geophysical surveys, more fields, hitherto overlooked, will be found. There would also seem to be opportunity for more detailed studies of prospective areas than have yet been made. Geophysical methods may be of great help in obtaining a clear picture of broad structural features of an entire district. For example, they may be of aid in deciphering California's extensive system of block faults. In any case, it is quite certain that geophysics will henceforth be regarded as a valuable tool of the geologist in his search for new oil reserves and that geophysical data will play an important role in future exploration (Lahee, F. H. 31).

AERIAL PHOTOGRAPHY

Older methods of gathering topographic detail in preparing maps for use in geologic reconnaissance have been supplemented during the last two decades by methods of mapping from the air. Photographs systematically taken from an aeroplane flying at constant elevation, in straight courses over the area to be mapped, are later fitted together to form a complete mosaic or "aerial map." Such maps possess a pictorial value beyond that of any other kind of topographic map and have to a considerable extent, supplanted ordinary topographic maps prepared by plane-table, transit, level and other conventional methods (English, W. A. 30). They have the additional advantage of being less costly, and they may be more rapidly assembled. Occasionally the outcropping strata are so clearly apparent on the photographs, especially when examined under the stereoscope, that it is possible to identify anticlinal structures without gathering the usual field data; but generally they are employed merely as a base upon which to assemble data gathered in the field survey.

DRILLING FOR STRUCTURAL INFORMATION

Where surface alluvium obscures outcrops to such an extent that the usual methods of gathering field data become impractical, the geologist may resort to the drilling of shallow wells merely for subsurface information. Small diameter wells, but a few hundred feet deep, cheaply drilled with portable drilling outfits, may afford stratigraphic information very helpful in determining the dip and strike of beds, often with sufficient accuracy to disclose the geologic structure. In localities where unconformities intervene between shallow and deep-seated formations, it will often be necessary in drilling wells to penetrate the formations below the plane of the unconformity. before the structural and stratigraphic conditions at depth may be determined. Cores taken at intervals will disclose the character of the sediments, and with the aid of modern methods of core orientation, the dip and strike of beds may be estimated. Measured depths to a recognizable marker bed in three wells, suitably spaced, afford a basis for determining the strike and dip of beds without the aid of cores.

IMPORTANCE OF CONTINUATION OF EXPLORATION ACTIVITY AND OF RECURRENT DISCOVERY OF NEW FIELDS

Available supplies of petroleum in present known California fields, have lately been estimated at 3.2 billion barrels, or about 12 years supply at the 1938 rate of production (American Petroleum Institute 39, p. 61). On January 1, 1938, California's natural gas reserve was estimated at 6.9 trillion cubic feet (Bauer, R. M. 39). At the current rate of withdrawal of about 350 billion cubic feet yearly, this is about 20 years' supply. While these estimates are probably conservative, yet when one considers the great economic importance of the oil and gas industries of California and the necessity for maintaining a continuing supply of essential petroleum products, they represent a rather slender reserve. Furthermore, because of decline in productivity of wells and fields, it would be difficult to maintain the current rate of production from these sources for more than a few years. Most of our current supplies of oil and gas are derived from recently discovered fields in flush production, and we are vitally dependent upon recurrent discovery of new sources of supply if we are to maintain or increase our current rate of production. Hence, it is important that those engaged in seeking new oil and gas fields be given every encouragement. If a suitable margin of profit is assured to cover the risks inherent in this highly speculative phase of the petroleum industry, we may hope to find many additional oil pools. Yet the current production rate is one that demands a considerable continuing activity in new exploration and development work, and increasing difficulty and cost of finding new reserves requires an ever-increasing amount of new capital to maintain the existing reserve. Inevitably, the time will come when we can no longer maintain the reserve: when the amount of new capital available for exploration and development will no longer be sufficient to find, each new year, as much oil as is consumed. Whether this time is near at hand or remote is a matter of opinion hinging upon one's ideas of the magnitude and availability of the undiscovered reserve.

New exploration may be effective in finding additional reserves in one of three ways: (1) by drilling in hitherto unexplored areas; (2) by exploring lateral extensions of areas already productive, and (3) by seeking deeper productive formations in present producing areas. Of late, new supplies of oil in all three categories have been found, and there would seem to be opportunity for further discoveries by each method. Geophysics has lately been of assistance in finding new and promising areas for exploration. Improved deep drilling technique has been largely responsible for the success that has attended some of these efforts. Certain it is that, without the ability to drill to depths greatly in excess of those attainable a decade ago, California would even today be experiencing a serious shortage of oil. Improved methods of exploration go hand in hand with improved methods of drilling. Both must undergo continuing improvement and development if we are to continue to find new reserves to offset the decline in production of our older fields.

DEVELOPMENT OF DRILLING EQUIPMENT AND TECHNIQUE IN CALIFORNIA FIELDS

EARLY DRILLING BY CABLE METHOD

Prior to about 1910, practically all drilling in the California fields was done with cable tools, light portable outfits and American "Standard" cable drilling rigs being exclusively used. The shallow wells characteristic of the early period could be quickly and cheaply drilled by this method, but as deeper horizons were exploited, wells became considerably more expensive and many months were necessary to complete them (Uren, L. C. 34, Chapt. V, VI). The cable-tool method is not well adapted to drilling in the semi-consolidated formations characteristic of the California Quaternary and Tertiary, much difficulty being experienced due to caving of the walls of the wells and in maintaining clearance and inserting casing. In many areas, casing had to be driven into the wells and individual strings quickly became frozen to the walls, so that as many as five telescoping strings of casing had to be used to reach depths of 2,000 to 3,000 ft.

A large number of the "stripper" wells that are still producing in the older California fields were drilled with cable tools. Such fields as the West Side Coalinga, Kern River, Midway-Sunset-McKittrick, Lost Hills, Belridge, Whittier, Los Angeles City, Salt Lake and the older portions of the Brea-Olinda and Santa Maria fields were developed almost entirely by this means. Altogether, it is probable that upwards of 15,000 wells have been drilled by the cable method in California. Many of these are, of course, now abandoned.

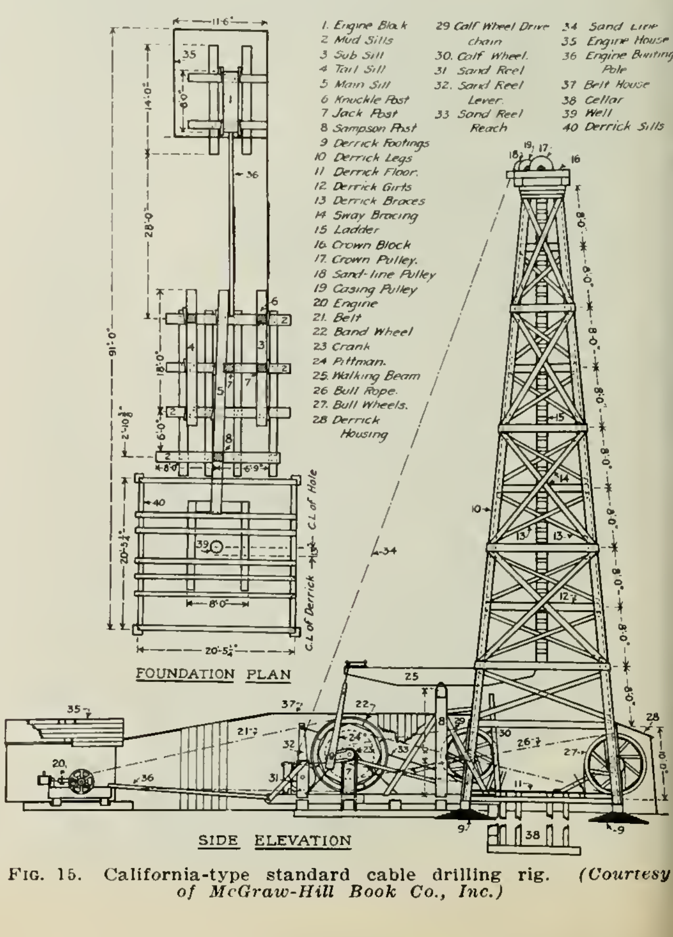

FIG. 15. California-type standard cable drilling rig. *(Courtesy of McGraw-Hill Book Co., Inc.)*

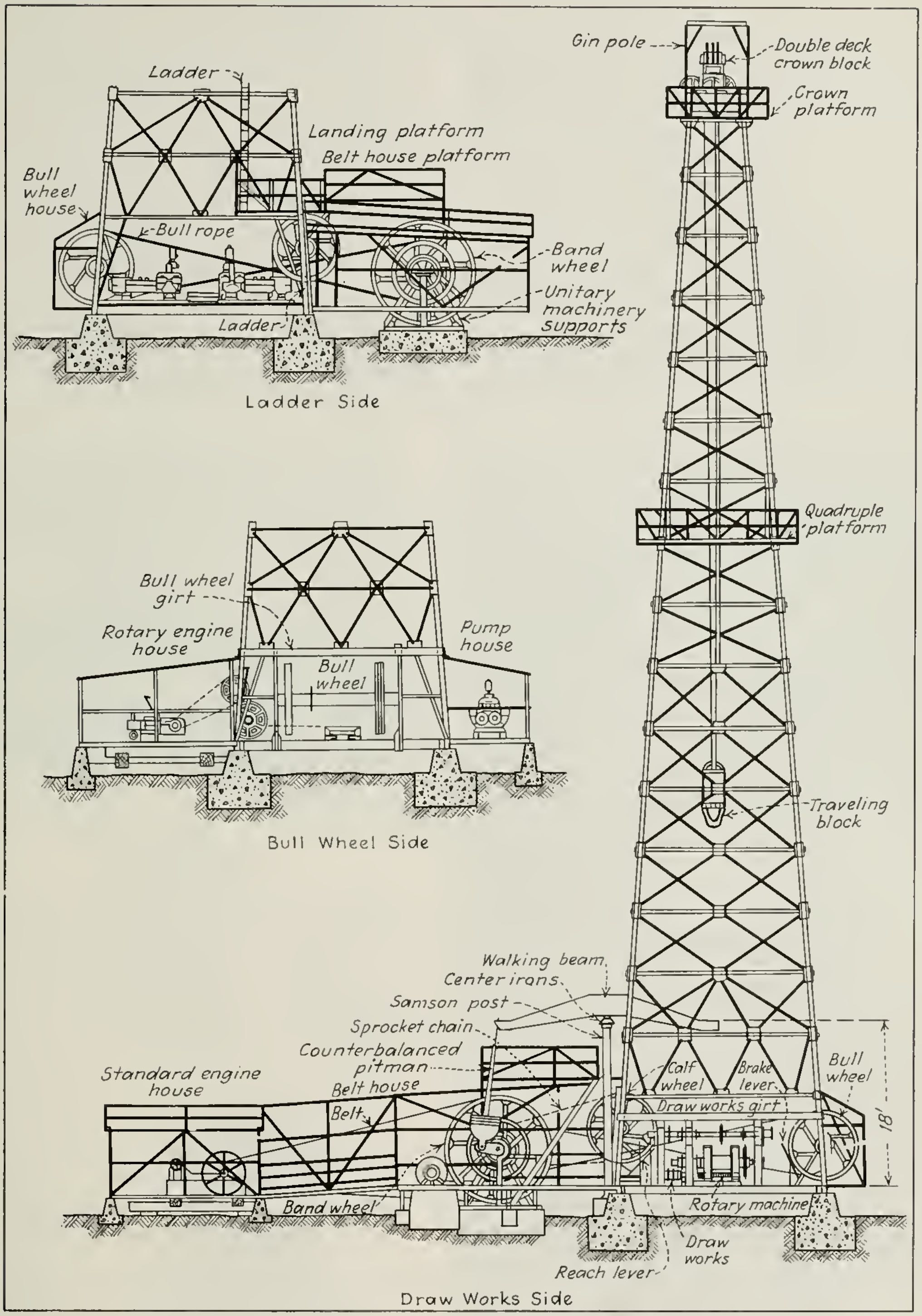

FIG. 16. California type combination drilling rig. *(Courtesy of McGraw-Hill Book Co., Inc.)*

ROTARY METHOD OF DRILLING

Successful use of the "hydraulic rotary" method of drilling in the Gulf Coast region of Texas, notably in the Spindle Top field, led to its early introduction into the San Joaquin Valley fields of California. In the early days of its development, the rotary method was thought to be suitable only for drilling in the soft, unconsolidated and semi-consolidated formations characteristic of this region. Drillers familiar only with cable equipment were distrustful of the new method and opposed its use. The early rotary rigs were light, their parts were poorly correlated and of rather primitive design. Frequent twist-offs of drill pipe and other mechanical difficulties afforded plenty of opportunity for criticism. It was charged that the method did not afford a dependable means of testing the formations penetrated and that prolific oil sands were frequently drilled through without recognition of their petroliferous character. Good producing sands were "mudded off" so that they never developed their normal productivity. The rotary method of drilling was therefore considered unsuitable for exploration drilling in new areas where a dependable log of the formations penetrated was a prime requisite. The fish-tail bits at first exclusively used, were unsuited for hardrock drilling, and were quickly dulled, so that much time was spent in drawing out and replacing drill pipe to change bits. Because of the greater power requirements, larger drilling crews, greater water consumption, larger derrick and higher initial cost for rotary equipment, the completion cost of the comparatively shallow rotary-drilled wells was as great or greater than when drilling was by the cable method. Yet, it was admitted that wells could be more quickly drilled by this method—an advantage under competitive conditions—and that the deeper wells could be completed with fewer strings of casing and with a saving in free working diameter at the level of the reservoir rock. Ability to control high-pressure gas encountered in drilling, and to complete wells without gas and oil wastage, was admittedly a great advantage of the rotary method (Uren, L. C. 34, Chapt. V, VII).

The real and fancied disadvantages of the rotary method, and lack of familiarity with it on the part of operators and drillers, were factors that prevented prompt and wide-spread adoption of the method during the early years, and its introduction was a gradual one that extended over a period of many years. Prior to 1910, practically all drilling in California was with cable tools; but by 1920, replacement of the cable method by the rotary method was almost complete. This was a result of gradual improvement in rotary drilling equipment and development of greater skill and confidence in its use. Also, deeper wells were becoming necessary, and with increasing depth, the advantage of the rotary method over the cable method became more apparent.

COMBINATION RIG

Realizing that each of the two methods of drilling possessed certain advantages for particular conditions, operators early conceived the idea of combining them so that either might be used alternately as conditions might warrant. It was found to be feasible to arrange all parts of both the rotary and cable equipment under one derrick in such a way that the driller could quickly change from one method to the other. Rigs so equipped were called "combination rigs" and a certain arrangement of the equipment became characteristic of California practice and led to the designation "California type combination rig."

Most of the so-called rotary rigs used in the California fields have really been combination rigs (Uren, L. C. 34, Chapt. V, VII). For a time, in the San Joaquin Valley fields, operators followed the practice of drilling from the surface down to the cap rock to the point where the water strings of casing are usually cemented, with rotary tools, and then "changing over" and drilling into the productive formation and completing the well with cable tools. By this practice, sealing off productive formations with clay from the drilling fluid was avoided: an advantage thought to be particularly important in drilling into low-pressure reservoir rocks where the subsequent flow of gas and oil was insufficient to drive all deposited clay from the pores of the reservoir rock about the walls of the wells.

STANDARD CIRCULATING SYSTEM OF DRILLING

In the early days of application of the rotary method of drilling in California, much emphasis was given to the advantages that the method offered in preventing wastage of high-pressure gas and oil during well comple-

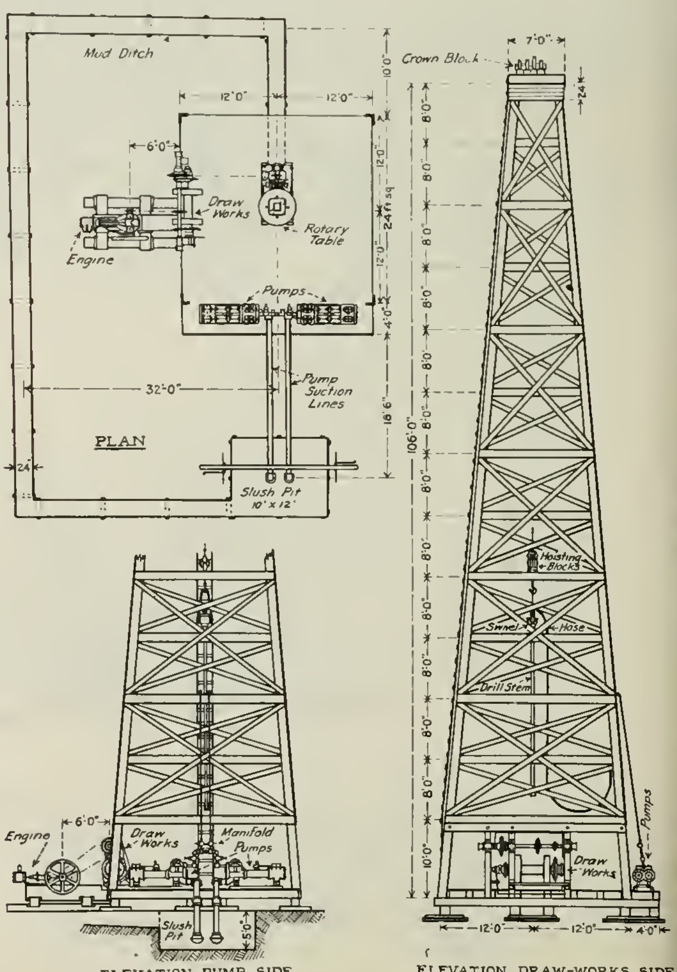

FIG. 17. A California-type rotary drilling rig. *(Courtesy of McGraw-Hill Book Co., Inc.)*

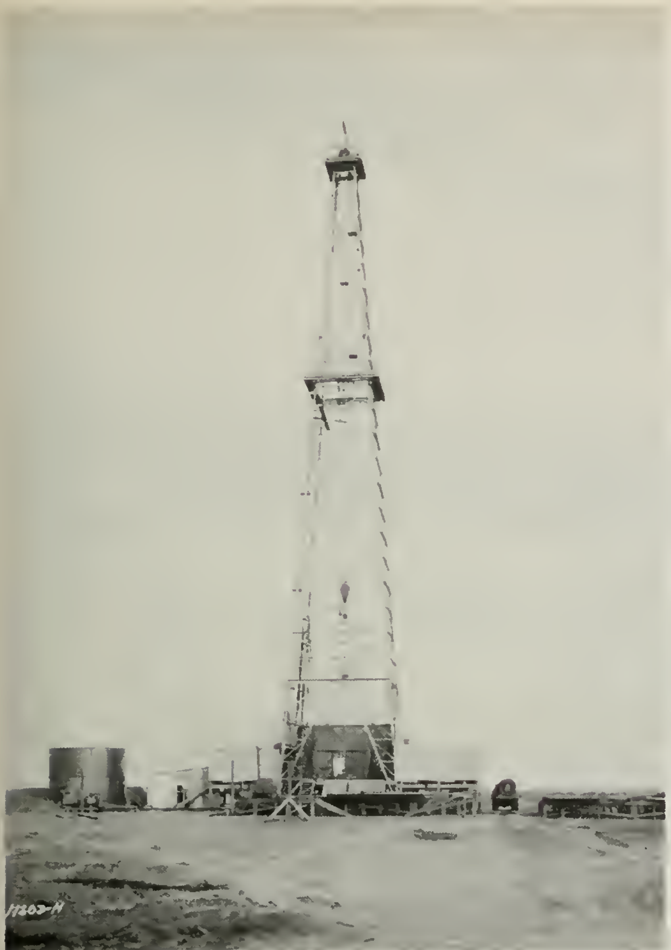

Fig. 18 A. Modern steel derrick of the type used in the California fields for deep drilling by the rotary method. *(Courtesy of National Supply Co.)*

IMPROVEMENT IN DERRICK AND RIG DESIGN AND CONSTRUCTION

Derricks and rigs used in the California oil fields until 1920 were constructed almost exclusively of timber. The sills, posts, walking beam and rig wheels (cable tool and combination rigs) were likewise constructed largely of timber and lumber. Even the corner foundations were usually constructed of a mat of timber. While mechanically inefficient, as a result of warping and yielding under stress, such rigs served well enough in drilling the comparatively shallow wells of the period in which they were used. Fabricated steel derricks made their appearance in considerable numbers in the California fields during the early post-war period, particularly for drilling in the deeper territory. Since that time, operators have shown a marked preference for the steel structures and the numbers of wooden rigs and derricks used have been continually diminishing.

Steel derricks have the advantage of better design, better to resist all of the stresses to which they are sub-

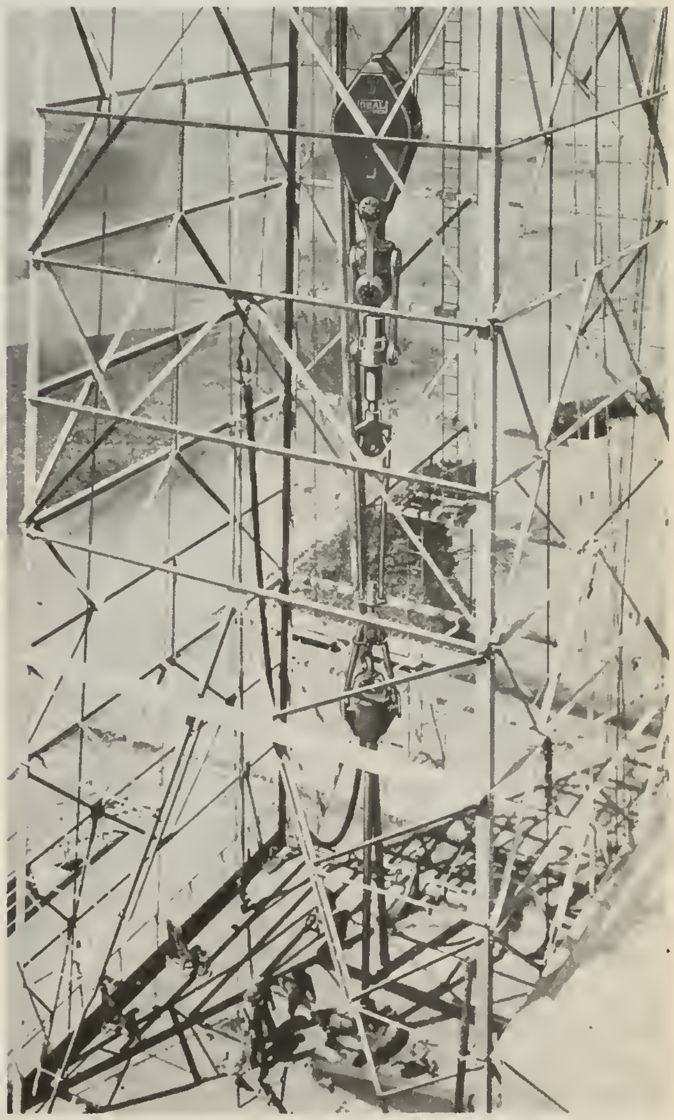

Fig. 18 B. Hoisting gear and rotary swivel suspended in the derrick. *(Courtesy of National Supply Co.)*

tions. In an effort to secure this advantage in the use of cable-drilling equipment, San Joaquin Valley operators devised the "standard circulating" system of drilling. In this method, excavation of the well was accomplished with cable tools, but instead of bailing out the drill cuttings, they were brought to the surface by means of a circulating fluid pumped down through a column of casing, returning to the surface through the annular space between the casing and the walls of the well. Suspended from a massive swinging spider at the level of the derrick floor, the casing was slowly raised and lowered to assist in keeping it free of the walls of the well. Thorough tests of the method showed it to be entirely practical, and it was found possible to drill wells through soft, caving formations to depths as great as 4,000 ft., using fewer strings of casing than would be necessary with the ordinary cable method. Yet, as the rotary method developed and found more sympathetic reception among San Joaquin Valley operators, it was realized that the standard circulating system possessed no real advantages over the rotary method, and that the latter was cheaper, faster and utilized less cumbersome equipment. As a result, the standard circulating system soon became obsolete (Lombardi, M. E. 16).

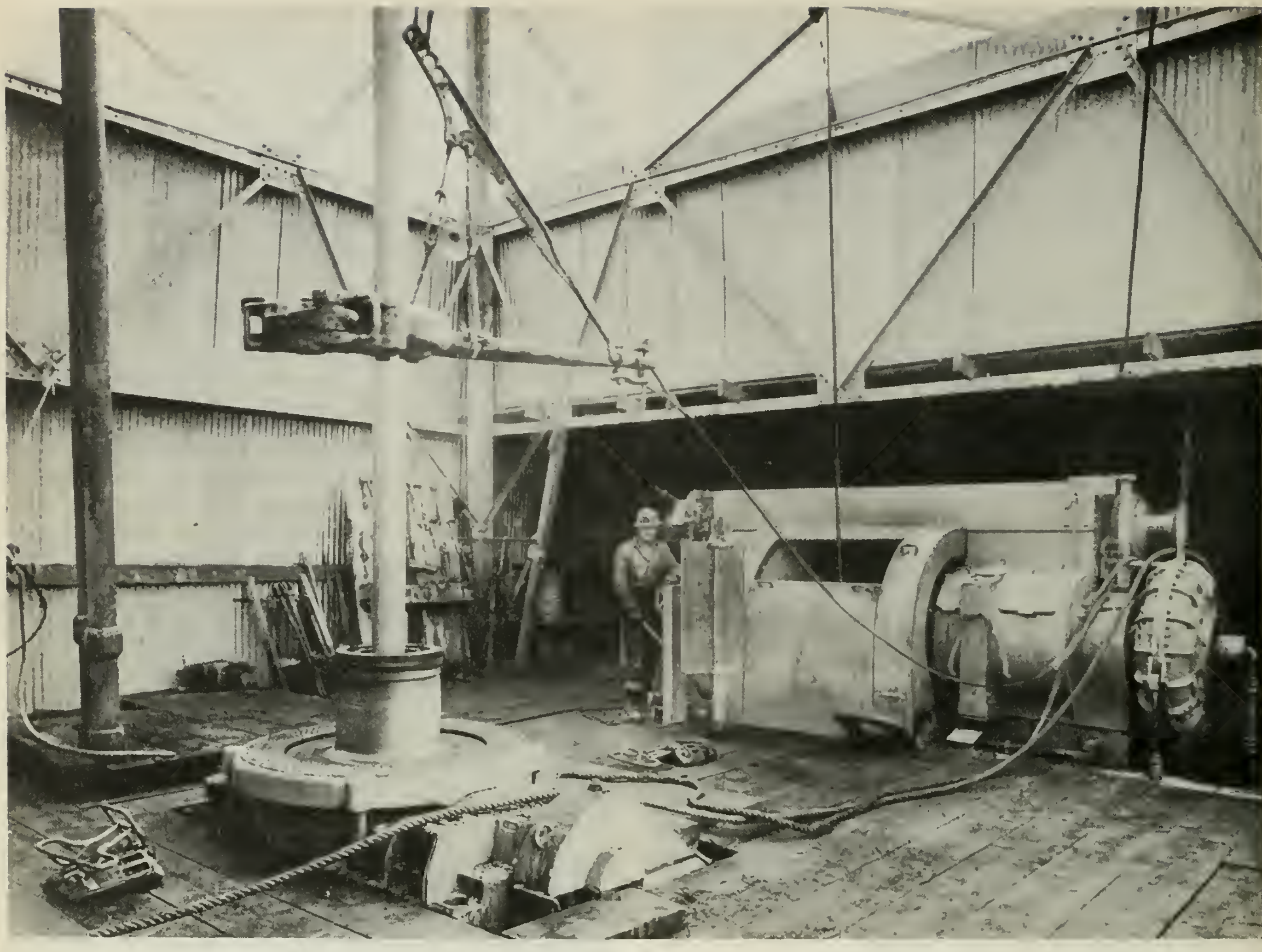

FIG. 19. Interior view of rig. Modern draw-works and rotary table equipped with under-floor drive. *(Courtesy of National Supply Co.)*

jected in service. The material is more uniform and dependable in its properties than timber. They are lighter and present less surface to the wind. They are not so easily distorted under stress. Steel derricks have a longer life than timber derricks and present less fire hazard. They have a greater salvage value and are readily disassembled and erected at a new location. Steel foundation members are more rigid than timber foundations. Steel rig wheels maintain their original form better than wooden wheels and are mechanically more efficient. Concrete foundation piers, generally used in supporting steel structures, provide a firmer support for the derrick and drilling equipment than timber (Uren, L. C. 34, pp. 126-142).

Steel derricks may be constructed either of structural steel forms or of tubular forms, but in the California fields, the structural steel type has been most used. They have been rigidly standardized as to dimensions and essential features by the American Petroleum Institute and are available from California and eastern manufacturers in size up to 175 ft. in height and 32 ft. square at the base. Constructed of steel of high-tensile strength and suitably reinforced, they are designed for safe working loads as great as 500 tons with a safety factor of two.

ROTARY CORING EQUIPMENT

As previously explained, one of the principal criticisms of the early rotary drilling equipment was that the finely pulverized drill cuttings brought to the surface by the circulating fluid did not afford a satisfactory basis for determining the character of the formation in which the drill was working. Seeking to overcome this difficulty, rotary core barrels were devised to secure undisturbed samples from the formation in the bottom of the well. Early core barrels were of primitive construction, designed merely to punch out a short section of the formation, usually but a few inches long. Such samples were often badly "burned" and distorted. Eventually, the double-tube core barrel was developed and perfected. Equipped with a suitable cutting head attached to the lower end of the drill pipe in place of the usual drilling tool, these improved core barrels are capable of securing cores of the formation penetrated by the well that are often as much as ten feet long and but little disturbed. They afford very satisfactory samples for all practical purposes, though in unconsolidated and semiconsolidated formations, they seldom secure more than 75% of the interval cored. The remainder, usually the softer strata, are disintegrated by operation of the cutting tool. Cores ranging from 2 to 5 inches in diameter are common.

Application of early patterns of core barrels required reaming of the well to enlarge the cored interval to full gauge, but more recent types maintain the full gauge of the hole as the core is cut (Uren, L. C. 34, pp. 262-268).

One reason why core barrels are not more generously used is the interruption in drilling progress and consequent lost time and expense in making two round-trips in and out of the well with the drill pipe to substitute the coring tool for the ordinary drilling bit, to cut the core and bring it to the surface. This may be avoided by use of a retractable core barrel that can be run to bottom on a wire line through the drill pipe. A special type drill is used with the central portion cut away and equipped with a locking device for engaging the core barrel while the core is being cut. The core barrel and core may then be retrieved and removed on a wire line through the drill pipe; or the drill pipe may be removed, bringing the core barrel and core to the surface. In this case, a core may be cut just before it is planned to remove the drill pipe to replace the drilling bit. Though somewhat smaller than cores cut by ordinary core barrels, they are satisfactory for most purposes.

Most operators now use mechanical coring but sparingly, particularly in testing formations for landing casing and in securing occasional samples of reservoir rocks. On the other hand, there are many instances where an accurate log is desired—as in the drilling of wildcat wells—in which hundreds of feet of formation have been continuously cored. A core is often taken to determine whether a prospective oil-producing sand is oil-saturated or "wet." The presence of oil in a core is often clearly apparent, but if there is little oil, a chloroform, ether, or acetone test may be necessary to determine whether or not oil is present. Presence of gas in a core is usually made apparent by "bleeding" or by frothing and expulsion of fluids from the pore spaces of the core as it is removed from the core barrel.

IMPROVEMENTS IN ROTARY DRILLING BITS

Early drilling with the rotary equipment was accomplished almost entirely with the fish-tail type of bit. This bit served satisfactorily in drilling shallow wells in soft formations, but as deeper drilling became necessary and harder formations were encountered, it became increasingly necessary to develop bits that were capable of drilling harder rocks and of achieving greater footages, requiring less frequent withdrawal of the drill pipe from the wells to change bits. For attaining greater footages in soft and moderately hard formations, disc bits were found useful, first in two-disc patterns, later styles being equipped with four discs and side reamers, in some cases with the edges of the bits "marcelled." For drilling in hard rock formations, fish-tail and disc bits are dulled rapidly and "rock bits" equipped with toothed cones or rollers are much more effective. Roller core bits are available for hard-rock coring. Special types of demountable bits are also effective in moderately hard formations. The Zublin bit, affording an unusual eccentric motion, has been popular in some California fields. Collapsible bits, permitting replacement of the cutting elements without withdrawing the drill pipe have found but limited use as yet.

Early bits were made of tool steel; later, special alloy steels were used, particularly chrome steel. Studies of

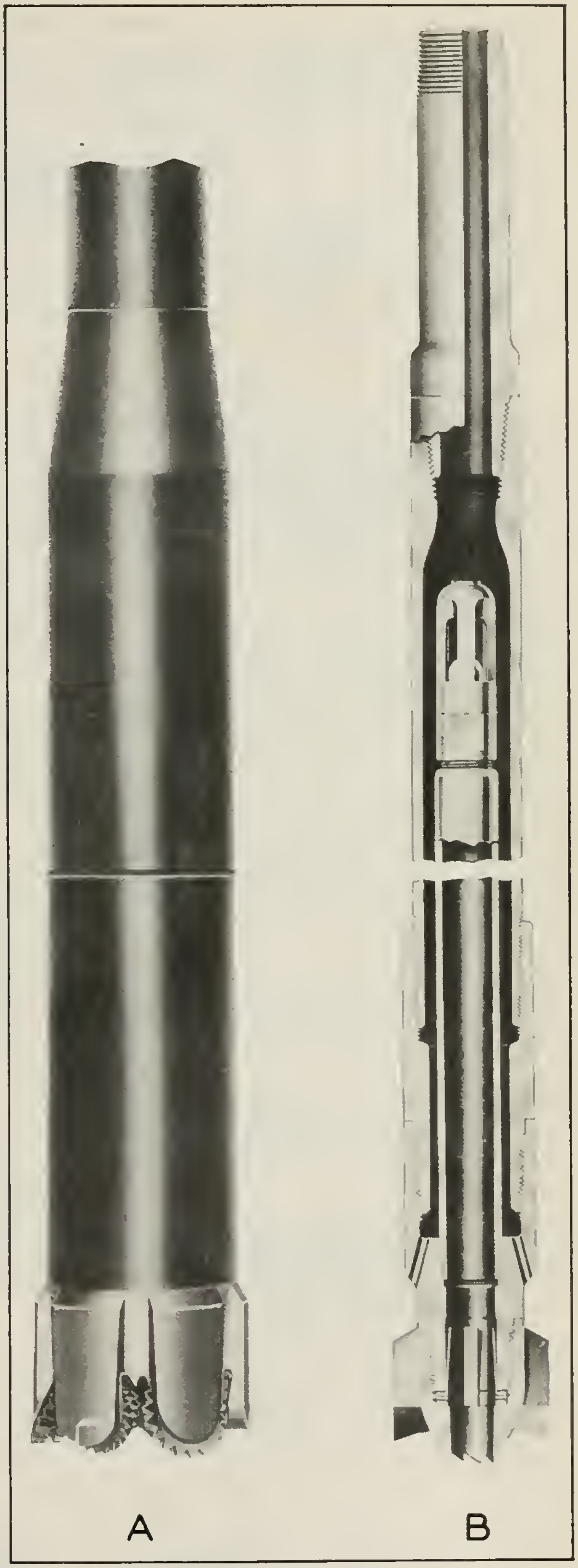

FIG. 20. Examples of modern rotary core barrels.

A. Hughes core bit equipped with hard formation cutter head. *(Courtesy of Hughes Tool Co.)*

B. Elliott rotary core drill. *(Courtesy of Elliott Core Barrel Co.)*

bit performance soon led to the use of special methods of heat treatment designed to develop properties of hardness and toughness assuring greater footage. Later, hard-facing metals were applied to the corners, edges and wearing faces, giving still better performance. And finally, tungsten carbide and related alloys of unusual hardness were perfected and applied to drilling bits as inserts and in powder form. Greatly improved performance followed this development. As a result of improved bit metals and use of super-hard alloys as facing materials, modern rotary bits are capable of achieving footages five times those of early and more primitive types (Uren, L. C. 34, pp. 208-212).

BIT-PRESSURE CONTROL DEVICES

Rotary drillers early appreciated the importance of maintaining a suitable pressure on the bit during drilling operations. This was regulated by suspending a suitable part of the weight of the drill pipe from the crown block on the hoisting cable. The adjustment of bit pressure was left entirely to the skill of the driller, based upon his observation of mechanical performance of the surface equipment. Often excessive pressure was allowed to fall on the bit, resulting in twist-off of the drill pipe or deflection of the well from the vertical. Twist-offs were a frequent cause of interruption in the early use of the rotary method, often leading to prolonged and expensive fishing jobs. That excessive bit pressure was also a cause of deflection of wells from the vertical was not appreciated fully until means were devised for surveying wells.

With the purpose of controlling bit pressure and relieving the driller, to some extent, of the responsibility of regulating the rate of feeding, a number of mechanical and hydraulic devices have been developed. The first of these was the Hild Drive which, by means of electrical controls and differential gearing, automatically regulates bit pressure to any desired value that may be considered suitable for the particular formation being drilled. Later-developed devices of a mechanical nature, designed for the same purpose, were the Halliburton Drilling Control, the Drillometer, and the General Electric Automatic Control using an auxiliary hoist. The Brantly Drilling Control, like the others that have been mentioned, is designed to regulate bit pressure and the rate of feeding, but unlike the others, utilizes hydraulic force rather than mechanical and electrical gear-driven devices. All of these controls received their first trial in the California fields (Uren, L. C. 34, pp. 220-222, 245-249).

Another device that has become almost a universal part of the rotary drilling rig is the Martin-Decker Weight Indicator. This device indicates but does not regulate the pressure on the bit. In effect, it registers the tension in the hoisting cable which, with proper allowance for the number of lines strung between the hoisting block and the crown block, is a measure of the weight of drill pipe supported by the surface equipment. The difference between this and the sum of the weights of the drill pipe, drill collar, bit, kelly, swivel and hoisting blocks, is the pressure on the bit. The weight indicator not only indicates but may also continuously record the tension in the hoisting cable (Uren, L. C. 34, pp. 220-222, 245-249).

HYDRAULICALLY CONTROLLED ROTARY EQUIPMENT

A notable development has been the perfection of a type of rotary drilling equipment in which the weight of the drill pipe in the well during drilling operations is supported by massive hydraulic jacks under the rotary table rather than by the hoisting gear and derrick. This principle, utilized in earlier types of diamond drills, has found expression in an entirely new type of rotary table in the so-called "Hydril" equipment. In addition to freeing the hoisting gear and derrick of the duty of supporting the drill pipe during drilling, the hydraulically supported rotary table permits more sensitive control of bit pressure than is possible by the ordinary type of rotary equipment. As a result, it is claimed that holes are straighter and there are fewer twist-offs of the drill pipe. The hydraulic equipment is also well adapted to "pressure drilling," a new technique discussed in a later section, and to conditions where high-pressure gas- or water-bearing formations must be penetrated in drilling (Uren, L. C. 34, pp. 254-259).

DEVELOPMENT OF LONG, HEAVY DRILL COLLARS

The drill collar was, until recently, but a few feet long. Its function was merely to connect securely the drilling bit to the lower end of the long column of drill pipe. Lately, much longer and heavier drill collars have been used, with the purpose of concentrating a sufficient mass of metal immediately above the bit to produce the requisite bit pressure, thus relieving the drill pipe of this function. When the drill pipe furnishes the bit pressure, the lower portion of it functions as a column under compression. As a result, deflection occurs and bending stresses are developed that are largely responsible for "twist-offs." When the necessary weight is concentrated in the drill collar, practically all of the drill pipe may be in tension instead of compression and twist-offs are much less frequent.

DEVELOPMENT OF RAPID ROTATIONAL SPEEDS

Earlier practice in rotary drilling was conducted with table speeds of from 50 to 150 revolutions per minute. More recently, in deeper drilling, it has been found advantageous to use rotational speeds as great as 450 revolutions per minute. By so doing, better progress is made in hard formations and, in conjunction with long drill collars, fewer twist-offs of the drill pipe occur.

IMPROVEMENT IN DRILL PIPE STRENGTH AND DESIGN

Such rapid rotational speed and such deep holes as are now drilled, would have been impossible with the drill pipe used a decade ago. Today, steel of much greater strength is used in drill pipe manufacture. Seamless tubing or electrically welded high-carbon or alloy steels are now used for this purpose. Better design of threaded joints gives greater security. Tool joints now used are so designed that they offer less resistance to flow of the drilling fluid than formerly. The drill pipe is now fitted with rubber "protectors" which reduce abrasive friction between the drill pipe and the inner wall of the well or the well casing. The results are longer life of the drill pipe and less damage to the casing (Uren, L. C. 34, pp. 205-208, 223-227).

IMPROVEMENT IN DRILLING FLUIDS USED IN ROTARY DRILLING

The great depth and rapid rate of progress attained today in drilling by the rotary method, would have been

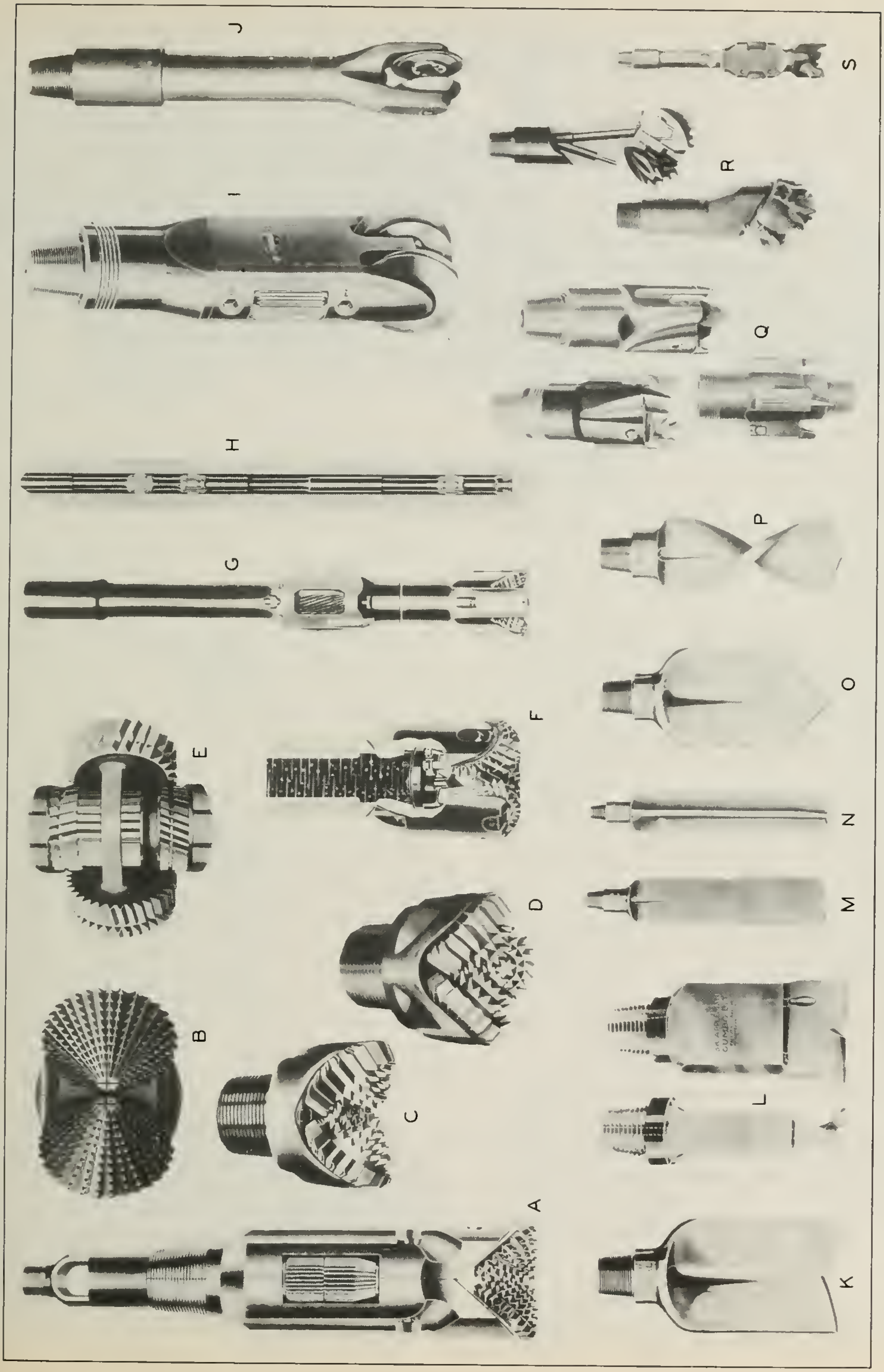

Fig. 21. Types of rotary drilling bits: A. Hughes simplex rock bit equipped with self-cleaning "Acme" cones. B. Bottom view of Hughes simplex rock bit equipped with old-style hard-rock cone cutters. C. Hughes two-cone and D, three-cone roller-bearing rock bits. E. Bottom view of Reed roller-bearing bit. F. Sectionalized view of Reed roller-bearing bit, showing method of discharging circulating fluid. G. Reed roller-bearing bit with three-point reamer and H, with three reamers in tandem. I. Guiberson four-disk reaming bit. J. Byron-Jackson two-disk bit. K. California type "Ideal" fishtail bit. L. Appleman gumbo bit. M. "Ideal" paddle reaming bit. N. Ideal four-wing reaming bit. O. Diamond-pointed bit. P. Side-tracking bit. Q. Three styles of Kennedye-Plumb replaceable-blade bits and reamers. R. External and sectional views of Zublin bit. S. Smith demountable bit and reamer. *(Courtesy of McGraw-Hill Book Co., Inc.)*

impossible without the improvements in drilling fluid preparation and conditioning that have been achieved in recent years. Originally, any clay found near the well was mixed with water to form the drilling fluid; or, drill cuttings from the clay and shale beds encountered in the well, on hydration, were considered to be an adequate source of clay. Today it is recognized that the properties necessary in a satisfactory drilling fluid are secured only by using carefully selected clay having special characteristics. Often a suitable clay is not found near at hand, but must be transported to the well over distances of many miles, at great expense. Freedom from sand and abrasives and well-developed colloidal properties are considered important in the clay used.

When the clay is thoroughly hydrated and suspended in water, the resulting drilling fluid must have a suitable density, viscosity and shear value. The colloidal properties, as indicated by the hydrogen ionization value, must be high. It must show a tendency to "gel" on standing at rest for a short time. The drilling fluid has a variety of functions to perform, some of which require the special development of certain properties. For efficiently lifting drill cuttings, the fluid must have proper density, viscosity and shear value. To form rapidly a sheath of clay on the walls of the well and seal off porous formations, it must have high viscosity and well-developed colloidal properties. To prevent blow-outs of high pressure gas encountered in the well, it should have high density and low viscosity.

Special properties are at times quickly developed in the drilling fluid by adding other materials. Finely ground bentonite marketed under the name of "Aquagel" develops high colloidal values. Finely ground barite, marketed under the name of "Baroid" and finely divided iron oxide, called "Colox," are added to increase the density of drilling fluids. Some chemical reagents, such as tannic acid ("Quebracho") or sodium silicate ("water glass"), increase the viscosity of clay-laden fluids, while sodium phosphate has the reverse effect.

Drilling fluids are ordinarily prepared at the individual wells, though in some fields they are prepared in community plants and delivered by pipe line or tank truck to the wells. Costs are likely to be lower in community plants and the product more uniform and dependable. Costs range from 10¢ to 50¢ per barrel of fluid, averaging perhaps $3,000 per well during recent years in the California fields. In one instance, the drilling fluid cost was as high as $50,000. As a measure of economy, some operators have given special attention to the problems of reconditioning drilling fluid for continued use. Such reconditioning involves separation of fine sand that may tend to remain afloat in the fluid, removal of entrained gas and restoration of proper density and viscosity after dilution or contamination during circulation through the wells. For removal of sand and gas in suspension, vibrating screens are widely used. Another method involves first diluting the fluid to promote settling of sand and then thickening to restore the fluid to its proper density and viscosity (Uren, L. C. 34, 227-236).

IMPROVED AND LARGER CAPACITY POWER PLANTS

Early cable-tool and rotary equipment was almost universally powered with steam boilers and engines and, because of its greater flexibility, most drillers had a decided preference for steam power over other prime movers. Steam power is still preferred, and a large percentage of the drilling rigs used during recent years were equipped with steam engines and direct-acting steam-driven pumps. Nevertheless, other types of power are finding increasing favor and may in future find wider use. Electric motors of special design have been found entirely satisfactory for rotary drilling, and economic where cheap utility service is available. Provision of expensive boilers and incidental steam equipment is avoided, as well as expense in development of a supply of water in quantities and of a quality suitable for steam generation. Internal combustion engines also share these advantages with the electric motor, it being only necessary to provide a supply of water for jacket-cooling purposes, and this need not be of the purity required for steam generation. Gas engines and Diesel and semi-Diesel engines operating on various grades of Diesel and fuel oils or crude are used for drilling purposes. Though somewhat less flexible than steam power, with proper intermediate gearing and transmission mechanism, they afford an entirely satisfactory source of power for drilling purposes. Some wells have been powered with Diesel-electric drives, the Diesel engine serving as a source of power which is applied through the somewhat more flexible electric motor. Internal combustion engines

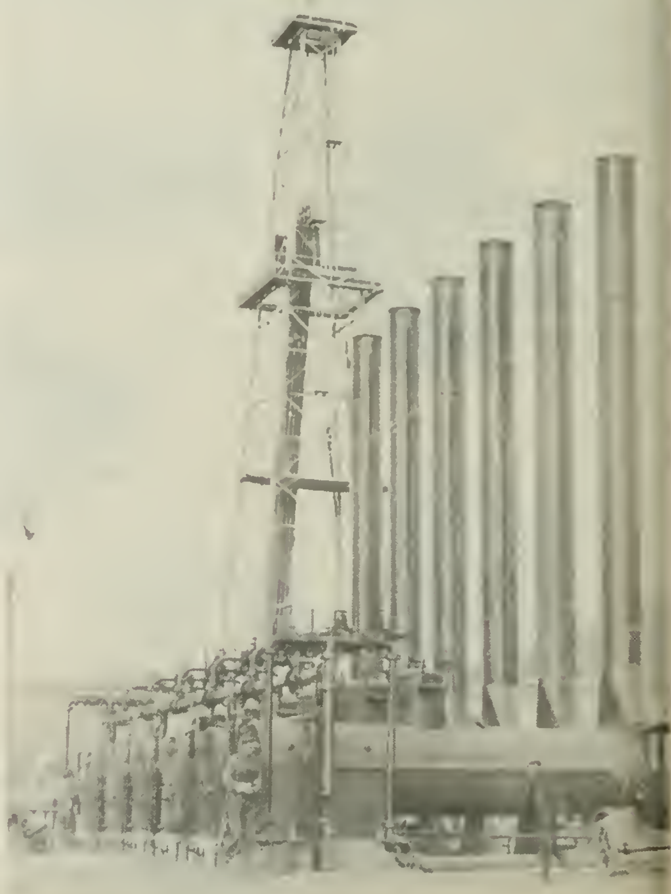

FIG. 22. Power plant for modern rotary drilling rig.

FIG. 23. Well-cementing equipment permanently mounted on motor truck. *(Courtesy: Perkins Cementing Co.)*

are well adapted to conditions presented in drilling "wild-cat" wells in areas remote from gas fuel supply. Both single-cylinder and multi-cylinder types have been adapted but the latter seem preferable. They are efficient from a power development standpoint and they may operate on liquid fuel which can be delivered by truck or tractor to the well. In some districts, gas engines using liquefied butane as a fuel provide a satisfactory solution for the power problem.

Many different "hook-ups" are employed in connecting the several parts of the rotary drilling rig with the power supply. If steam power is employed, the horizontal twin-cylinder engine generally used to drive the draw works and rotary table, is usually connected with the line-shaft of the draw works by a chain-and-sprocket drive. Different chain-and-sprocket drives between the line-shaft and drum-shaft, with suitable clutch controls, afford three speeds for the drum-shaft. If additional flexibility is desired, it may be achieved by interposing an assemblage of speed-reduction gears between the engine and draw works, thus providing as many as six drum-shaft speeds. Originally, the rotary table was driven by a chain-and-sprocket drive from the line-shaft of the draw works. In the more modern three-shaft draw works, the table is driven from the jack-shaft of the draw works. Some operators now provide a separate, smaller engine to drive the rotary table, this engine often being placed below the derrick floor. Preference has been shown by some drillers for vertical steam engines, which are available in either twin-cylinder or three-cylinder patterns. If internal combustion engines are used, one large unit operating singly, or two smaller units "hooked" together to operate simultaneously, may be used to drive the draw works and table. Electric motors may similarly be applied.

When steam power is used, modern practice gives special attention to economy and efficiency of operation. Preheaters for the boiler water and super-heaters for the steam are now frequently employed, though formerly almost unknown in oil-field practice. Boiler settings and steam mains are now well insulated. Fuel and feed-water pumps are automatically controlled and many safety features are incorporated that enable the boiler plant to operate with less manual supervision than was formerly necessary. In earlier periods, little attention was given to such refinements. Natural gas, produced in great quantities with the oil in many fields, was a waste product. Used as a boiler fuel and costing little or nothing, there was no incentive to seek efficiency in power development. Today, however, there is a profitable market for natural gas in most California fields; or the gas may be stored and put to economic use by reinjection in the reservoir rocks to assist in producing additional oil. Under these conditions, there is every incentive for economy in gas consumption and operators are finding profitable the refinements necessary to secure greater efficiency in steam development and transmission (Uren, L. C. 34, pp. 236-244).

LARGER CAPACITY AND HIGHER PRESSURE CIRCULATING PUMPS

Early types of mud pumps used in rotary drilling were designed for capacities of less than 100 gallons per minute and for low pressures. Steam ends were often designed for steam pressures of 150 lb. per sq. in. and water ends for pressures not exceeding 300 lb. With deeper drilling has come the necessity for much heavier and larger capacity pumps, some models recently employed having a capacity as great as 1,450 gal. per minute, with 500 lb. steam pressure and with water ends designed for delivery pressures as great as 3,750 lb. per sq. in. For the same size hole and drill pipe, circulating pressures increase directly with depth. Modern cementing operations also place an increasing burden on the pumps. So large have the pumps become, that they are now generally placed outside the rig rather than on the derrick floor, as formerly. Elevation of the derrick floor, several feet above the prevailing level of the ground, permits the placing of pumps on a lower level, reducing the suction lift of the pumps and increasing their operating efficiency. For use with rigs powered with electric motors or internal combustion engines, pumps driven by belt or rope drives are customarily used.

TREND TOWARD UNITARY CONSTRUCTION OF DRILLING EQUIPMENT

In earlier periods, it was usual to spend from two to three weeks in preparing the site, erecting a derrick and "rigging up" in preparation for the drilling of a new well. This was because of the multiplicity of parts and because of the necessity of framing much of the rig timber in the field. Today, steel derricks are prefabricated and, with a skilled crew of rig builders, can be erected in a day or two. Within the last few years also, important progress has been made in unitary construction of the mechanical elements of rotary drilling rigs, so that they too may be quickly assembled. Draw works are now often mounted on steel A-frames and supports so that all parts are permanently assembled and adjusted by the manufacturer and moved into the field and from rig to rig as a unit. The rotary table, the mud pumps, and power plant are frequently also mounted with their assembled parts, on their own individual steel skids, so that they can be moved from one location to another without necessity for disassembling. Under favorable conditions, even complete derricks, once assembled in the field, can be "skidded" from one location to another without tearing down. The result has been that equipment may now be brought into the field, set up in operating position and all made ready for "spudding" in less than half the time formerly necessary. Not only is time saved, but the equipment has higher salvage value and can be used in the drilling of a greater number of wells.

STAND-BY EQUIPMENT

Modern rotary rigs are frequently equipped with a power-driven sand reel to assist in bailing operations, running retractable core barrels and drilling bits and like purposes. For deep drilling, larger stand-by hoisting drums are also frequently provided to assist in handling drill pipe. In drilling very deep wells, a third slush pump is provided in addition to the customary two. These features were unknown in the earlier types of rotary rigs.

GREATER UTILITY OF PORTABLE RIGS

Portable and semi-portable drilling rigs have been used for many years in drilling shallow wells by the cable-tool method. Some of the heavier patterns of portable churn-drilling rigs are capable of drilling to depths as great as 4,000 ft. In recent years, considerable advance has been made in the development of rotary portable equipment capable of drilling to comparable depths. The draw works and rotary machine are mounted on one truck, tractor, or trailer, and the circulating pumps on another. A braced mast provides overhead gear for handling drill pipe and casing. Light portable rigs of both churn and rotary types are now commonly employed for structure drilling and for drilling shot holes in seismic exploration.

TREND TOWARD DEEPER DRILLING

With the exhaustion of the shallower accumulations of petroleum, operators have been compelled to seek deeper sources of supply. Improved drilling equipment and methods have made deeper drilling less expensive than formerly, and have thus brought the deep-seated deposits within the realm of economic exploitation. The higher formation pressures and greater quantities of dissolved gas in the oil, characteristic of the deeper deposits, often result in very prolific wells, so that while deep wells are costly to drill, yet they may quickly repay their cost if not too closely spaced and if allowed to produce without undue proration restriction.

In 1910, wells in excess of 3,000-ft. depth were uncommon. By 1920, with the widespread use of rotary equipment, depths in excess of 6,000 ft. were being successfully drilled, and by 1930, a depth of 8,500 ft. had been attained. During the last decade, new drilling depth records have frequently been achieved, reaching 12,500 ft. in 1935 and 15,000 ft. in 1938. The maximum depth to which it would be possible to drill with present-day equipment and methods, is a matter of conjecture, but some authorities believe that 20,000-ft. wells are not impossible under present-day conditions.

IMPROVEMENT IN MATERIALS EMPLOYED IN MANUFACTURE OF DRILLING EQUIPMENT AND WELL EQUIPMENT

No small part of the superior performance and greater strength of modern rotary equipment is due to the use of materials especially selected for the heavy duty imposed. For example, electric cast steel and manganese steel drive sprockets, chrome steel forged and heat-treated shafts, steel castings, rolled and forged alloy steel brake rims and manganese steel clutches and cat heads are used in most of the heavier and costlier draw works. Crown block and hoisting block sheaves and shafts, casing hooks, swivel gudgeons and bails, casing and drill pipe elevators, rotary table bearings and raceways and other structural details have received careful study from the design standpoint and the best materials obtainable used in their manufacture. Use of high tensile strength steels has also been extended to materials used in derrick construction and in casing manufacture. Use of tungsten carbide and other hard-facing metals on drilling bits has been previously mentioned.

LARGER AND HEAVIER EQUIPMENT FOR DEEPER DRILLING

The present record depth of about 15,000 ft. for rotary-drilled wells in California, would have been quite impossible with the drilling equipment of ten years ago. The ever-increasing depth to which wells have been drilled during recent years, has required the development of larger and heavier equipment, better correlation of equipment, stronger materials and superior workmanship. Manufacturers of drilling equipment have been largely responsible for this advance.

The larger and heavier rotary rigs that have lately been used in drilling in the deeper fields of the southern San Joaquin Valley, have utilized the most advanced and most highly developed equipment that has yet been made available for drilling purposes. Equipment employed in the so-called "super rig" used by the Superior Oil Company may serve as an example of forward-looking planning for even deeper drilling than any yet attempted. In this rig, the derrick used was 178 ft. high and 32 ft. square at the base, constructed of high tensile strength structural steel and designed for a safe working load capacity of 500 tons. The rig was powered with five 130-h.p. steam boilers of locomotive type, developing 500-lb. steam pressure and capable of delivering 3,000 boiler horse-power for a short period of time. Superheaters heat the steam to 610° F. The draw works was driven by a 15-in. by 14-in. twin-cylinder steam engine, rated at 1,950 h.p. at 250 r.p.m. with 500-lb. steam pressure. A separate twin-cylinder engine, 12-in. by 12-in. in size, placed beneath the derrick floor was used to operate the 20¼-in. rotary table. A three-speed draw works with 10½-in. drum-shaft, 9-in. line-shaft and a drum capacity of 4,690 ft. of 1¼-in. hoisting cable, and equipped with a 40-in. double-rotor type Parkersburg Hydromatic brake, was used. The two mud pumps were 15½-in. by 9¼-in. by 22-in. steam-driven pumps, designed for a maximum pressure of 3,750 lb. per sq. in. and capable of delivering 1,450 gal. per minute. The swivel and hoisting gear were designed for a maximum drill-pipe load of 300 tons. The swivel hose is of steel, 5 inches in diameter, and designed for fluid pressures as high as 6,000 lb. per sq. in.

With this equipment, under the conditions presented in the Rio Bravo field, Kern County, California, in one well, 7,000 ft. of 12¼-in. hole were drilled in eight days. Total elapsed time from spudding date to completion at 11,445 ft., was only 57 days and this included the time spent in inserting and cementing casing and inserting the liner and tubing (Sawdon, W. A. 39). Another well, drilled by the Union Oil Company of California in the Rio Bravo field, was drilled to a depth of 11,415 ft. in only 46 days, including the setting of 1,515 ft. of 13⅜-in. casing and 11,166 ft. of 7⅝-in. casing and 5¾-in. liner.

IMPROVEMENT IN TRANSPORTATION FACILITIES

Many tons of mechanical equipment, drill pipe and casing, cement and drilling-fluid components and rig and derrick materials, must be transported to the site selected for a well. In drilling "wild-cat" wells, fuel and perhaps even water may have to be hauled to the well. Some parts of the equipment, such as steam boilers, are not only heavy but also bulky. Suitable facilities for transport are therefore of vital importance. Because of generally favorable climatic conditions and gently sloping, open terrain and accessibility to sources of supply, transportation into the oil fields of California has never been as difficult a problem as in most other oil-producing regions. Nevertheless, delivery of materials and equipment has been greatly facilitated during the last two or three decades by the development of California's excellent highway system and by modern types of motor trucks, trailers and tractors especially adapted to the handling of oil-field equipment. Much of the machinery and equipment is manufactured in communities within a few hundred miles of the oil fields and is moved directly to the point of use by motor truck. Stocks are maintained by manufacturers of practically all oil-field supplies and equipment in warehouses near the important centers of oil industry activity.

IMPROVEMENTS IN WELL CASING AND CASING PRACTICE

All wells must be cased to prevent caving of the walls, to confine high pressure fluids, and to exclude water from oil and gas bearing formations. Great quantities of casing are used in the development of California oil and gas fields; in many instances, as much as one-third of the total cost of drilling and completing wells is represented by this item.

Formerly, the casing used was manufactured by lap-welding and was available in many different sizes and weights. The material used was either wrought iron or mild steel. One of the first efforts of the American Petroleum Institute following its organization, was to standardize well casing sizes, weights, materials, and threaded connections. As a result, the industry is now served with fewer sizes of casing, and the materials used have more dependable properties. In casing the deeper wells, stronger steel than that formerly used must be employed. Whereas the mild steel formerly employed possessed a tensile strength of only 55,000 lb. per sq. in., the stronger grades of high-carbon steel used today develop tensile strengths as great as 110,000 lb. per sq. in. Where still greater strength and ductility is needed than can be secured with ordinary steels, casings made of special grades of alloy steel are available. Single strings of large-diameter pipe as much as 13,000 ft. long and weighing more than 200 tons have been placed in some of the deeper wells drilled in the southern San Joaquin Valley.

Modern casing practice involves careful selection of sizes, weights, and lengths of individual strings, with due regard to the purposes that they must serve and the stresses which they may be called upon to sustain. Where fluid accumulates to depths of thousands of feet behind a column of casing cemented to the formation at its lower end, very great collapsing pressure is developed: sometimes so great as to result in failure. Casing or threaded casing joints are sometimes pulled apart by excessive tensile stress developed in pulling on columns of pipe frozen to the walls of wells. The "pull-out strength" of threaded joints is a matter of importance in this connection and can be increased by proper design of threads and collars. Casing may buckle as a result of "column action" when allowed to rest on the bottom of the well. Casing and casing heads are sometimes subjected to large bursting pressures when high-pressure gas must be confined.

In addition to ordinary collared-joint casing, special types of inserted-joint and flush-jointed casings are now available for use under circumstances such that collars would be disadvantageous. Long columns of casing are at times formed of joints welded together without collars of any kind. The old style of "stove-pipe" made of thin sheet-metal with riveted joints, is now rarely used. Instead, surface and conductor strings of large diameter casing are often of corrugated form or, are of thin-walled rolled steel, equipped with bell-and-socket joints, held together by spot-welding (Uren, L. C. 34, Chapt. VIII).

The lowermost string of casing in the well, extending through the oil-producing formation, is customarily perforated to admit fluids from the formation. The perforated sections are made up of screen pipe, available in a variety of forms. The older types of wire-wrapped screen pipe, though still widely used in some regions, are today little used in the California fields. Most California operators prefer a slotted pipe in which narrow longitudinal slots disposed in several rows about the pipe circumference, are cut by the oxyacetylene torch. Two types of "button screen pipe" are also used, in which round holes are fitted with bronze or brass discs containing slot-shaped openings. Gun-perforating devices, developed during recent years, are now used for shooting pointed steel bullets through casing in wells. By this means, blank pipe may be perforated opposite any desired interval, after placement in the well. The gun perforator has also been a useful device in connection with certain types of cementing operations. A type of cement-lined perforated casing has been found helpful under conditions that required circulation of fluid through the casing after it is in place in the well. After circulation, the perforations are opened by "scabbing-off" the thin cement lining. Recently, use has been made of magnesium alloys in manufacture of short sections of casing, for use under circumstances that require the casing to be dissolved by acid subsequent to placement.

WATER EXCLUSION PRACTICES

Efficient production of petroleum requires exclusion of water from that portion of the well that yields the oil. If both oil-bearing and water-bearing formations have access to the well, it will produce mostly or entirely water; and the water may force its way into the oil-bearing strata, driving the oil away from the well and waterlogging the wall rocks so that they may never produce oil in commercial amounts. Underground losses of oil resulting from failure to exclude water from wells and from the oil-bearing formations were serious during the earlier period of oil production in California, but were eventually recognized by producers as of suffiicent importance to justify conservation legislation and regulation of well drilling and producing operations by the State. In accordance with this legislation, the California State Mining Bureau was charged with the responsibility of prescribing appropriate measures for exclusion of water in oil-field exploitation, and a State Oil and Gas Supervisor was appointed to administer the law and make field studies and tests on all drilling wells to ascertain that the California oil fields were adequately protected against water incursion. The Oil and Gas Supervisor's department, which has been operative since 1914, has since been divorced from the State Mining Bureau or State Division of Mines, and is now a separate Division of the State Department of Natural Resources and is known as the Division of Oil and Gas. The Supervisor maintains headquarters in San Francisco, and field offices conveniently situated with respect to the active oil-producing areas. A staff of engineers and inspectors gather detailed subsurface information concerning every oil field in the State. Logs of every well are filed with the Supervisor by the operators. Casing programs and drilling procedure designed to prevent water incursion are prescribed and tests are made to assure that water is properly excluded from every well drilled. Reports on quantities of oil, gas, and water produced by each well are furnished monthly by the operators to the Oil and Gas Supervisor's department, which thus maintains a continuous record of the entire productive history of each well drilled and operated. On the basis of such production records, the Supervisor may take steps to enforce appropriate measures to exclude water from wells which may threaten the security of surrounding producers. On abandonment, all wells must be suitably plugged to prevent the possibility of water subsequently entering them and flooding productive oil- and gas-bearing formations.

Early methods of water exclusion in the California oil fields included use of packers, which were manipulated between the casing and walls of the well, and "formation shut-offs," in which the column of casing, equipped with a reinforcing shoe on its lower end, was driven into an under-sized hole drilled into a hard layer of shale or other competent, impermeable stratum. Later, cementing methods were introduced, designed to accomplish the placement of a substantial quantity of fluid cement between the walls of the well and the casing, where it was permitted to set and harden. In this way, the annular space about the lower end of the casing, between it and the wall of the well, is completely filled with a solid body of impermeable cement that effectively excludes top waters from that portion of the well below the casing shoe.

Cement was first placed in the wells with the aid of dump bailers. Later, methods were devised for pumping fluid cement to the bottom of the well through auxiliary tubing specially inserted inside the casing for the purpose. A packer between the tubing and casing prevented the fluid cement from rising in the annular space, thus forcing it under the shoe of the casing and up into the space between the casing and the wall of the well. Eventually, the Perkins process for placing cement in wells was developed. This involved pumping the fluid cement down through the casing between a pair of moving wooden plugs that serve to separate the cement from the well fluid. After the cement, forced under the shoe of the casing and up into the annular space about the pipe by the pump pressure, is hardened, the plugs and small amount of cement within the lower end of the casing are drilled out with the drilling tools. For many years, the Perkins Cementing Company, a California service organization, has been engaged in cementing operations of this character in the California oil fields, contracting cementing jobs and furnishing skilled personnel and special equipment brought to the wells on motor trucks. More recently, the Halliburton Well Cementing Company, a Mid-Continent and Gulf Coast organization, controlling a number of patented improvements in well cementing technique, has also entered the California industry.

In addition to the usual methods of cementing casing in wells, a variety of more intricate special practices have been developed within recent years. For example, a rather common practice today is that of cementing through perforations. This practice is used when it is desired to spot cement at a particular depth in the well without forcing it under the shoe of the column of casing and cementing a long intermediate interval. Holes are punched or shot in the casing at the desired depth, a plug is set in the casing immediately below, and fluid cement is forced through the perforations under pump pressure, into the annular space outside the casing. For this and other special procedures, the "cement retainer," manufactured by the Baker Oil Tools Co.—a California organization—has been found especially helpful. This company also manufactures a wide variety of cement shoes and collars, baskets, plugs, and other devices especially designed to assist in cementing operations.

Success of a modern well cementing operation may involve rapid mixing and placement of a large volume of cement. Cement mixers appropriate for this purpose have been devised and large-capacity high-pressure pumps for handling the cement-water mixture, while special cementing heads are available to facilitate rapid connection with the casing head. As much as 2,500 sacks or 237,500 lb. of cement have been mixed with the proper proportion of water and pumped into place at the bottom of a well 11,520 ft. deep, in only 54 minutes. Portland cement usually takes its initial set in from one to two hours and it is imperative that the cement be at rest in the position it is to occupy in the well before the initial set occurs. The "hardening set" is a slower process, ordinarily requiring from 7 to 28 days. Formerly it was necessary to allow a well to stand after a cementing job for this period of time, but the use of a small amount of a suitable accelerator, such as calcium chloride, hastens the hardening set so that the cement may be drilled out of the casing and deeper drilling resumed after only three or four days of setting. To save time, accelerators in the cement are today almost universally used.

Difficulties sometimes develop in cementing operations, perhaps occasioning failure and repetition of the work. Dilution of the fluid cement with ground water containing certain dissolved salts may alter the setting properties, delaying or hastening the setting time and perhaps rendering the cement "unsound." Unusually high ground temperature encountered especially in deep wells, greatly hastens the setting time. Contamination with mud or clay in the well weakens the cement. Natural gas blowing through the fluid cement in the well leaves it porous and permeable and may prevent it from setting properly. The cement sometimes does not distribute itself uniformly about the casing, leaving channels through which water may subsequently find its way. Successful handling of cementing operations is secured only by careful engineering supervision and by employing skilled personnel in the work (Uren, L. C. 34, Chapt. X).

LOCATING SOURCES OF WATER INCURSION IN WELLS

Before water exclusion operations are undertaken, it is necessary to determine the exact depth at which the water enters the well. For this purpose, special electrical devices have been developed. Oil-field ground waters are often highly saline and one method, utilizing the "Water Witch," measures the electrical conductivity of the well fluid. The point at which the well fluid reaches its highest electrical conductivity is that at which the water enters. In another method, the fluid in the well throughout the interval where water is thought to enter is conditioned by adding an electrolyte that develops galvanic activity. Influx of water dilutes the well fluid locally, opposite the point of entry, and exploration with the "Lo-kate-it" device discloses this point. In still another device, a photo-electric cell is utilized (the Dale Water-Locating Instrument). Lowered through the drilling fluid in the well, it develops a greater electrical response at the point where the fluid has been locally diluted by infiltration of water from the formation. More primitive methods of locating the source of water in a well involve plugging the well in stages from the bottom up, until the water is eliminated, or plugging to a point well above the source of water and then drilling out in stages until water again appears.

WELL SURVEYING EQUIPMENT

Until about 1920, operators had no convenient and dependable means of surveying wells to determine their course. It was generally believed that wells drilled by either the cable or rotary methods were reasonably straight and vertical, but the first dependable surveying instruments developed indicated that they were often crooked and at times departed widely from the vertical. This knowledge, and consideration of the problems arising therefrom, stimulated interest in the subject of well surveying until today many wells are surveyed so that their actual course beneath the surface can be charted with fair accuracy.

The pioneer well surveyor of California was Alexander Anderson, who developed instruments and offered the services of his highly skilled personnel to operators in the California oil fields. During the period 1920 to 1937, when it was acquired by the Layne-Wells Company, many hundreds of thousands of feet of hole were surveyed by the Anderson organization. Other well surveying organizations meanwhile entered the California fields with other types of instruments and with service organizations equipped to undertake surveys on a contract basis. Other well known names in this field are the Eastman Well Surveying Company and the Sperry-Sun Company.

Instruments used in making well surveys may be classified into two groups: first, those which merely determine the amount of deflection from the vertical (clinographs or inclinometers), and second, those which measure both the amount and direction of the deflection (directional clinographs). Instruments of the first group are comparatively simple. Perhaps the simplest and most widely used inclinometer is the hydrofluoric acid bottle. The Syfoclinograph and Totco instruments are also widely used devices of this group. The direction of the deflection may be determined by orienting an inclinometer of suitable design into and out of the well on drill pipe or tubing. However, some well surveying instruments use a series of compass observations to indicate the course of the hole. Under favorable conditions, the magnetic compass may be used for this purpose in open hole, but the Surwel Clinograph utilizes a gyroscopic compass as a direction indicator. Directional clinographs are either "single-shot" instruments or are designed to record continuously or intermittently data as they are lowered or raised through the well. From these data the deflection and azimuth of the well at numerous points may later be computed. Descriptions of these and many other interesting instruments designed and used for this purpose may be found in generally available books on petroleum engineering (Uren, L. C. 34, pp. 487-499).

Well surveys have indicated that comparatively few wells are straight and vertical, irrespective of the method of drilling. In some instances, wells 5,000 to 10,000 ft.

deep have been found to wander many hundreds or even thousands of feet laterally from their starting points. In many cases, boundary wells have trespassed on neighboring properties, securing production from acreage not owned or controlled by the owner of the well. Where loss has resulted from trespass of this character, damages may be claimed and secured by litigation. Confusion has arisen in some instances through efforts to use the logs of crooked holes in geologic correlations or in structural interpretations, wells appearing structurally lower than they should be, by reason of the greater footage necessary to reach a particular stratigraphic horizon in a crooked hole. On the other hand, where wells wander up-dip, they may encounter a particular reference horizon at shallower depth than would be the case in a vertical hole. In some jurisdictions, state authorities restrict the amount that a well may deviate from the vertical: for example, 5° deviation from the vertical may be the maximum deflection permitted. Rules of this character become necessary where an effort is made to regulate the spacing of wells.

DIRECTIONAL DRILLING

Knowledge of the readiness with which wells deviate from the vertical, and of the causes therefor, have led in some instances to intentional deflection of wells with the purpose of reaching objectives not readily attained by drilling vertical wells. Control of the drilling conditions and use of special types of equipment in such a way as to promote deflection of wells toward a desired objective some distance laterally from their surface locations, is called "directional drilling." Well surveying instruments are necessarily used in this procedure to follow the course of the well and to orient the equipment used in producing deflection of the drilling bit.

Deflection of the well from the vertical may be accomplished at any depth by placing a "whipstock"—a long, slender, metal, wedge-shaped tool in the hole and orienting it so that it will deflect the drilling bit in the desired direction. Special eccentric bits may be used, or a "knuckle joint" in the drill collar which promotes deflection of the well along the course determined by the slope of the whipstock. Wells may be drilled at an

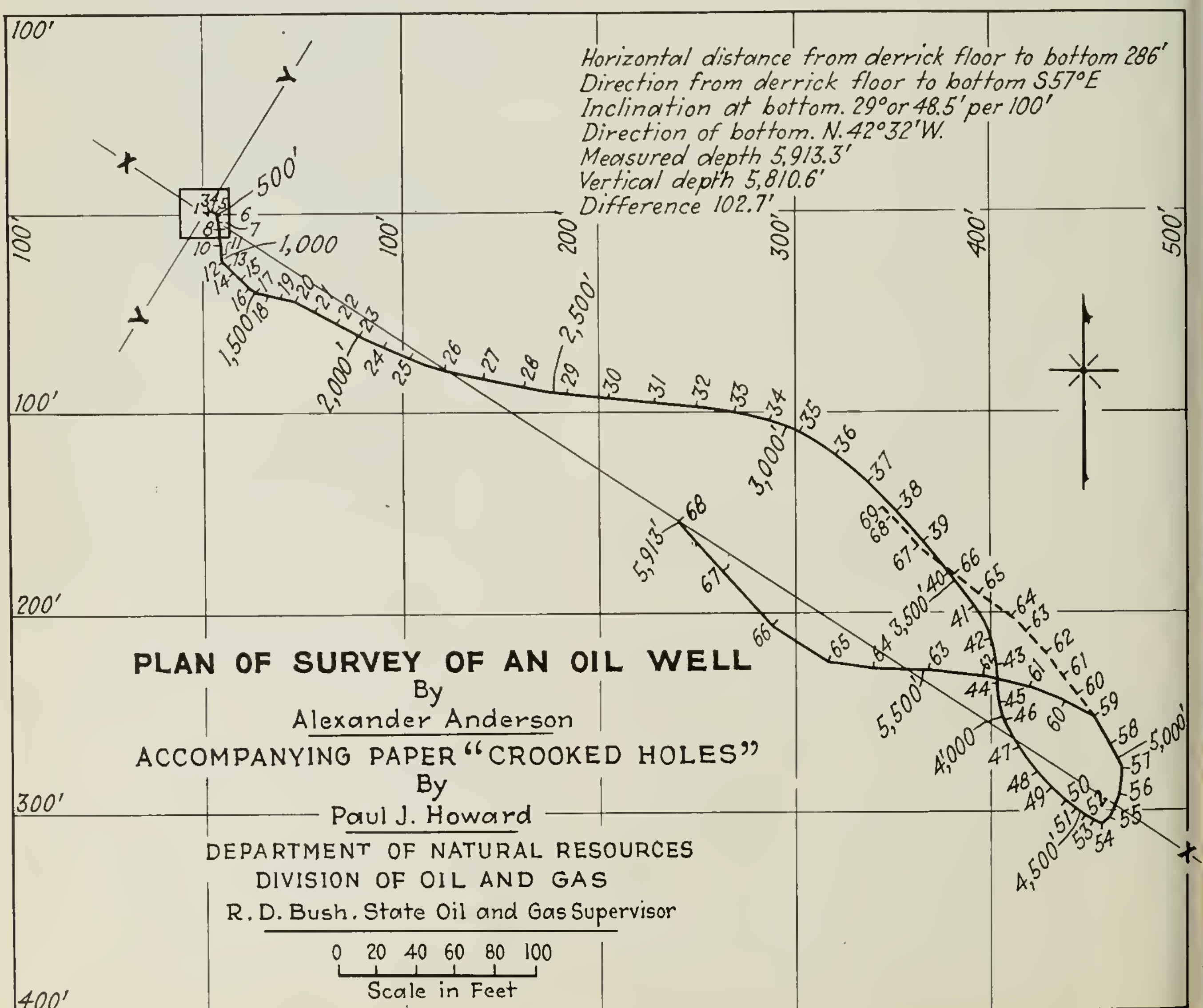

FIG. 24. Map showing course of a crooked well. *(After P. J. Howard)*

angle from the surface, by slightly elevating one side of the rotary table so that it is slightly higher on the side toward which the hole is to be deflected.

Directional drilling has been employed by some operators as a means of accomplishing illegal trespass on another operator's property. For example, in some California fields, wells which, by their structural position, should have encountered edgewater, have been deflected up-structure to secure production from areas above the edgewater line. In the Huntington Beach field of California, a part of the productive area of the field lies beneath tidelands along the shore of the Pacific Ocean. Littoral owners have in many cases deflected wells so that they are bottomed in the tideland area. In some instances, the bottoms of wells in this area are as much as half a mile from their surface locations. Where productive oil sands lie beneath townsites and drilling restrictions are imposed, wells may be drilled from locations in out-lying tracts beyond the restricted area. Wells may be deflected to pass under the overhanging edges of salt domes to reach underlying oil accumulations, rather than drill through the salt core and the hard capping overlying it. Wells may be deflected to reach oil accumulations in the foot-wall side of a fault plane, rather than attempt to drill through the fractured and "slickensided" material in the overlying faulted zone. In one instance, a well was deflected to encounter another well at depth, with the purpose of pumping water and mud into the well to extinguish a surface fire that had defied other extinguishing methods. By directional drilling, it is possible to drill two or more wells from one surface location, bottoming them in the productive formation in different areas properly spaced. This has been successfully accomplished in drilling from steel piers extending off-shore in the Elwood field on the Pacific Coast of California.

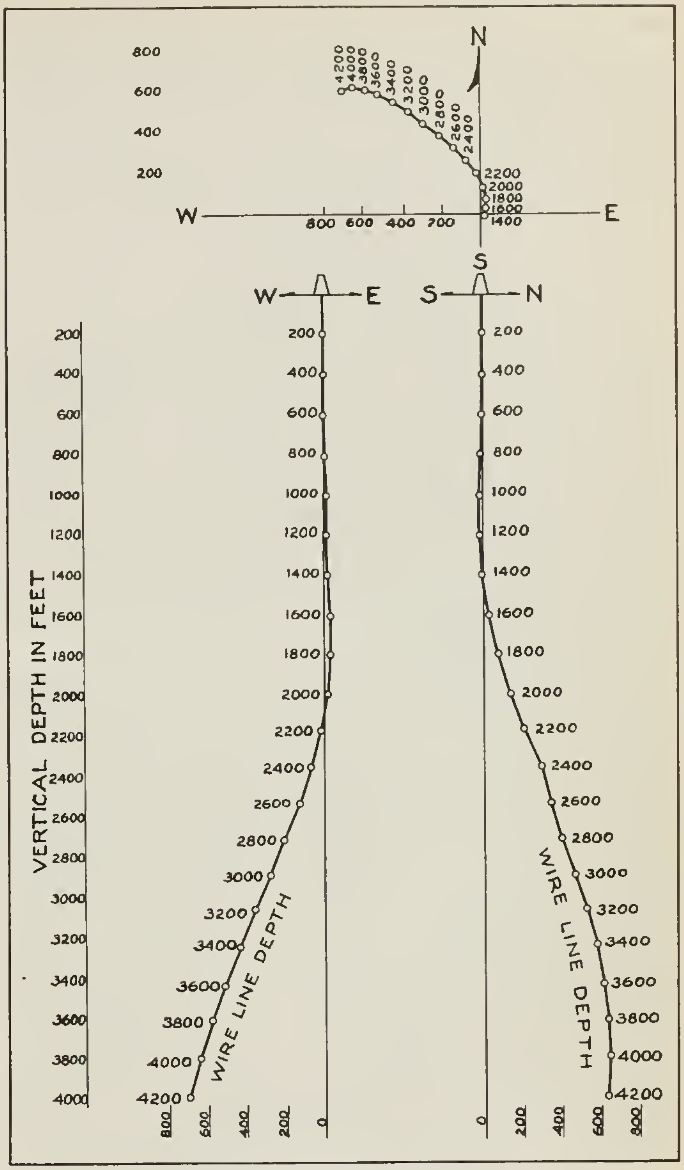

Fig. 25. Vertical section showing deflection of a well from the vertical. *(Courtesy of McGraw-Hill Book Co., Inc.)*

IMPROVEMENT IN WELL COMPLETION METHODS

In the earlier period of exploitation in the California oil fields, there were many instances in which high-pressure wells were "brought-in" out of control. Unexpectedly high gas pressures, or absence of suitable control equipment on the well head, often resulted in destructive "blow-outs" and wasteful gusher production of oil and gas. In the case of the Lakeview No. 1 gusher, situated in the Sunset field of Kern Country, control of the well was lost after drilling into the producing sand, and months passed before the flow of oil and gas could be shut in. During this period, it is estimated that ten million barrels of oil were discharged at the surface, much of which had to be stored in open earthen reservoirs, so that serious evaporation and seepage losses occurred. Gusher production was not uncommon during the earlier period of the California oil industry when wells were drilled with cable tools.

One of the principal advantages of the rotary method of drilling is its ability to control high pressure fluids and prevent blow-outs, so that occurrences of this character have been less common since the rotary equipment has come into general use. Proper control of the circulating fluid and provision of a suitable blow-out preventer on the casing head will permit safe drilling into a high-pressure formation. Today, wells are completed and brought in, and production is turned to the flow tanks with little or no loss of oil and gas. Indeed, it is now regarded as evidence of unskillful drilling technique or use of inadequate control equipment if a high-pressure well is allowed to get out of control.

With modern methods of formation testing, coring and electrical logging, it is now possible to determine the intervals within the formations penetrated by a well that are likely to yield oil, gas, or water. The casing "string" to be placed in the lower part of the well may then be made up at the surface, with perforated pipe opposite in the oil and gas yielding intervals and blank pipe opposite the water-yielding intervals. Cementing these blank sections to the wall of the well through perforations excludes all water; or, an entire column of blank liner may be cemented in the lower part of the well and gun-perforated in the oil- and gas-yielding intervals. Recently developed methods of gravel-packing perforated liners in wells involve reaming the productive intervals to as large a diameter as is economically feasible and then circulating gravel (⅛″ to $1/10$″) into the space between the wall of the well and the exterior surface of the liner. Gravel so placed prevents caving of the walls of the well, prevents sand incursion, and permits more efficient drainage of oil from the surrounding reservoir rock.

Concern is often expressed by engineers over the tendency of clay-laden fluids used in rotary drilling to seal the pore spaces of the wall rocks of wells, possibly to such a degree that access of oil and gas to the wells is permanently restricted. It would appear that this is especially likely to occur in drilling into low-pressure reservoir rocks where the clay is able to penetrate deeper into the wall rocks and where there may be insufficient gas to clear the pores of accumulated clay when the wells are brought in and placed on production. Much may be done in preventing this by proper conditioning of the drilling fluid. In addition, the walls of the well may be thoroughly scraped to remove the mud sheath, or finely ground limestone may be added to the circulating fluid and the well treated with acid after drilling is completed. Reaction between the acid and limestone, with formation of carbon dioxide gas, results in thorough disintegration of the mud sheath.

The sealing effect of the drilling fluid on the reservoir rock exposed in the wells may be avoided by using oil as a drilling fluid instead of mud fluid while drilling through the reservoir rock. This practice leaves the wall rocks entirely free of accumulated colloidal material, so that there is nothing to restrict flow of oil and gas into the well. "Pressure drilling" is a closely related technique. Here, the pressure differential between the formation and the well is so adjusted that oil and gas flow into the well is permitted to some extent while drilling is in progress. Such flow prevents accumulation of a mud sheath on the walls of the well and the pores of the wall rocks are kept free of detrital material so that when the well is eventually completed a maximum rate of production for the particular reservoir conditions obtaining will be secured. Pressure drilling requires special control equipment on the well head and the pressure conditions within the well must be carefully controlled. As yet, the process has been used in the California fields only to a limited extent, but it would appear to possess attractive possibilities for future development.

IMPROVEMENT IN FORMATION SAMPLING AND TESTING TECHNIQUE

In the earlier period of field exploitation in California, when wells were drilled by the churn or cable tool method, the nature of the material in the bottom of the well was determined by examination of fragments brought to the surface by the bailer or clinging to the drilling bit. Such samples afforded a fairly satisfactory basis for determining lithologic properties and the presence of oil could usually be determined by sight inspection or by testing with chloroform or ether.

Early rotary drilling did not afford satisfactory formation samples, the drill cuttings being generally too finely ground to allow more than approximate identification of the material brought to the surface by the circulating fluid. However, as explained in a previous section, this difficulty was overcome by the development of rotary coring tools. Under favorable circumstances, a core taken with a rotary core barrel may furnish an eminently satisfactory sample of the formation exposed in the bottom of the well. It is brought to the surface with the component strata practically undisturbed. The bedding planes are often clearly apparent, and if the core can be oriented and a survey showing the declination of the well at the point where the core is taken is available, it is possible to closely estimate the dip and strike of the strata. Orientation of cores was a matter of some uncertainty until recently, when it was discovered that certain minerals often present in sediments retain some degree of polarity imposed by the earth's magnetic field, and delicate magnetic instruments permit of orienting the core at the surface in the same position relative to the compass that it occupied while in its natural position in the earth.

Core samples of reservoir rocks, if unbroken and continuous, afford a means of determining the storage capacity of the rock for fluids and the resistance offered to movement of fluids. These are factors of importance in estimating reserves and determining productive capacities of wells and suitable spacing intervals for wells. The storage capacity of a reservoir rock is estimated by determining its percentage porosity. This is accomplished with approximate accuracy with the aid of one or another of several types of porosimeters. The resistance offered by a rock to flow of fluids through its pore spaces is measured by its permeability, which may be determined by means of especially designed apparatus, and reported in terms of a unit of permeability called a "darcy." Thus, a rock having a permeability of say, 500 milidarcys offers a certain resistance to flow, and engineers familiar with these tests are able to compare such a rock with other rocks of known permeability and to predict the performance of wells producing from them. Screen analyses are also made of granular rocks, after disaggregating them, to determine the size distribution of their component grains, such tests being helpful in predicting the permeability and drainage characteristics of reservoir rocks. Many of the larger oil producing companies today maintain well equipped field laboratories in which tests are regularly made on selected formation samples from drilling wells, to determine porosity, permeability, oil saturation, water saturation, grain size distribution, or other special lithologic properties which may be of importance for certain purposes (Uren, L. C. 34, pp. 455-480).

WALL-SAMPLING DEVICES

The usual coring devices are designed to cut a core from the formation exposed in the bottom of a well. After a well is drilled to a depth in excess of that at which a core is desired, it is necessary to resort to the use of a wall-sampling device. Two such devices are available. The Baker Oil Tool Co. offers a mechanically actuated tool which punches a small core sample out of the wall of the well when properly manipulated; and the Schlumberger Well Surveying Corporation offers its services in the use of a device which drives small retrievable core-cutting cylinders horizontally into the wall of the well with the aid of explosives.

While these wall-coring devices produce smaller cores than vertical core barrels, they are satisfactory for most purposes and are the only sampling devices available for use in sampling reservoir rocks exposed in the walls of

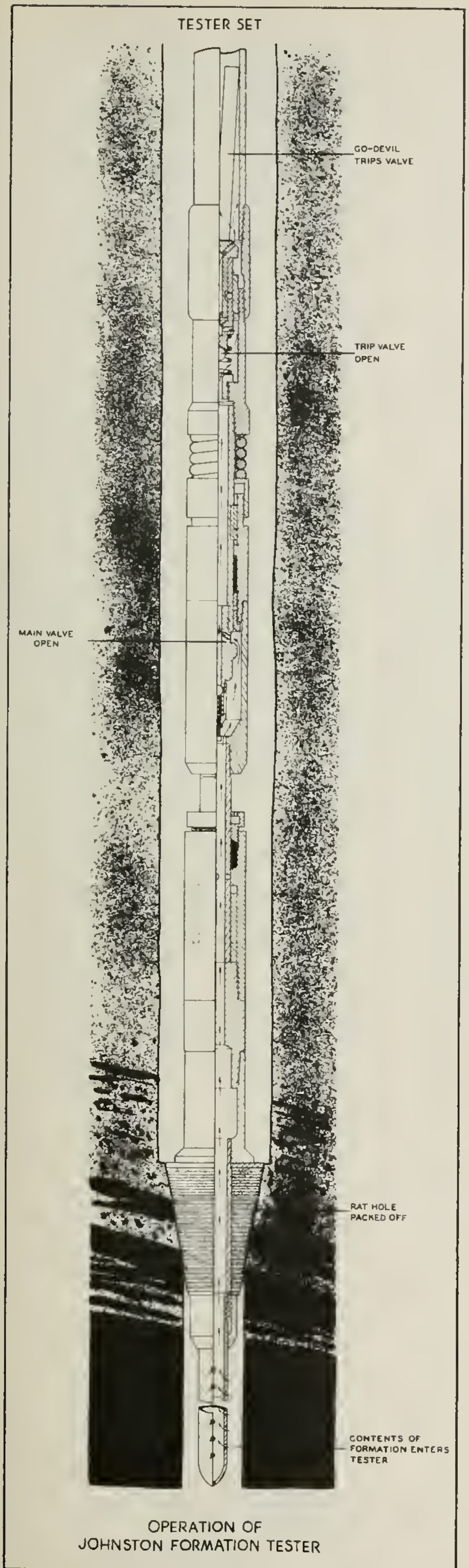

FIG. 26. Formation tester. *(Courtesy of Johnston Formation Tester Co.)*

wells in the older fields that were drilled before core drilling came into use. Such sampling is necessary in making engineering studies of partially depleted oil fields with the purpose of applying secondary recovery methods. If core samples of the producing formation are necessary, the only alternative beside the use of these wall sampling devices in the existing wells, is to drill new wells from the surface and take cores in the desired intervals with ordinary vertical core barrels.

HEAVY MINERAL SEGREGATION AND PETROGRAPHIC INSPECTION

For correlation purposes, formation samples are sometimes subjected to careful microscopic inspection under binocular or petrographic microscopes. Binocular microscopes are used for preliminary inspection of samples to determine the lithologic character of rock fragments and to roughly determine the mineral content. Disaggregated grains of sand or sandstone may be floated on bromoform or other heavy liquids to segregate the heavier minerals which are sometimes characteristic of the strata in which they are found. Petrographic microscopes are used to identify individual sand grains mineralogically. It will often be found, as a result of microscopic examination or heavy mineral segregation, that some unusual mineral occurs in a formation sample from a particular stratum cored in a certain well (Hanna, G. D. 24; Tickell, F. G. 39). Identification of this mineral in a formation sample from a stratum cored in another near-by well, may afford a basis for correlation of strata between the two wells. The presence of unusual quantities of some less common rock-forming mineral, conferring a characteristic color or texture, may also serve to identify a particular "marker bed." Where such occurrences may be used to identify a particular stratum, so that it can be identified over wide areas or perhaps throughout an entire field. the conduct of drilling operations is greatly facilitated. Determination of landing depths for casings, estimates of depths to production, and interpretation of sub-surface structural conditions, may rest upon accurate identification of stratigraphic "markers."

IDENTIFICATION OF MICRO-FOSSILS FOR CORRELATION

Formation samples from drilling wells often contain fossil remnants of former plant and animal life, which may be used as a means of correlation. Fossils may be of macroscopic size, in which case, mere fragments of the complete fossil form may be all that will be found; or they may be complete fossils of microscopic proportions. The latter are common and most useful. Of the several microfossils commonly found in sedimentary formations, the foraminifera and diatoms have been most useful for correlative purposes. Micropaleontologists specializing in this type of work are employed by many of the larger oil companies, and laboratories with the specialized equipment necessary are provided. Selected portions of all cores taken for correlation purposes are sent from the field to the laboratory and there disaggregated, examined for fossils, which are separated from the inorganic material and identified under the microscope. In some regions, research has resulted in the assemblage of tables of microscopic life forms sufficient to identify every part of the geologic column penetrated by the wells in reaching the oil-producing horizon. Microfossils may serve to correlate particular horizons over the entire area of a field, but because of lateral variation in life forms at a particular time in geologic history, cannot be depended upon as a means of correlating formations in widely separated regions (Hanna, G. D. 24; Tickell, F. G. 39).

ELECTRICAL LOGS

A notable advance in the development of methods of identifying the characteristics of formations penetrated by a well has been made during the current decade with the development of the electrical method of logging. Originally perfected and applied in the California fields by the Schlumberger Well Surveying Corporation, the method has more recently been offered to the industry, in slightly modified forms, in such devices as the "Geoanalyzer" and the "Strata-graph." Both methods measure the comparative resistivity of the individual strata penetrated by the well and afford an index of the relative permeabilities and fluid content.

The Schlumberger Well Surveying Company offer an electrical logging service with trained personnel and equipment mounted on trucks ready to respond promptly to calls from operators in any California field. Each truck carries hoisting gear and a reeled armored, insulated, multi-wire conductor cable of sufficient length to reach to the depth to be surveyed. On the lower end of this cable, electrodes are placed, usually three in number, spaced a few feet apart. A supply of direct current from the motor truck is transmitted to the lowermost electrode. This current is transmitted through clay-laden fluid with which the well is filled, and enters the formation opposite. The difference in potential between the upper two electrodes, determined by a potentiometer at the surface, is a measure of the resistivity of the formation opposite which the lowermost electrode is suspended. Because of its superior static pressure, the drilling fluid slowly penetrates the wall rocks at a rate that is proportional to the rock permeability. Electro-filtrative effects, or the chemicoelectrical effect created at the interface between the drilling fluid and the formation fluid, result in a self-induced current of small magnitude which, by suitable arrangement of circuits, may also be indicated and recorded by instruments at the surface (Schlumberger, C. 32; 33; 33a).

The usual method of conducting an electrical survey of a well is to lower the electrodes through the drilling fluid at the well, recording on photographic film in the service truck, two (sometimes three) parameters. One of these indicates the relative resistivity in ohms and the other the relative permeability in millivolts. A third parameter, sometimes recorded, is a function of the resistivity and indicates comparative resistivities over a greater distance from the wall of the well than the regular resistivity parameter. The resulting profiles are printed on photographic paper, as illustrated in Fig. 27, and afford continuous records, drawn to scale, of relative resistivities and permeabilities of all strata within the interval surveyed. The work may be rapidly done, an hour or so being sufficient to obtain a complete electrical log of several thousand feet of hole.

The fluid content of each stratum, whether water, oil or gas, can be determined by inspection of the resistivity

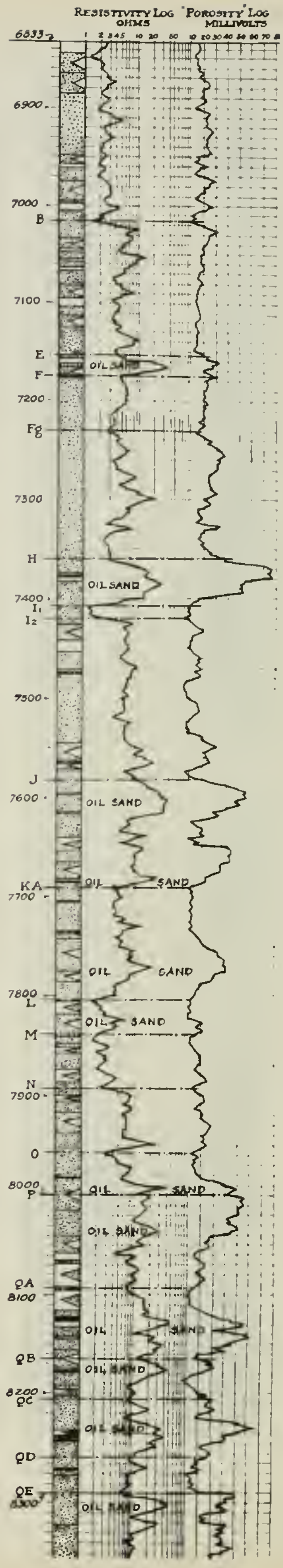

FIG. 27. Schlumberger electrical log of a well.

profile by one skilled in its interpretation. The ability of each stratum to yield its contained fluid to the well, is also indicated in a comparative way, by the permeability profile. The formations likely to produce water or oil or gas to the well may thus be estimated with fair accuracy. The data are helpful not only in indicating the intervals in which liners should be perforated to receive production, but are also useful in correlation work and in estimating reserves. Resistivity logs are also helpful in indicating accurately the depth of the lower end of a column of casing in a well, or in locating metallic "junk" that has been side-tracked in the walls.

Electrical measurements may also be used as a means of indicating the amount and direction of dip of formations exposed in the walls of a well at any point, and of making directional surveys of wells. The Schlumberger Well Surveying Corporation offers these services in addition to its electrical logging service.

TESTING TO DETERMINE FLUID CONTENT OF STRATA PENETRATED BY WELLS

When a porous and permeable stratum, suitably capped, that may serve as a reservoir rock, is encountered in the drilling of a well, it will be important to determine at once whether it contains water, gas, or oil. For this purpose, a "formation tester" may be used. This is a device, lowered on drill pipe or tubing into the well, equipped with a substantial wall packer and suitable control valves, and so designed that the packer may be securely seated on a prepared shoulder on the wall of the well. The tester is then manipulated in such a way that the lower part of the well below the packer—in which interval the formation to be tested is situated—is effectively sealed off from the portion of the well above the packer. With the interval below the packer freed of the hydrostatic pressure of fluid in the well above the packer, valves are opened to admit fluid from the formation into the tubing or drill pipe on which the tester is suspended. The tubing has been lowered into the well with the inside "dry," or containing too little fluid to exert the normal hydrostatic head. With pressure thus relieved in the interval below the packer, a differential pressure is created causing fluid to flow from the formation into the well and up through the drill pipe or tubing toward the surface. Formation fluid rises in the tubing until an equilibrium static head is attained opposing further admission of fluids from the formation. The tester is then lifted and a valve closes in the tester, imprisoning the fluid in the tubing above. The tubing is then withdrawn to the surface and uncoupled and the fluid examined. Quantitative measurements of the amounts (or number of feet or "stands" of pipe) of oil, gas, salt water, and drilling fluid, will give evidence of the character of fluid that might be expected in subsequent production from the interval tested. If the formation pressure is sufficiently high, sustained flow of fluid from the interval under test to the surface may result, affording an actual production test. Repeated application of the formation tester at different depths in a well will show the character of production and comparative productivities of the different intervals tested.

In addition to formation samplers which depend upon securely seating a packer against the wall of the well, fluid sampling devices, designed merely to entrap a small sample of the well fluid at any desired depth, are also available. Before the development of formation testers, fluid samples were obtained with greater difficulty and delay in drilling operations. A string of casing had to be set and perhaps cemented to exclude top waters, and fluid was then bailed from the well until the fluid level fell to the level of the casing shoe, when samples of fluid from the formation below that point could be obtained.

ANALYSIS OF FORMATION WATERS

To facilitate their identification at a future time, analyses may be made of all ground waters obtained during the course of drilling. Such an analysis may be a complete chemical analysis from which the reactivity of the water may be predicted; or the salinity is determined and only the chloride content in parts per million is reported. If a complete chemical analysis is available, the chemical character of the water may conveniently be expressed in accordance with the Stabler-Palmer System of chemical hydrology and graphically charted on triangular coordinates (Uren, L. C. 34, pp. 481-485). Ground water analyses, suitably expressed and coordinated with the stratigraphic record, may be found helpful during the future period of productivity of a well in identifying the sources of entering waters. Differences in the chemical character of ground waters in different strata may serve as a basis for correlation of strata between wells. Knowledge of the chemical relationships may also enable one to predict whether a particular water sample is "top water" or "edgewater."

IMPROVED FIELD DEVELOPMENT PRACTICES BASED ON BETTER KNOWLEDGE OF DEEP-SEATED RESERVOIR CONDITIONS

A notable advance has been made during the last fifteen years in our understanding of the manner of occurrence and behavior of oil and gas in deep-seated reservoirs. That formation pressures are high was previously known, but no dependable means of determining them with accuracy was available until the development of bottom-hole pressure-recording devices. Studies of the pressure and energy gradients within the reservoir rock have brought new concepts of the mechanics of radial drainage. Accurate studies of the geothermal gradient in many oil fields have afforded more dependable data on the actual temperature of the reservoir fluids than previously existed. Studies of the solubility of natural gas in crude petroleum have disclosed that at high formation pressures, very large volumes of gas may be held in solution in the oil and that in this condition, the viscosity and surface tension of the oil is much reduced. The volume is increased and the density diminished. Knowledge of these factors, together with studies of hydrocarbon phase relationships and compressibilities of natural gases at high pressures have enabled research workers to determine the formation volumes of oil-gas mixtures when in place in the reservoir rock. Studies have also indicated that reservoir rocks apparently saturated with oil and gas, may contain important quantities of connate water in their interstitial pore spaces. Laboratory research and application of the concepts of fluid mechanics to oil reservoir conditions have contributed much to our knowledge of the characteristics of flow of gas-oil mixtures through reservoir rocks.

Better understanding of the conditions existing within oil reservoir rocks and of the factors influencing drainage have within recent years begun to influence field development practices. More careful consideration has been given to the problem of economic well spacing, with the result that there has been a decided tendency toward wider spacing of wells than formerly. New systems of field development have come into vogue, emphasizing the necessity for preservation of gas caps and control of edgewater incursion. Conditions in the California fields have focused attention especially upon field development systems adaptable to multi-zone deposits throughout great thicknesses of producing formations. Modern theories of drainage have emphasized the necessity for proper methods of field pressure control.

These topics that have been dismissed with hardly more than a sentence of comment, are in reality subjects of great interest to the modern petroleum engineer. They are the avenues by which we may hope to approach a future system of oil field exploitation far more efficient than any that has been known in the past. Yet they represent but one of many phases of California's great oil and gas industries that are being currently advanced by application of modern scientific knowledge and engineering skill.

FIG. 27 A. In Pennsylvania, Drake brought in his historic first well in 1859. This view was taken in 1863. Colonel Drake is in the foreground, wearing the high hat. *(Courtesy of Standard Oil Company of California.)*

FIG. 27 B. Recent photograph of Pico No. 4 well, Pico Canyon, near Newhall. Drilled to 370 feet in 1876 and pumped 25 bbls. oil per day; later deepened with better results. If not the earliest, this represents one of the first successfully productive wells in southern California. (This field will be described in Part Three.) *(Courtesy of Standard Oil Company.)*

MECHANICS OF CALIFORNIA RESERVOIRS

By Stanley C. Herold*

OUTLINE OF REPORT

SCOPE OF RESERVOIR MECHANICS

Reservoir mechanics, as a science, progressed rather leisurely through many years in California until several months ago, when it broke into prominence, attracting the attention of petroleum geologists and petroleum engineers. The problems of migration, accumulation, well spacing, reserves, ultimate recovery, percentage recovery, repressuring, pressure maintenance, gas energy, edgewater energy, edgewater encroachment, paths of fluid movement, pressure gradients, velocity gradients, bottom-hole pressures, indices of productivity, and the application or interpretations of gas-oil ratios, core analyses, porosity, permeability, surface tension effects in mixtures of gas and oil or water and oil, require the consideration of theoretical and applied mechanics. It is not unfair to state at the present time that merely a beginning has been made in the study of these matters.

CONDITIONS ENCOUNTERED IN CALIFORNIA

The class of reservoirs encountered in California is not confined to this State, but exists in the other fields of the world where production is obtained from formations of Cenozoic age. Notably it is in the United States, east of the Rocky Mountains, where production is obtained from formations of Paleozoic age, that another great class of reservoirs is encountered. Peculiarly enough, the reservoirs within formations of Mesozoic age appear to be divided, some belonging to the one, and some belonging to the other class. These classes are entirely distinct in their performance. The respective wells respond differently when we manipulate the production coming from them. That which is good practice in the one region is not necessarily good practice in the other.

Many of our California reservoirs lie at great depths varying between 8,000 and 13,000 ft. below the surface. These in particular demand our attention in mechanics. The drilling of a single well means an investment of between $100,000 and $350,000, exclusive of expensive mishaps. Natural flow from these wells offers no difficulty, but gas-lift and pump problems are serious. We must do what we can to force the wells to produce the greatest possible quantities of oil at the least cost. The proper mechanical completion of such wells is also a serious matter. Producing zones vary in thickness between 100 and 3,000 ft. Zones consist of massive sand bodies separated often by impermeable layers of shale from 2 to 200 ft. in thickness. Sometimes the massive sands of different porosities and permeabilities lie in contact without the intervening layers of shale.

The shales are of ordinary firmness, while the sands vary in competency. Small samples frequently crush easily in the hand, others will withstand a light blow from a hammer, and a very few possess the hardness of older sedimentaries. No shooting is required to bring in a California well. In fact, perforated pipe must be used to prevent the formation from coming to the surface in separated sand grains. According to the records of mechanical and electrical logging, the shales are more continuous over a structure than the sands which are lenticular. Laterally they are not homogeneous in texture, in firmness, or in thickness. Although in single profile sections the lenses appear separated and overlapping throughout a zone, from the behavior of wells in the zone we are certain that no lenses are entirely sealed off so as to be mechanically independent of edgewater pressure. If we could construct a complete system of parallel profile sections we evidently would be able to trace each lens outward to the edge of the pool. A completely sealed lens, if encountered, can be recognized, because a well penetrating it would give only gusher production, and would at no time be endangered by encroaching edgewater.

Outcrops of producing sands are at elevations varying between 400 and 1,800 ft. above sea level. Hydrostatic heads measured from producing horizons to these outcrops are sufficiently great to account for closed-in reservoir pressures varying between 2,000 and 4,000 lb. per sq. in.

MECHANICS OF NATURAL PRODUCTION

Gusher production is caused by the energy of the compressed gas which is present with the oil; settled production is caused by energy of the edgewater. In the former period the gas expands and performs work upon the oil; in the latter period the gas continues to expand as it approaches the well, but it does so merely to accommodate itself to a decreasing pressure. It does no work

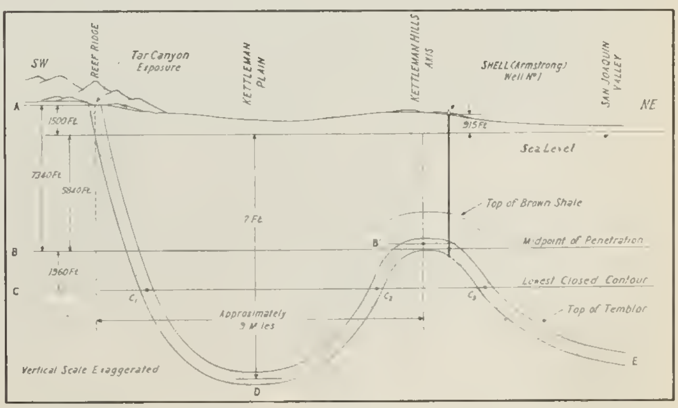

Fig. 28. Cross-section showing Temblor formation, from Tar Canyon to Shell Armstrong Well No. 1. Direction N. 40° 30′ E.

*Consulting Geologist and Engineer, Los Angeles, California. Manuscript submitted for publication July 1, 1939.

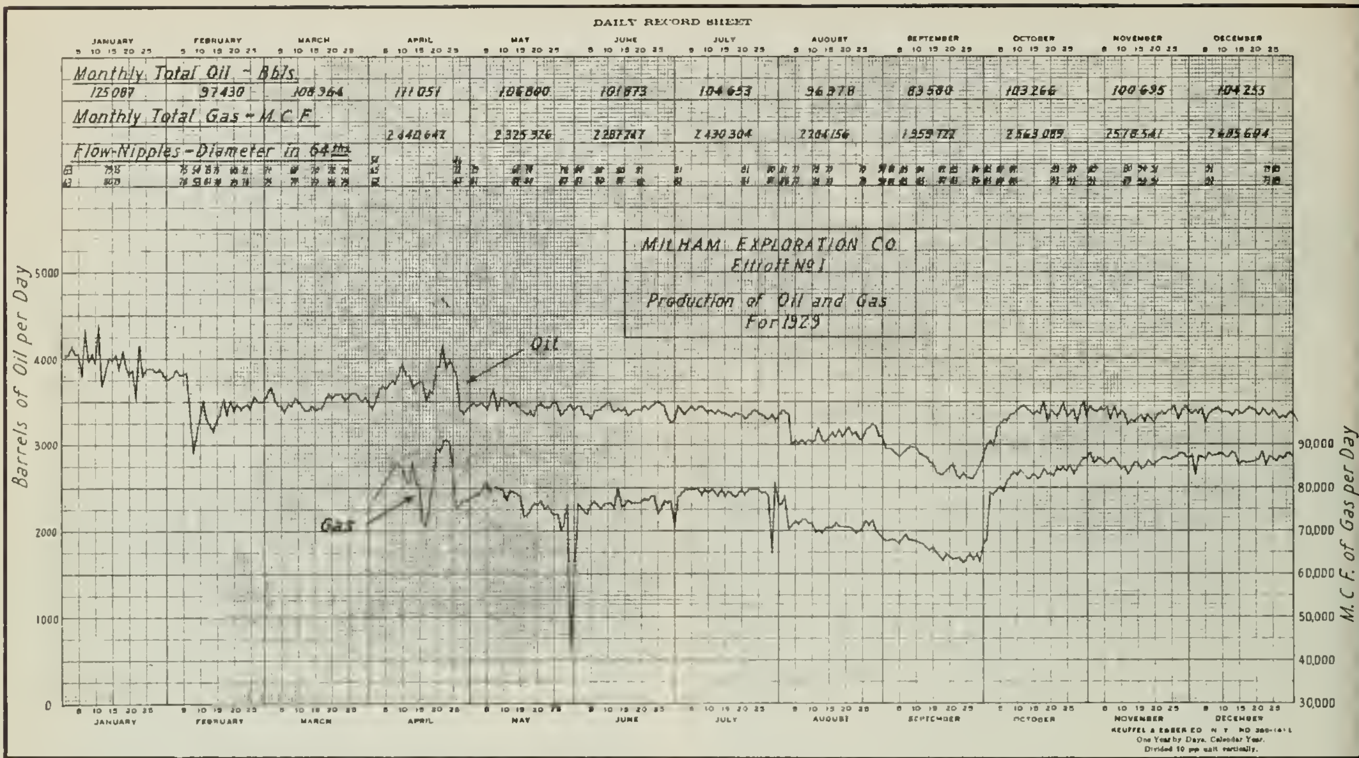

FIG. 29. Daily production record for 1929 of Kettleman Hills discovery well.

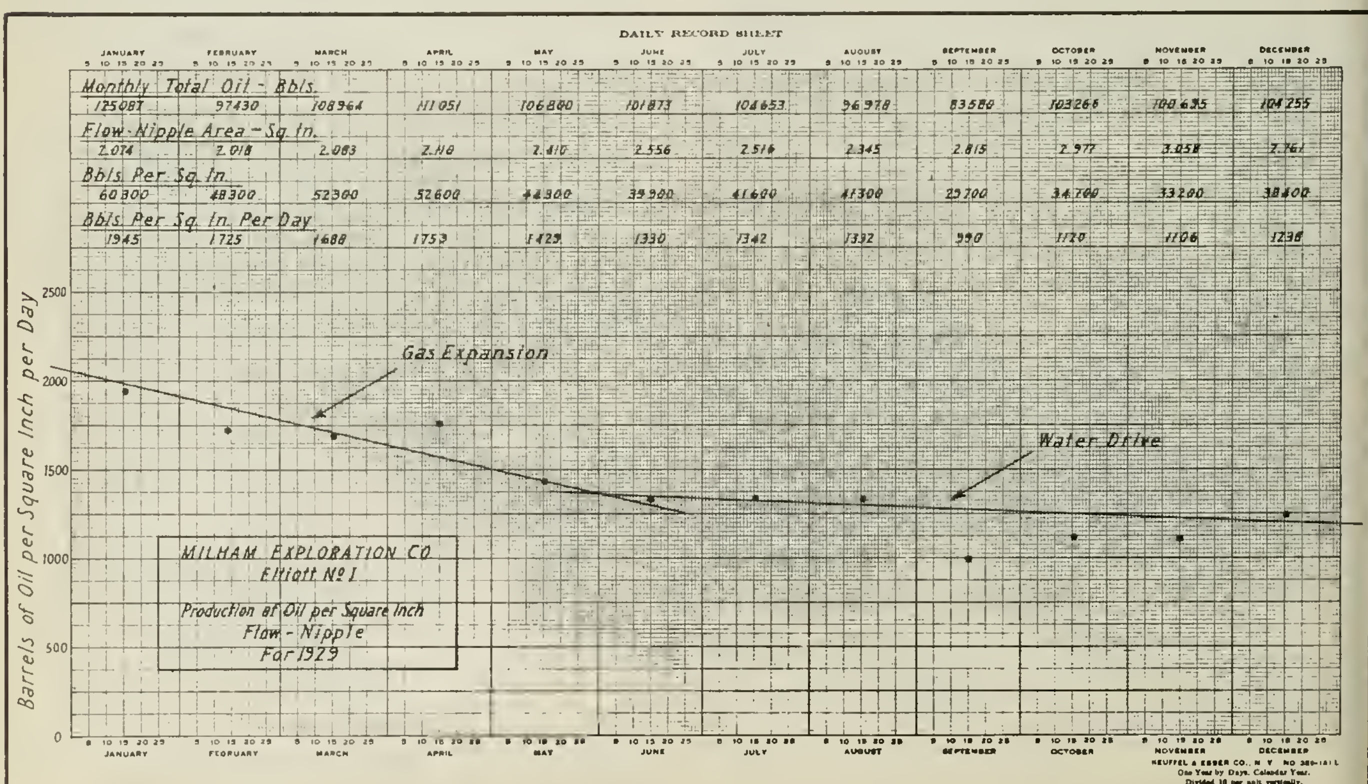

FIG. 30. Recomputed production record for 1929 of Kettleman Hills discovery well.

upon the oil at this time. Edgewater performs work by virtue of encroachment upon the pool.

Before curtailment, the production curves of California wells clearly indicated the class of reservoirs from which they produced. Manipulations of the wells to suit allotments of production of course interfere with the normal paths of decline dictated by nature.

A typical mechanical profile of a producing California field appears in Fig. 28. This happens to be designed to meet conditions at Kettleman Hills, but with different scales it can be made to suit any simple anticlinal structure in the San Joaquin Valley, the Los Angeles Basin, or the Coastal area of the State. Structures other than simple anticlines require slight modifications in accordance with known conditions. Nevertheless, the general mechanical situation is the same. All energy possessed by gas on the crest of the structure is the result of the pressure of the column of water which extends upward toward the outcrop.

The discovery well at Kettleman Hills, Milham Exploration Company Elliott No. 1, produced approximately a year without the competition of offset wells, and without curtailment. Its daily production record appears in Fig. 29. The daily irregularities in production are typical of wells with high gas-oil ratios wherein the amount of oil at the bottom of the hole continually changes, offering a variable back pressure against the face of the sand. In this case, more prominent irregularities were caused by changes made in the flow nipple at the head of the well in an attempt to get the best production results.

The first set of irregularities may be removed by computing averages for the month, and the second set can be largely nullified by calculating production rates per sq. in. of flow-nipple area. Thus the decline is shown as in Fig. 30. The drop in September marks the time when the first offset well began to produce. Its effect was of short duration. The change from gas expansion to water drive took place about June first, eight months after the well was brought in. With less gas the period of gas expansion would have been shorter. The usual time in other California fields varies between four and six months.

Had other wells not been drilled, and had production continued from this well uninterruptedly, the water drive would have continued on a straight line until a point had been reached when another turn would have made the continued record lie on a straight horizontal line. Then there would have been no further decline in the rate of production. In such an event, however, the oil would inevitably have been replaced by water, although this would have required many years, in view of the location of the well with respect to the edgewater.

The production from other wells provides for a greater decline before the curve strikes off horizontally.

MECHANICS OF FORCED PRODUCTION

The gas lift and the pump rejuvenate wells by reducing the back pressure against production. They perform no other function. There is a decided advantage in conserving reservoir gas during the stage of natural flow. Such conservation puts off the day when the artificial gas lift must be installed. Thus may total compression costs be reduced.

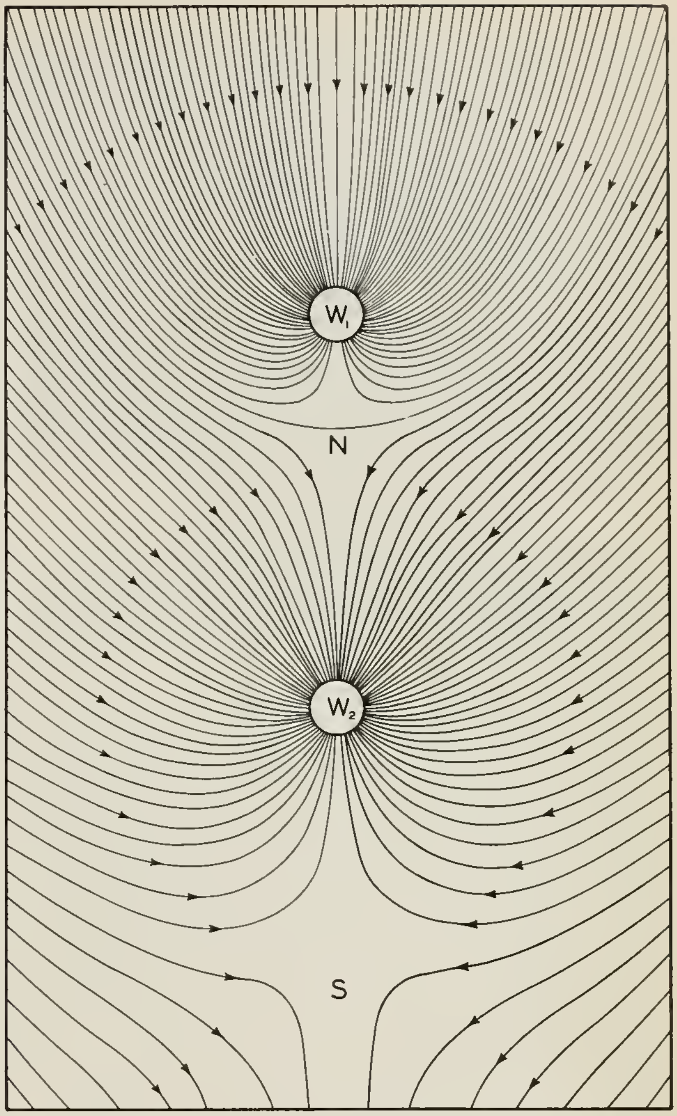

Fig. 31. "Lines of flow into two interfering wells in a region in which the ground water has a motion in a general direction. The diagram assumes that the general motion of the ground water is from north to south."
(Reproduced from Slichter, C. S. 99, p. 370, fig. 85.)

At the end of the period for the artificial gas lift all gas energy in the reservoir has been squared off. The oil remaining must either be pumped or abandoned. Whether the amount of this oil is or is not dependent upon conservation or waste of gas energy during natural flow is a controversial question among engineers.

The problem of pumping wells that exceed 8,000 ft. in depth as yet has not been solved.

DRAINAGE

Technological features of drainage in particular fields have not been studied seriously. In California the underground flow lines for oil and gas are the same as the ordinary flow lines for water anywhere in the world. (Flow lines in the class of oil reservoirs encountered in Paleozoic formations are quite different. Undoubtedly this fact has hindered the study of drainage patterns in general.)

Everyone is familiar with the design of Fig. 31, (Slichter, C. S. 99, p. 370, Fig. 85). W_1 may be assumed to be a well a considerable distance down the flank of a structure, while W_2 is a well higher on the flank. Off the diagram at the base another well, W_3, may be imagined on the crest of the structure. Production of these wells causes a movement of oil and gas from the top to and beyond the bottom of the figure. A perfectly homogeneous sand is assumed. In actual field cases certain variations are brought into play. Wells are frequently numerous, although generally spaced equally; they are sometimes staggered with respect to the edgewater line, or staggered with the direction of flow lines up the structure; and production rates are seldom equal at the various wells. Furthermore, the sands are heterogeneous.

Wells in California can not produce beyond their gusher stage without draining oil and gas (or water) from adjoining property. Thus a well may produce more oil than can be contained in the total amount of pore space underlying a particular property.

EFFECT OF CURTAILMENT

Curtailment is technologically beneficial to the recovery of oil in this State. Slower rates of production permit the leveling off of edgewater at the base of the structures, and they reduce the amount of gas by-passing the oil in the movement of gas and oil toward the wells.

The use of production curves has been greatly restricted since the introduction of curtailment. It is practically impossible to obtain any such curve as is shown in Fig. 30. However, one remedy seems possible, and that is to change the abscissas and ordinates to accumulated production and closed-in bottom-hole pressures, respectively. Thus the element of time, as it now appears in both coordinates, is avoided. The resulting curve will appear exactly the same as in Fig. 30, except as to the scales, with their titles as stated.

CONCLUSION

Economic conditions require the immediate consideration of well spacing, reserves, percentage recovery, and pressure maintenance. Along these lines there is much divergency of thought undoubtedly caused by the absence of any underlying system of mechanics to describe competently the events and conditions within a producing reservoir. Unity of thought based upon a system is essential before we can accomplish our aim in technology.

GEOPHYSICAL STUDIES IN CALIFORNIA

By F. E. Vaughan*

OUTLINE OF REPORT

INTRODUCTION

One of the greatest steps in the advancement of the geological sciences made during the past half century is the development of physical methods for field studies. For more than 16 years rather extensive surveys have been made in connection with the search for oil and other mineral accumulations. Several methods have been employed in California and it is the purpose of this paper to show in a general way the progress of geophysical studies in this State.

Since geophysical surveys are rather expensive, special emphasis is usually placed upon their usefulness in directly determining local structures of economic value. However, they are fully as important in throwing light upon many of the more fundamental problems of tectonic geology; indeed, they promise to afford definite solutions of some problems heretofore held to be entirely of a speculative character. The importance of this phase of geophysical work should be stressed, since proper theoretical considerations are of great value to the economic geologist in helping him gain and retain a clear picture of the structural relationships throughout a large district and enabling him to focus more effectively his attention upon certain restricted portions of the district.

We shall take up the various methods which have been employed here, outlining some of their more outstanding accomplishments and, in a general way, indicating the usefulness and limitations of each.

EÖTVÖS TORSION BALANCE SURVEYS

The usefulness of any gravimetric method is dependent upon the principle that distributions of gravitational forces over the earth's surface are in some measure indicative of the distributions of masses below the surface, and that a knowledge of such distributions of masses affords evidence of geologic structure. The Eötvös torsion balance was the first field instrument capable of making gravimetric surveys of sufficient accuracy to show clearly the influence of local distributions of masses. Surveys with this device were begun in California in 1924 by the Shell Oil Company. Later the Texas Company, Western Gulf Oil Company, and Pure Oil Company made important surveys. Other companies were also active from time to time, but their work was by no means so extensive as that carried out by the four companies mentioned.

Torsion balance surveys were extended to cover the Los Angeles Basin, Santa Maria Valley, Oxnard Plain, southern portion of the San Joaquin Valley, and a small part of Imperial Valley. In two areas, the San Joaquin and Santa Maria Valleys, torsion balance surveys effected a considerable revolution in the understanding of the structures buried beneath the flat valley floors.

SAN JOAQUIN VALLEY

To the east of the San Joaquin Valley rise the Sierra Nevada, the outcropping basement complex comprising granitic rocks with important included masses of slates, schists, and other metamorphics. The densities of these rocks vary from 2.5 to 2.8, the average being approximately 2.7. The lighter rocks are slates, granites, and granodiorites, the heavier are gabbros and dark hornblende diorites. In a general way these rocks constitute a huge tilted block rising eastward to the high summits of the Sierra Nevada and dipping westward beneath the San Joaquin Valley. This block has long been understood as belonging to the Great Basin structural system. Its eastern limit is a great fault whose vertical displacement in some places approximates 7,000 ft. This fault now finds topographic expression in the Sierra Nevada scarp facing the Basin Ranges. The Wasatch block in Utah with its conspicuous westward-facing scarp, constitutes a member somewhat similar to the Sierra Nevada block. Between these widely separated units, downfaulted and tilted blocks comprise the Basin Ranges.

West of the San Joaquin Valley are the Coast Ranges, the slopes of which rise rather more abruptly from the valley floor than does the slope of the Sierra Nevada on the east side. The maximum elevations attained by the former are less than half as great as those attained by the latter. The Coast Ranges comprise a great mass of Cretaceous and Tertiary sediments with occasional outcrops of granite and Franciscan (Jurassic ?) rocks which, however, are very important in certain areas. The sediments vary in density from 1.9 to 2.5, averaging approximately 2.35. The entire mass has been subjected to strong compressional forces which have produced numerous folds and overthrusts, features recognized as of Appalachian character. The eastward dips, seen in the outcrops along the western margin of the San Joaquin Valley, give the impression that there is a major synclinal axis beneath the valley floor.

Such is the general picture of the structural environment of the San Joaquin Valley. The structure out beneath the valley floor was unknown before the introduction of the torsion balance. Three notions were rather generally accepted: (1) a dominant synclinal axis was believed to lie somewhere near the geographical axis of the valley; (2) the valley was believed to be a zone of demarcation separating two entirely different

*Geologist, Los Angeles, California. Paper presented before the American Institute of Mining and Metallurgical Engineers October 1939; permission to publish granted by the Secretary of the Institute, January 23, 1940.

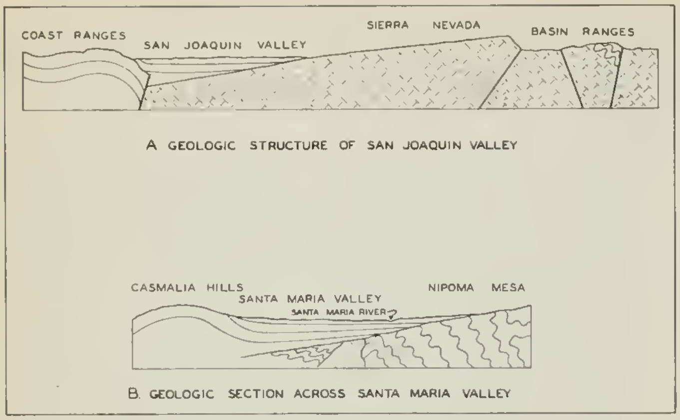

FIG. 32.

types of structure, the block faulting of the Basin Range system and the structures of Appalachian type of the Coast Ranges; (3) the valley was believed to be a great trough sinking beneath a load of sediments brought down from the Sierra Nevada.

Complete description and a complete detailed analysis of the torsion balance data do not lie within the scope of the present paper; rather, we are primarily concerned with the actual results in terms of geologic structure. The torsion balance work showed that the Sierra Nevada block continues westward beneath the San Joaquin Valley almost to the flanks of the Coast Ranges. It is clear, therefore, that the San Joaquin Valley is strongly asymmetric, the synclinal axis lying close to the western margin. No longer can we consider this valley as separating two entirely different types of structure. On the contrary, we see that the Basin Range type of structure really extends to the margin of the Coast Ranges; indeed, it seems likely that these latter are themselves a part of the same structural system. The structural differences that exist between the Coast Ranges and the Basin Ranges appear to be due to the differences in the types of rocks upon which the orogenic forces have been working; that is to say, they are due to the great mass of weak rocks in the Coast Ranges in contrast to the strong rocks of the Sierra Nevada. There is an abundance of evidence indicating that the western part of the Sierra Nevada-Great Valley block did not sink because of the load of sediments upon it, but because of the same compressive forces as are evidenced by the folds and overthrusts of the Coast Ranges. Under these forces the great block was tilted, the western part being forced down below its position of isostatic equilibrium, while the eastern part was raised above its position of equilibrium.

Considerable difficulty was experienced in attempting to determine local structures of economic value by means of the torsion balance. Local variations in density near the surface are frequently so great as to obscure the influence of structures at greater depths within the sedimentary mass. In many places, particularly along the eastern portion of the valley, the variations of density within the basement complex influence the distributions of gravitational forces more strongly than the structures within the sedimentary blanket. This is unfortunate, since these latter are the structures of primary interest to the petroleum geologist. The torsion balance did not lead directly to the opening of any new field, but did give a more exact knowledge of the general geologic structures in the various areas and paved the way for later work which has succeeded in finding new fields.

SANTA MARIA VALLEY

The Santa Maria Valley opens westward toward the Pacific Ocean. The Santa Maria River skirts the northern border of the valley, and farther to the north stretches the Nipoma Mesa. For the most part the older rocks are hidden by recent sediments, old sand dunes being rather extensive. A few outcrops of Franciscan (Jurassic?) and Tertiary sediments are found, but they tell little of the geologic structure. The Casmalia Hills bordering the valley to the south are due to a rather important anticline involving Tertiary sediments. The north limb of this anticline dips toward the valley. The structure beneath the valley floor was unknown, but one conjecture seemed to prevail. Because of the strong development of the Casmalia Hills anticline and the general northward slope of the valley floor, it was thought likely that there were other folds immediately to the north, more or less parallel to the Casmalia Hills anticline and becoming less important toward the Santa Maria River. Because of the general southerly slope of the Nipoma Mesa and numerous southerly dips farther to the north, it was thought that the general structure in this area also dipped toward the river. Thus in a general way it was believed that the axis of a broad synclinal trough was near the Santa Maria River.

The torsion balance survey completely upset the foregoing conception. It showed that the surface of the basement rocks slopes southward beyond the Santa Maria River and almost to the southern margin of the valley. The north limb of the Casmalia Hills anticline was found to continue its steep dip northward into the valley. Thus it became clear that the Santa Maria Valley is structurally a broad asymmetric syncline whose axis lies close to the southern margin of the valley.

LOS ANGELES BASIN

The torsion balance survey did not change greatly the conception of the structures underlying this area. Hydrographic surveys had already shown the presence of a basin separated from the ocean by a structural high along the coast except for an opening to the ocean northwest of Newport Beach. The torsion balance survey indicated that the deepest part of the basin lies near Huntington Park and that from this locality a synclinal trough extends toward Anaheim and then southward to the ocean northwest of Newport Beach, thus agreeing in the main with the earlier conception.

IMPERIAL VALLEY

Only a small area was covered and this was done under contract for some eastern company. However, little was learned of structures within the sedimentary mantle. The more important features in the gravitational field here are due to density variations within the basin complex including those due to dikes and volcanic necks.

OXNARD PLAIN

The most interesting observation on the work here is that a large part of the gravitational field is completely dominated by the heavy igneous masses at the northern extremity of the Santa Monica Mountains. These masses extend beneath the plain and beneath the ocean for a considerable distance north of the most northerly outcrops.

MAGNETOMETER

The magnetometer was introduced into California in 1926 and has been used from time to time ever since by various companies. The Standard Oil Company made the most extensive surveys, covering the Oxnard Plain and a large part of the San Joaquin Valley.

In a general way it can be said that the magnetometer was not able to find structural features that could not be determined either by the torsion balance or by the regular field methods of mapping. It was very much cheaper than the torsion balance, but far more limited in its range of usefulness. In some places it supplemented the torsion balance; as for example along the east side of the San Joaquin Valley, where variations in the magnetic field were found to be in marked agreement with variations in the gravitational field. Magnetometer surveys carried eastward beyond the contact between the sediments and the basement complex showed that a number of features in the distribution of magnetic forces extend across this contact entirely uninfluenced by it. It is clear, therefore, that these features must be due to variations within the basement complex.

In the Oxnard Plain the magnetometer showed the dominance of the influence of volcanic rocks at the north end of the Santa Monica Mountains in somewhat the same manner as did the torsion balance.

Perhaps the greatest importance of magnetic studies has not been in the usefulness of the magnetometer itself in exploration work, but in an outgrowth from this work. I refer to the method of orienting cores as developed by Edward D. Lynton and Henry N. Herrick (Lynton, E. D. 37, 38; Roberts, D. C. 39).

HOLWECK-LEJAY PENDULUM AND THE GRAVIMETER

The Holweck-Lejay inverted pendulum is intended for making general gravimetric surveys over large areas. About three years ago the Shell Oil Company began work near Hanford and carried the gravimetric survey northward to include virtually the entire Sacramento Valley. This survey confirmed what had already been inferred from previous work in the San Joaquin Valley —that the Sacramento Valley is structurally similar to the San Joaquin Valley and that the two valleys are structurally a unit. The Sierra Nevada basement block slopes westward beneath the Sacramento Valley and the axis of the synclinal trough of the valley is close to the western margin.

Gravimeters are used for making both general and detailed gravimetric surveys. A considerable number of designs are employed, but all depend on measuring the force due to gravity upon a mass suspended by some sort of a spring device.

In California the Continental Oil Company has made gravimeter surveys in the Los Angeles Basin, the Santa Maria Valley, and the San Joaquin Valley. The Western Gulf Oil Company also made extensive gravimeter surveys in the San Joaquin Valley and may have carried on similar work elsewhere. The results of these surveys are not known to the writer, but it seems likely that they have yielded somewhat the same geological information as has the torsion balance or the Holweck-Lejay pendulum, depending upon the spacing of the points of observation.

REFRACTION SEISMOMETRY

This work is essentially the study of artificial seismic waves set up by heavy explosions which have penetrated the earth to deep high velocity zones and then have come back to the surface. Experimental work was carried on in California early in 1925, but not until the summer of 1927 was there any regular survey made. At that time the Shell Oil Company began operations in the San Joaquin Valley. Later the Standard Oil Company did some work on the west side of the San Joaquin Valley. Several parties were active from time to time for the next three years, but they were on contract work and it is not known with certainty for what companies they were working. No really extensive surveys were carried out, as it was soon learned that in California the usefulness of this method is rather limited. Moreover, the costs of operations were very high; dynamite alone was a considerable item as some parties used more than two carloads per month. Damage claims were frequent, and, although actual damage done was slight, they offered a real obstacle to the progress of operations in populated areas such as the Los Angeles Basin and the Oxnard Plain.

The method was useful in definitely proving the correctness of some of the interpretations of torsion balance surveys; for it must be remembered that the earlier work was of a pioneering character without the background of experience and it was felt that many of the findings were so radical as to require additional support. The seismograph was able in some instances to give approximate quantitative results where the torsion balance findings had been purely qualitative. A good example of this is afforded in the San Joaquin Valley where it not only confirmed the understanding of the general structure as determined by the torsion balance, but also showed the general conformation of the surface of the basement complex under the eastern part of the valley floor. In the latitude of Hanford the basement surface was followed from the eastern margin of the valley to a point four miles west of the town. At this locality the strike of the surface is approximately N. 20° W. and the dip is approximately 5° SW. While it would have been possible to follow the basement farther to the west, this was not done, as interest was centered primarily in structures involving the overlying sediments. However, refraction studies of these sediments showed clearly, although indirectly, that the general attitude of the basement surface as found near Hanford, and eastward to the margin of the valley, continues westward into a synclinal trough well over toward the west side of the valley, close to the margin in some places. While subject to a considerable error, the results seem to justify an estimate of at least 30,000 ft. for the depth to the basement complex in the trough of the syncline near the western margin of the valley east of the Coalinga nose. This more exact knowledge of the structure of the valley afforded some clues regarding the actual mechanics of the formation of the valley, a matter which cannot be dealt with properly in this paper.

In the Santa Maria Valley the refraction seismograph also gave quantitative results where previously only qualitative had been obtainable. The survey showed that from a point on the Santa Maria River about six miles northwest of the town of Santa Maria the basement surface slopes approximately 7° southward to the vicinity of Betteravia.

ELECTRICAL METHODS

There are many electrical methods in existence, each one of which places emphasis on some particular phenomenon. They include studies of natural currents in the earth, direct current, alternating current, electromagnetic waves, resistance, inductance, capacitance, etc. Some of these have been tried in California, but none has proved to be a noteworthy success as a means of field exploration in the ordinary sense of the term. However, an outgrowth of this work, the Schlumberger electric log, has proved to be exceedingly valuable in the study of drilling wells.

REFLECTION SEISMOMETRY

Reflection seismometry is the study of artificial seismic waves, generated by small shots of dynamite, which have penetrated the earth to some depth and have been reflected back to the surface of the ground from boundary surfaces between rocks which transmit seismic waves with different velocities. This method is somewhat slower than the refraction method in covering large areas in those regions where both will discover the important structures, as for example in the Gulf Coast region where both have been successful in finding salt domes. However, it has proved to be effective in many areas where no other method has been at all satisfactory. It is capable of measuring dips and strikes and of carrying correlations in structures of small pattern. Besides its success in making measurements it has a distinct advantage over gravimetric, magnetometric, and electrical methods in that the quantities used are familiar to the geologist.

Reflection seismometry has met with considerable success in California. Some of the more important discoveries for which it is responsible are the Ten Section, Greeley, Cole's Levee, and Terminal Island fields. All of the major companies in California, and some of the independents as well, recognize its value and are very active in its application. Most of the more generally recognized oil territory in California has been shot over at least once. This includes the Los Angeles Basin, Oxnard Plain, Santa Maria Valley and the San Joaquin Valley south of Hanford. Some work has also been done in various parts of the Great Valley northward nearly to Red Bluff.

Reflection shooting has added considerably to our knowledge of the general tectonic geology in several parts of the State. In this connection I wish to draw special attention to some work done in the Los Angeles Basin under the supervision of B. Gutenberg and J. P. Buwalda of the California Institute of Technology (Gutenberg, B. 35). Many geologists have long believed that block faulting has been important in the development of the Los Angeles Basin, and the work by Gutenberg and Buwalda bears out this conception. They adduce evidence which seems to show that there is a huge block of the basement mass dropped down between the Inglewood and Norwalk faults. The upper surface of this graben lies some 45,000 ft. below the surface of the ground. Other blocks on either side lie at depths of from 10,000 to 20,000 ft.

Methods and equipment used in reflection shooting have been improved greatly during the past four years, and some areas have been shot over as many as three times by the same company. Judging from the history of similar activity elsewhere as well as the progress here up to the present time, it seems likely that this work will continue in California for several years.

GEOCHEMICAL PROSPECTING FOR PETROLEUM

By E. E. Rosaire*

OUTLINE OF REPORT

GEOCHEMISTRY OF A PETROLEUM DEPOSIT

The mining geologist finds it quite necessary that consideration be given to the geochemistry as well as the geology of an ore deposit, yet, in exploration for petroleum, there has been no fundamental recognition of the possible existence of the geochemistry of a petroleum accumulation.

In fact, there has been a tendency to consider the oil and gas in place as an inert and static mass, similar to a coal seam. This existing viewpoint is natural in consideration of a stripper field, where work must be done to extract the petroleum from its sedimentary environment.

Consideration of a wild well, however, will lead to a better understanding of the conditions existing in an untapped petroleum accumulation, where rock pressures drive the hydrocarbons into and through the immediately surrounding sediments. Even though the sediments are considered relatively impermeable, one must admit, as a minimum, the leakage of minute amounts of hydrocarbons at slow rates outward from the deposit, along the bedding planes of the more permeable zones and across bedding planes through normal joints and fissures.

Even though such leakage is small, and takes place at a slow rate, accumulated over long geologic time, it can today be measured in several ways with relative ease. Proper recognition and consideration of these phenomena permit the organization of rational prospecting techniques which aim at the recognition and location of the petroleum itself, not just the geometry of traps within which petroleum might possibly be accumulated.

TYPES OF PHENOMENA RECOGNIZED IN GEOCHEMICAL PROSPECTING

In geochemical prospecting, we recognize two general types of phenomena, the near-deposit type, and the near-surface type. The former is of importance in geochemical well logging, accomplished by analysis of cuttings and cores from wells. The near-surface phenomena are of importance in prospecting along the surface, accomplished by the chemical analysis of soil samples, and the physical measurement of the properties of the near-surface sediments.

The element of depth enters into the near-deposit phenomena, whereas the element of geological time, rather than depth, enters into the near-surface phenomena.

*Geophysicist and Geochemist, Subterrex. Manuscript submitted for publication February 9, 1940.

NEAR-DEPOSIT PHENOMENA

Geochemical well logging is a recently developed technique which depends upon the analyses of cuttings and cores from drilling wells. Figs. 33A and 33B illustrate the differences observed between a dry hole and a producing well. The observed differences are many times the observational errors in the analytical determinations, and show how the geochemical influence of a petroleum accumulation may extend as much as a thousand feet or more above the actual producing horizon.

These geochemical well logs are made up, ordinarily, from the cuttings secured in routine drilling, and have been of assistance in drilling wells to production at depths below those at which they ordinarily would have been abandoned.

NEAR-SURFACE PHENOMENA

As the escaping hydrocarbons pass through the shallower sediments, they evaporate ground water, which then is replaced by normal sedimentary fluids migrating laterally inward. The process, taking place over long geologic time, results in the concentration of normal ground minerals in and close to the path of the escaping hydrocarbons.

These secondary concentrations of ground minerals modify the normal properties of the near-surface sediments, and so make possible the use of prospecting methods like soil analysis, gravity prospecting, and the Eltran (electrical transient). These reconnaissance methods block out areas within which significant geochemical anomalies exist, to be regarded as significant only if, by soil analysis, the leakage of significant hydrocarbons (Ethane, Propane, and Butane) is established.

In order to obtain more information than can be secured by near-surface prospecting, relatively shallow core tests are drilled across the prospect, and geochemical logs are made of them. From these logs, a "high-grade" spot can be located, where the final, relatively expensive test hole to the pay horizon should be drilled. If this test well is also geochemically logged, it is possible to predict the presence of a petroleum accumulation in the untested sediments 500 to 1,000 ft. ahead of the drill.

CONCLUSIONS

Geochemistry has revolutionized prospecting for petroleum. We no longer need look only for structures which may contain petroleum: we can now explore for evidences of the presence and location of the petroleum deposit itself. Though a relatively virgin field, geochemical prospecting has already placed on record several case treatments* where subsequent drilling has confirmed, to a remarkable degree, the predictions, made on the basis of the original exploration data, as to the areal extent of production.

* *Editor's Note:* The author cites success at Wasco, Kern County, California, by George F. Getty, Inc., No. 1 Jannsen, completed September 1939 for 1,500 bbl. per day, at a depth of 13,131 ft., as confirmation of "ETHANE-PROPANE-BUTANE halo drawn from 'One-Eyed' Soilane survey made in May 1939, for George F. Getty, Inc." (Rosaire, E. E. 39, p. 59.)

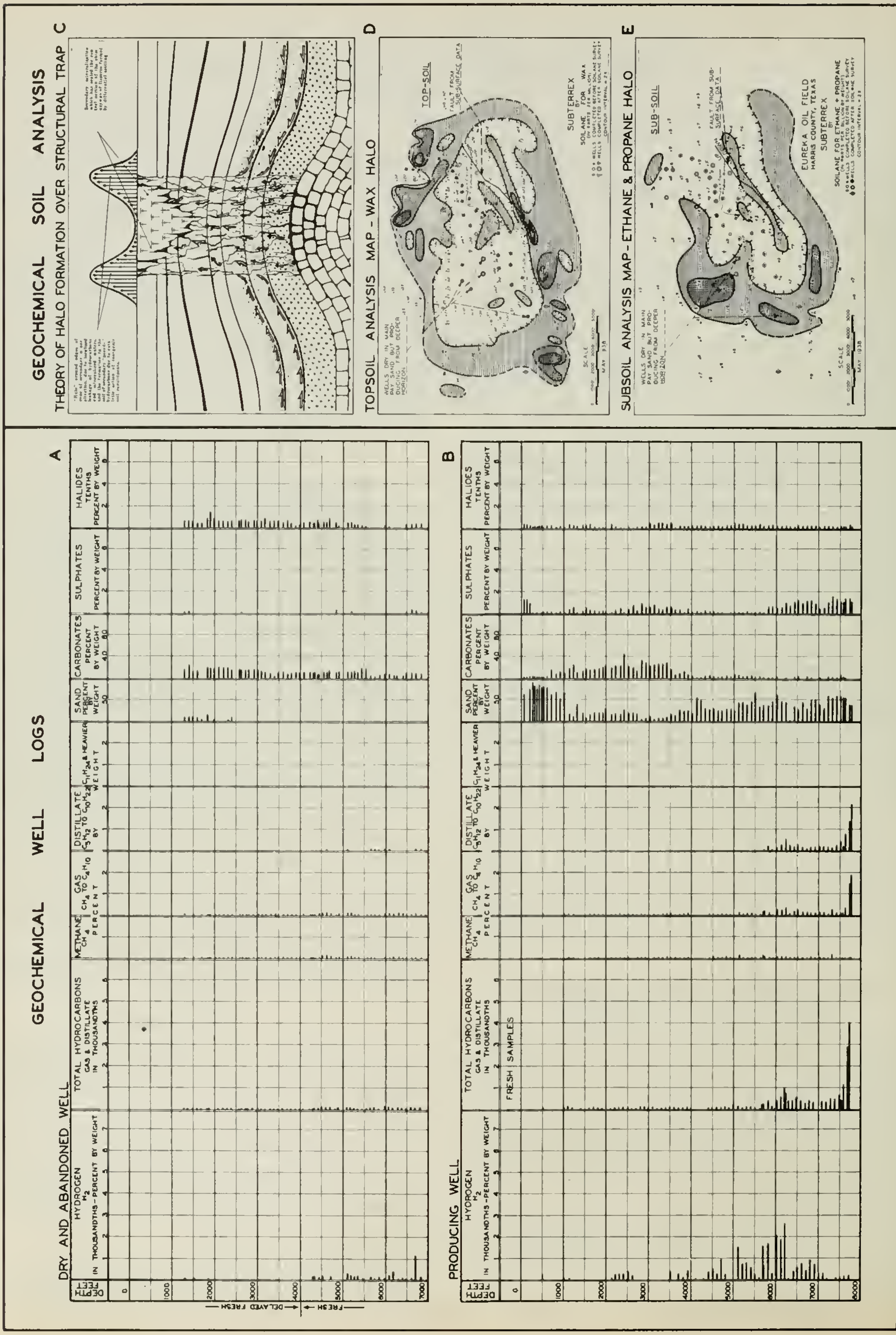

FIG. 33. A, B, C, D, and E.

Chapter III

Early History

CONTENTS OF CHAPTER III

Editorial Note: Since the history of the prolific oil and gas regions of southern California may be found in Part Three of this bulletin, incorporated with descriptions of the individual fields, the following chapter is devoted largely to the known aboriginal record and to the early explorations in the northern coastal region.

FIG. 33 F. The famous tar pool or oil seepage of Rancho La Brea, from which Indians secured tar and into which many animals, including pre-historic ones of the Pleistocene, became entrapped. View looking north from Wilshire Boulevard and La Brea Avenue, Los Angeles, taken March, 1915. (The Salt Lake oil field appearing in the background, will be described in Part Three of this bulletin.) *(Photo by courtesy of the Museum of Paleontology, University of California.)*

ABORIGINAL USE OF BITUMEN BY THE CALIFORNIA INDIANS

By ROBERT F. HEIZER*

An excellent general treatise on the Old World use of bitumen, and the methods of distillation in antiquity, has been written by R. J. Forbes (36); accounts by H. Köhler (13) and the Philadelphia Commercial Museums (00) show how widely this substance was known and used by the ancients; but apparently no general, published statement on the use of asphaltum by the earliest California petrologists, the Indians, is in existence.

Bitumen, dug from surface land seepages (Eldridge, G. H. 01), or collected along the beaches all the way from Point Conception to San Diego in the form of lumps exuded from submarine seeps, was an important adjunct to native technology, serving as a caulking material for boats, as an adhesive, or for waterproofing baskets. The accompanying map shows various sources of native supply which are known to have been exploited by the Indians; these locations have been derived for the most part from journals of eighteenth and nineteenth century explorers who saw the Indian cultures, now vanished under Caucasian impact, in full operation.

The Spanish explorer Fages, in 1775, said that "At a distance of two leagues from this mission [San Luis Obispo] there are as many as eight springs of a bitumen or thick black resin which they call *chapapote*; it is used chiefly by these natives for caulking their small water craft, and to pitch the vases and pitchers which the women make for holding water." Fr. Pedro Font, in 1776, while near Goleta in Santa Barbara County wrote ". . . much tar which the sea throws up is found on the shores, sticking to the stones and dry. Little balls of fresh tar are also found. Perhaps there are springs of it which flow out into the sea, because yesterday on the way the odor of it was perceptible, and today . . . the scent was as strong as that perceived in a ship or in a store of tarred ship tackle and ropes."

Bitumen was dug out of tar seeps, or picked up in lumps on the beaches and stored in baskets or large shells. The famed La Brea asphalt pits, the deathtrap of the ages, occasionally caught a luckless Indian whose bones and implements along with plant remains and animal skeletons, have been recovered (Merriam, J. C. 14a; Hrdlička, A. 18; Woodward, A. 37).

Along the Santa Barbara Channel the Chumash Indians had perfected a wooden canoe made of a great number of small planks tied or "sewed" firmly together by small ropes. This unique canoe (Heizer, R. F. 38) was essential to the life of the natives, but without asphaltum to caulk the plank interstices and binding holes, it could not have been constructed.

The Chumash Indians also used bitumen liberally for such purposes as an adhesive to fix arrowpoints to the shafts; for mending broken stone vessels or pestles; as an adhesive for stemming pipes with bone mouthpieces; as a mastic or setting for inlaying small pieces of shell as decorations; and as a filling to rub into incised lines in order to bring out the designs in contrastive black color (Harrington, J. P. 28, pp. 105-106). Ingenious methods for applying the bitumen had been developed by these Indians—a long, slender stone was heated and placed in contact with the asphaltum lump; this caused the substance to flow freely upon the object where it was required. This is the same process as our soldering technique. Baskets were coated inside with a thin layer of bitumen in this manner: lumps of asphaltum were put in the cavity of the basket and with them a number of very hot round pebbles. The contact of the heated pebbles reduced the tar to a fluid state, the basket was shaken round and round until an even coating had been applied, the weight of the pebbles being sufficient to press the liquid asphalt into the interstices of the basket (Rogers, D. B. 29, pp. 396, 398). Flat stones with a basketry rim firmly attached with bitumen served as mortars for grinding seeds.

The area *par excellence* of native utilization of bitumen seems to have been the Santa Barbara region where aboriginal technological attainments were complex enough to create an extensive demand and wide use of the material. The Yokuts tribes of the southern San Joaquin Valley were the first exploiters of the bitumen springs, the outward evidences of what was later to develop into the great Bakersfield petroleum area (Gifford, E. W. 26, p. 53). Farther up the central valley limited use was made of asphaltum as an adhesive material by the ancient peoples of the delta area; the probable sources of supply are shown on the accompanying map (Schenck, W. E. 26, p. 212).

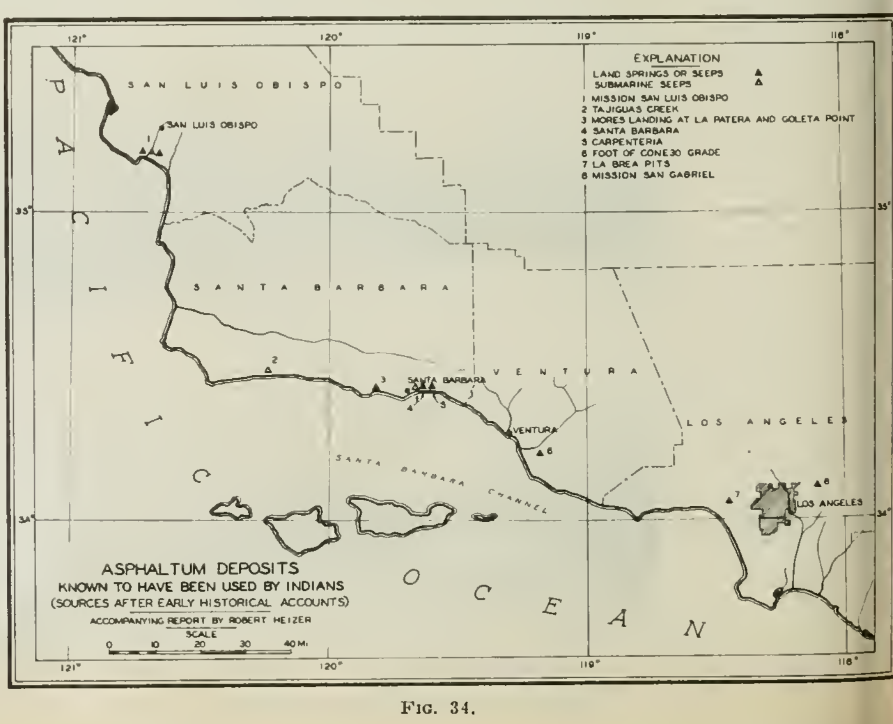

FIG. 34.

* Department of Anthropology, University of California. Manuscript submitted for publication January 22, 1940.

HISTORY OF EXPLORATION AND DEVELOPMENT OF GAS AND OIL IN NORTHERN CALIFORNIA

By Walter Stalder*

OUTLINE OF REPORT

INTRODUCTION

It may be news to many readers that the earliest drilling and refining activities in the California gas and oil industry were in the central and northern portions of our State. In the succeeding pages some of this pioneering history is reviewed with the idea of giving its proper position in relation to our early gas and oil history. Since space will not permit mention of all past activities, the selection as herein made will afford a fair picture of progress in this region.

EARLY HISTORY

FIRST ECONOMIC DEVELOPMENT

The first economic use of natural gas in California was from the famous Court House well at Stockton, San Joaquin County, bored to a depth of 1,003 ft. (1854-1858). (Weber, A. H. 88, pp. 181-182.)

As early as 1856 Andreas Pico distilled oil, for use in illuminating the San Fernando Mission, from seepages in northern Los Angeles County. In 1857 Charles Morrell, a druggist from San Francisco, erected a distilling plant near the maltha seepage at Carpinteria in Santa Barbara County and produced illuminants, but without commercial success (Hanks, H. G. 84, pp. 293-294).

THE CAMPHENE DISTILLERS; THEIR INTEREST IN CALIFORNIA OIL

Before 1859, when kerosene began to come into wide commercial use, camphene was the principal illuminating fluid burned in lamps throughout the State. It was originally obtained by distilling turpentine over lime; and as early as 1851 a camphene still was erected in San Francisco by George Dietz and Company (Mining and Scientific Press 60). In 1858 six similar plants were operating in the same city (San Francisco City Directory 58). George Dietz and Company, Stott and Company, Stanford Brothers, and later Hayward and Coleman were among the most progressive operators of such plants. Their crude turpentine was imported from the southern states, and came around Cape Horn.

After the successful completion of the Drake discovery well in Pennsylvania in 1859 a keen interest was manifested in California crude oil for the production of kerosene; as prospects were developed, their production found its way to the various camphene stills about San Francisco.

THE SCOTT INTERESTS

Probably the strongest financial group active in the development of a commercial oil industry in California was the one headed by Colonel Thomas A. Scott of Pennsylvania. Scott was vice president of the Pennsylvania Railroad, and was later the projector of the Texas and Pacific Railroad, which he contemplated building from Marshall, Texas, to San Diego, California (National Cyclopaedia of American Biography 06; Young, J. P. 12, vol. 2, p. 588).

During the first oil development in Pennsylvania, Andrew Carnegie (National Cyclopaedia of American Biography 99), a young associate of Scott, induced Scott and J. E. Thomson, president of the Pennsylvania Railroad, to purchase with him the Storey farm on Oil Creek. Bearing in mind that one year's return from this $40,000 investment was more than $1,000,000, and that the stock of the company attained a value of $5,000,000, it is easy to understand Scott's interest in the purchase of prospective oil lands in connection with his early plans for a railroad to California, and his sending an expedition (1863-1864) to buy gold lands in Arizona and oil lands in California (The Road 75). Professor Benjamin Silliman, Jr. (65; 65a; 65b), of Yale University, came to California, and reported on certain lands in connection with this enterprise. As a result, the Scott group purchased the following ranchos: Simi (113,000 acres), Las Posas (26,500 acres), San Francisco (48,000 acres), Calleguas (10,000 acres), Colonia (45,000 acres), Cañada Larga (660 acres), and Ojai (16,000 acres); a large part of the town of San Buenaventura; all in what is now Ventura County; and also some 12,000 additional acres located in Los Angeles and Humboldt counties—making a total of 277,000 acres. To develop these holdings, the Philadelphia and California Petroleum Company, the California Petroleum Company, and the Pacific Coast Petroleum Company were formed (Gidney, C. M. 17, vol. 1, pp. 358-359); to manage these California holdings, Scott sent a progressive young attorney, Thomas R. Bard, who arrived in California in January, 1865.

*Consulting Geologist, San Francisco, California. Manuscript submitted for publication January 25, 1940. In addition to the sources of information cited throughout his paper, Mr. Stalder has made frequent reference to the work of his late father, Joseph Stalder; to information furnished by the late Josiah W. Stanford, son of Josiah Stanford of Stanford Brothers; to information supplied by Mr. W. W. Orcutt, Vice President of the Union Oil Company of California; to conversations with "old-timers" at Petrolia, Humboldt County; to articles in a scrap-book kept by the author and his late father since 1899; to data collected during numerous visits to the areas discussed, and during contacts with operators of properties; to information supplied by Mr. G. C. Gester, Chief Geologist, Standard Oil Company of California; to the records in the Humboldt County Assessor's office; to records of the Secretary of State at Sacramento; and to data from the Belcher Abstract Company at Eureka.

The Scott group became interested in Humboldt County oil lands through J. W. Henderson, who, while in that northern county in 1864, secured some samples of seepage oil, high in illuminants and closely resembling Pennsylvania oil (Semi-Weekly Standard 01). Henderson returned to Humboldt County as manager of the Scott interests there, and proceeded to purchase land with Indian scrip and school warrants. This land purchasing was conducted in cooperation with Levi Parsons (Appleton's Cyclopaedia of American Biography 88) who was evidently the person through whom Henderson brought about Scott's activities in Humboldt County. The surface of these lands was later sold, but the mineral rights were retained (Humboldt Times 19).

As early as November 1861 there is mention of a well being drilled on the Davis Ranch in Humboldt County, after the manner of artesian wells. It appears to be the earliest well so sunk for oil in California (Mining and Scientific Press 61).

THE FIRST CALIFORNIA OIL BOOM (1865-1866)

In 1865 the first California oil boom was born. People became interested not only in the crude seepage oils of Humboldt, Colusa, Santa Clara, and San Mateo counties, but also in the asphalt seepages and bituminous residues occurring in Mendocino, Marin, Contra Costa, Santa Clara, and Santa Cruz counties. In the south the large bituminous seepages in Ventura (formerly a portion of Santa Barbara), Santa Barbara, Kern (formerly Tulare) and Los Angeles counties received the most attention. It should be remembered that the oil industry was at that time in its infancy, and that very little was known of the laws governing the accumulation of gas and oil. Consequently, the tendency was to carry on operations near seepages or near oil-sand outcrops. Trenches, pits, tunnels, shafts, and shallow wells drilled either with spring poles or with light steam-driven engines were the instruments of production.

The Union Mattole Oil Company, which caused much of the Humboldt County excitement in 1865, filed its articles of incorporation with the Secretary of State in Sacramento March 25, 1865. It had as its first three directors Thomas Richards, William Ede, and Edward Bosqui, all business men of San Francisco (San Francisco City Directory 66; 67). Its first well was located on the picturesque North Fork of the Mattole River in Sec. 30, T. 1 S., R. 1 W., H. Drilling was inaugurated promptly, and on June 10, 1865, the Humboldt Times carried the following item:

> "The First Shipment of Coal Oil from Humboldt County. On Wednesday last, Mr. F. Francis of Ferndale brought into town six packages of from 15 to 20 gallons each of coal oil taken from the well of the Union Mattole Oil Company. This will go to San Francisco by the present trip of the steamer and is the first shipment of crude oil from the oil regions of this county."

The first shipment reached San Francisco June 12, 1865, and credit for its refining goes to Stanford Brothers, whose camphene still was located at the northeast corner of Chestnut and Taylor streets. The product was sold for $1.40 per gal. (San Francisco Bulletin 65; 65a). This appears to be the first oil, from a drilled well in California, to be distilled and sold on the market.

The Stanford brothers directly interested in the camphene plant were Josiah, A. P., and Charles. Josiah Stanford, however, was the moving spirit in the organization (San Francisco City Directory 66a).

TABLE I—WELLS DRILLED (1865-1866) IN MATTOLE, BEAR RIVER, AND OIL CREEK DISTRICTS OF HUMBOLDT COUNTY, CALIFORNIA*

Name of well	*Sec.*	*Location T.*	*R.*	*Merid.*	*Remarks*
Scott and Parsons**	15	1 S	2 W	H	Also known as Noble well, J. W. Henderson, supt.-mgr.
Sutter and Allen** (5 wells)	29, 30	1 S	2 W	H	Located in McNutt Gulch; Wm. Muldrow, supt.
North Fork**	25	1 S	2 W	H	Capt. W. C. Martin, supt.
Union Mattole Oil Co.** (2 wells, 1 pit)	30	1 S	1 W	H	Mr. Bosqui, supt.
Irwin Davis	33	1 S	2 W	H	Reported depth 1,170 ft., deepest test in county in 1866.
Paragon	30	1 S	1 W	H	T. G. Duff, supt.
Brown and Knowles	25	1 S	2 W	H	
Fonner (3 wells)	28, 33	2 S	1 W	H	
Mattole Pet. Co.					Located North Fork of North Fork of Mattole River
Jeffrey	28	1 S	2 W	H	
Buckeye					Located on Conklin Creek; Capt. W. C. Martin, supt.
Hawley					Located on Bear River; Mr. Wattles, supt.
Davis					Located on Bear River
Johnson Farm					Located on Bear River; Mr. Kirk, supt.
Fortuna					Located on Bear River
Oil Creek Pet. Co. (2 wells)	22, 32	2 N	2 W	H	Located on Oil Creek, at head of its northeast branch; Capt. Knypthausen Greer, supt.

*Data from files of Humboldt Times, 1865-66-67, and Mining and Scientific Press, 1865-66-67.

**Shipped oil to San Francisco.

On Thursday, August 24, 1865, the steamer Del Norte left Eureka with 16 bbl. and 27 half barrels of oil from the Union Mattole Company, and several "packages" ranging from five gallons to a barrel each from the Noble (Scott and Parsons) well and from the Sutter and Allen well. On September 9, 1865 there were 40 "packages" of petroleum at Centerville awaiting transportation to Eureka for shipment to San Francisco (Humboldt Times 65; 65a). Other shipments were made later.

An analysis of oil from the well of the Sutter and Allen Company was made by Rowlandson (Humboldt Times 65a):

Material	*Per cent*
Good burning oil	77
Amber colored light machine oil	5
Dark colored machine oil	4
Loss and residue	14
	100

None of the wells actively producing in Humboldt County during 1865 and 1866 was over 260 ft. deep.* The Union Mattole well No. 1 was the best, and evidently it had a strong appeal to the Stanford Brothers, for they entered the market for Union Mattole stock and secured control (Mining and Scientific Press 66d). In 1867 they drilled a well to the depth of 1,003 ft. beside Union Mattole well No. 1, but it was not successful (Irelan, W. 88b, p. 197). The casings of both wells still protrude from the ground, and oil can be dipped from No. 1.

All of the producing wells in Humboldt County soon developed troubles, mostly with caving, water, crooked holes, or too small production. Pennsylvania oil took a great drop in price which affected California prices. Transportation of oil from the wells was expensive

* The Mining and Scientific Press, Aug. 18, 1866, gives depth of North Fork well as 260 ft. The Mining and Scientific Press, Dec. 2, 1865, p. 345, gives depth of three Union Mattole wells as 135 ft., 167 ft., and 20 ft., respectively. Mining and Scientific Press, Dec. 16, 1865, p. 369, gives depth of oil production in Noble (Scott and Parsons) well on Joel Flat as 210 ft. The Humboldt Times, Sept. 7, 1865, gives depth of Sutter and Allen wells in McNutt Gulch as 173 ft., 125 ft., and 130 ft., respectively. These were the producing wells of the time.

(Semi-Weekly Standard 01; Leach, F. A. 17, pp. 98-99); oil was shipped in small containers on mule-back to Centerville, a distance of 30 miles; there it was loaded into trucks and hauled an almost equal distance over bad roads to Eureka; from Eureka it was transported by steamer 216 miles to San Francisco. To add to all these difficulties, the United States Government, under date of March 17, 1865, sent out orders to withhold Humboldt County oil lands from disposal, making most titles questionable. Under these accumulated discouragements, the first California oil boom died in 1866 (Ball, M. W. 16, pp. 59, 60; Irelan, W. 88, p. 199). Attempts were made in 1894, 1899, 1900, 1907, 1921, and 1935 to bring about better production with deeper wells, but without success.

SOUTHERN CALIFORNIA

Contemporaneous with the Humboldt County activity of 1864, 1865, and 1866, was the attention given other oil-seepage areas of California. The Philadelphia and California Petroleum Company (Scott interest) made application for a license to distill oil from springs (San Jose Mercury 65). The Scott interests, under the management of Thomas Bard, also drilled six exploratory wells on the Rancho Ojai on the north flank of Sulphur Mountain in Ventura County (Oil Weekly 21).

The first five wells were not successful, but the sixth became a producing well in 1866, making a settled production of about 20 bbl. per day. This well was shut down because there was no market for the oil. The Scott well in Humboldt County was also shut down because of caving and small production. Over $200,000 was spent by this group; however, they owned their lands and could wait (Gidney, C. M. 17, vol. 1, pp. 358-359).

The former camphene distillers of San Francisco also looked to the south for a source of crude oil. Charles Stott exploited oil seepages and started his own refinery in Santa Paula in 1866 (Hanks, H. G. 84, p. 295). Hayward and Coleman and Stanford Brothers also exploited seepages and drove tunnels into the flank of Sulphur Mountain, and obtained a production of a few barrels of oil per day. This, together with oil purchased from others, formed the source of the crude supply for their San Francisco refineries.

Colonel Thomas Scott died in 1881. Prior to that date Hardison and Stewart, two enterprising Pennsylvania operators, active in Ventura and Los Angeles counties, built the foundation for a successful oil business after many disappointments. Thomas R. Bard, to whom fell the task of disposing of the Scott interests, brought about a combination of the Hardison and Stewart interests and certain of the Scott oil holdings as the Union Oil Company of California, incorporated in 1890 (Petroleum Register 37).

E. Benoist was a student of early California refining problems. He had an oil laboratory on Third Street in San Francisco (Mining and Scientific Press 65 p.). With Stephen Bond as a partner, he attempted to drill a well at Buena Vista in Kern County (then Tulare County) at the east end of the present McKittrick field. The attempt resulted in failure when the drilling bit became hopelessly stuck in the hole. Benoist and Bond did obtain oil, however, from pits in the same region (Secs. 19, 20. 29, T. 30 S., R. 22 E., M. D.). These pits were usually about 20 ft. deep, 5 ft. wide, and 8 ft. long; each produced in 24 hours about 300 gal. of crude oil containing 40% light and 50% heavy or lubricating oil. The claim was worked from February 1864 to April 1867, when the local demand was fully supplied, and the low price of oil made its preparation for the San Francisco market unprofitable. (Browne, J. R. 68, p. 263; Hanks, H. G. 84, p. 296.)

CENTRAL AND NORTHERN CALIFORNIA

In 1861 workmen discovered an oil seepage while cutting saw logs for Moody's mill in Moody's Gulch near Lexington in Santa Clara County (Mining and Scientific Press 61a).

In April 1865 the Santa Clara Petroleum Company put down a well in the Moody Gulch region, and the Shaw and Weldon Petroleum Company sank a shaft that "struck a vein of finest quality" at 30 ft. (San Jose Mercury 65a). During the same year the Pacific Petroleum Company was incorporated to operate near Lexington (San Jose Mercury 65b); and in October 1865 a shipment of 60 gal. of oil was made from a Lexington well to San Francisco (San Jose Mercury 65c). The Alta Californian of October 11, 1865, tells of a shipment of oil from Lexington to New York, and of a 100-gal. shipment to San Francisco, to show the excellent character of the oil.

The crooked McLeran well, which reached a depth of 470 ft., cut several oil sands, but no water sands. Although five barrels of oil could be pumped from the well each morning, drilling was suspended (San Jose Mercury 66). By this time (1866), the fact that oil was present in the field had been demonstrated, but it remained for more experienced operators to develop it.

In 1864 and 1865 works were erected at the bituminous oil seepages on the Sargent Ranch (Sec. 36, T. 11 S., R. 3 E., M. D.) in Santa Clara County to distill coal oil. The operation was successful for a time, but eventually halted (Hanks, H. G. 84, pp. 288-289).

On the Medar ranch at Santa Cruz, the Santa Cruz Petroleum Company erected six retorts in 1864 to convert the asphaltum found there into coal oil and lubricating oil, grease, etc. (Alta Californian 64). Although the refinery itself was not a success, the output of bituminous rock has been fairly consistent since that early date. The same company also drilled a well for oil, but, like all later prospect wells in this neighborhood, it was not successful. (Browne, J. R. 68; Yale, C. G. 94; 00; Walker, D. H. 07; 07a; Boalich, E. S. 11; Bradley, W. W. 15; Symons, H. H. 28).

The Point Arena Petroleum Mining Company, organized in 1864, erected a plant near the Point Arena wharf in Mendocino County to convert bituminous rock to coal oil, but this operation was a failure.* Wells drilled later (1907-1909 and 1918), none of which were successful, all reported penetrating tar sands from which the fluid could not be pumped because of its viscosity (Mining and Scientific Press 64). A deep well drilled in 1929 by the Twin States Oil Company less than ¼-mile south of the Port of Point Arena (Sec. 14, T. 12 N., R. 17 W., M. D.) was abandoned in 1932.

* Data collected in 1910 from the late Porter O'Neal and Thomas O'Neal of Point Arena, California.

J. D. Whitney (65, p. 12), in his report on the geology of California, mentions that a well was bored in 1862 to a depth of 87 ft. on the west side of San Pablo Creek about four miles slightly south of east of the town of San Pablo, Contra Costa County. This 87-foot well is apparently the second to be bored for oil in California. Whitney also mentions the erection of works at this locality for the purpose of distilling the bituminous matter in the out-cropping rocks, and any oil from the well. The work was evidently not profitable, however, for it was discontinued.

Late in December 1864 the Adams Petroleum Company was formed to drill in the SW¼ Sec. 15, T. 1 N., R. 1 E., M. D., Contra Costa County, where they obtained a greenish oil, but in too small amounts to be profitable. All efforts at this place and elsewhere in Contra Costa County have produced no commercial gas or oil; but gas and oil showings have been manifest in several wells (Mining and Scientific Press 64a; 65q).

In 1865 the Bolinas Petroleum Company began operations in Arroyo Hondo on the Bolinas grant in Marin County, being attracted by the asphalt seepages and outcrops about that part of the Point Reyes peninsula. This and a later attempt about 1902 to secure commercial oil production were failures (Hanks, H. G. 84, p. 295; McLaughlin, R. P. 14, p. 473).

In regard to oil seepages in San Mateo County, the Mining and Scientific Press for May 6, 1865, p. 279, states:

"We understand that oil has been discovered on Bell's ranch about fifteen miles below Halfmoon Bay where oil had previously been discovered on Purissima Creek."

A tunnel was run on Purisima Creek and some oil obtained, and a well at Bellvale found a little oil, but not in commercial quantity. Later developments at Purisima Creek resulted in the establishment of a small, high-gravity oil field.

Along Bear Creek, chiefly in T. 15 N., R. 5 W., M. D. in Colusa County, several wells were drilled (1865-1866) near outcropping oil sands or seepages of high grade oil not unlike that of Humboldt County. None of these wells was successful; but wells drilled later, to the east in T. 15 N., R. 4 W., M. D., (McLaughlin, R. P. 14, pp. 441-442) and two wells drilled by the Continental Oil Company (Sec. 31, T. 18 N., R. 4 W., M. D.) north of Sites (1925-1926) afforded information that had a bearing on subsequent developments in the Sacramento Valley at Sutter (Marysville) Buttes.

Dexter Cook was an industrious laborer, who built many of the stone walls about Sutter Buttes in Sutter County, and dug many water wells for the ranchers.* On the south flank of these Buttes in the NW¼ Sec. 36, T. 16 N., R. 1 E., M. D., is a spot where the rocks have been slightly clinkered by the burning of escaping natural gas. This exposure is not unlike the clinkered rocks that frequently accompany coal outcrops in the Rocky Mountains. Cook decided to explore at this place for coal. In February, 1864, he started a shaft, and from the bottom drifted a tunnel. Gas was struck, and becoming ignited, exploded. Cook was more frightened than injured, but during the remainder of his life kept in closer contact with the occupation that he knew (Watts, W. L. 94, p. 9). His findings, however, afforded part of the information from which resulted the commercial gas development at the Buttes.

*Data from James D. Carroll of West Butte, and the late Lewis Stohlman of Sutter, California.

THE DOLDRUMS (1866-1875) AND SUBSEQUENT DEVELOPMENTS

Failing to obtain a large high-grade crude oil supply with which to compete with cheap Pennsylvania oil that was arriving in San Francisco at lower and lower prices, the refiners in San Francisco and those located closer to the southern sources of crude asphalt oils found increasingly greater difficulty in keeping their stills going with California oils. In this relation, J. Ross Browne (68, pp. 261-262) wrote:

"Between 1865 and 1867, Haywood and Coleman, a firm in the oil business in San Francisco, made 40,000 gallons of illuminating oil from springs of petroleum near Santa Barbara, but suspended operations in June 1867 because imported oil was selling for 54¢ to 55¢ per gallon, a price so low as to render the manufacture unprofitable owing to the high prices of cases to contain it, transportation and labor.

"Stanford Brothers have also expended capital and labor in efforts to manufacture oil from California petroleum and have succeeded so far to make oils but not with profit. Up to July 1867, this firm made 100,000 gallons of illuminating oil and nearly an equal quantity of lubricating and have been making about 20,000 gallons of illuminating oil per month since. Their works are still in operation. This firm purchased their crude oils from several localities but obtain their chief supply from tunnels and pits near San Buenaventura."

In November, 1869, Stanford Brothers sold their business and plant to Allyne and White. John W. Allyne was a nephew of the Stanford brothers and had acted as their bookkeeper. This new firm imported its crude oil from Pennsylvania, opened quite a trade in kerosene throughout the State, and later went into the manufacture of tree sprays. In 1882, after the California oil industry had demonstrated that it was no longer an uncertainty, the Standard Oil Company entered the State, bought the business of Allyne and White. This stopped operations at the plant that refined the first oil from the historic Union Mattole well.

After 1866 the oil industry of California was in the doldrums for several years. It remained for the Southern Pacific Railroad to really bring success by solving the transportation problem for the prospective oil district through which it passed between San Francisco and Los Angeles. In 1876 it was completed through Newhall, Los Angeles County (San Francisco City Directory 77, p. 22; 78, p. 20). Prior to that date, oil had been obtained in this neighborhood mostly by means of pits near seepages. In 1875 three shallow wells were drilled in Pico Canyon with spring poles, and actual development with steam machinery was begun in 1877 by men with a wide practical experience in the oil business. Oil was rapidly developed near Newhall, both in Los Angeles and in Ventura counties. The founders of the Pacific Coast Oil Company acquired a small refinery at Newhall in 1876, and built a larger one at Alameda Point in Alameda County after the incorporation of the company, September 10, 1879 (Hanks, H. G., 84, p. 300, *et seq.*). Hardison and Stewart, the two Pennsylvania operators, were also active in Los Angeles and Ventura counties at this time, and had spent $130,000 in prospecting. Their Mission Transfer Company soon became an influential factor in the development of these two southern counties (McLaughlin, R. P. 14, p. 369).

The Pacific Coast Oil Company had as its officers C. N. Felton, President, D. G. Scofield, Auditor, and L. D. Fisk, Secretary. The offices were at 402 Montgomery

Street, San Francisco (Munro-Fraser, J. P. 83, p. 409). This company operated until 1902, when it was absorbed by the Standard Oil Company of California.

In 1878, C. N. Felton, after his successful start in Los Angeles and Ventura counties, moved with P. C. McPherson, a successful Pennsylvania operator, from Newhall to Moody Gulch in Santa Clara County. In one of the wells already drilled in the field, McPherson obtained for a time, 60 bbl. of 46° to 47° B. oil from a depth of 700 ft. This oil was sent to the Newhall refinery as the plant at Alameda Point had not yet been constructed. In addition, the field was on the railroad, thus facilitating such shipments. Ten wells were drilled by the Santa Clara Petroleum Company (1879-1888). These wells were drilled to depths varying between 800 and 1,615 ft., and, as a rule, penetrated several sands. Only five of the wells were really successful; they had initial productions of from 10 to 100 bbl. per day. In 1884 this oil was being shipped to the Pacific Coast Refinery at Alameda Point, but in 1888 it was being sold to the San Jose Gas Works for $3.00 per bbl. The production to 1886 was reported as 80,000 bbl. (Foote, H. S. 88, pp. 164, 165; Hanks, H. G. 84, p. 295). This small field. which is still being developed, has since that time been an intermittent producer.

The Sargent Ranch field (Sec. 36 and vicinity, T. 11 S., R. 3 E., M. D.) on the line of a railroad in Santa Clara County, also received new attention. In 1884 asphaltum from the seepages on Tar Creek was being cleaned and shipped to San Francisco; in 1888 some of this same material was being used in the gas works at Gilroy. Drilling is reported to have been started in 1886. At the time of the writer's last visit to this field (1920), nine wells with an average depth of about 1,200 ft. were being operated by the Watsonville Oil Company with a total output of 55 bbl. per day. (Hanks, H. G. 84, p. 289; Irelan, W. 88c, p. 548; McLaughlin, R. P. 14, p. 470).

In 1884 the field at Tunitas Creek in San Mateo County was visited by the State Mineralogist; by this time several wells had been sunk, and from one of them (O'Brien Ranch) some oil had been pumped (Goodyear, W. A. 88, p. 100). The Purisima Creek region also received attention, and from a limited area a few small wells were brought in at the rate of 10 to 20 bbl. per day; but this production declined rapidly. About 20 wells were drilled here, most of them to depths of 700 or 750 ft. where oil sands occur.* The oil, which is very light, was refined by a Mr. Knapp at Halfmoon Bay prior to 1908; it was afterward shipped out in drums, and by 1915, production had dwindled to one carload per year.** In this region the Shell Oil Company, the Traders Oil Company, and later the Wilshire Oil Company drilled deep wells, but without success.

NATURAL GAS IN NORTHERN CALIFORNIA

After the discovery of natural gas at Stockton (1854-1858) many wells in the region encountered gas in drilling for water. Much of this gas was used for manufacturing and domestic purposes. In 1885 the Standard Gaslight and Fuel Company was formed at Merced with the object of developing natural gas in the San Joaquin Valley. Operations were commenced in the spring of 1886, at Stockton. In the summer of 1886, the California Well Company was organized at Stockton for the same purpose, and began operations immediately. The Crown Mills well, drilled in 1886, developed a gas flow of 18,000 cu. ft. per 24 hours, from a depth of 1,220 ft. Lighting of the plant required 6,000 cu. ft., and the remainder was used for fuel. The city gas supply of Stockton has been almost continuously augmented by natural gas from water wells. The greatest yearly production was 313,392 M. cu. ft. in 1910, valued at $159,-451. The recorded production of gas for San Joaquin County from 1899 to 1916 was valued at $2,284,635. The producing wells varied in depth from 1,000 to 2,000 ft. Gas and water were always produced together. (Symons, H. H. 35, pp. 220-221).

In 1891 gas was discovered in water wells near Sacramento. This was also put to use. Production in 1913 was valued at $33,000, and from 1899 to 1916, at $758,-073. (Symons, H. H. 35, pp. 208-209.)

Two successful gas wells have been developed in Humboldt County. One, drilled at Briceland in Sec. 18, T. 4 S., R. 3 E., H., has been supplying that hamlet with natural gas since May 1894.* The Texas Company now has a 500,000 cu. ft. gas well shut in on Tompkins Hill in Sec. 22, T. 3 N., R. 1 W., H., and at the present time is drilling another in the same section. The Texas Company operation, however, is in the Humboldt Basin, which has no connection with the earlier areas of exploration. Work has also been proceeding on Joel Flat near the site of the old Scott and Parsons well, with results to date about equal to those obtained by Scott and Parsons.

In 1901 the Rochester Oil Company drilled a well to a depth of 1,820 ft. in NE¼ Sec. 24, T. 5 N., R. 1 W., M. D., Solano County, in the vicinity of surface gas blows (Secs. 11 and 14, T. 5 N., R. 1 W., M. D.). The gas yield of 20 M. cu. ft. was used to supply the towns of Suisun and Fairfield, for a number of years. Between 1908 and 1913 the value of the gas produced was $61,311 (Symons, H. H. 35, p. 237; Vander Leck, L. 21, p. 55).

Near Petaluma in Sonoma County, prospecting for gas and oil has been carried on since 1909. Some strong gas blow-outs occurred in drilling wells, but no production was made until Herbert N. Witt and associates. drilling on the Ducker Ranch in Lot 269 of the Petaluma Rancho survey, found oil at 900 ft. with an initial flow of 20 bbl. per day of 19° B. oil.** This oil was sold to the Shell Oil Company for use in drilling deeper wells, which encountered a great thickness of basalt. The wells were then abandoned (Laizure, C. McK. 26b, p. 354). About 5,000 bbl. of oil were reported from this well; 3,000 bbl. were sold to the Shell Oil Company for $1.00 per bbl. and the remainder used in drilling.**

The first northern California high-pressure water-free gas well to be brought in was The Buttes Oilfields, Inc., Sophie Davis No. 1, in Sec. 36, T. 16 N., R. 1 E., M. D., at Sutter (Marysville) Buttes, Sutter County. This well was located ¼ mile southeast of the spot where Dexter Cook encountered gas in his shaft of 1864. Well No. 1 was brought in at 2,727 ft. under a pressure of 1,420 lb. per sq. in., February 9, 1933, and gauged 3,425

*Data from S. A. Guiberson, Jr., who drilled five of the wells on Purisima Creek.

**Personal communication from J. W. Crosby, secretary of the former Ocean Shore Railroad, to Mr. F. W. Bradley, May 15, 1915.

* Communication from Albert Etter of Ettersberg with data from Mrs. J. W. Bowden, who taught school at Briceland when gas was first used.

** Data from Herbert N. Witt, Mining Engineer.

M. cu. ft. initial production. At the present time, well No. 6 is being drilled. The output is being sold to the Pacific Gas and Electric Company to supply domestic and manufacturing needs in nearby areas. A condensate resembling lubricating oil accompanies the gas. Between 13,500 and 20,000 acres are considered tentatively proven. This field was discovered by the application of geological methods (Stalder, W. 32, pp. 361-364).

The Pure Oil Company in November 1934 brought in their well No. 1 (Sec. 7, T. 10 S., R. 14 E., M. D.) in Madera County, and opened up production in the Chowchilla gas field. The well is 8,030 ft. deep and gauged 15,000 M. cu. ft. initial production. The gas contains impurities that reduce its heat value. This field was located with a seismograph (Petroleum World 38a, p. 134).

The Tracy gas field (Secs. 15, 22, 23, T. 2 S., R. 5 E., M. D.) in San Joaquin County was brought in by well No. F. D. L. 2 of the Amerada Petroleum Company August 12, 1935 and gauged 35,000 M. cu. ft. from a depth of 4,063 ft. The gas is sold to the Pacific Gas and Electric Company. The proven area consists of about 350 acres. The Tracy field was discovered with the seismograph (Petroleum World 38a, p. 134).

The McDonald Island gas field was discovered by the Standard Oil Company of California with their McDonald Island Farms well No. 1 (Sec. 25, T. 2 N., R. 4 E., M. D.) at 5,227 ft. June 2, 1936. Initial production was 26,647 M. cu. ft. The proven acreage is 5,000. This field is a seismograph discovery, and is located on McDonald Island, San Joaquin County (Petroleum World 38a, p. 134).

The Rio Vista gas field was brought in June 1936 by Amerada Petroleum Corporation with their Emigh No. 1 well in Sec. 35, T. 4 N., R. 2 E., M. D., Solano County. The initial production was given as 81,250 M. cu. ft. per day. The depth of the well is 4,410 ft. A gasoline condensate accompanies the gas. In 1938, some 5,000 acres were considered proven, but the field has since been extended southeast into Sacramento County, and its limits are not yet known. There are 22 producing wells at present. This is the most productive straight gas field in California. Knowledge of the gas blow-outs that occurred in Secs. 11 and 14, T. 5 N., R. 1 W., M. D., and some scattered rock exposures about this field, suggested its presence, which was more definitely verified by use of the seismograph (Petroleum World 38a, p. 134).

Fairfield Knolls gas field in Yolo County was discovered November 6, 1937, when Standard Oil Company of California brought in well No. 1 (NE¼, Sec. 32, T. 9 N., R. 1 E., M. D.). This well had been drilled to 5,181 ft. and plugged back to 3,700 ft. It is rated as a 3,500 M. cu. ft. gasser for conservative delivery. Prior to drilling in this field, Standard had drilled on a structure in the Dunnigan Hills. Their Peter Cook well No. 1 was drilled to 5,009 ft. and abandoned October 27, 1937, because the gas sands were too tightly cemented to yield commercial gas. Both the Fairfield Knolls and Dunnigan Hill areas are topographically high. Structure was verified by use of the seismograph.

The Potrero Hills gas field of Solano County was brought in by the Richfield Oil Company with their Potrero Hills No. 2 well (Sec. 10, T. 4 N., R. 1 W., M. D.) completed in December, 1938, at a depth of 3,265 ft., with an initial production of 5,000 M. cu. ft. This structure had previously been prospected to a depth of 3,128 ft. by the Honolulu Oil Corporation in 1920. The field was discovered through geology.

Ohio Oil Company Willard well No. 1 (Sec. 18, T. 20 N., R. 2 W., M. D.), in Glenn County, blew in January 7, 1938, out of control, from just below 4,400 ft. The derrick was engulfed and went out of sight. A crater 150 ft. in diameter was formed, and much equipment was lost. The crater spouted gas, mud, and salt water for over two weeks.

To date no prolific oil fields have been discovered in northern California. Along the Ukiah-Tahoe highway in Sec. 31, T. 15 N., R. 4 W., M. D., Colusa County, is an outcropping porous sandstone well impregnated with petroleum. About 1925 a shallow well drilled into it produced a very small amount of oil. Later the Calvada Oil Company drilled three shallow wells down the dip of this steeply tilted sand; they also obtained small amounts of oil. In the Rumsey Hills of Yolo and Colusa counties, this same sand is calculated to underlie the large Nigger Heaven dome at a depth somewhere between 7,500 and 9,000 ft. In August, 1930, George F. Getty, Inc., started a well on this structure (Sec. 22, T. 12 N., R. 3 W., M. D.) which was later taken over and drilled deeper by the Nigger Heaven Dome Oil and Gas Company. It reached a depth of 6,764 ft. before drilling was suspended in 1934. Water, gas, and oil globules now flow from it.

CONCLUSION

While progress in central and northern California has been slow, the rapid strides that have been made in southern California are well known. It is now possible to drill a well to 10,000 ft. in almost the same time that it took the pioneers of 1865-1866 to drill 250 ft. In the San Joaquin Valley many new fields are being found at depths of 10,000 ft. or over. When the oil industry actively returns to the northern areas and seriously attacks the many problems there presented with well-located and scientifically drilled wells to depths now within range of the drill, it is trusted that the work begun by the early pioneers will at last be completed and in addition to present large commercial gas fields, more definite data will be available regarding oil as well.

FIG. 35. From the historic Union Mattole Oil Company well (Sec. 30, T. 1 S., R. 1 W., H.M.) early in June 1865 the first shipment of crude oil was made to San Francisco. Although oil from pits had been refined in California, this was the first *drilled* well in this state to send oil to the refineries in San Francisco and the product sold to the trade. The above photograph taken in May, 1935, indicates that oil can yet be dipped from the hole. *(Photo and caption by Walter Stadler, May, 1935.)*

GEOLOGIC FORMATIONS AND ECONOMIC DEVELOPMENT OF THE OIL AND GAS FIELDS OF CALIFORNIA

Part Two

Geology of California and the Occurrence of Oil and Gas

Editorial note:

PART TWO represents the second of four divisions of Bulletin 118, and is intended, *first,* to outline the broader features of the geology of California and to indicate their significance and relationship to the mineral industry; *second,* to review the stratigraphic and structural history of the State, more especially of the better-known parts of the coastal region; *third,* to present pertinent and well-established conceptions of the complicated stratigraphic correlation of the upper Mesozoic and Cenozoic sedimentary rocks involved in the exploration for oil and gas; and *fourth,* to discuss the processes of oil generation and accumulation. It is hoped that the many accompanying charts and maps, explicitly prepared for frequent reference, together with carefully chosen photographs of characteristic fossils, may materially assist geologists in future exploration not only for new deposits of oil and gas, but for all manner of valuable mineral resources. A better understanding of the extremely complex history and structure of the sedimentary rocks of California is in itself an accomplishment of lasting importance to the whole scientific, engineering, and industrial world. Since Part Two is an assemblage of articles written by individual authors, it should not be expected that all interpretations will be found in perfect harmony. The variety in point of view should lend flavor to the reading of factual details.

The following chapters are included in PART TWO:

Chapter IV

Introduction to the Geology

CONTENTS OF CHAPTER IV

GEOMORPHIC PROVINCES OF CALIFORNIA

By Olaf P. Jenkins *

OUTLINE OF REPORT

SIGNIFICANCE OF THE NATURAL FEATURES

Even before the natural resources of this country were developed, early explorers and settlers established the main avenues of travel and located most of the strategic points where great cities of the future were to be built. They knew the mountains and valleys better than do most of us today. To them a knowledge of the surface relief and, in fact, all physiographic features, was vital.

Since then, physiographic features have continued to be a constant guide to civilization. The supply, location, and accessibility of natural products have, to a large extent, controlled the development of industry.

MAJOR GEOMORPHIC PROVINCES

As we come to know more of the geologic history and structural evolution of the State (Reed and Hollister 36) we begin to realize how closely associated are its physiographic and geologic features. That a definite relationship exists between the major topographic features and the distribution of the rock formations, may readily be seen if the relief model of California is viewed side by side with the geologic map.

Though extremely varied in detail, certain large areas of the State have many features in common. These natural divisions are the physiographic or geologic provinces (Reed, R.D. 33; Hulin, C.D. 33). They have been outlined on Sheet III of the Geologic Map of California (Jenkins, O.P. 38) and also on the accompanying relief map. They have been designated *geomorphic provinces* to indicate that the divisions have been made with due respect to the rock structure and its development throughout geologic history. These provinces, however, are well known and easily recognized. Their principal features, together with the position of the oil and gas deposits within them are outlined in the following paragraphs.

Most of the oil and gas fields are found to be fairly well centralized in an area 230 miles long in a northwest-southeast direction, and 100 miles wide. All of the known oil and gas deposits of the State occur in five of the eleven provinces listed below. They are found (1) at the southern end of the Great Valley (also gas in the central portion); (2) in the southwestern foothills of the Sierra Nevada; (3) at the southern end of the Coast Ranges; (4) at the western end of the Transverse Ranges; and (5) in the Los Angeles Basin, or northwestern end of the Peninsular Ranges.

* Chief Geologist, California State Division of Mines. Manuscript submitted for publication July 22, 1940.

LIST OF PROVINCES

Great Valley of California
Sierra Nevada
Cascade Range
Modoc Plateau
Klamath Mountains
Coast Ranges
Transverse Ranges
Peninsular Ranges (includes Los Angeles Basin)
Colorado Desert
Mojave Desert
Basin-Ranges

Provinces in which oil and gas fields occur are shown in boldface type. Also the Colorado Desert contains a carbon-dioxide gas field.

Great Valley of California

The Great Valley of California is a central alluvial plain about 50 miles wide by 400 miles long, lying between the Coast Ranges and the Sierra Nevada, and containing a basin of interior drainage at its southern end. Locally, the northern part of the plain is called the Sacramento Valley, while the entire southern part is referred to as the San Joaquin Valley. The Sacramento and San Joaquin rivers, which join and enter San Francisco Bay, drain the great alluvial plain, with the exception of its southern extremity, though in time of high floods and with the aid of artificial canals, much of the water of this area may reach the master stream.

The eastern border of the Great Valley joins the westward-sloping Sierra Nevada. The bedrock surface of this mountain range, in part covered by volcanic debris and in part by ancient stream gravels, continues westward beneath the alluvium and underlying Tertiary and Cretaceous sediments of the valley plain.

The entire western border of this central plain is underlain by east-dipping Cretaceous and Cenozoic strata, which form a geosynclinal trough, lying beneath the Great Valley and closely skirting its western side.

In the San Joaquin Valley, many prolific oil and gas fields are located on anticlinal uplifts which arch the immense thickness of sedimentary strata found deeply buried beneath the plain. Along its southern, southwestern, and southeastern borders, extensive oil fields are located in the foothills which flank the surrounding mountains. On the west side of the valley the fields are on the edge of the Coast Ranges, while those on the east side north of Bakersfield, and on the southeast side, are in the foothills of the Sierra Nevada. All these prolific producing areas are usually listed in the one general district of the San Joaquin Valley.

Commercial gas fields have recently been developed in the delta area where the northern end of the San Joaquin Valley merges into the southern end of the Sacramento Valley.

To the north, where the monotonous plain of the Sacramento Valley is interrupted by the Marysville

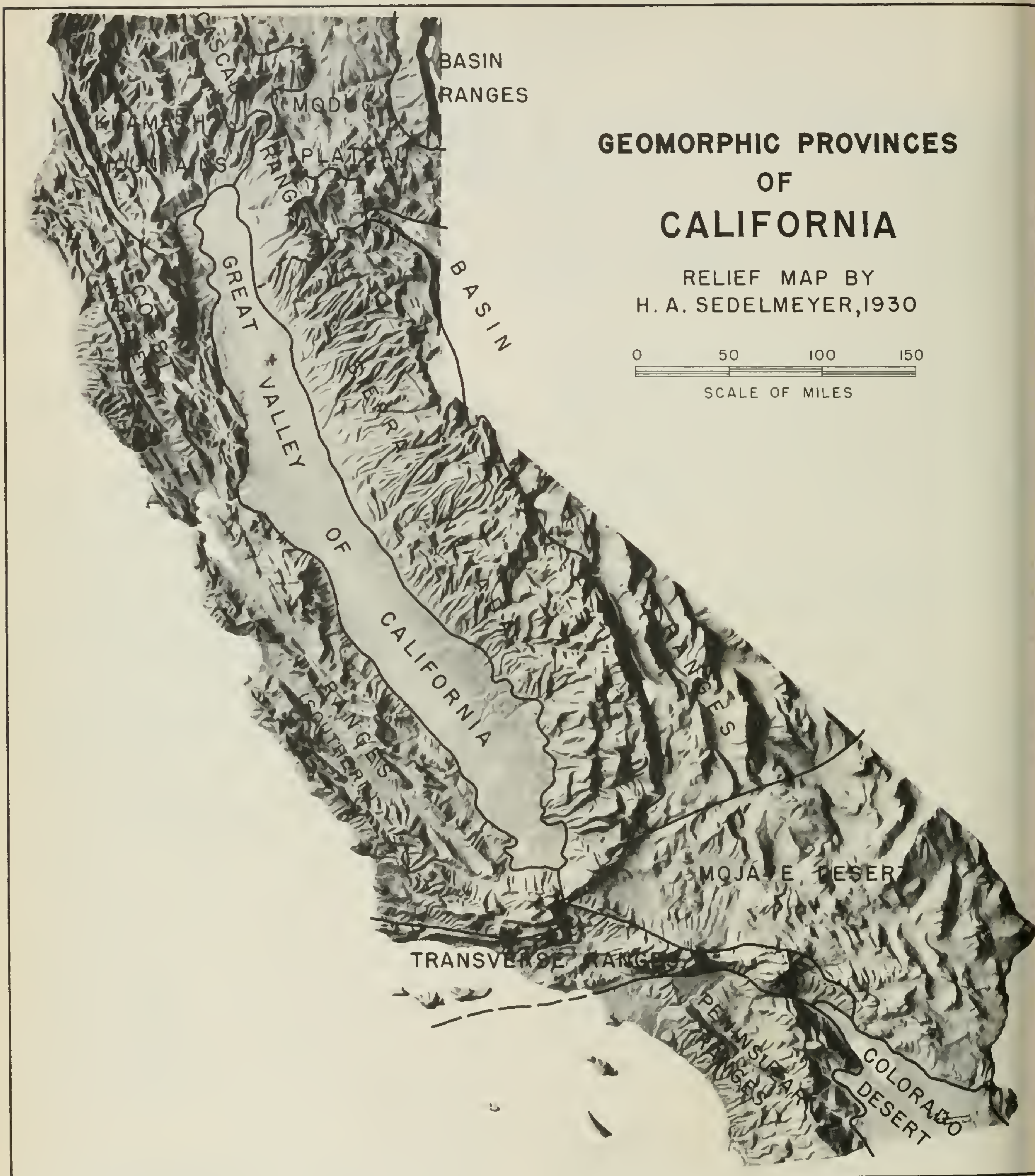

FIG. 36. Relief map of California showing the geomorphic provinces as related to the topography. *Photo of relief map (copyright) by courtesy of H. A. Sedelmeyer, Berkeley, California.*

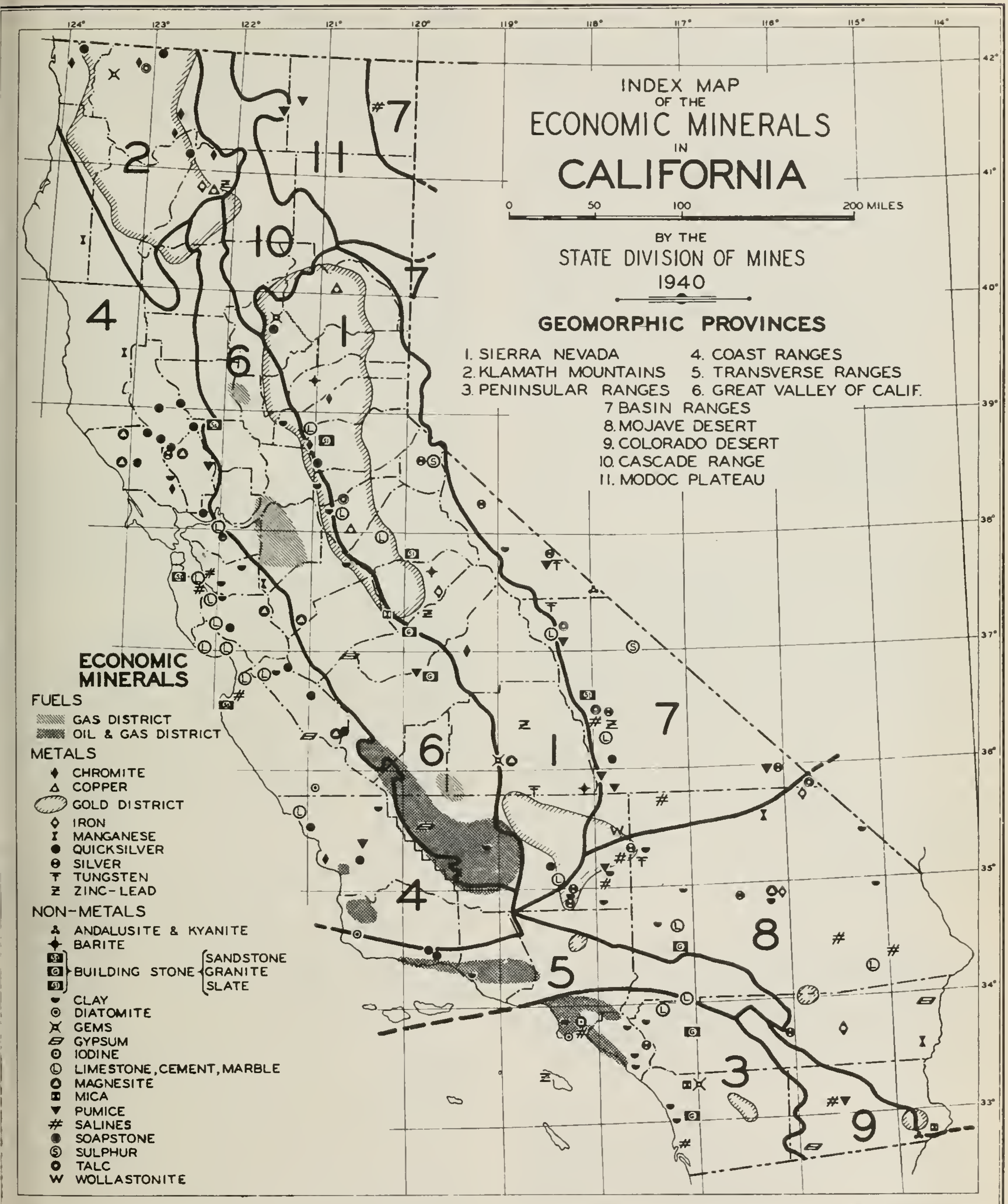

FIG. 37. Outline map of California showing the geomorphic provinces as related to the distribution of commercial mineral deposits.

Buttes, gas has been found in the upturned strata which flank this isolated and dissected dome of eruptive Tertiary rocks.

Along the western border of the Sacramento Valley, only small amounts of oil have been found, and here it is in the rocks of Mesozoic age.

Sierra Nevada

The Sierra Nevada represents the dominant mountain range of California, a singular fault block of great magnitude, nearly 400 miles long, presenting a high multiple-scarp face on its east front, in contrast to the gentle western slope (about 2°), which disappears under the sediments of the Great Valley. Deep river-cut canyons dissect its western slope. Their upper courses, especially in the massive granites of the higher Sierra, have been modified and rounded by glacial sculpturing.

Near the eastern boundary of the province stands the continuously high crest-line of the Sierra, which culminates in Mount Whitney (elevation 14,496 ft., the highest point in the United States). Jagged canyons dissect the eastern scarp zone, formed by a series of great faults and dropped blocks. Along the base of the range, glacial moraines and alluvial fans spread out from the mouths of the canyons and conceal the more recent fault rifts, many of which may be of great magnitude.

The southern Sierra, characterized by massive granites, which have been raised higher and eroded to greater depth than the rocks of the northern end of the range, is terminated by the Garlock fault, which forms the northern border of the Mojave Desert. The southern tip of the Sierra Nevada ends at Tejon Pass, near the junction of the Garlock and San Andreas faults, where three other geomorphic provinces also join—the Coast Ranges, Transverse Ranges, and Mojave Desert.

The north end of the Sierra Nevada terminates abruptly where the older rocks completely disappear beneath the Cenozoic volcanic cover of the Cascade Range and Modoc Plateau. In this part of the province, the older formations, composed of a metamorphic series of sediments and igneous rocks, form a huge northerly plunging anticlinal structure, the arching of which predates the time of granitic intrusion. Gold-bearing veins, for the most part with north-south structural trend, have enriched the metamorphics along the western flank and northern end of the Sierra.

The western foothills of the Sierra Nevada gradually merge into the Great Valley. They are comprised of bed-rock, of Eocene sediments, of mud-flow materials, largely volcanic (Miocene and Pliocene in age), and of old alluvial gravels. To the south, these foothills are underlain by marine Cenozoic sediments and many important oil fields have been developed in them.

Cascade Range

The Cascade Range, which extends through Washington and Oregon, also reaches into the northern central part of California. This province is represented by a chain of volcanic cones, dominated by the magnificent, glacier-mantled Mount Shasta, elevation 14,162 feet above sea level. Lassen Peak, the only active volcano in the United States, terminates the Cascade Range at its southern end. Pit River, after winding across the interior Modoc Plateau *en route* to the Sacramento River, cuts a deep canyon transecting the range in the region between the two major volcanic cones, Shasta and Lassen.

The foothills of the southwestern border of this province merge with the northeastern side of the Sacramento Valley, as in the case of the Sierra Nevada, and are comprised of volcanic mudflow beds, underlain by Eocene and Cretaceous sediments and overlain by old alluvial gravels.

Modoc Plateau

An interior platform (elevation 4,000 to 6,000 ft. above sea level) lies to the east of the Cascade Range, forming the southern extension of the immense volcanic plateau that covers eastern Oregon and southeastern Washington. It consists of a thick accumulation of lava flows and tuff beds and many small volcanic cones. Occasional lakes, marshes, and sluggish streams are found on its surface. Locally the province is known as the Modoc Plateau. It is bounded indefinitely on the east and south by the Basin-Ranges, and includes some of the characteristics of this eastern province as well as some of those of the Cascade Range.

Klamath Mountains

The topography of the Klamath Mountains is rugged and complex. Prominent peaks and ridges rise 6,000 to 8,000 feet above sea level. The drainage is transverse and irregular, having developed on an uplifted plateau. Winding across the entire mountain mass through a deep and rugged canyon is the Klamath River. Successive benches with gold-bearing gravels occur on the sides of this and many of the tributary canyons.

This province is more closely allied to the Sierra Nevada than to the Coast Ranges, and it continues into Oregon. Hard pre-Cretaceous rocks are exposed by deep stream dissection. Later volcanic rocks of the Cascade Range form the eastern boundary of the province, while Cretaceous sediments flank it on the southeast. Franciscan and younger Coast Range formations bound the province on its southwest side, where longitudinal faults and folds control the topographic features.

Coast Ranges

In a general sense the Coast Range system may include the coastal mountains throughout the entire length of California; but in a more restricted sense, the Coast Ranges are terminated on the north by the Klamath Mountains and on the south by the Transverse Ranges. For the sake of convenience, the province may be divided by San Francisco Bay into the Northern and Southern Coast Ranges.

The Coast Ranges are characterized by longitudinal mountain ranges (2,000-4,000, and occasionally 6,000 feet above sea level) and intervening valleys trending N.30°-40°W. Folding and faulting control the trend of the ranges.

The province is terminated on the east where the strata dip beneath the alluvium of the Great Valley, and on the west by the shore of the Pacific Ocean. In many places, the coastal mountains rise sharply from the water's edge, and wave-cut, terraced flanks testify that they have recently been uplifted.

The continuity of the coastal mountain trend is cut off obliquely by the coast line, especially to the north. Many submarine canyons and scarps transect the continental shelf forming a rugged undersea topography. Some of these canyons have characteristics of surface erosion, others of fault scarps. The greatest of the submarine canyons is several thousand feet in depth and extends from Monterey Bay westward. On the other hand, opposite San Francisco Bay and the Golden Gate, through which the drainage of the Great Valley now reaches the sea, there is no submarine canyon, and the continental shelf is the widest to be found along the California coast.

The northern Coast Ranges are dominated by irregular knobby, landslide topography characteristically developed on the Franciscan Jurassic formation. It contains many fault valleys as yet unmapped. The eastern border is characterized by strike ridges and valleys developed in upper Knoxville Jurassic and Cretaceous strata that border the western side of the Sacramento Valley. Volcanic cones and flows are prominent in the Northern Coast Ranges south of Clear Lake.

The Southern Coast Ranges, including also the partially submerged area about San Francisco Bay, are more diversified and complex. The topography is largely controlled by the geologic structure of Cenozoic, Cretaceous, and Franciscan sediments. The recently active San Andreas fault forms a dominating rift which trends slightly oblique to the adjacent ranges and reaches from near Point Arena, in the Northern Coast Ranges, to the Gulf of California, a distance of more than 600 miles. A granitic core occurs in the Coast Ranges, extending from the southern extremity of the province, where it meets the southern tip of the Sierra Nevada, northwestward to Point Reyes Peninsula and the Farallon Islands. It is bordered on the east by the San Andreas fault, and on the west by a complicated system of earlier thrust faults and complex structures, sometimes referred to as the Nacimiento fault zone.

Oil has been found in various places in the Coast Ranges and developed on a large commercial scale in the southern part of the province. Great oil fields follow anticlinal uplifts, which extend southeastward from the foothills of the southern Coast Ranges and disappear under the plains of the San Joaquin Valley; as for example, the Coalinga anticline which continues into the Kettleman Hills and southward to form Lost Hills. Likewise, farther south Belridge and McKittrick-Sunset follow uplifts along the foothills bordering the San Joaquin Valley. Along the coast, the Santa Maria Basin, a major oil district, lies in the southern extremity of the province. Development began in other minor fields of the Coast Ranges many years ago, but production from them has been small: Arroyo Grande, not far from San Luis Obispo; Sargent, south of San Jose; Moody Gulch and Half Moon Bay in the Santa Cruz Mountains; Mattole River Basin, Humboldt County, in the northern end of the province. In the foothills which border the western side of the Sacramento Valley minor amounts of oil and gas have been found in the upper Mesozoic strata.

Transverse Ranges

The Transverse Ranges consist of a complex series of mountain ranges and valleys distinguished by a dominant east-west trend in contrast to the northwest-southeast direction of the Coast and Peninsular Ranges. Subordinate trends, both northwest-southeast and northeast-southwest, are present, and are significant in the formation of important oil field structures. One of the thickest Cenozoic sedimentary sections occurs in the Transverse Ranges. The western limit of the province is found in the island group consisting of San Miguel, Santa Rosa, and Santa Cruz Islands. The eastern extent of the Transverse Ranges is within the Mojave Desert. The province includes the San Bernardino Mountains lying on the east side of the San Andreas fault, which in this region trends N.60°W., a change of 20° in its direction (N.40°W.) found in the Coast Ranges.

A large number of oil fields occur within the Transverse Ranges in the very thick series of Cenozoic sediments deposited in the Ventura Basin. Along the coast, east and west of Santa Barbara and even beneath the water of the ocean are important fields; also in the mountainous region of the Ojai and Santa Clara Valleys are numerous small and scattered fields.

Peninsular Ranges (Including the Los Angeles Basin)

The Peninsular Ranges, separated by long intervening valleys, conditioned by erosion along faults which are active branches of the San Andreas system, trend northwest-southeast. This trend is characteristic of the Coast Ranges, but the geology, excepting that of the Los Angeles Basin, is more like that of the Sierra Nevada. The dominating rocks are granitic, having invaded an older metamorphic series. The province is continuous into Lower California. It is bounded on the east by the Colorado Desert through a series of right-angle jogs due to interruptions of fault traces.

The Los Angeles Basin and the island group consisting of Santa Catalina, Santa Barbara, and the distinctly terraced San Clemente and San Nicolas Islands, are included in this province. The submarine topography in this island region indicates the presence of numerous fault scarps and troughs.

The Los Angeles Basin is one of the most important oil districts in California. It is an area of deep Cenozoic marine deposition and contains a large number of prolific producers within a limited and highly populated area of 25 by 35 miles. Some of the fields extend westward under the sea. A large part of the basin is covered by alluvium, though many good exposures of the oil-bearing sediments may be seen in road cuts.

Colorado Desert

Dominated by the Salton Sea, the Colorado Desert is a low-lying basin in part below sea level (minus 245 ft.). The province is a depressed block between active branches of the alluvium-covered San Andreas fault zone. The southern extension of the Mojave Desert bounds the province on the east. Ancient beach lines and salt deposits of the extinct Lake Cahuilla characterize the topography near the boundaries of this province.

Although no commercial oil or gas fuel deposits have been developed in the Colorado Desert, carbon-dioxide gas (from which dry ice is made) has been produced from wells of this province south of the Salton Sea. They lie directly above a branch of the San Andreas fault. The whole area is a structural trough and contains a basin of sediments surrounded and underlain by igneous and metamorphic rocks.

Mojave Desert

The Mojave Desert, lying in the southeastern part of the State, includes a broad interior region of mountain ranges, separated by expanses of desert plains. Except for the immediate region of the Colorado River, bordering the province on the east, the drainage is inclosed and playas are numerous. The more prominent trend of the faults is northwest-southeast, while the secondary trend is east-west, in apparent alignment with the Transverse Ranges, which seem to intercept the central part of the Mojave Desert and disappear into its alluvium-covered desert expanses.

To the west, the province is wedged in a sharp angle between the Garlock fault (the southern boundary of the Sierra Nevada) and the San Andreas fault (here the eastern boundary of the Transverse Ranges) where it bends eastward from its major Coast Range trend. The Garlock fault separates the Mojave Desert on the north not only from the Sierra Nevada, but from the Inyo Mountains which represent a part of the Basin-Ranges province. The southern and eastern part of the Mojave Desert is often included in the Colorado Desert, but in this report the latter name is applied only to the structural trough about the Salton Sea.

The greater part of the Mojave Desert is covered by alluvium, and extensive buried areas are thus concealed. The known geologic conditions of the province, however, indicate that it is underlain largely by metamorphic and igneous rocks, with intervening areas covered by continental sediments, such as lake beds, mud flows, and alluvium.

Basin-Ranges

Lying wholly within the Great Basin drainage area, and distinctly characteristic of Nevada, the physiographic province known as the Basin-Ranges occurs in California, east of the Sierra Nevada and Modoc Plateau, and north of the Garlock fault. It is a region of interior drainage with lakes and playas. Roughly parallel ranges alternating with basins and troughs are controlled by typical fault block structure; Death Valley (280 feet below sea level) is one of these troughs or *grabens;* another is Owens Valley, lying between the Inyo Mountains and the bold eastern fault scarp of the Sierra Nevada.

Igneous and metamorphic rocks comprise most of the mountains of this area, though intervening valleys are covered with alluvium, lake beds, and other continental sediments.

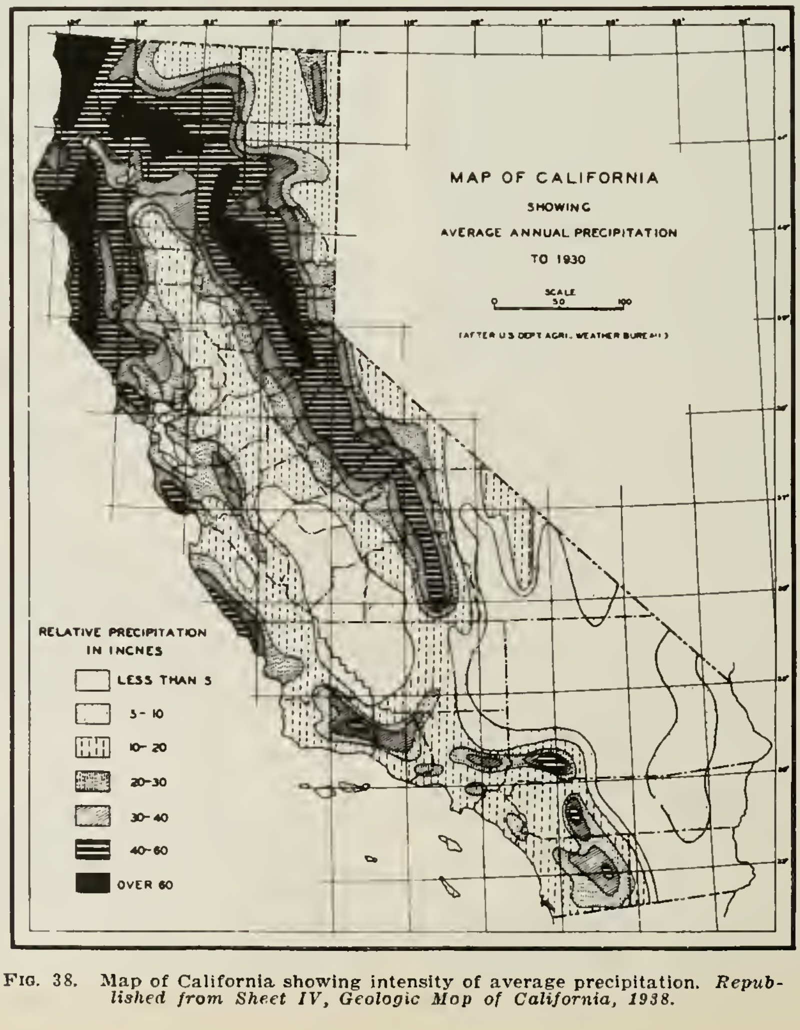

FIG. 38. Map of California showing intensity of average precipitation. *Republished from Sheet IV, Geologic Map of California, 1938.*

SALIENT GEOLOGIC EVENTS IN CALIFORNIA AND THEIR RELATIONSHIP TO MINERAL DEPOSITION

By Olaf P. Jenkins *

OUTLINE OF REPORT

SIGNIFICANCE

The manifold variety of physical features of California is well matched by a most varied and eventful geologic record. This record, well chronicled from the earliest known rocks through every major period in the earth's time scale down to the very active present, places California in an especially favored position for the study of historical geology.

The salient events in this long geologic record appear to be closely connected with the processes responsible for the physical features, and also for the origin and accumulation of the State's mineral deposits. From these deposits, during the past 92 years, 9¼ billion dollars worth of mineral products have been extracted. Nearly 60% of this mineral wealth came from the oil and gas industry alone. Though this industry is the largest and most progressive in the State, it has made its phenomenal growth only during the last 30 years.

Exploration and discovery of the oil and gas fields of the State have largely been in the hands of geologists, who have made an intensive study of the geological formations and history of the rocks most closely associated with oil and gas. These formations are for the most

* Chief Geologist, California State Division of Mines. Manuscript submitted for publication July 22, 1940.

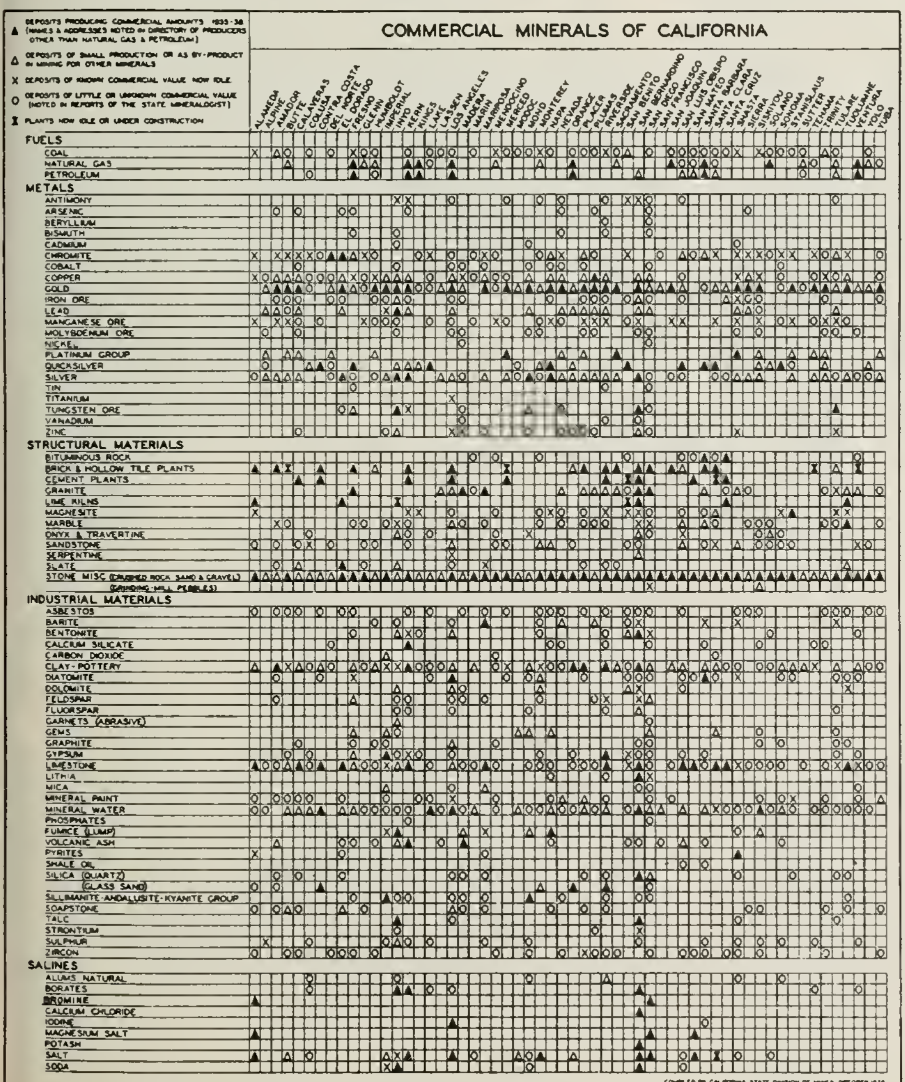

Fig. 39. Chart giving list of commercial minerals produced in California, and showing how each county has contributed to this production. *Prepared by the California State Division of Mines.*

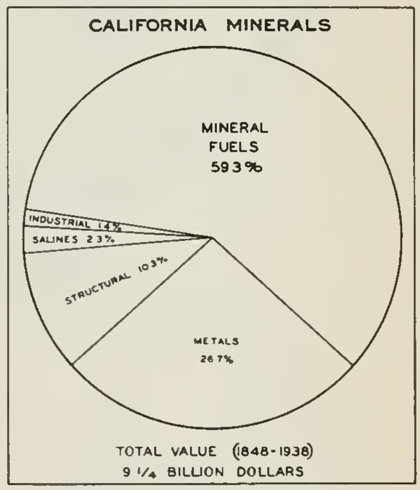

Fig. 40. Graph showing comparative total values on groups of commercial minerals produced in California, 1848-1938.

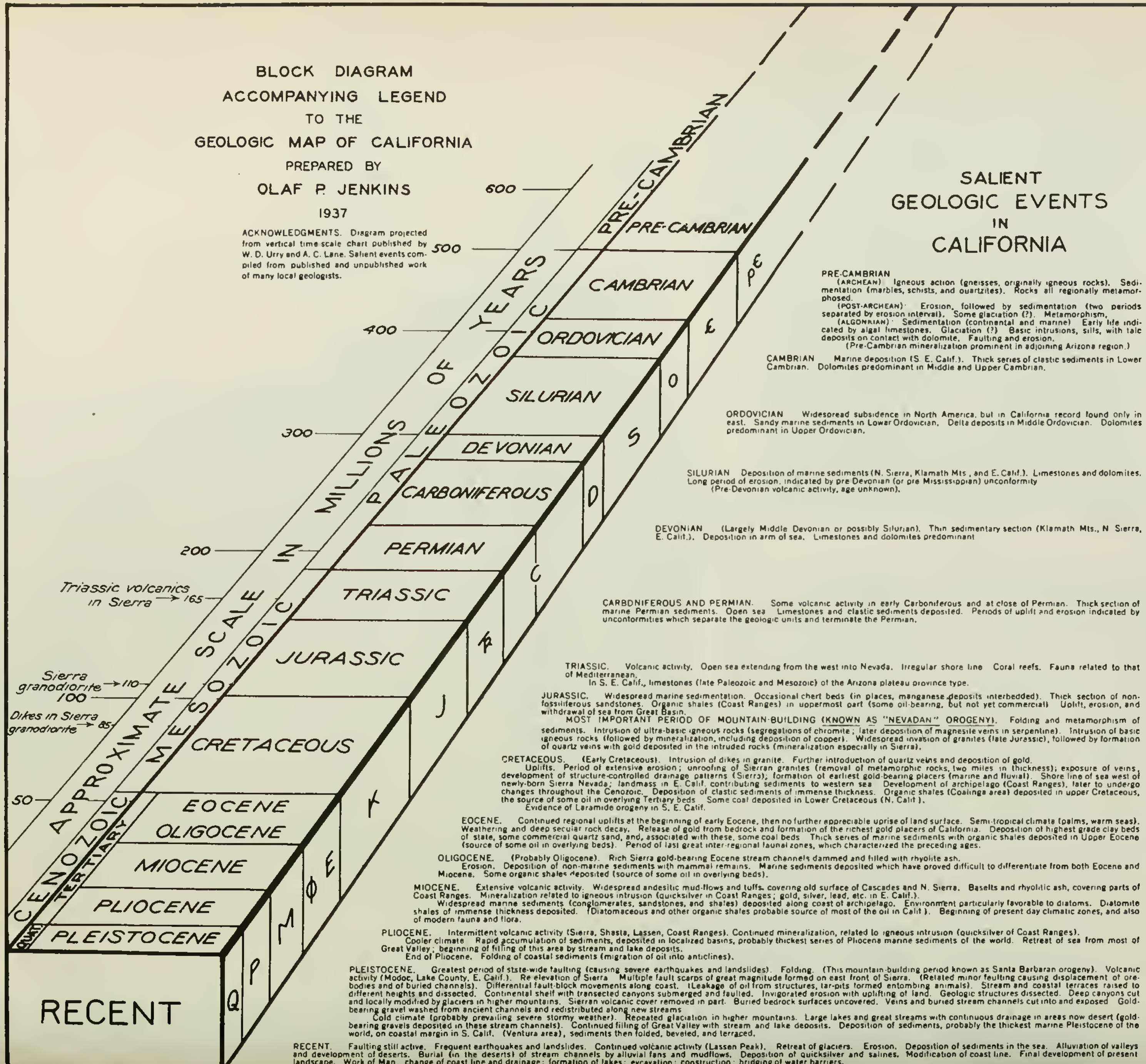

FIG. 41. Diagram to give the idea of "looking back in geologic time." The salient events in the geologic history of California are also briefly outlined.

part the marine sediments of the middle and upper Cenozoic. Recently, however, gas in commercial quantities has been produced from the Cretaceous as well as from lower Tertiary strata, leading geologists to focus more attention on these older beds.

Pre-Cretaceous rocks, though they represent only the "basement" in the oil fields of California are of enormous thickness and wide areal extent. Most of the gold deposits and many of the other commercial minerals are associated with the pre-Cretaceous rocks, especially with those of the Jurassic. Tertiary mineralization, however, is also important; it is associated with igneous activity of that age.

The accompanying diagram, which also appears on the margin of Sheet V of the Geologic Map of California (Jenkins, O. P. 38), was drawn to give an idea of "looking back in geologic time." Some of the most "salient geologic events in California" are listed on this chart. By examining it, together with the State map, one may realize the importance of that limited part of the historic record which concerns particularly the oil and gas industry.

PRE-CAMBRIAN: THE OLDEST ROCKS

To assign rocks definitely to the pre-Cambrian (estimated to be over 500 million years old), it is necessary to have Lower Cambrian beds present and in proper structural relationship to the older formations lying beneath them. This situation is found in the desert mountains of San Bernardino and Inyo counties, where there are two great series of pre-Cambrian rocks—the older a highly metamorphosed group, the younger a series of marine sediments, in part algal limestones with intruded basic igneous sills.

The oldest important mountain-making event in the geologic history of the State may be found recorded by pre-Cambrian igneous intrusions and by the accompanying regional metamorphism. This event seems to have had pre-Cambrian mineralization associated with it.

Ancient schists occurring in other parts of the State may in some cases also be pre-Cambrian in age. These would be the highly and regionally metamorphosed rocks; for local well-formed schists of much younger age are frequently found in the Jurassic, and most of the pre-Jurassic rocks are at least in part metamorphosed.

PALEOZOIC

Practically the entire Paleozoic column is found in Inyo and San Bernardino counties. The lower part of the section, including the Cambrian and Ordovician, is known definitely to occur in this southeastern desert region of California. In the northern Sierra Nevada and Klamath Mountains, rocks known to be of Silurian, Devonian, Carboniferous, and Permian age have been described and mapped; but there has never been discovered any clue as to the geologic period to which the still older rocks of the Klamath region belong. Many of the so-called "pre-Devonian" rocks of the Klamath Mountains may extend down into the pre-Cambrian. The ancient schists, which are quite extensive in this region, appear to be very old; indeed, it is quite likely that many of them represent the pre-Cambrian.

Outstanding events, such as mountain-building, appear to be lacking in the history of the Paleozoic of California; and there seems to be no great period of mineralization for that era. Broad seas stretched across areas now covered by the northern mountains, and the resulting marine deposition spread limestones, shales, and other sediments over very large areas. A change in this monotonous condition may have come in the latter part of the Paleozoic, recorded by some indications of volcanic activity.

One may wonder if the extensive marine sediments of the California Paleozoic might not have once contained oil and gas, as they now do in the middle-western States. If so, such deposits have long been obliterated, undoubtedly as a result of the severe treatment received during the geologic events that followed the Paleozoic era in California.

MESOZOIC

As a time of great events, no part of the geologic record of California is so impressive as the middle of the Mesozoic. Clearly, it was a period of mountain-building and igneous intrusion which affected the older rocks throughout practically the entire State. As a result, the rocks older than this so-called "Nevadan" orogenic period of the Jurassic are of entirely different character and structure than any of the rocks which were formed after this series of harsh episodes.

Volcanic activity, definitely recorded in the Triassic, probably initiated the great orogenic epoch which followed. Widespread seas fringed with coral reefs still existed during the early Mesozoic, as an inheritance from the late Paleozoic.

Thus limestones and dolomites, so prominent in the Paleozoic and Triassic, gave place to the Jurassic detrital sediments, the result of extensive erosion. During this period, the sediments were folded, metamorphosed, and intruded by igneous rocks both basic and granitic. Volcanic action was prominent, for the sediments of the Jurassic contain much intercalated extruded material, such as breccias, pillow basalts, etc. All this activity was so widespread that it extended from one end of the State to the other. With the basic intrusions of the Sierra Nevada and Klamath Mountains, copper was deposited. Gold-bearing quartz veins, as the end products of granitic intrusive action in these same regions, were formed during the latter part of the Jurassic and the early Cretaceous.

In the Coast Ranges, ultra-basic rocks—serpentines and the like—were intruded into the Upper Jurassic sediments. These rocks are found to contain chromite as magmatic segregations, and magnesite as a later leached product of serpentine. Red radiolarian cherts interbedded as lenses within the sandstones and shales, are prominent, and in places contain manganese bodies deposited contemporaneously with the sediments. That some oil was formed within these Jurassic marine sediments of the Coast Ranges, and then largely destroyed is indicated by a few very small seepages in the Franciscan and Knoxville formations of northern California. In places, they are associated with mineral springs and quicksilver deposits, usually in fault zones, fractured during late Cenozoic time. The Franciscan Jurassic formation of the coast, together with its intruded serpentine is so badly fractured and contorted nearly everywhere, that the broken material near its present surface is prone to move readily as landslides.

That an outstanding period of erosion should follow the most important orogenic epoch of the State's history would be expected. A complete change in the distribution of the land and water, so that mountains were left standing where once was a broad expanse of sea, certainly presented a topographic condition which favored widespread erosion of newly formed land, together with deposition of clastic sediments in the sea. The shoreline of this period—the Cretaceous—lay west of the present Sierra Nevada, for the earlier broad inland sea that stretched across the region was wiped out of existence by the rising mountains. Several miles of stratigraphic thickness of conglomerates, sandstones, and shales, deposited in the Cretaceous sea, now give testimony of this period of widespread erosion. The sediments may be found throughout the coastal part of the State from Oregon to the Mexican border.

TERTIARY

Some uplifting in the Coast Ranges continued from the Cretaceous into the early Eocene, but it is hardly regarded as a prominent orogenic period. Evidence of Laramide orogeny, the great mountain-building period of the Cordillera farther east, has been recognized in the southeastern part of the State.

The lowest part of the Eocene, or Paleocene,[1] is so intimately associated with Upper Cretaceous that it is only with difficulty that the two series of rocks may be separated.

Of all the rock series of the Tertiary, those of the Eocene have the widest, most continuous distribution. Together with the Cretaceous, the Eocene extends from the Oregon boundary to Mexico. Certain features of the Eocene show that its environment was singularly different from the periods preceding or antedating it. Fossil and other evidence show it to have had a tropical or semi-tropical climate. This feature, together with the fact that it was a time of no appreciable uplift, gave rise to deep secular decay and advanced weathering, which resulted in: (1) the formation of high-grade clays, both along the base of the western slope of Sierra Nevada and in the northwestern part of the Peninsular Ranges; (2) the formation of low grade coals associated with the clays; (3) the deposition of quartz sands in the foothills bordering the San Joaquin Valley; and (4) the releasing of gold from bed-rock formations, permitting it to be washed into stream channels, some of which became buried beneath volcanic blankets that covered the Sierra Nevada during Miocene and Pliocene time.

Recently discovered prolific oil fields in the marine Eocene sediments, and important commercial gas fields in both the Eocene and its close associate, the Cretaceous in northern California, have added immense potential wealth to the rocks of these periods.

Undoubtedly the ancient archipelago, which characterized the physical aspect of the Coast Range region during the Tertiary, began in the Upper Cretaceous, gradually developed during the Eocene, was highly advanced in the Miocene and Pliocene, then disappeared in the Pleistocene. The remnant of this physiographic condition is now found only in the Channel Islands.

[1] A name now generally adopted.

Deep troughs, more or less land-locked, which lay between the islands and land masses, may have been responsible for the accumulation of organic materials to form the prolific oil and gas fields of southern California.

The diatomaceous and foraminiferal shales so prominent in the formations of the later Tertiary, began to appear prominently in the Upper Cretaceous. All periods of the Tertiary have these organic shale representatives.

Tertiary volcanic activity in the late Eocene and Oligocene caused the first thin layers of rhyolite ash to be distributed as local lake beds over the ancient gold-bearing stream channels of the Sierra Nevada. A much more violent volcanic activity, widespread and prominent throughout the State in the Miocene and Pliocene, continued into the Pleistocene; and, though it has waned considerably, it has not entirely stopped, even today.

Lava flows completely covered to great depth the northeast part of the State. Mudflows, now partly removed by erosion, blanketed the northern Sierra Nevada. Basalts and rhyolites, together with submarine expulsions of volcanic material, characterize many of the Tertiary rocks of the Coast Ranges. The thick diatomaceous accumulations in the Tertiary have been attributed to a siliceous condition of the sea water, caused by the volcanic activity. Mineral deposits of the southeastern part of the State were associated with vulcanism of the Tertiary.

As this volcanic activity waned in the Coast Ranges, mineral and hot springs continued along the fracture planes which extend far down into the hot magmatic portion of the earth's rocks. These deep fracture zones, developed in the late Jurassic through faulting, crushing, and the expansion of basic igneous rocks during their alteration into serpentine, were re-fractured and faulted during the later geologic periods. The fracture zones thus formed have supplied avenues by which mineralizing solutions containing quicksilver were brought near to the surface. California's quicksilver mining districts constitute one of the world's chief sources of this liquid metal.

PLEISTOCENE

Though much folding was going on during the Miocene as well as throughout the entire Cenozoic, these slower movements became more especially active in the Pliocene. The Pleistocene, however, is especially marked as a period of State-wide faulting, not only in the coastal regions, as along the San Andreas and Garlock fault rifts, but in the Basin Ranges. The great displacements along the eastern front of the Sierra Nevada are particularly impressive.

It is not unreasonable to attribute a large part of the migration of oil into anticlines to the folding of the Pliocene. On the other hand, leakage from some of these accumulations along faults certainly took place in the Pleistocene and Recent, as evidenced by many large brea pits.

A period of orogeny is attributed to the Pleistocene, and variously called by such names as "Santa Barbaran" or "Pasadenan." Volcanic activity still continued in some regions as in Modoc and Lake counties. The Sierra Nevada was re-elevated to a great height, and deep canyons were cut in these westward-tilted mountains. Glaciers were prominent in the high mountain valleys. Deep canyons were also cut in the uplifted and emerged continental shelf, which now rests far beneath the ocean's surface. Stream dissection of geologic structures in the Coast Ranges, and the uncovering of volcanic blankets in the Sierras, characterize the work of the Pleistocene. This led to the formation of thick gravel deposits both on land and in the sea. Probably the thickest Pleistocene marine deposits in the world occur in Ventura County, and their tilted and faulted condition shows much activity since that time.

RECENT

The climate of the Pleistocene was cold. Inland lakes of broad extent were a common feature of the landscape. As these lakes disappeared and the mountain glaciers retreated, a more arid climate developed as of today. Volcanic activity quieted down; but occasional earthquakes indicate that faults are still active.

The physiographic features as we see them now are an evolutionary outgrowth of an older varied and eventful history, recorded faithfully for more than half a billion years. But the periods closer to us in time have affected the surface features the most. Thus, as we look back in geologic time, the actual record disappears in the distance as the vanishing point in perspective, while the features which appear the largest and most important to us, are often the result of things that have happened nearest to us in geologic time.

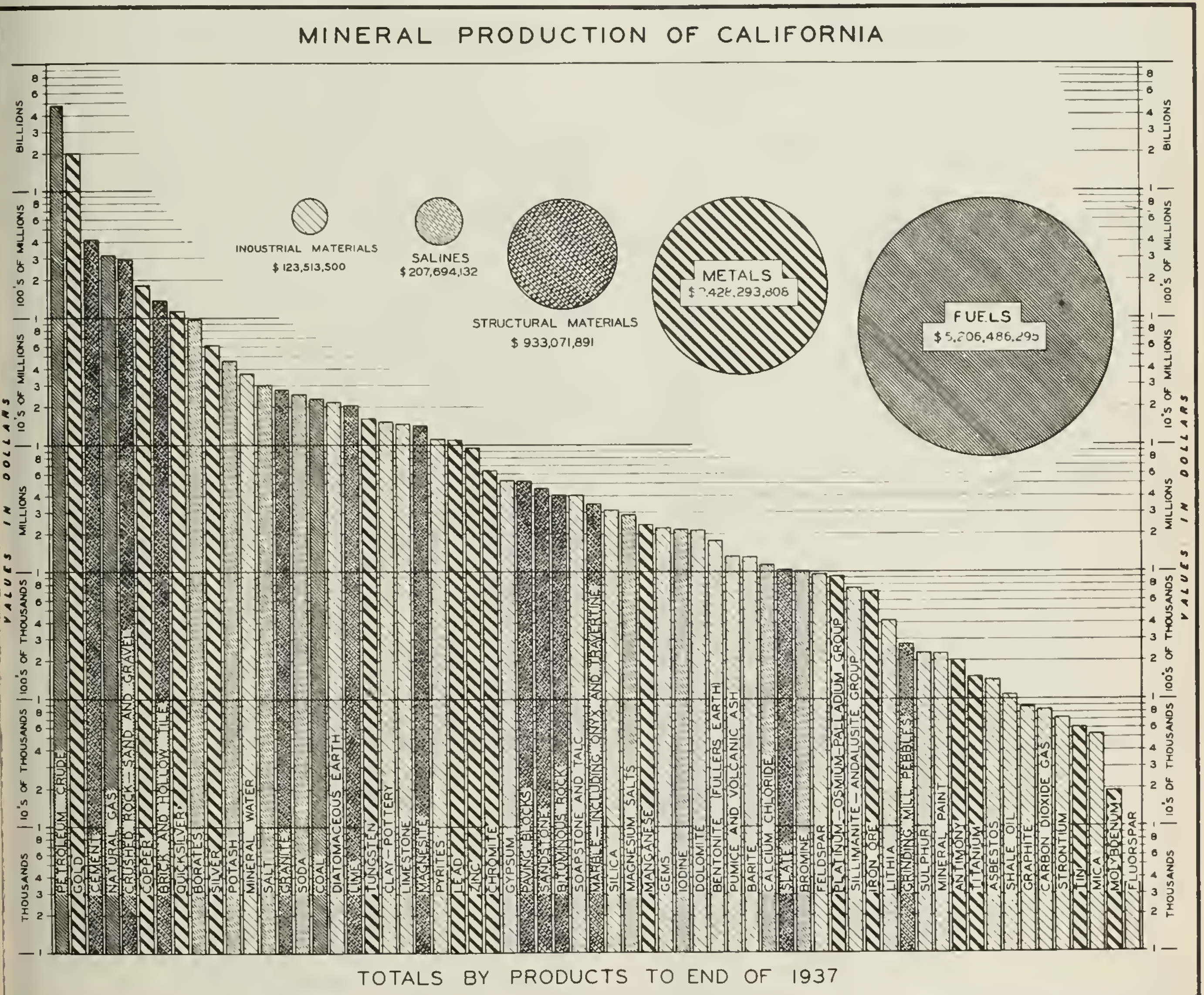

Fig. 42. Chart, drawn on logarithmic scale, to show relative importance of various commercial minerals produced in California. *Reprinted from Economic Mineral Map of California No. 1 Quicksilver.*

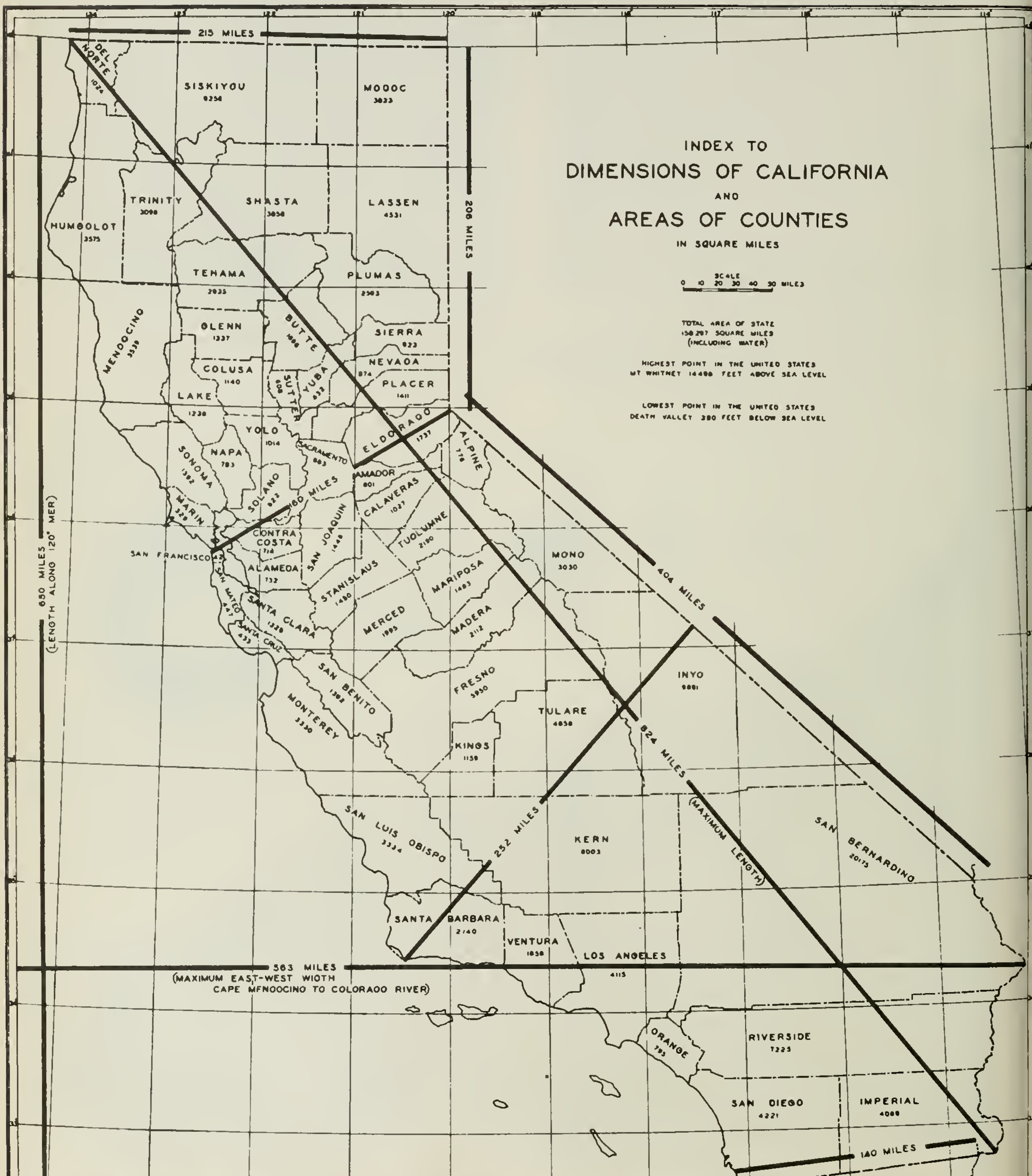

FIG. 43. Map showing size and dimensons of California and its 58 counties. *Republished from Sheet V, Geologic Map of California, 1938.*

POSITION OF THE CALIFORNIA OIL FIELDS AS RELATED TO GEOLOGIC STRUCTURE

By Ralph D. Reed *

OUTLINE OF REPORT

REGIONAL STRUCTURE

Important oil resources are found only in a small part of California; specifically in a part of the coastal mountain-and-valley province. We tend to think of oil as a Coast Range product, but we have to recognize that thus far we have failed to find it in paying quantities anywhere in the Northern Coast Ranges or in approximately half of the Southern Coast Ranges. If we recognize the Transverse Ranges as a region separate from the Coast Ranges proper, we may almost say that oil is a product of the Transverse Ranges and some of the intervening and adjacent valleys, and that much the greater part of the Coast Ranges is entirely barren of producing wells at present.

The oil-producing region has been classified structurally in several different ways, and other classifications are no doubt possible. The Reed and Hollister classification (Reed, R. D. 36, p. 14, ff.) makes use of provinces distinguished by the evolutionary course through which they have passed. Provinces underlain by granitic basement and characterized by a notably discontinuous blanket of Cretaceous and Tertiary strata are given names ending in "ia", and are three in number. They are called Mohavia, Salinia, and Anacapia. Provinces with a Franciscan basement, if they were strongly negative during the later Mesozoic but acted in a dominantly positive manner during the Tertiary, are called "uplifts", and are also three in number: the Diablo, San Rafael, and Catalina uplifts. Provinces underlain at least in large part by Franciscan rocks but strongly negative throughout the Tertiary are called embayments—San Joaquin, Santa Barbara, and Capistrano embayments. The landward end of each of these embayments is a place of particularly rapid subsidence during the Tertiary, and is called a basin. Like the embayments, they are three in number—the Maricopa, Ventura, and Los Angeles basins. One other uplift, the Oakridge uplift, is recognized. It subsided strongly during the Paleogene[1] but was emergent during most of the Neogene.[2] It may be thought of as a Neogene development from a part of the Santa Barbara embayment. There is also a fourth important basin, that of Santa Maria, which, like the Oakridge uplift, developed after the Paleogene. Before that it was a part of the San Rafael uplift.

Figure 45 shows the provinces just defined, and the location of the more important oil fields of California. A study of this map shows some interesting relationships that may be important: (1) Salinia and Anacapia have no oil fields, though the former has many seepages and has been widely recognized as a promising area for prospecting. (2) Mohavia has no oil fields, though the Bakersfield district might be thought of as belonging rather to the western, buried edge of that province than to the San Joaquin embayment. (3) The Diablo uplift has no oil fields. (4) The Catalina uplift has several oil fields near its boundary with the Los Angeles Basin, west of the Newport-Inglewood belt. This producing area, which has furnished the Torrance, Playa del Rey, and several more recent fields, is often considered a part of the Los Angeles Basin but belongs, in its structural aspect, to the Catalina uplift. (5) The San Rafael uplift has the oil fields of the Santa Maria district in the area that became a basin after the Paleogene. (6) The Oakridge uplift has several oil fields, most of them near its boundary with the Ventura Basin, but a few (Simi and Tapo Canyon fields) much farther away. (7) The greater number of the more important fields and many of the less important ones lie in the San Joaquin, Santa Barbara, and Capistrano embayments, and show a distinct tendency to be concentrated in the landward ends, deepest parts or basins, of these embayments.

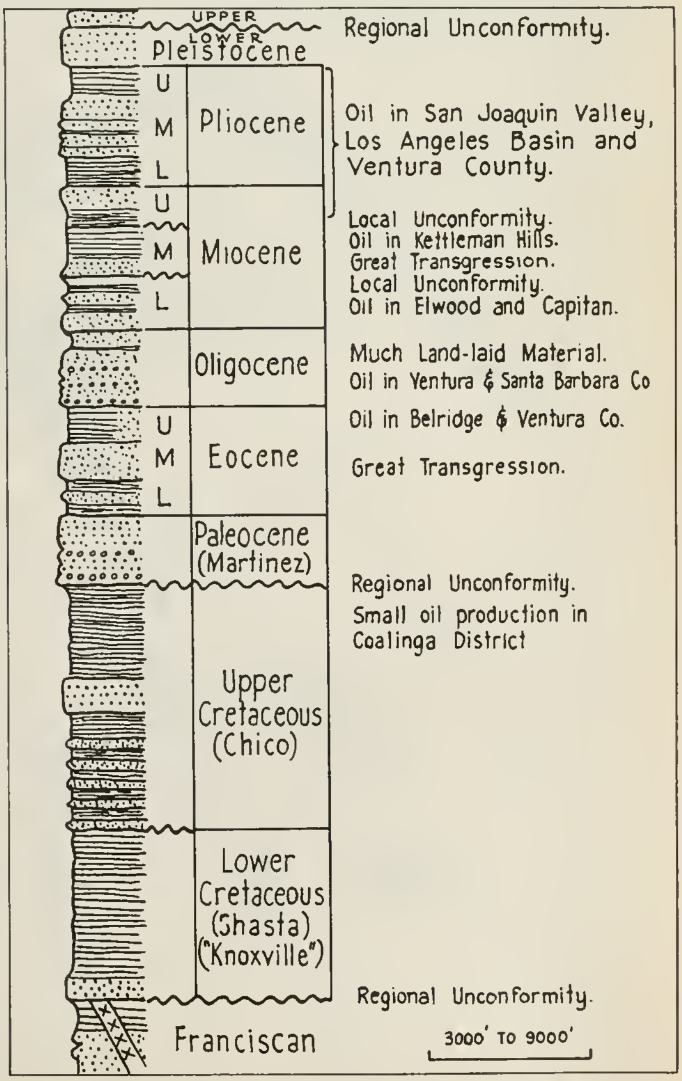

Fig. 44. Generalized stratigraphic column of the Coast Ranges showing positions of major oil zones.

* Chief Geologist, The Texas Company of California. Manuscript submitted for publication May, 1939. Dr. Reed died January 29, 1940.

[1] *See* pp. 117-118.

[2] *See* pp. 112-116.

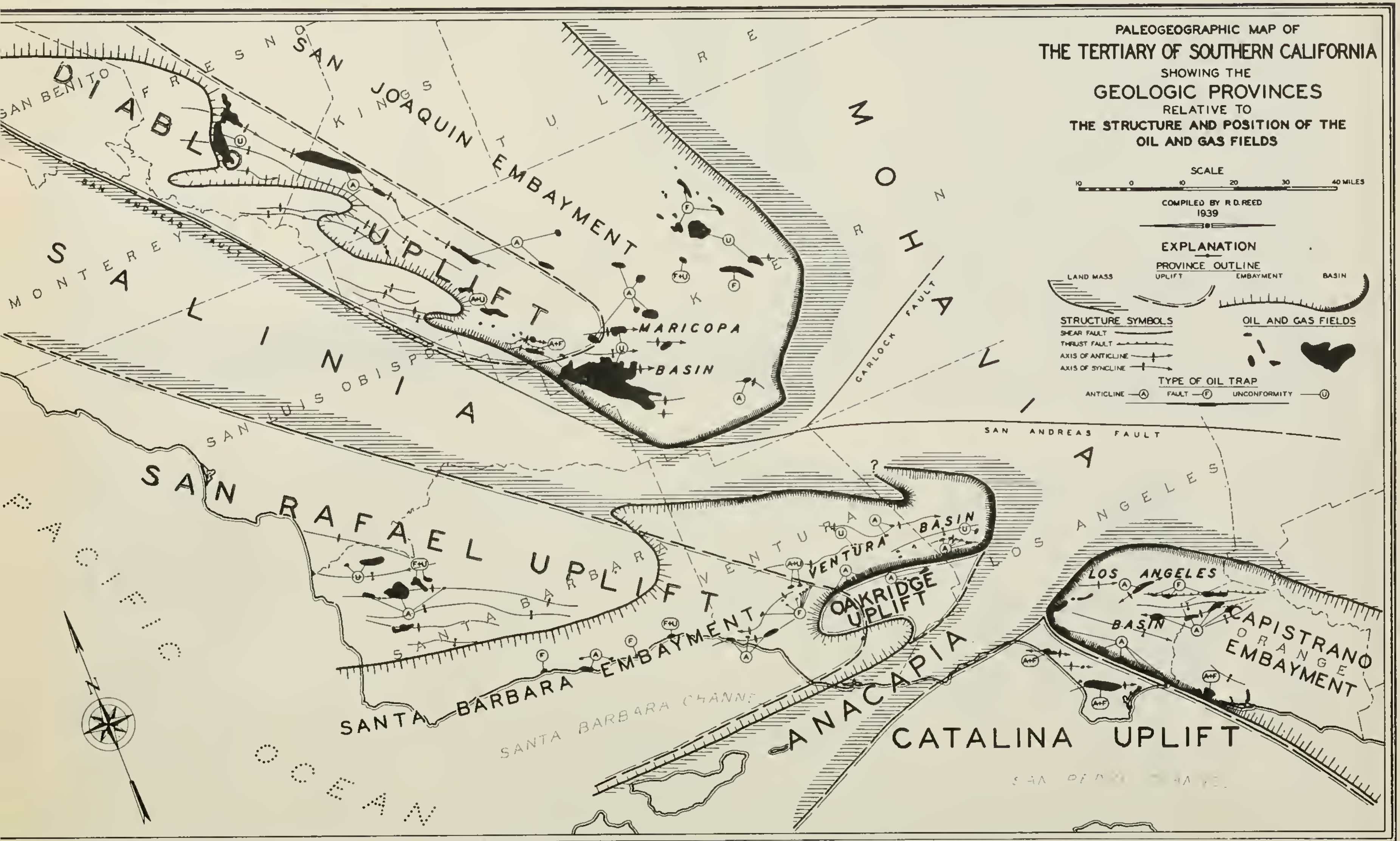

FIG. 45. Map showing positions of the oil and gas fields of southern Califorina in relation to geologic structure and paleogeography. (See also figures 52 to 55, inclusive, of Chapter V.)

It is perhaps worth noting as an interesting coincidence that Tertiary volcanic rocks tend to be concentrated just in those types of province that have the smallest number of important oil fields.

LOCAL STRUCTURE

The local structure of oil accumulations will be perceived more readily by perusal of the pages that follow this introduction than by any amount of general discussion. All that can be attempted here is a classification of the more important types of structural trap that have yielded oil in California and a brief discussion of a few of the more important structural problems that have not yet been satisfactorily solved for some fields.

It will be noticed that a good many of the older fields are classified only provisionally, or not at all. The reason for this procedure is chiefly a lack of data. It should be recalled that records are not available for many of the older wells, and that records showing the data now considered necessary to keep are not available for any of them. For most fields, oil field stratigraphy scarcely existed before 1920. Well logs showed, in general, no markers that could be recognized from well to well, except oil sands. Very little was known even about the sands, and substantially nothing about the shales. Something could be learned under favorable circumstances, but most of the problems about subsurface stratigraphy and structure in which oil geologists are now interested were in the earlier years only matters for surmise.

During the last fifteen years there has been a great change. The introduction of coring, of micropaleontology, and of the Schlumberger logging method have led to a detailed study of many subsurface phenomena about which geologists were formerly very much in the dark. The recognition of thin microfaunal zones or of numerous Schlumberger "markers" permits us to form opinions about the occurrence of oil in the formations, about the presence or absence of faults, and about the details of folding. We are thus better informed about subsurface conditions in the North Dome of Kettleman Hills than we are likely ever to be in the old Coalinga Eastside field. Unconformities in the more recent fields are known, in the older fields they must be largely inferred from very sketchy evidence.

With these facts in mind, we may find it useful to examine the following list, in which oil fields are classified according to what seems to be the dominant type of structural control. Many of the older and less important fields are omitted, as are some recent fields in which development has not yet gone far enough to furnish a very trustworthy basis for an opinion.

TABLE I

TYPES OF OIL ACCUMULATION IN CALIFORNIA, WITH EXAMPLES.

A. Accumulations in normal closed anticlines; faulting minor or not of such type as greatly to effect accumulations; unconformities supposed to be absent or of slight importance.	1. North Dome of Kettleman Hills 2. Middle Dome of Kettleman Hills 3. North Belridge (middle and lower Miocene oil) 4. Ten Sections (faulting possibly influential) 5. Rio Bravo (faulting possibly influential) 6. Wheeler Ridge 7. Elwood (marginal faulting important?) 8. Ventura Avenue 9. Dominguez (Pliocene oil) 10. Santa Fe Springs 11. West Coyote 12. Seal Beach
B. Accumulations in anticlines, with faulting an important secondary control.	1. South Mountain (data not very conclusive) 2. Inglewood 3. Dominguez (Miocene oil) 4. Long Beach 5. Santa Maria or Orcutt 6. McKittrick 7. Huntington Beach 8. Wilmington 9. Richfield
C. Accumulations in anticlines, with overlap or unconformity as essential secondary control.	1. Elk Hills (particularly eastern development) 2. Buena Vista Hills (particularly northwestern area) 3. North Belridge (Pliocene oil) 4. Belridge (Pliocene oil) 5. Playa del Rey
D. Accumulations in sand lens on plunging anticline, possibly without effective unconformity.	1. Coalinga Eastside (Eocene oil)
E. Accumulations due to unconformity, type of fold incidental or secondary.	1. Coalinga Westside 2. Midway-Sunset fields 3. Santa Maria Valley 4. Edison
F. Fault accumulations.	1. Mt. Poso 2. Round Mountain 3. Mountain View 4. Whittier 5. Brea-Olinda

Chapter V

Geologic History and Structure

CONTENTS OF CHAPTER V

CALIFORNIA'S RECORD IN THE GEOLOGIC HISTORY OF THE WORLD

By Ralph D. Reed *

OUTLINE OF REPORT

PRE-CRETACEOUS

General Discussion

Inasmuch as the pre-Cretaceous formations of the Coast Ranges carry no more than traces of oil and gas, they may be grouped together in a discussion of oil deposits and called ''basement.'' Ordinarily this basement is divided into a ''granitic'' and a Franciscan series—structurally important divisions that are fairly easy to distinguish. The pre-Cretaceous stratigraphic units that are commonly used elsewhere are, in fact, recognizable only very locally among the older rocks of the coastal mountains of California; and it is only in eastern California, particularly in the eastern Mojave Desert, that these strata are sufficiently unmetamorphosed to have furnished thick and well-classified sections of the Paleozoic and pre-Paleozoic (Hazzard, J.C. 37, pp. 289-339). The Paleozoic strata are sufficiently fossiliferous to be divided into several formations, referable to the various systems that are found in other parts of the world. All of the Grand Canyon formations of both Paleozoic and pre-Paleozoic are found in eastern California with little change except an increase in thickness; and between some of them are new formations not represented at all in the Grand Canyon section.

Just what happens to these older formations farther west toward the Coast Ranges is not clear. Limestone and schist of possible or probable Paleozoic age occur in many places, as in the San Bernardino, Santa Lucia, Gabilan, and Santa Cruz Mountains, but the absence of identifiable fossils makes their age uncertain. They may all be Carboniferous; they may represent the whole Paleozoic; they may include both Paleozoic and pre-Paleozoic; or they may be entirely pre-Paleozoic. In view of the uncertainty, the casual way in which some writers deal with the question of a Paleozoic ''Cascadia'' to the west of the marine deposits of known Paleozoic age in California and Nevada is likely to rouse either considerable admiration or doubt. If Cascadia existed, where are the clastic deposits that accumulated near its borders?

* Chief Geologist, The Texas Company of California. Manuscript submitted for publication May 1939. Read before the Sixth Pacific Science Congress at Berkeley, California, July-August, 1939. Dr. Reed died January 29, 1940.

The problem of the southward extension of the formations of the Cordilleran geosyncline is not much simpler and is almost equally important. The southernmost section of known Paleozoic rocks is that of the San Bernardino Mountains, discussed by Vaughan (Vaughan, F.E. 22), and also by Woodford and Harriss (Woodford, A.O. 28, p. 270). The fossiliferous formation, designated Furnace limestone by Vaughan, is about 4,500 ft. thick and consists of limestone with schistose and graphitic horizons; it lies upon the Arrastre quartzite, mostly thin-bedded and more than 2,500 ft. thick; and is overlain by the Saragossa quartzite, 3,500 or more feet thick, with pebbly and cross-bedded layers. The few fossils found in the Furnace limestone are considered to be Carboniferous in age; the quartzites are presumably Paleozoic; but the older members might be of any age from Ordovician—perhaps even from Cambrian—to Carboniferous, the younger may be Carboniferous or Permian. Most interest attaches to the quartzites from the exceptional degree of coarseness which they impart to the 10,000-ft. series of Paleozoic strata comprising the San Bernardino Mountain section,

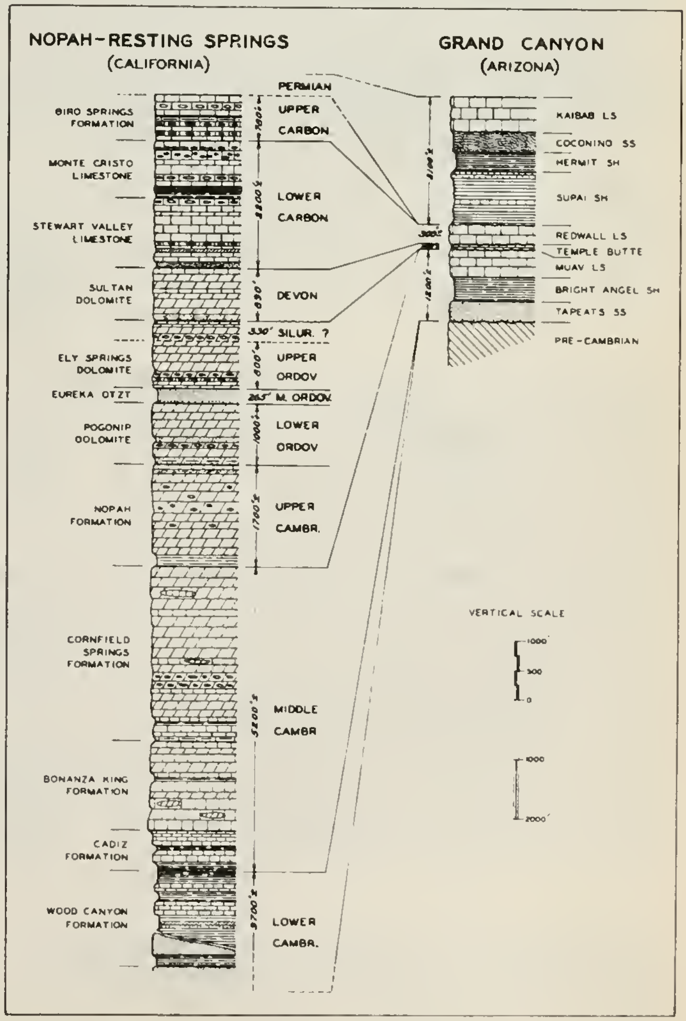

Fig. 46. Comparative columnar sections of the Paleozoic in California and Arizona.

Table 1

PALEOZOIC FORMATIONS OF NOPAH AND RESTING SPRING MOUNTAINS, AFTER J.C. HAZZARD.

Note that fossils are absent below the middle of the Wood Canyon formation. Thus, several thousand feet of strata are referred to Lower Cambrian because they lie above the "marked unconformity" at the base of the Noonday dolomite; an unconformity that looks like a good lower limit to the Paleozoic rocks but is not otherwise closely dated.

CARBONIFEROUS	3,000 ft.	
Upper		Bird Springs formation, 780+ ft., mostly limestone; fossils near top
Lower		Monte Cristo limestone, 987+ ft., massive, crinoidal; fossils 300-350 ft. above base
Possible unconformity		
DEVONIAN (Middle)	900 ft.	Sultan dolomite, 890 ft., fossils
Unconformity		
SILURIAN (or ORDOVICIAN)	335 ft.	Unfossiliferous dolomite
ORDOVICIAN	2,100 ft.	
Upper		Ely Springs (?) dolomite, 800 ft., fossils in lower part
Middle		Eureka quartzite, 265 ft., fine-grained, no fossils
Lower		Pogonip (?) limestone, 1,040 ft., largely dolomitic, fossils near top
CAMBRIAN	16,598 ft.	
Upper		Nopah formation, 1,740 ft., dolomitic limestone with 100-ft. shaly zone at base
Middle		Cornfield Springs formation, 2,975 ft., chiefly limestone, thin fossil-bearing shaly limestone at base Bonanza King formation, 1,515 ft., mostly limestone Cadiz formation, 692 ft., limestone and shale, fossils near top
Lower		Wood Canyon formation, 3,033 ft., quartzite, shale, and limestone, fossils in upper half Stirling quartzite, 2,593 ft., no fossils Johnnie (?) formation, 2,550 ft., shale, etc., no fossils Noonday dolomite, 1,550 ft., no fossils
Marked unconformity		
PRE-CAMBRIAN		Varied rocks of unknown thickness

more than 6,000 ft. of which is quartzite. It is hard to point to any other Paleozoic section of the State that is equally coarse. Is the coarseness due to deposition near an upland which lay, in general, either too far west or too far south to furnish similarly large amounts of clastic material to the Paleozoic formations of the Inyo Mountains, the Death Valley region, or the area near Cadiz?

A further inteiesting fact about the Paleozoic is that no fossiliferous formations of this age have thus far been found in the Transverse Ranges east of the San Bernardino Mountains or anywhere to the south of them in California.[1] The whole area is in need of detailed mapping and much of it even of reconnaissance study; but enough has been examined so that the total absence of Paleozoic fossils begins to be suggestive. It suggests the possibility of a western extension of Mazatzal land which, according to Professor Stoyanow (Stoyanow, A.A. 36), separated the Paleozoic sea of northwestern Arizona from that of southeastern Arizona. Both faunal and lithological considerations, he says, bear out this interpretation. Since Mazatzal land is a direct eastward continuation of the Transverse Ranges province of southern California, the facts suggest that perhaps this area marked the southern terminus of the Cordilleran geosyncline. This possibility is further supported by the fact that the Transverse Ranges mark the southern terminus, so far as now known, of the great belt of eastward-thrust faults which extends from the Canadian Rockies through western Montana and Wyoming, the Wasatch Mountains, the Muddy Mountains and Goodsprings region, at least to the Shadow Mountains of eastern California. If the belt of thrusting, which for many hundreds of miles follows the eastern edge of the geosyncline, terminates north of the Transverse Ranges, it seems likely that the geosynclinal belt either terminates there too, or else that it takes a sharp bend to the west and passes into an area where its presence has never been proved.

Enough has been written, perhaps, to demonstrate again the fact that much more work needs to be done on the Paleozoic rocks of western and southern California. It is also a fact, however, that much additional work is needed on the known Paleozoic sections in eastern California and Nevada. As is well known, the western part of this belt was strongly affected by the Nevadian[2] (Upper Jurassic) period of folding, the eastern part by the Laramide (Upper Cretaceous to Tertiary) period. Nolan has summarized (Nolan, T.B. 28) the evidence tending to show that in later Paleozoic time the Cordilleran geosyncline was divided into two parts by a north-south central area of relatively slow subsidence, and Stille has synthesized (Stille, H. 36) the data that suggest a different age for the folding of these two parts and for the varying igneous histories of the two.

Since Lower Paleozoic rocks are entirely unknown in the Coast Ranges and nearly so in the Sierra Nevada, they will not be further discussed here. The Upper Paleozoic—Devonian, Carboniferous, and Permian—is a little more widespread and may therefore be worth a brief summary.

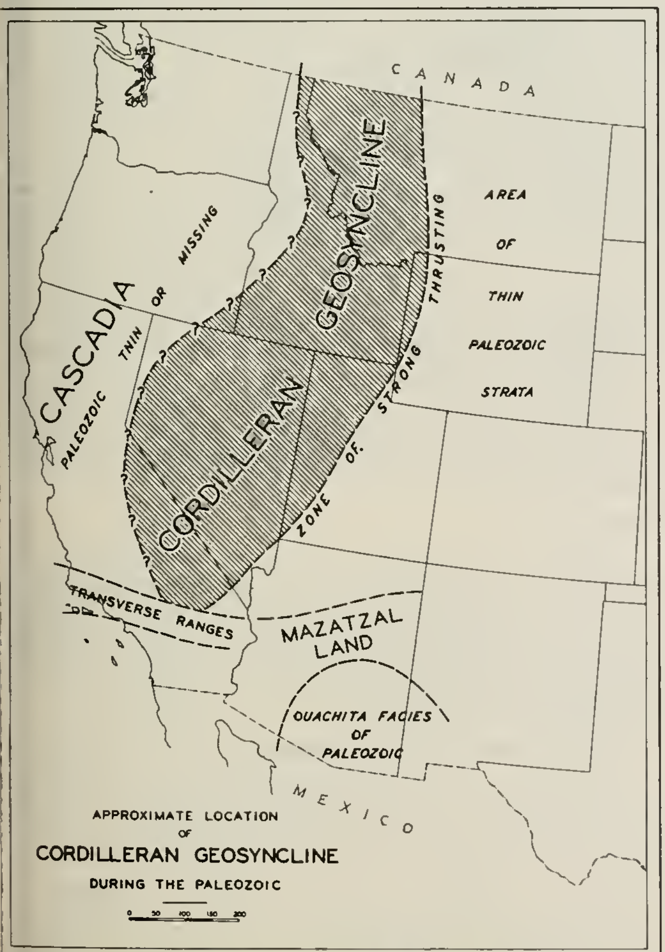

FIG. 47. Map showing some of the possible geographic conditions of the Paleozoic.

Devonian

According to Stauffer (Stauffer, C.R. 30), the Devonian of California is chiefly or perhaps entirely Middle Devonian, with a fauna not very different from that of the widespread Onondaga limestone of eastern North America and even closer to the fauna of the *Calceola* beds (Eifelian) of the Rhenish Slate Mountains.[3] Notable, on the other hand, is the absence from the California Devonian strata of the Old Red sandstone facies of the system, which is widespread in Great Britain and also in eastern New York. The Devonian record in California is thus only a fragment representing the most widespread division of the marine development of the system. In southeastern California the Devonian strata everywhere lie either upon Ordovician or upon unfossiliferous beds that may be Ordovician. In northern California, on the other hand, it lies in some areas upon fossiliferous beds of Silurian age. A mild "Caledonian" disturbance is strongly suggested throughout the Cordilleran region.

Permo-Carboniferous

If we consider all the lands in the world, probably no group of rocks has been the subject of more, or more thorough stratigraphic studies than the post-Devonian

[1] A Mississippian coral has now been found somewhat south of the Transverse Ranges. *See* Webb, R.W. 39. *Note supplied the editor by A. O. Woodford, September 19, 1940.*

[2] Also called "Nevadan."

[3] But see also C. W. Merriam (40). *Note supplied the editor by A. O. Woodford, September 19, 1940.*

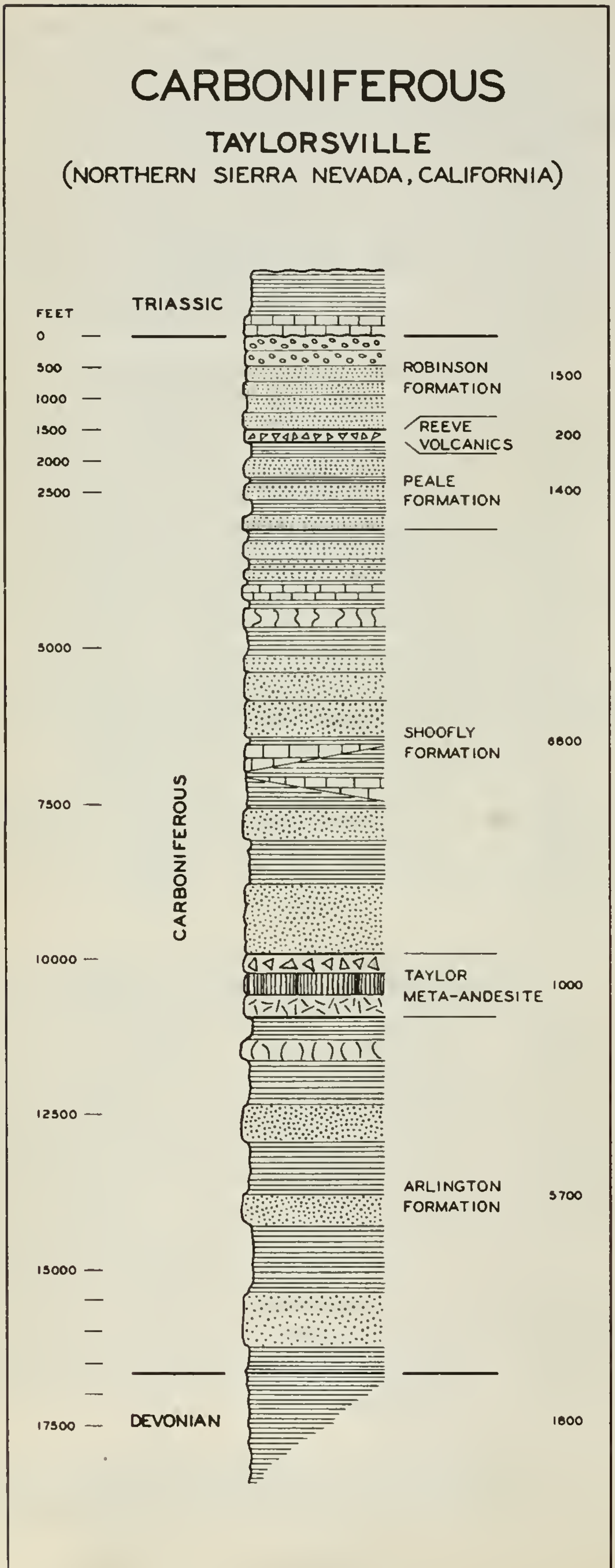

Fig. 48. Columnar section of the Carboniferous in northern California.

Paleozoic. Owing partly to their content of coal, oil, and gas, even their subsurface distribution is well known in many areas such as western Europe and eastern and central United States. It is thus not surprising that complex systems of classification have come into use and that they are undergoing continual modification. When we turn to the post-Devonian Paleozoic rocks of California, we find only a few formation names in use and not very many facts with which to characterize most of the proposed formations. Of the complex and interesting history deduced from the corresponding formations in the eastern United States there are few traces. No coal, no oil, no very definite suggestion of strong folding —nothing but limestone deposition occasionally interrupted by an influx of classic sediments, seems to have taken place during Permo-Carboniferous time in our supposedly mobile Cordilleran province, or at least in the part of it where conditions may be most readily studied.

Longest known of the Carboniferous occurrences of California is the fossiliferous limestone northeast of Redding, which was recognized by John B. Trask (55) in 1855, and has been more intensively investigated since by J. S. Diller (06), J. P. Smith (16a, p. 28), and recently by Harry Wheeler (36). According to Wheeler, the Baird shale, which unconformably underlies the McCloud limestone, is Upper Dinantian, or Mississippian; the McCloud limestone is Uralian (uppermost Carboniferous, or Lower Permian) at base, possibly Artinskian (Lower Permian) in the middle, and of unknown age, because of poor fossils, at the top. It is overlain by the Nosoni tuffs, possibly Kungurian (Middle Permian).

The Carboniferous strata of the Sierra Nevada and of the San Bernardino Mountains are less understood faunally than the Redding section, and the supposed Carboniferous of the Coast Ranges may, of course, turn out to be of some other age. Better sections than any of those mentioned are found in the Inyo Mountains and farther east, but they will not be discussed here. Nothing will be said about the perplexing problems of Permo-Carboniferous paleogeography, and nothing more about the implied history, except to note Knopf's (Knopf, A. 29, p. 9) suggestion of a period of possible diastrophism near the end of the Paleozoic in the Mother Lode district.

Triassic

Rocks of Triassic age are known in the Santa Ana Mountains, at Mineral King in the Sierra Nevada, in Shasta County, and in the Inyo Mountains. Beds of more or less probable Triassic age are very widespread in coastal California and also in the eastern desert region. They include the Santa Monica phyllite and part of the Franciscan series.

Before attempting to summarize the Triassic history of California, it may be interesting to recall what was happening during this time in the rest of the world. Aside from the uplands, which included most of the ancient shields, there were vast lowland areas of continental deposition, such as western Germany, the Colorado Plateau, the eastern Rocky Mountains, and the Newark belt of eastern North America. Open seas were found nearly everywhere on those parts of the present continents where young, high mountains now exist; that is, in the Alps, the Himalayas, the Malay Archipelago, Japan, Alaska, and parts of the Pacific coast of North and South America.

From the syntheses of Stille (Stille, H. 24), Kossmat (Kossmat, F. 36, pp. 132-149, Tafel IV, 1), and others, the geologic history of these mobile belts during Triassic time may be summarized as follows. After a period of moderately strong local folding at the close of the Paleozoic, sandy shales and similar beds of the Scythian stage were deposited in the geosynclines. During the succeeding (Anisic) stage, limestone deposition became more common and extended locally beyond the borders of the geosynclines into areas that remained generally continental, perhaps desert, during the Triassic period. In the next (Ladinic) stage, there was much crustal unrest, with local folding or warping and with much extrusion of lavas and tuffs, which became intercalated with the generally calcareous deposits of the geosynclines. These conditions continued during the Karnic, with widening seas, more cosmopolitan faunas, more limestone. Noric time had the widest seas, with deposition of the purest and thickest limestone. It was followed by strong folding movements (early Cimmerian of Stille), and by deposition of dark marl and clay, the Rhaetic, latest Triassic or earliest Jurassic.

That California shared in this history is suggested by Table 3, based on publications of J. P. Smith (32, p. 13, ff.). So few and small are the remnants of Triassic deposits preserved in the State, however, and so complex and far-reaching the tectonic events since Triassic time, that there is little present prospect of ever knowing definitely the position of Triassic sea boundaries in the California province.

It is nevertheless interesting and instructive to study the most nearly complete sections of the Triassic in California and Nevada, and to compare them with the sections of the Alps. The Lower Triassic shale, sandstone, and impure limestone of the American west are not so different from the Scythic sandy shale of the Alps. The tuffs, shales, and andesitic breccias with interbedded chert of our Middle Triassic recall the varied sedimentary facies and plentiful volcanic rocks of the Alpine Ladinic; while the Noric and Karnic limestones of the two widely separated provinces seem

Table 2

EUROPEAN TRIASSIC STAGES AND FOLDING MOVEMENTS,
FROM KOSSMAT, GIGNOUX, STILLE, KAYSER, AND RENNGARTEN.

All stages above the Anisic are correlated with the Keuper of extra-Alpine regions. The California Triassic is "Alpine", and is classified in the terms of the table; that of the Colorado Plateau and the Rocky Mountains is extra-Alpine and generally nonmarine, like that of western Germany and England. The dividing line between the two facies in southeastern Nevada and California is not far from the Colorado River.

STAGES	TYPICAN FORMATIONS	COMMON FOSSILS
Rhaetic (transitional)	Kössen marl	_Avicula contorta_ and bonebeds
EARLY CIMMERIAN FOLDING (of Stille)		
Noric	Main dolomite and Dachstein limestone	_Turbo solitarius_ and many other fossils
Karnic	Raibl and Hallstatt beds	
"LABINIAN" DIASTROPHISM AND VULCANISM (of Renngarten and Kossmat)		
Ladinic	Ramsau dolomite and Wetterstein limestone	_Daonella lommeli_, etc.
Anisic (Virglorian)=Muschelkalk	Nodular limestone of Reifling, etc.	_Ceratites trinodosus_
Scythic (Werfenian)=Buntsandstein	Werfen shales and gypsum	_Tirolites_, _Pseudomonotis_, etc.
PFALZIAN DISTURBANCE, mild and local		

to have much in common in addition to the fossils. Finally, the Rhaetic period saw the reintroduction of shale deposition in both areas.

In Europe, according to Stille, the period of Triassic sedimentation was ended by the early Cimmerian folding movements, which, perhaps because of the fragmentary record, are not known to have affected the western United States. A very strong orogeny locally affected western Nevada not so long after the close of the Trias, but Ferguson and Muller (Ferguson, H. G. 37) believe that its climax came toward the end of the Lias (Lower Jurassic). If so, it is more nearly equivalent in time to Renngarten's "Donetz" phase (Renngarten, W.P. 29) of the Caucasus than to the early Cimmerian of western Europe.

Jurassic

With the Jurassic, the sedimentary record of California becomes more voluminous, but scarcely more legible, than it is for earlier periods. In the part of the State west of the crest of the Sierra Nevada, much of the pre-Cretaceous basement is more or less confidently assigned to the Jurassic, but the total quantity of dependable evidence is distressingly small.

Thus the Sierra Nevada granite intrudes Kimmeridgian and older rocks and therefore is, at least locally, post-Kimmeridgian. The granite and associated slates are unconformably overlain by flat-lying Upper Cretaceous, which elsewhere overlies Lower Cretaceous and uppermost Jurassic with almost complete conformity. Thus the granite is considered to be pre-Portlandian, or at least pre-Cretaceous, by many geologists, but is classed as early Cretaceous by some.

To consider a second example, the widespread Franciscan series is commonly referred to the Jurassic. The published evidence is very meagre, however, and much of it erroneous. The famous Slate's Springs "Franciscan" fossils are Upper Cretaceous (Nomland, J.O. 32). Most of the Jurassic fossils found in supposed Franciscan rocks are thought by some authorities to have come out of the Knoxville, of which the relations to the Franciscan are still controversial.

In the case of the Mt. Jura section of the northern Sierra Nevada, fossils are relatively plentiful and many faunal zones are represented, but the structure is so complicated that it can only be deciphered by relying upon a paleontologist's interpretation of the faunas.

These examples show with sufficient clearness that the California Jurassic is more like that of the Alps than that of southwestern Germany or eastern England. It has the scarcity of fossils and complexity of lithology and structure that are characteristic of the geosynclinal, rather than of the epicontinental facies. Its paleogeography and geologic history may thus be expected to teem with uncertainties and difficulties, instead of yielding clear and beautiful results as does the Jurassic of Great Britain.

Before discussing the Jurassic problems of California, it may be interesting to recall something of the paleogeographic conditions and geologic events that characterized the period in other parts of the world.

Table 3

TRIASSIC ALPINE STAGES. CALIFORNIA AND WESTERN NEVADA.

Data from J.P. Smith and S. Muller.

RHAETIC		Western Nevada
NORIC	Pseudomonotis zone	Genesee Valley, Brock Mountain, American River Canyon
	Coral zone	Shasta County (Muller considers some occurrences Karnic)
KARNIC	Tropites subbullatus zone Juvavites subzone	Brock Mountain and Genesee Valley
	Trachyceras subzone	Brock Mountain, Genesee Valley, Feather River, and West Humboldt Range, Nevada
	Halobia rugosa zone	Brock Mountain
LADINIC AND ANISIC	Ceratites trinodosus zone	Pit River, California; West Humboldt Range, Nevada
	Parapopanoceras zone	Inyo Mountains
SCYTHIC	Columbites zone	(Idaho)
	Tirolites zone	(Idaho)
	Meekoceras zone	Inyo Mountains

NOTE: The Mineral King Triassic is Upper, and that of Santa Ana Mountains, though tentatively referred to Middle Triassic by J.P. Smith, seems likely to prove Upper Triassic also, thinks S. W. Muller, on the basis of newer collections.

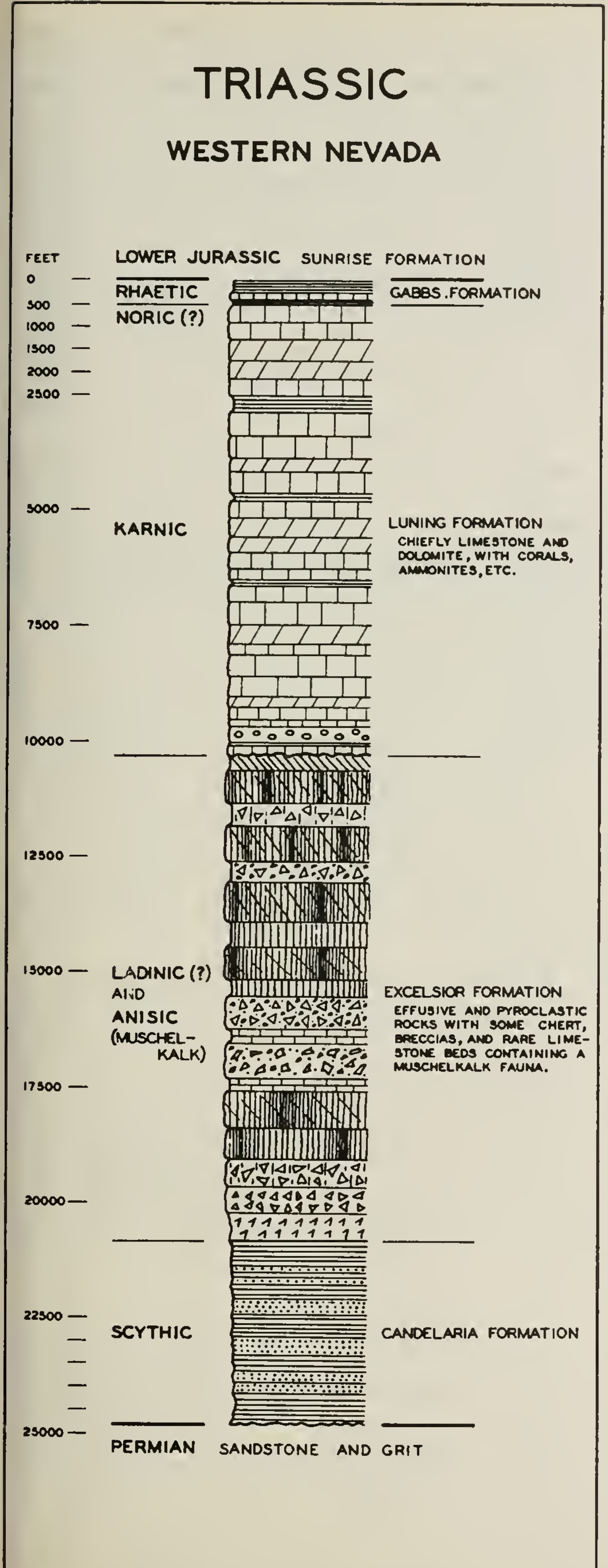

FIG. 49. Columnar sections of the Triassic of California.

As suggested earlier, the Triassic ended with locally strong folding movements, the early Cimmerian of Stille, typically displayed in the Crimea. The Palisades disturbance of eastern North America may have taken place at the same time. Nearly contemporaneous with these disturbances was the peculiar Rhaetic transgression, which flooded marginal lagoons in many desert areas (England, Germany), and led to the making of thin but extensive bone beds. The typical marine fossil is *Avicula contorta.* The stage is generally considered Triassic by German stratigraphers, Jurassic by the French, and is sometimes treated as a separate unit by the British.

The Lower Jurassic (Lias or Black Jura) was an epoch of deep and shallow seas, with shifting borders and uneven bottoms. Epicontinental deposits are chiefly dark shale and limestone; many coarse breccias occur in the geosynclines, such as the Alps and western Nevada. Very strong local folding took place near the close in western Nevada and also in the Caucasus Mountains. It was accompanied by andesitic outbreaks (northern Sierra Nevada), and in some areas (western Europe) by the uplift of certain deeply weathered old mountain masses covered with lateritic soil. Oil shale with beautifully preserved Icthyosaurs and Plesiosaurs is found in Swabia. Excellent Liassic ammonite zones occur in the mobile belts all over the world.

The Middle Jurassic is also called the Dogger or the Brown Jura. Lower Middle Jurassic (Bajocian) is commonly transgressive and carries ferruginous sands and limestones in France and Germany. Upper Middle Jurassic (Bathonian) is regressive, with strong volcanic action in western North America. Strong post-Dogger folding is reported from East Africa and may have occurred in certain other places (Hennig, E. 37).

The Upper Jurassic (Malm or White Jura) begins with the Callovian, a time of widespread seas in all Mesozoic geosynclines and in many adjacent lowlands, such as the Wyoming district, which lay east of the Cordilleran geosynclinal trough. The Callovian was followed, says Crickmay (Crickmay, C.H. 31, pp. 45, 67), by very strong crustal movements, the Agassiz orogeny, in western Canada. After a middle Upper Jurassic transgression came the late Cimmerian disturbances of Europe and the correlative Nevadian fold-

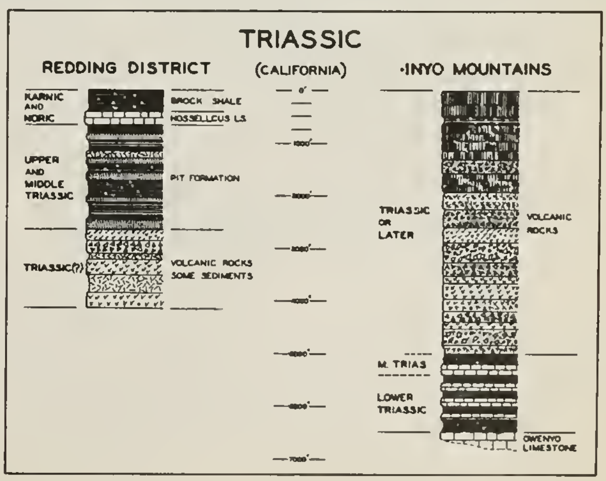

FIG. 50. Columnar section of the Triassic of Nevada.

ing and plutonism of western North America. A later transgression, the Portlandian, lasted into the Lower Cretaceous in many areas, but was interrupted by an epoch of swamps in western Europe, and perhaps by folding in the Franciscan belts of California.

Upper Jurassic time may be thought of as the period of the white limestone with many sponge and coral reefs and with the wonderfully fossiliferous lithographic limestone of Germany, of the upper oölites of England, of the peculiar greenstone-radiolarian chert—ophiolite series of Franciscan-like rocks that stretches from northern Italy to Asia Minor and the Oman region (Kossmat, F. 37; *compare* De Böckh, Lees, and Richardson *in* Gregory, J.W. 29, pp. 133, 134). In California it may be thought of as the time of gold-quartz vein filling in the eastern mountains that were crumpled and thrust together toward the end of the period. Upper Jurassic in age, furthermore, are the famous Morrison beds of the Rocky Mountain region, from which many of North America's most stupendous dinosaurs have been disinterred.

In contrast to most of North America, which has either no record of the Jurassic or a clear record of some small part of it, California has a complete record that is extremely difficult to decipher. In a small area of the northern Sierra Nevada is the Mt. Jura section, which has been hailed by competent authority as "the finest in America." To look at this section, however, is to realize how poor the others must be. It is certainly not much like the fine sections of Swabia, of the Jura, of Lorraine, and of Dorsetshire. It is structurally so complex that a formation placed at its base by one of the two chief authorities is placed by the other authority at its top.[4] Most of the sedimentary rocks are so dense and dark-colored as greatly to resemble igneous rocks. The content of marine fossils in some of the formations looks distinctly out of place. The section is intruded by several bodies of igneous rock and many of the bedded members are more or less clearly pyroclastic.

In addition to the small Jurassic area of the Taylorsville district (Mt. Jura), the Sierra Nevada has vast expanses of the important gold-bearing, granite-intruded Mariposa slate. It has yielded a few fossils that are certainly Upper Jurassic in age, some of them Kimmeridgian. There are some inconclusive reasons for supposing that the folding of the slate and its intrusion by granodiorite magma occurred about the end of Kimmeridgian time, contemporaneously with the late Cimmerian orogeny of the Caucasus and many other regions. Some authorities have—without much evidence—dated the folding a little later, however, either latest Jurassic or early Cretaceous.

The two probably Jurassic formations of the Coast Ranges, the Franciscan and Knoxville, were formerly considered to be Cretaceous. Their relations to one another and to other older and younger formations has long been a matter of doubt and disagreement. The commonly accepted view at present is that the Franciscan is Jurassic but pre-Portlandian, possibly including some pre-Jurassic strata; and that the Knoxville is Portlandian or Tithonian. The pre-Portlandian age of the Franciscan is now disputed by one of its most competent students,[5] however, and the Knoxville is still classed as Lower Cretaceous by the United States Geological Survey (Wilmarth, M.G. 38, pp. 1115-1116).

From a consideration of the most nearly complete Jurassic section of California, that of Mt. Jura, we may deduce the following series of historic events (Crickmay, C.H. 33):

1. Deposition during the Lower Jurassic of dark-gray calcareous sandstone and shale (Lilac formation), followed by that of red, but highly fossiliferous arkose (Hardgrave).

2. With the beginning of Middle Jurassic time—the period of iron-ore deposition in Lorraine and of strong local folding in western Nevada—the Fant andesites were erupted. They were followed in late lower Middle Jurassic by the deposition of fine-grained red marine tuff and blue-gray limestone (Thompson) and then, after an erosion interval, by the accumulation of nearly a thousand feet of generally fine-grained red and green fossiliferous arkose (Mormon). During lowest upper Middle Jurassic came the deposition, probably also in the sea, of the Moonshine conglomerate, shale, and tuff beds. The rest of the Middle Jurassic saw the accumulation of 700 ft. of coarse green agglomerate and red or green tuff, without fossils.

3. At the beginning of the Upper Jurassic came the accumulation of a marine arkose, the Hinchman formation, then of a poorly fossiliferous agglomerate, the North Ridge, and of a light-gray shale, the Foreman. About the middle of this epoch there was renewed vulcanism, recorded in the thick, 900 to 1,900-ft. agglomeratic Cooks Canyon formation, with fossil wood. Micaceous sand and dark clay, with few fossils, were next deposited (Lucky S formation), to be followed by the accumulation of the Trail formation, 2,000 ft. or so of coarse conglomerate and tuff beds, without

[4] *Interpretations of the Mount Jura Section:* The writer has been requested to comment on the various interpretations of the Mount Jura section and since this subject lies outside the scope of the paper prepared by him for this bulletin, it is given here as a footnote.

The original interpretation of Diller, based on many years' work, has been revised, reinterpreted, and greatly modified by Crickmay, but without the presentation of structural or cartographic evidence. Although the writer has not studied the region in detail and is hesitant in expressing a positive opinion he has visited the region a number of times and has collected fossils from a few localities. Since the beds are metamorphosed the preservation of the fossils leaves much to be desired and the writer believes that the very precise age determinations made by Crickmay are not wholly justified by the usual condition of the fossils. Fossils were collected from the north and northeast sides of Mount Jura and submitted to a thoroughly qualified expert on the Mesozoic faunas but, because of the distortion due to crushing, he did not feel justified in assigning them to a definite position in the Jurassic.

The writer can see no justification for the Combe formation of Crickmay and its assignment to the Tithonian. A number of days were spent collecting fossils from the area in which this formation is supposed to occur and in the surrounding region but the lithology is not as described. The Combe formation is a part of Diller's Foreman formation and the fauna appears to be even earlier than the Mariposa. There is no evidence for and much evidence against, both structurally and faunally, the statement that the Mount Jura section contains beds younger than the Kimmeridgian.

The Trail formation was placed at the base of the Jurassic section by Diller and near the top by Crickmay although it is largely volcanic and contains no fossils. There is no evidence, either faunal or structural, for removing the Trail formation from its position at the base of the local Jurassic section. Evidence for its position at the base is the fact that, in the less disturbed eastern part of the region, it everywhere overlies the Triassic Hosselkus limestone; on the western side, near the town of Taylorsville, lower Paleozoic is thrust eastward over the Jurassic, overturning it and concealing the lower part of the section beneath the thrust. The Lilac formation may be the lowest division exposed on the west but there is no evidence that it forms the base of the Jurassic section and is older than the Trail. The writer is of the opinion that Diller correctly interpreted the general features of both the structure and stratigraphy. *Note supplied the editor by N. L. Taliaferro, September 12, 1940.*

[5] N. L. Taliaferro, oral communication.

fossils. The latest Jurassic or Tithonian saw the accumulation of the fossiliferous Combe formation, a sandstone containing granitic cobbles considered by Crickmay (33, p. 902) to be mid-Upper Jurassic in age. If the age of these cobbles is correctly determined, the Nevadian crustal disturbance, with its intense folding, metamorphism, and mineralization of the Mariposa slates and other formations, had receded so far into the past before the close of the Jurassic as to permit the plutonic rocks of that disturbance to be stripped of their cover and to have become subject to erosion.

This Nevadian disturbance, post-Kimmeridgian and perhaps pre-Portlandian in age, is generally believed to have affected the Franciscan rocks of the Coast Ranges, though positive evidence is lacking. If the Franciscan turns out to be entirely Portlandian, as Tallaferro suggests, and if the disturbance turns out to be entirely pre-Portlandian, the belief will of course have to be given up.

The Knoxville series was long considered to be Lower Cretaceous and to be included in the Shasta series. In recent years, however, the Knoxville has been commonly referred to the Upper Jurassic by stratigraphers, but not always separated from the Lower Cretaceous by those engaged in field mapping. According to F. M. Anderson (33), the Knoxville con-

Table 4

THE JURASSIC SYSTEM Data from Gignoux, Stille, and others.		
UPPER JURASSIC or MALM (White Jura)	Purbeckian (Aquilonian) Portlandian (includes Solenhofen beds)	Tithonian of Alps, Lower-Volga stage of Russia, etc.
	LATE CIMMERIAN FOLDING (of Stille)	
	Kimmeridgian	Black marls in Dorsetshire, etc.
	Lusitanian	Includes older Corallian
	Oxfordian	Black marls of Oxford (strong transgression in Mexico)
	AGASSIZ OROGENY (of Crickmay)	
	Callovian	Formerly classed as uppermost Middle Jurassic
	← STRONG TRANSGRESSION (Russia, etc.)	
MIDDLE JURASSIC or DOGGER (Brown Jura)	Bathonian Bajocian	Much of the iron ore of western Europe occurs in the Middle Jurassic
LOWER JURASSIC or LIAS (Black Jura)	Aalenian Toarcian Charmouthian Sinemurian Hettangian	Much dark-colored shale, including oil-shale deposits and highly fossiliferous beds, in these stages
	Rhaetic	(Included by Gignoux in Lias)
	EARLY CIMMERIAN FOLDING (of Stille)	

tains a fauna dominantly of Aucellas, belonging to several Upper Jurassic horizons from Portlandian to Purbeckian (Aquilonian).[6]

CRETACEOUS

Lower Cretaceous

The Lower Cretaceous, except for an historical accident, might have been called uppermost Jurassic. In the part of northwestern Europe where our stratigraphic system was originally set up, the strata referred to Lower Cretaceous consist of a varied series of marine and nonmarine clays and greensands lying between the Jurassic Oölites and the Cretaceous Chalk. Since most of the marine fossils are in the upper part of the series, they naturally resemble Chalk species more nearly than Oölite species. Thus, the whole series, except the basal beds at Purbeck, has come to be considered Cretaceous. There are, however, as Kossmat (Kossmat, F. 36, p. 172) observes, many reasons for thinking of the Lower Cretaceous as merely a final division of the Jurassic, though it is hardly worth while to undertake to change long-established usage.

With this condition in mind, it is not surprising to learn that in many places over the world, particularly in the geosynclines, Upper Jurassic grades into Lower Cretaceous so imperceptibly that only an arbitrary line can be drawn between them. Marine Lower Cretaceous was deposited, in general, in all the continents of the world where Mesozoic geosynclines existed, and the deposits are now found chiefly in young mountain ranges of folded Tertiary type. In the United States it has become customary to refer these deposits to the Comanchean series, thus correlating them with the older part of the Texas Cretaceous. The recognition of the Comanchean of Texas was undoubtedly an important accomplishment, but since the Comanchean series includes only the upper part of the Lower Cretaceous, there is not much probability that the term will ever attain world-wide usage. Though recognized many years ago, the Lower Cretaceous of California has been a stumbling-block to stratigraphers. At present the views of F. M. Anderson (38a) are beginning to prevail, and the publication of his recent memoir should accelerate the process. In much of the Coast Range area south of San Francisco, however, the Lower Cretaceous and Knoxville strata have not yet been discriminated carefully and will need a vast amount of additional study before their relations are well understood.

As Table 5 illustrates, Dr. Anderson finds that the Lower Cretaceous strata (Shasta series) are divisible into two groups; an older or Paskenta group, and a younger Horsetown group. The Paskenta group corresponds to the Infra-Valanginian and Valanginian stages in the European sequence; its fauna consists largely of Aucellas, and in part of cephalopods, and its lithology is dominantly shaly with some sands and locally with basal conglomerates. In the mountains west of Coalinga, the Paskenta group contains a fossilif-

[6] Following Oppel, many writers adopt the term "Tithonian" for these uppermost Jurassic stages, or sometimes for the uppermost only. This term should, however, probably be restricted to the ammonite-rich deposits of Alpine type. The reason for using "Aquilonian" for the older "Purbeckian" is apparently that the type Purbeck beds are largely nonmarine.

Table 5

LOWER CRETACEOUS OF CALIFORNIA (Shasta series),

Its major subdivisions, and their relation to the European standard, adapted from F.M. Anderson (1938).

UPPER CRETACEOUS	Chico series	Danian to Upper Albian		
	Unconformity			
LOWER CRETACEOUS	Shasta series	Albian	Hulen beds	Concretionary sandy shale, good cephalopod fauna in Cottonwood district, northern California
		Aptian Barremian Hauterivian	Horsetown group	Upper members mostly shale, locally good cephalopod faunas Lower member (Ono zone) shale, sandstone, conglomerate, with rich cephalopod fauna
		Valanginian Infra-Valanginian	Paskenta group	Sandy shale, locally conglomeratic at base, faunas largely of Aucellas, with local cephalopods
UPPER JURASSIC			Knoxville	

erous basal conglomerate and unconformably overlies Knoxville strata. The Horsetown group was recognized very early in northern California and was long supposed to be absent south of the Mt. Diablo district. It has recently been found much farther south, and will probably be found at least as far south as the north edge of the Transverse Ranges. The Horsetown group is shaly or sandy, locally with a coarse basal member, the Ono zone, which carries a rich cephalopod fauna of Hauterivian age. The upper members of the Horsetown range upward in age to upper Middle Aptian; they are largely shales and carry good local faunas of cephalopods. They are overlain by the Hulen beds, sandy and concretionary, fossiliferous, and Albian in age. Unconformably above the Hulen beds comes the Chico series, Upper Cretaceous shale and sandstone.

Upper Cretaceous

Rocks of undoubted Upper Cretaceous age are very widespread in the California Coast Ranges. In some places, however, the lower boundary is uncertain, and in many places there is at least a little doubt as to the exact location of the upper boundary. Much of the uncertainty is due to inadequate study of the fossils, or to local poverty of fossils. Even where good fossils exist and have been carefully collected and studied, the correlation with the Danian-Montian horizons of Europe offers some difficulties.

During the last few years there has been a marked increase of interest in the California Cretaceous as a possible bearer of oil and gas deposits. The strata are therefore being actively mapped and studied at present, and will probably soon be better understood. In the hope of aiding this increase of knowledge, F. M. Anderson has recently compiled [7] a stratigraphic chart, based on fossils collected during many years. Within the beds commonly classed as Chico in years gone by, he now recognizes faunas ranging in age from Upper Albian to Danian, with a stratigraphic and faunal break about at the base of the Senonian. His results suggest that the Upper Cretaceous history of the Coast Ranges, when it is worked out, will have many analogies with that of the Tethyan districts of the Old World, with a "Cenomanian" transgression, a "Subhercynian" disturbance, and an Upper Senonian or Maestrichtian epoch of non-clastic deposition. The work of Popenoe [8] shows, furthermore, that at least one phase of the "Laramide" disturbance at the end of the Mesozoic took place between uppermost Chico and Martinez time, as those terms are used in southern California.

Marine deposits of the Upper Cretaceous underlie much of California west of the Sierra Nevada and the

[7] Anderson, F. M. Chart and talk presented before Cordilleran Section of Geological Society of America, April 1, 1938.

[8] Popenoe, W. P. Oral communication concerning an area on the west slope of the Santa Ana Mountains.

Table 6

UPPER CRETACEOUS (Chico series) OF CALIFORNIA, PROPOSED CLASSIFICATION AFTER F.M.ANDERSON.

Thickness Given Under Heading "feet" Are Dr. Anderson's Estimates For The Divisions Found In The San Joaquin Valley.

EUROPEAN STAGES	FORMATIONS	FEET	FOSSILS
Danian-Maestrichtian	Orestimba group Volta, Garzas, Quinto, and Moreno	5,000 ±	Baculites occidentalis, Phylloceras, many diatoms and foraminifera
	Panoche group Los Gatos fm.	2,400	Parapachydiscus catarinae, Desmoceras, Hauericeras, etc.
Campanian	Joaquin fm.	3,700	Inoceramus sakhalinensis, Phylloceras gargantuum, etc.
Santonian	Butte fm.	4,000	Mortoniceras templetoni, Paleatractus crassus, etc.
Coniacian	Yolo fm.	4,500	Placenticeras pacificum, Baculites inornatus, Thyasira cretacea, etc.
Conglomerates and reworked fossils in many sections			
Turonian	Pioneer group Bellavista fm.	3,325	Prionotropis bakeri, Oregoniceras oregonense, etc.
Cenomanian	Gains fm.	3,975	Turrilites oregonensis, Acanthoceras cf. cumingtoni, Puzosia jimboi (nov.)
Uppermost Albian			

Peninsular Ranges. Even in the Klamath Mountains they are found in patches, generally of conglomerate and coarse littoral sandstone. In most Coast Range exposures sandstone occurs prominently and huge conglomerate lenses are common and conspicuous, though thin or thick beds of more or less sandy shale make up the greater part of the mass. A thick deposit of brownish or purplish, more or less siliceous, locally diatomaceous and foraminiferal shale (Moreno formation) forms a conspicuous upper member along the east

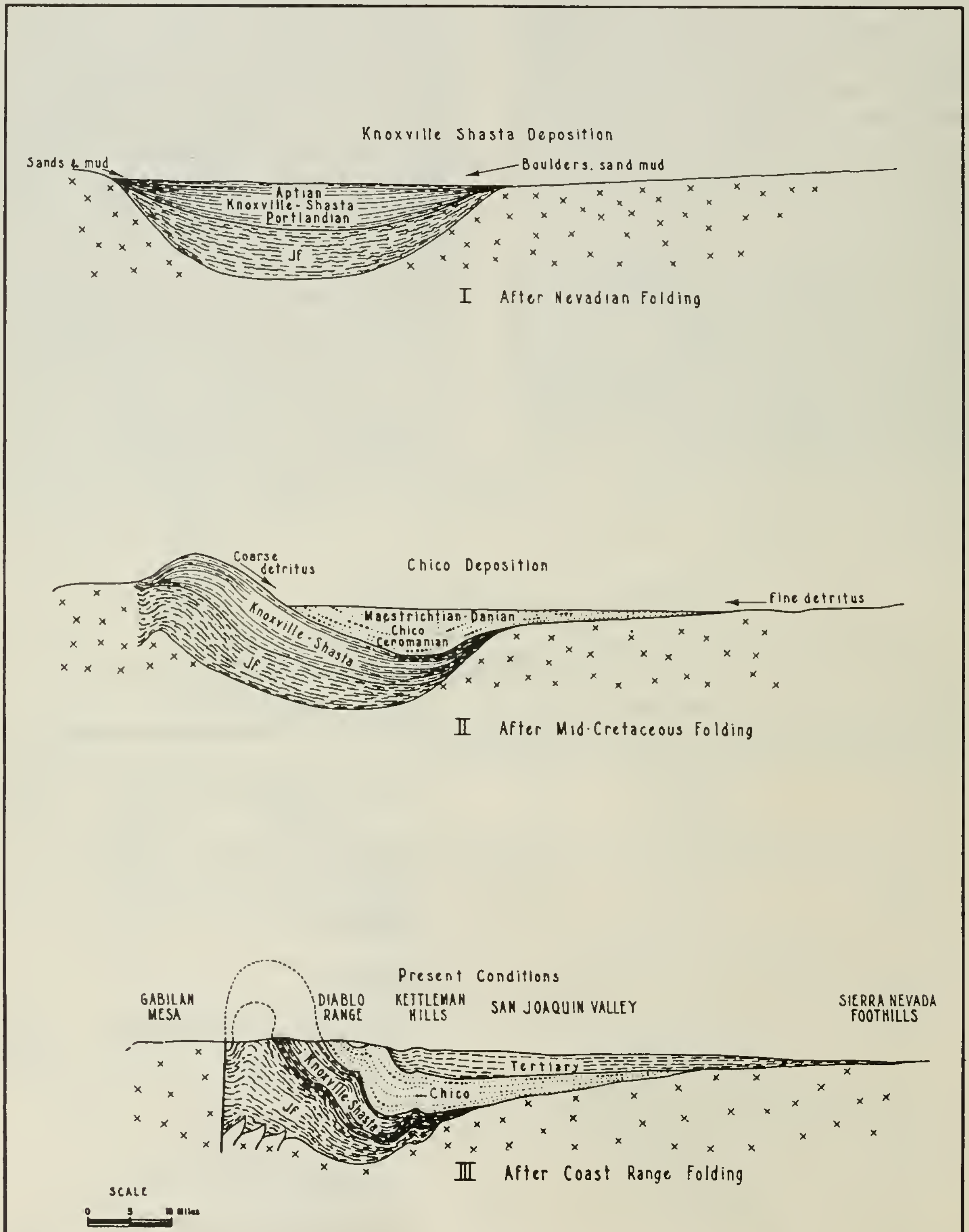

FIG. 51. Diagram of Jurassic-Lower Cretaceous paleogeography, showing development of structure in the Great Valley.

slope of the Diablo Range from Mt. Diablo south to Coalinga. It is interesting as being the only member of the California Cretaceous that suggests, even remotely, the Chalk of certain other Cretaceous areas.

Marine fossils of many types are found in many exposures of the Cretaceous, but good collecting localities are few and thick sections with fossils distributed throughout are almost nonexistent. One of the best is the Santa Ana Mountains section of southern California, which represents only a fraction of the Upper Cretaceous.

As Pack and English recognized (Pack, R. W. 14, p. 127) long ago, and as later workers have repeatedly corroborated, the Chico beds of the Diablo Range in several places approach 25,000 ft. in thickness. They are locally unconformable on Lower Cretaceous, and have several horizons at which thick lenses of coarse conglomerate occur locally. The significance of these conglomerate horizons has never been made clear by detailed mapping and collecting, but it is not improbable that they may be found to separate the formation into several distinct units. Very recently, as a matter of fact, F. M. Anderson (38a) has stated that he finds persistent coarse strata at the base of the Chico—Upper Albian to Cenomanian—and at a horizon within it—Coniacian. A striking peculiarity of these conglomerate lenses is that they seem to die out eastward toward the San Joaquin Valley.

The Marysville Buttes Cretaceous is generally fine-grained, and even the outcrops along the Sierra Nevada foothills are sandy rather than conglomeratic. Deep wells drilled in the central valley area have penetrated great thicknesses of Cretaceous shale, but even the Pure Oil Company's Chowchilla Ranch well, drilled near the center of the Valley a few miles south of Merced, and carried to granitic basement rock at about 8,300 ft., found above the basal conglomerate of the Chico only shale and fine-grained sandstone. A western source thus seems to be indicated for the pebbles of the conglomerate lenses.

Since the pebbles of the Chico conglomerates are only in minor part of Franciscan derivation, and since the only granitic area now emergent west of the San Joaquin Valley is the narrow belt lying between the San Andreas and Nacimiento fault zones, it seems inevitable at first glance that this narrow belt, Salinia, must have contributed to the Upper Cretaceous detritus. Further study shows, however, that a considerable part of Salinia itself is covered with coarse Upper Cretaceous strata thousands of feet thick (Reiche, P. 37, p. 137 ff.). This condition may not have existed on the broader, northwestern continuation of Salinia that is now submerged beneath the Pacific Ocean, but this area is a long way from the north Coalinga region where the most striking masses of Chico conglomerates are now known.

Interesting in this connection is the question of the age of the granite found beneath the Chico of the central San Joaquin Valley in the well drilled near Merced. In appearance this rock resembles the Jurassic granodiorite of the Sierra Nevada. If it is Jurassic in age, it must have been intruded into Jurassic and older strata during the Nevadian revolution—post-Kimmeridgian, and pre-Cretaceous. The cover must then have undergone erosion during latest Jurassic and Lower Cretaceous so as to expose the coarse-grained plutonic mass by the time of the latest Upper Cretaceous transgression in the central Valley area. Where did the products of this erosion and of the erosion of the Sierra Nevada mass go? If they were carried eastward they stopped only in Utah, since Lower Cretaceous deposits do not occur in the intervening area. If they were carried toward the west, they could have come to rest in the northern Franciscan area or farther west, where deposition was taking place generally during the period in question. Perhaps we may be justified in seeing in the products of this great period of post-Jurassic and pre-Upper Cretaceous erosion, a probable source for the thick Lower Cretaceous deposits of the California Coast Ranges.

If so, and if the unconformity between Lower and Upper Cretaceous turns out to be widespread and of considerable magnitude, we may perhaps then go one step farther and see in the folded and uplifted Lower Cretaceous strata of the Coast Ranges the desired western source for the immensely thick Upper Cretaceous deposits of the west edge of the San Joaquin Valley. Opposed to this hypothesis is the prevalent idea that the Knoxville Lower Cretaceous deposits are generally finer in grain than those of the Upper Cretaceous. Further studies of the distribution and character of Lower Cretaceous and Knoxville strata will be needed to determine this point. In any event, it now seems clear that the width of the belt of very thick Upper Cretaceous is very much less than might be guessed at first sight; if so, the problem of finding a source for these sediments is somewhat lessened.

The Cretaceous marine faunas of California are partly Boreal and partly Indo-Pacific in character. Ammonites, baculites, and pelecypods are prominent among the larger invertebrates, foraminifera among the smaller ones. A few large reptiles have recently been found in the Moreno shale. Diatoms are locally prominent in the formation. Fragments of wood and leaves are common in many Cretaceous beds, but identifiable plant material seems to be scarce.

The only nonmarine Cretaceous that outcrops in California is the red Trabuco conglomerate, apparently barren of fossils, that lies at the base of the Chico beds in the Santa Ana Mountains. Recognizable volcanic rocks are limited to probable ash beds in the Moreno shale.

Periods of strong folding seem to have occurred only at the beginning and end of the period. The post-Turonian orogeny (Stille's Subhercynian), supposedly important for the Andes and perhaps also for Mexico, is suggested for the Coast Ranges only by the occurrence of the conglomerate mentioned by Anderson as characterizing the various sections in which he has found faunas of Coniacian age. Its traces may be recognized more widely when the great areas of Chico deposits are carefully mapped. The importance and extent of Austrian (pre-Cenomanian) and Laramide disturbances are also in need of additional study; but both disturbances are clearly more important than anybody has suspected until very recently.

Rocks of Upper Cretaceous age are not noted for their mineral content. Gold placers have been worked in Cretaceous gravels in the Klamath Mountains and elsewhere. At New Idria, part at least of the quicksilver ore is taken from Upper Cretaceous sandstones, but the mineralization is post-Cretaceous. Oil is produced from sands within the Moreno shale in the very small Oil City field. Gas comes from Cretaceous rocks in the Tracy gas field, and perhaps from uppermost Cretaceous in the McDonald Island gas field; also, gas is found in the Cretaceous of Marysville Buttes and elsewhere in the northern Sacramento Valley. Although none of these occurrences of oil or gas compares in importance with many Tertiary occurrences, the possibility of discovering other and more important Cretaceous deposits is not exhausted. During the next few years, as a matter of fact, the oil and gas possibilities will almost certainly be investigated more thoroughly than ever before. One certain outcome of this investigation will be the possibility of writing an account of Cretaceous deposits, their stratigraphy, structure, paleogeography, and geologic history, that will make such an account as the present one seem hopelessly antiquated and full of errors.

TERTIARY

General Statement

About a century ago it became customary to divide the Tertiary of the world into Eocene, Miocene, and Pliocene divisions. Lyell (33, p. 53, ff.) even had two Pliocenes, an older and a newer, but the newer eventually came to be called Pleistocene, following Edward Forbes' use (1846) of a term (Wilmarth, M.G. 25, p. 48) invented by Lyell to designate something else. In 1854 Beyrich described as Oligocene (Wilmarth, M.G. 25, pp. 53-54) some transitional Eocene-Miocene deposits in West Germany, and 20 years later W. P. Schimper used the term Paleocene for earliest Tertiary strata of France and elsewhere (Wilmarth, M.G. 25, pp. 54-56). Since the difficulties in making long-range correlations increase rapidly when we turn from pre-Tertiary to Tertiary strata, there is no certainty that the California use of such terms as Oligocene and Miocene coincides exactly with the use current in western Europe. The terms are nevertheless common in California, though there is much uncertainty as to the proper use of two, Oligocene and Paleocene.

In the following discussion I find it convenient to divide the Tertiary deposits into four groups, and to make the dividing lines at places other than those commonly used. I shall therefore revert to another early classification of the Tertiary, dividing it in the middle and calling the two parts Paleogene and Neogene (Kayser, E. 24, p. 230); each of these groups I shall further divide into Upper and Lower. These terms are not meant to replace those in common use, but they will be useful in this discussion for two reasons: first, because they allow the Tertiary to be split at horizons that are widely recognizable throughout the Coast Ranges; second, because the groups so produced have a considerable degree of unity and thus permit some simplification of the Tertiary history of the Coast Ranges.

Base of the Tertiary

The Cretaceous-Tertiary contact is locally an angular unconformity, with Paleocene, later Eocene, or still younger strata forming the superjacent member. In some localities, as in the northern San Joaquin Valley, an unconformity is absent and there is uncertainty as to the age of unfossiliferous sandy strata lying between fossiliferous Eocene and Cretaceous. There is even a possibility that part of the Moreno formation, as mapped, may belong in the early Paleogene.

Lower Paleogene

The most important and persistent negative areas of the Lower Paleogene were three embayments that developed at the beginning of the Tertiary and persisted

Table 7

TYPICAL FORMATIONS IN CALIFORNIA	AGE ASSIGNMENTS		
	CURRENT USAGE	GROUPING BY R.D. REED	
Upper San Pedro	Upper Pleistocene	Pleistocene	
Lower San Pedro, Saugus, Tulare	Lower Pleistocene	Upper Neogene	NEOGENE
Etchegoin, Pico, Repetto	Pliocene		
Santa Margarita, Monterey, Modelo, Topango, Temblor	Upper and Middle Miocene	Lower Neogene	
Vaqueros, Temblor, Pleito, San Lorenzo, San Ramon	Lower Miocene and Oligocene	Upper Paleogene	PALEOGENE
Kreyenhagen, Tejon, Capay, Domengine, Meganos, Martinez, Ione, Poway	Eocene and Paleocene	Lower Paleogene	

Tertiary and Pleistocene formations of California.

throughout. They have been called the San Joaquin, Santa Barbara, and Capistrano embayments. In addition, there were several straits; among them the Markley strait or trough north of Mt. Diablo, and the San Benito trough stretching from the Vallecitos area (north of Coalinga) to the vicinity of Halfmoon Bay. Some lowland areas adjacent to the troughs and embayments were also flooded during more or less of the Paleogene epoch. Such areas have thinner, more discontinuous sections of rock than those classed as embayments or as troughs.

The chief upland areas were Mohavia—greater by far in area than all the others combined; parts of Salinia and Anacapia, and three areas that have been called "uplifts": the Diablo, San Rafael, and Catalina uplifts. The last-named area is now so widely covered by the ocean that any conclusions about its history must be based largely on indirect evidence. The two others, being on land, are much better known. They were emergent at the beginning of the Lower Paleogene but became partly submerged later on. The San Rafael uplift locally became stripped of its Cretaceous cover during the epoch, and furnished Franciscan detritus to adjacent parts of the sea. The Diablo uplift, on the other hand, seems to have retained its Cretaceous cover, except in a few small areas, until during, or perhaps near the end of, the Upper Paleogene.

Among the formations referred to Lower Paleogene are several that throw interesting light upon problems of paleogeography and geologic history. Among them are the Martinez sandstone and conglomerate; the coal, leached clay, glass sand, orbitoid limestone, and reddish marine shale of the middle Eocene; the Kreyenhagen siliceous shale, fossiliferous Tejon sandstone and sandy shale, Poway conglomerate, and continental red beds of the lower Sespe, all of upper Eocene age. Almost the only volcanic rocks are more or less altered ash beds in the Simi Valley and in the Kreyenhagen shale area of the Coalinga district. Compared to the Coast Ranges of Washington, where thick sheets of Eocene basalt are conspicuously present, the California Coast Range Eocene deposits are remarkably free from inclusions of igneous rocks.

With reference to the sedimentary formations, even a brief examination shows that the older of the Lower Paleogene beds are generally coarse, variable in lithology, and of restricted distribution. Those with good marine faunas are, in fact, limited to a few small areas. During the middle of the epoch the beds deposited were generally finer in grain and more uni-

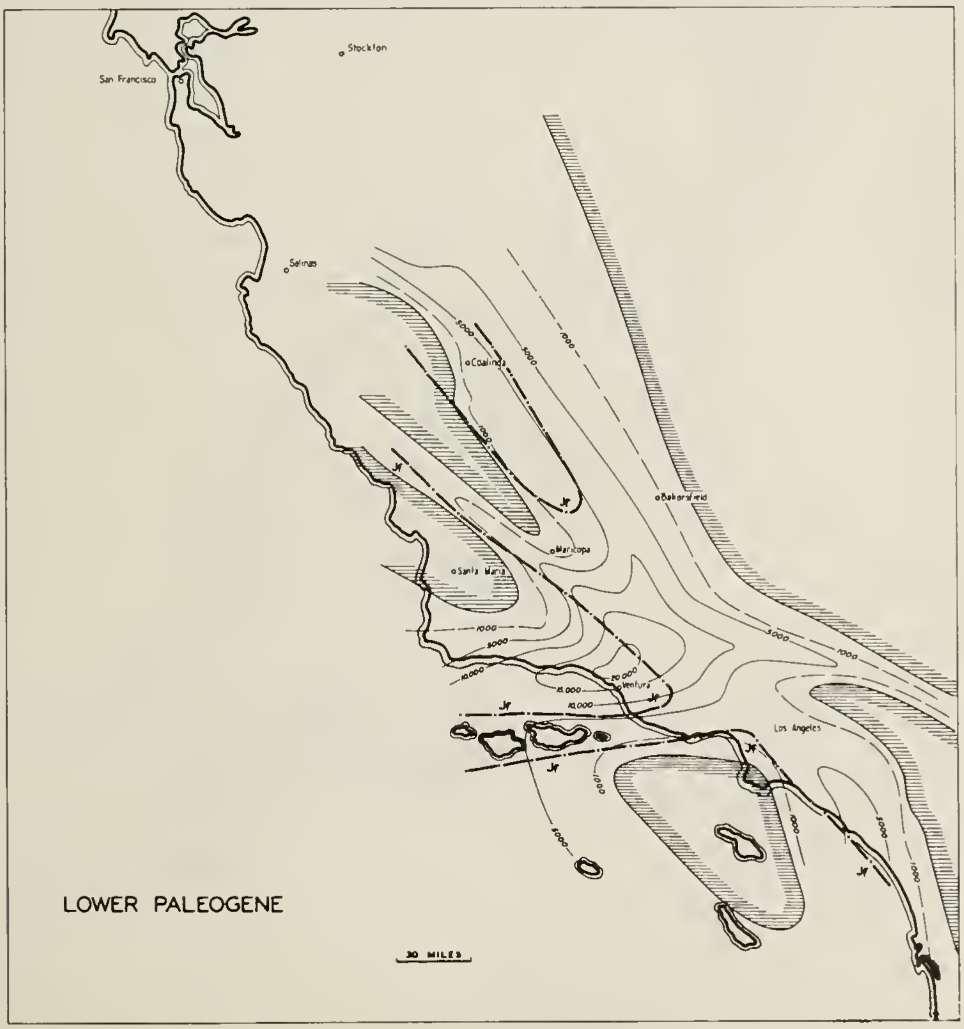

FIG. 52. (See Fig. 55 for explanation). Paleogeographic map of the lower Paleogene

form in character—Capay silts, Domengine and Ione sandstone—and were spread over earlier Paleogene deposits as well as considerable areas that had not been covered by them. Toward the end of the epoch the areas of deposition remained large but the facies represented became highly varied. They include the Poway conglomerate, lower Sespe continental red sandstone, Coldwater and Tejon marine sandstone and sandy shale, and the Kreyenhagen siliceous shale.

Faunas and floras as well as lithology suggest clearly that Lower Paleogene, particularly the middle of the epoch, was a time of considerable warmth and humidity. Earlier and later parts of the epoch are less distinctly tropical, and the red beds of the lower Sespe have even been considered evidence of aridity, though a consideration of their mammalian remains has shown that this idea is erroneous.

From the point of view of their economic deposits the Lower Paleogene formations are or have been important for coal, oil, gas, pottery clay, glass sand, and gold. Owing to the poor grade of the coal beds and their complex structure, production has now ceased, but may become important again at some time in the future. Oil and gas are produced at present chiefly in the Simi Valley and in the Coalinga region, gas alone at Rio Vista and perhaps McDonald Island. Many additional deposits may be found in the future. Pottery clays and glass sands come from those areas in which the middle Eocene Ione formation crops out. Gold placers are found in the Sierra Nevada foothills in rocks of middle Eocene age. Pottery clays, glass sands, and gold fragments are all products of the tropical weathering conditions of the middle Eocene.

Upper Paleogene

Upper Paleogene time saw a great increase in size of land area, considerable parts of which received thick deposits of Sespe type. Marine deposits seem to have accumulated chiefly in a part of the San Joaquin embayment and near it. Later on in Vaqueros time, the sea invaded much of the Sespe lowland, and continued to spread until the end of the epoch. It finally became a very widespread body of water, in which accumulated muds carrying foraminifera of the shallow-water type.

The conditions in the San Joaquin embayment during the early part of the epoch are particularly interesting because they seem likely to have been favorable for the genesis of oil. The time was that of the deposition of the upper (Oligocene) part of the Kreyenhagen shale, which graded into marine sandstone toward

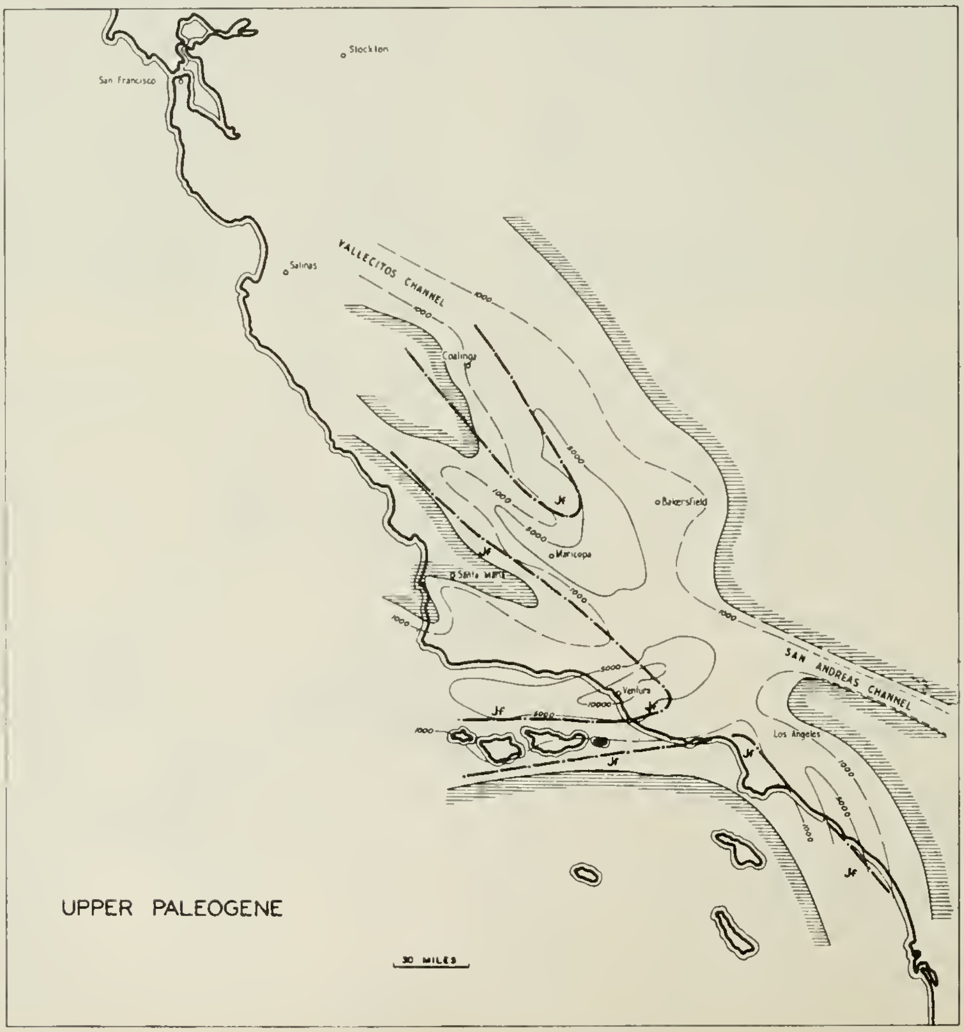

FIG. 53. (See Fig. 55 for explanation). Paleogeographic map of the upper Paleogene.

the south and southwest margins of the embayment. Farther to the southwest lay the great areas of deposition of the Sespe red beds. The communication with the western ocean was along the San Benito trough. The embayment was thus semi-enclosed, and its waters were probably deeper than those of the trough, where mollusk-bearing sandstone and siltstone are well represented. A deep, semi-enclosed sea basin, becoming gradually filled with highly organic silt and ooze, the embayment had, at that time, several features suggestive of the Black Sea at the present. Bottom muds in the embayment may thus have been deficient in oxygen, like those of the Black Sea, and their organic content may have become bituminized rather than completely oxidized.

As is well known, many geologists have long favored the view that the Kreyenhagen shale is the source of the oil in the Coalinga oil fields. The favorable evidence was derived from local stratigraphic conditions observed in the Coalinga district, and may now be supplemented by the paleogeographic considerations summarized in the preceding paragraph.

Despite the increase in size of land areas at the beginning of the Upper Paleogene, the general arrangement of uplands and basins persisted as in the Lower Paleogene. The Santa Barbara embayment, though above sea level during the Sespe, was strongly negative as shown by the great thickness of its Sespe deposits. A part of it, the Oakridge uplift, ceased to subside so rapidly at the end of the Sespe, but the remainder continued to subside throughout the Tertiary at a rate that has given this area Miocene and Pliocene deposits as thick as any that are known in any part of the world.

Salinia was generally emergent at first, but later subsided irregularly, perhaps with the development of fault troughs of deposition. The Diablo uplift, probably the Catalina uplift, and at least the eastern end of Anacapia were also upland, and so was a vast area of Mohavia, though a basin of continental deposition is known to have developed at that time where the eastern edge of Death Valley now lies. Several other similar basins may have come into existence on Mohavia toward the end of the epoch by the time that the deposition of coarse clastic deposits had ceased over the greater part of the Coast Range embayments.

In contrast to the Lower Paleogene conditions, Upper Paleogene time began with facies heterogeneity and concluded with a marked degree of homogeneity. Sespe-upper Kreyenhagen time (early Upper Paleogene) was succeeded by the epoch of Temblor-Vaqueros sand-

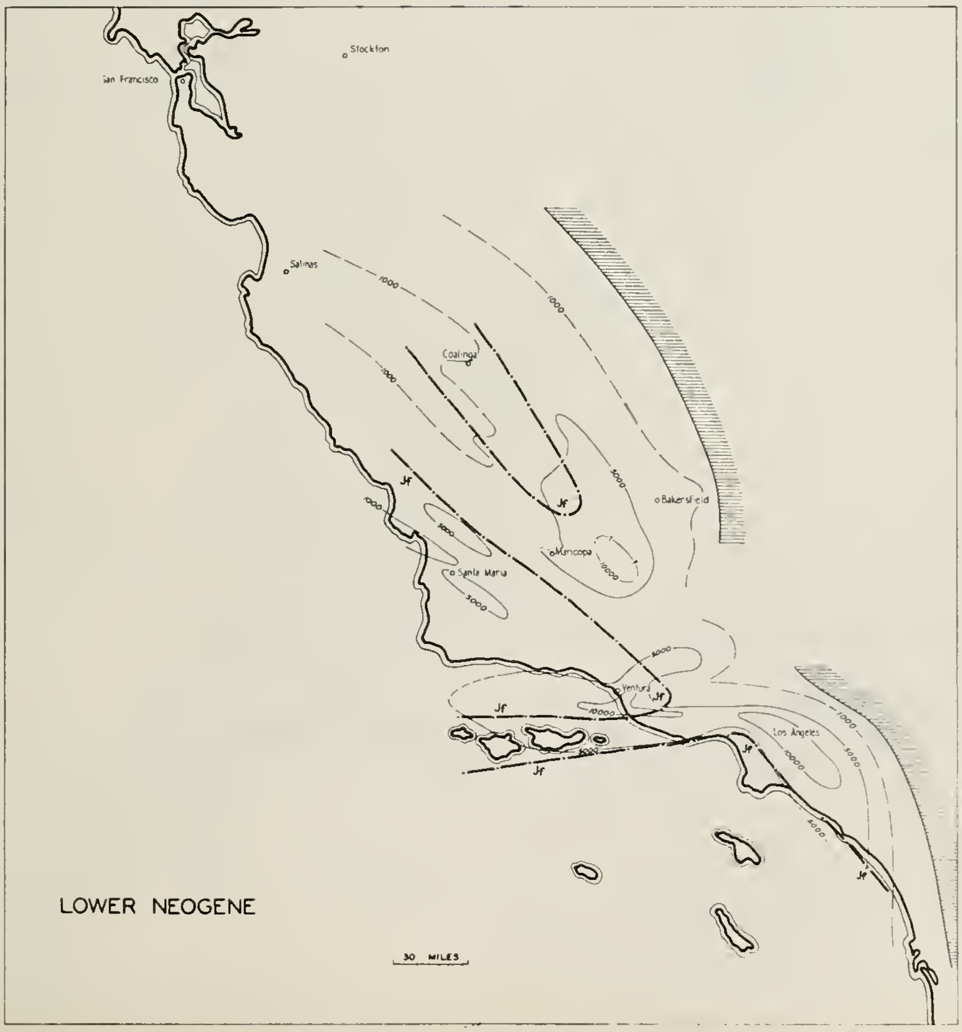

Fig. 54. (See Fig. 55 for explanation). Paleogeographic map of the lower Neogene.

stones, and this by the era of the Media and Rincon clay shales (late Upper Paleogene). Volcanic activity, on the other hand, was weak or absent at first but increased sharply toward the end of the epoch and reached a maximum approximately at the very end.

The climate was apparently warm throughout this epoch, but the amount of rainfall certainly decreased locally and probably everywhere in coastal California.

The most important economic product of the Upper Paleogene strata is undoubtedly oil. The combination of basal organic shales and overlying coarse marine sandstones has given rise to several large and valuable accumulations about the margins of the San Joaquin embayment, and more complicated relations have led to some important accumulations in comparable horizons in coastal California. Coalinga and Kettleman Hills in the former area, and the Elwood and South Mountain fields in the latter, are good examples.

Transition, Paleogene to Neogene

The transition from Paleogene to Neogene comes within the Miocene, as that term is commonly used in California. It comes at the base of the "button bed" (Anderson, F.M. 05), uppermost member of F. M. Anderson's type Temblor of Carneros Creek in the Temblor Range; at the base of the "third zone" in the producing formations at Kettleman Hills; approximately at the contact of clay shale and siliceous shale members of the Santa Barbara Miocene beds; at the base of the Topanga formation of the Santa Monica Mountains; and probably at the base of the San Onofre breccia, southeast of the Los Angeles Basin. In the terminology of R. M. Kleinpell (34a; 38), which is rapidly coming into general use in California, the transition comes between the Saucesian and Relizian stages, or between lower and middle Miocene.

The importance of this horizon for historical geology was not fully recognized by the pioneers in Coast Range geology. The reason is simple; the pioneers were dependent upon the larger invertebrates for correlations, and the larger invertebrates do not seem greatly to respect this boundary. Some of the Temblor index fossils occur both above and below it. The type Temblor, as suggested above, though chiefly Upper Paleogene, includes at the top a calcareous sandstone, or "reef bed," that belongs to the Lower Neogene. This member, the "button bed," was early recognized to be locally transgressive, however, and additional field mapping has added greatly to the number of localities in which this condition can be observed. A very striking

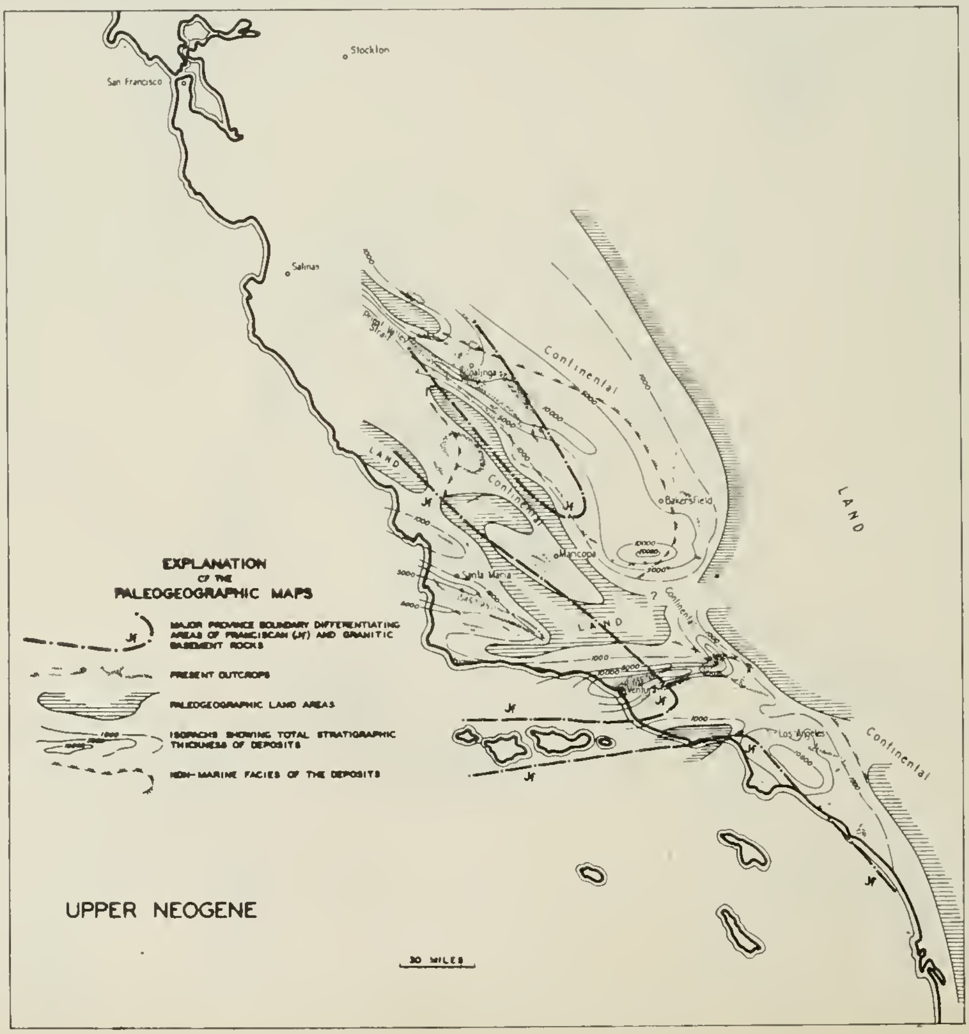

FIG. 55. Paleogeographic map of the upper Neogene.

one, in the central part of the San Rafael Mountains, has been described and figured in an earlier publication (Reed, R. D. 36). The button bed horizon is one of the few horizons in the Coast Range Tertiary at which fossiliferous, more or less pure limestone lenses are common. Even the button bed and the reef beds of which it is a member, may be properly described as very sandy limestone.

Lower Neogene

In a broad way, the Lower Neogene may be described as the period of deposition of siliceous shales of the Monterey type. It is true that deposits of this type began in uppermost Paleogene in the Maricopa district, and that they persisted into Upper Neogene in such areas as the Santa Maria district, but the general relation is clear and striking. To an almost but not quite equal degree, the Lower Neogene is also the time of eruption of Tertiary volcanic rocks in the Coast Ranges. Similarly, it is the time during which accumulated nearly all the masses of coarse Franciscan detritus of which the San Onofre breccia and the Big Blue are the best-known examples; and it is the time of accumulation of the great majority of Tertiary nonmarine basin deposits of the Mojave Desert area. It is the time, finally, of the most striking indications of orogenic activity to be found in the Tertiary deposits of the Coast Range province.

That all these exceptional phenomena are interrelated is an almost inevitable conclusion. Thus, the basin development and filling on Mohavia and Salinia served to restrict the entrance of non-Franciscan detritus into Coast Range seas. The great outpourings of volcanic rocks and accompanying liquids and gases, and perhaps the weathering of the rocks, presumably helped to determine the siliceous type of shales deposited in some of the embayments, perhaps in part by determining the type of life that thrived within their waters. Orogenic and epeirogenic movements in the restricted upland areas gave rise to the local supplies of coarse Franciscan detritus, and later, no doubt, to the supplies of coarse granitic sand that accumulated as the Santa Margarita sandstone.

The widespread seas of varying depth, with a large content of organic matter in their quieter parts, were apparently favorable for oil genesis at certain times and places. The Santa Maria Basin seems to be one of the places. In eastern California some of the volcanic intrusions carried valuable deposits of gold, silver, and tungsten ores. And in some of the Coast Range basins deposits of exceptionally high-grade diatomite accumulated.

A study of the paleogeographic map will show that the major basins of the Coast Ranges continued to subside during the Lower Neogene at a greater rate than the areas of the Tertiary uplifts, even though the latter were largely submerged during part or all of the epoch. On Anacapia and Salinia, however, Lower Neogene deposits accumulated in some newly-formed basins in thicknesses comparable to those of the embayments.

Upper Neogene

The change from Lower to Upper Neogene corresponds to the change from Miocene to Pliocene in the ordinary stratigraphic classification. It was a time when the "uplifts" reasserted themselves, as did parts of Salinia, Anacapia, and Mohavia. In the last-named province basin-formation and filling seems to have ceased for a time, and external drainage was reestablished. The sea persisted at first in some of the newly formed coastal basins, such as the Santa Maria and Paso Robles basins, but in nearly all cases the basins became much smaller than they had formerly been. Even in the three great embayments only the landward ends remained strongly negative: the Maricopa, Ventura, and Los Angeles basins. The increase in area and elevation of the uplands, and the diminution in size of the areas of deposition led to an increase in the clastic content of the sediments and to a cessation of deposition of siliceous shale of the Monterey type.

The smaller size of basins of deposition and poorer communication between those that persisted led to more provincial faunas. Even at the present time, with all the paleontological work that has been done upon larger and smaller marine Pliocene fossils, it is possible to correlate deposits of the San Joaquin and Santa Barbara embayments only in a general way. The Santa Barbara and Capistrano embayment deposits are readily correlated by means of microfossils, but the succession of microfaunas is generally recognized to be a succession of similar facies. Many of the most diagnostic forms of the several faunas are still living offshore from the coast of southern California. If we use the present distribution of these faunas as a means of interpreting the conditions that existed in the Upper Neogene, we conclude that the major coastal basins were some thousands of feet deep in lower Upper Neogene and that they became gradually shallower until near the end of the epoch when, as has long been known, they were above sea level. The history of the younger basins, such as the Santa Maria and Paso Robles basins, seems not to have followed that of the major basins in all details, but additional work is needed in each of them before we can be sure just what happened.

The bottom relief during early Upper Neogene may have been an important factor in producing conditions favorable for the accumulation of the mother-rock of petroleum. The seaward margins of the Los Angeles and Ventura basins received accumulations of highly organic siltstone during Repetto (earliest Upper Neogene, or lower Pliocene) time, while thick sandstone lenses and bodies were accumulating nearer shore and in shallower parts of the basins. Anticlines involving these sand lenses have produced millions of barrels of oil in such fields as Long Beach, Santa Fe Springs, and Ventura Avenue. That the Repetto formation furnished the source rock for the oil is, of course, not fully proved, but is believed by probably a large majority of the geologists familiar with conditions in these and similar oil fields. There seems to be good evidence that the Maricopa basin was not as deeply submerged during the Upper Neogene as the coastal basins, though the evidence hardly applies at present to all parts of the basin. Whether or not the basin was a deep one, it was partly enclosed, the bottom was deeply covered with silts, and the conditions about some of the oil fields, notably Buena Vista Hills and Elk Hills, have been interpreted as favoring a Pliocene origin for the oil.

What little is known of Upper Neogene flora suggests that the climate was drier than it had been during the early Tertiary; and the evidence of some of the late Upper Neogene faunas found in the San Pedro district shows that it became definitely cooler at that time than it had been earlier.

Close of Upper Neogene and Post-Tertiary Record

During the later Neogene time the widespread basin areas continued to subside to depths of some thousands of feet, but marine waters covered only their coastal margins. Mountain areas were large enough and high enough to keep the greater part of the lowlands filled above sea level and to permit the accumulation of the nonmarine Tulare formation and the dominantly nonmarine Paso Robles and Saugus formations. After this period came a time of strong folding, which affected not merely the mountainous areas but also the margins of the basins of deposition. This was the "mid-Pleistocene," "Coast Range," or "Pasadenan" disturbance.

In spite of its recency the date of this disturbance is not easy to determine in terms of the standard stratigraphic section. Present-day paleontologists are responsible for referring it, somewhat tentatively, and not quite unanimously, to the middle Pleistocene. H. R. Gale's discussion (Grant, U.S. 31, pp. 61, 63, etc.) is fairly typical, though his conclusions are more definite than those of some other workers. Vertebrate paleontologists have not been able to contribute as much to the solution of the problem as the abundance of good material might lead one to expect. The difficulty comes from the fact that the very good localities, such as Rancho La Brea, McKittrick, and Carpinteria, occur where there is a scarcity of good stratigraphic information. As a matter of fact, the fossils of these localities occur in strata that seem to be distinctly superficial, and perhaps younger than any of the beds that have been strongly and generally folded. O. P. Hay held (27, p. 189, ff.) that the Rancho La Brea and upper San Pedro fossils are Aftonian. Later workers have doubted this correlation because the traces of fossils found in such highly folded beds as basal Tulare, Lomita beds, and others, seem not to be older than latest Pliocene, and more likely to be Pleistocene. If Hay is right, then such uppermost Pliocene strata as the lower San Pedro certainly have a high percentage of living species; and the cool-water marine faunas known in the later formations of California are all Pliocene.

The age of the late folding episode must thus be left uncertain, though it is not older than the end of the Pliocene and is very possibly younger. Its main phase is not as late as the end of the Pleistocene, but its dying phases seem to be still going on.

In view of the fact that the exact date of the folding is easy to determine, even in terms of the California stratigraphic section, only in a comparatively few places, and that recent work has tended to stress the importance of pre-Pasadenan Tertiary diastrophism in the Coast Ranges, some workers have come to doubt if the "mid-Pleistocene" orogeny ever existed as a definite period of heightened crustal movement. Stress is laid on the fact that earlier movements took place and that in mountain areas where later Cenozoic beds are absent and where earlier strata are strongly folded, there is often some doubt that the deformation of the beds actually found took place after the Pliocene. This view is very attractive to those who like to think of folding and faulting as long-continuing processes, creating their effects by acting throughout periods comparable to those in which a formation or several formations may be deposited. Unfortunately, the conditions in many parts of California do not make it easy to decide between such workers and those who like to have their diastrophism episodic. As explained elsewhere (Reed, R. D. 36, p. 50), the writer finds evidence of each kind of deformation, the long-continued and the episodic, but is inclined to the view that the Pasadenan folding period belongs to the latter type; and furthermore, to the view that many of the folds of interest to oil geologists owe much the greater part of their deformation to this period of folding.

The Kettleman Hills anticline will serve as an excellent example. In it the Tulare formation, which nobody would consider older than latest Pliocene (though many would make at least its upper part younger), is folded as strongly as the formations that underlie it. The anticline simply did not exist in anything comparable to its present form until after Tulare time. After it was made, furthermore, it was worn down by streams until thousands of feet of rock had been removed from its axial part. Toward the south end it was reduced to a featureless plain which later became buried in alluvium, and the alluvium was then arched into a new, though gentle fold. The northern part, the North Dome, was not so deeply buried in alluvium, but the evidence of peneplanation and later warping is, in my opinion, conclusive. In any case, the time that has elapsed since the first folding must be reckoned as a good many thousands of years.

If we class latest Tulare deposits as uppermost Pliocene—the oldest we can possibly make them—then the entire period of diastrophism and the period of peneplanation must belong to the Pleistocene, and must have taken place in some such period as a million years unless the Pleistocene was much longer than is now commonly believed. The later warping and subsequent erosion may then be Pleistocene or post-Pleistocene. The more we study the facts and their possible interpretations, the more we seem forced to the conclusions first, that the folding movements were episodic rather than secular; and second, that even with the Tulare classed as older than most stratigraphers believe it to be, it is hard to find time for all the post-Tulare events that are definitely and conclusively indicated.

In coming to these conclusions, we should not lose sight of the fact that many anticlines of the Coast Ranges were certainly marked out and more or less clearly foreshadowed by pre-Pasadenan deformation; and that in the mountain areas this condition was more marked than in the margins of the basins. Paleogeographic studies show clearly enough that basins of deposition became gradually smaller throughout the Cenozoic; and studies of structural evolution seem to show equally clearly that this result was due, in part at least, to a gradual migration of the folding from upland areas to or toward the basins of deposition.

GEOLOGIC HISTORY AND STRUCTURE OF THE CENTRAL COAST RANGES OF CALIFORNIA

By N. L. Taliaferro*

OUTLINE OF REPORT

INTRODUCTION

This paper is a summary of the writer's views regarding the structure, diastrophic history, and certain phases of the stratigraphy of the central Coast Ranges. Presentation of evidence is reduced to a minimum and all references to the literature have been omitted for the sake of brevity. Evidence for the conclusions reached will be submitted in detail in future papers on various areas and phases of the subject. The conclusions presented here are based on 15 years' detailed mapping in the Coast Ranges, assisted by approximately 20 students each year, on the work of graduate students of the University of California in adjacent areas, and on many reconnaissance trips throughout the Coast Ranges. Studies in the Sierra Nevada and in the northern Coast Ranges have greatly influenced some of the conclusions.

The area treated is roughly that part of the Coast Ranges between the latitude of San Francisco Bay on the north and Santa Barbara County on the south, excluding that part of the San Joaquin Valley and the adjacent mountains south of Kettleman Hills and west of the Carrizo Plain, a region in which the writer has done no detailed mapping. Not every part of this large and often rugged area has been mapped and the present paper should be regarded as a progress report. However, its presentation at this time, even though detailed evidence is omitted, is believed to be justified as it contains much that is new and unpublished.

Although there are many gaps in our knowledge of the details of the central Coast Ranges it is believed that the major features of their complex history are fairly well known. Practically all of the Santa Lucia Range and the Gabilan mesa and much of the Diablo Range have been mapped. The widest gaps in our knowledge are in the northern part of the Diablo Range and the southeastern part of the Santa Cruz Mountains.

Equality of treatment of all of the chapters of the history of the central Coast Ranges has not been attempted. Since most of the writer's investigations, outside of the areas mapped in detail, have been connected with the Upper Jurassic and Cretaceous and since he believes that much of his information regarding these beds is new, a much fuller treatment is given these earlier rocks. The literature of the Tertiary of this region is voluminous and hence there is little necessity for any but the broadest treatment of the later sediments.

This report is written primarily for those who are familiar with the geography and stratigraphy of the Coast Ranges. It has been impossible to prepare the maps that would be necessary for those unfamiliar with the region. Since reference is rarely made to any smaller unit than part of a county or quadrangle only two general maps have been included, one showing the counties and ranges and the other the quadrangles in and adjacent to the central Coast Ranges. Locations of the accompanying cross-sections are shown on these maps.

NEW AND REDEFINED GEOGRAPHIC NAMES

As certain geographic names have been used in senses slightly different from those usually employed and as one or two new names have been introduced these will be defined.

Santa Lucia Range

On the various topographic maps of the region this name is applied to the mountainous region extending from Monterey Bay to the Cuyama River. Immediately south of the Cuyama River the name San Rafael Mountains is used. This is illogical as there is no break at this point and the same beds and structures cross the Cuyama River. As used here the Santa Lucia Range is the mountainous area between the Salinas Valley and the coast which extends from Monterey Bay to the central part of San Luis Obispo County. As thus defined it is not only a geographic but a structural unit. It is approximately 110 miles long and 15 to 30 miles wide.

* Professor of Geology and Chairman of Department of Geological Sciences, University of California, Berkeley, California. Manuscript submitted for publication, December 8, 1940.

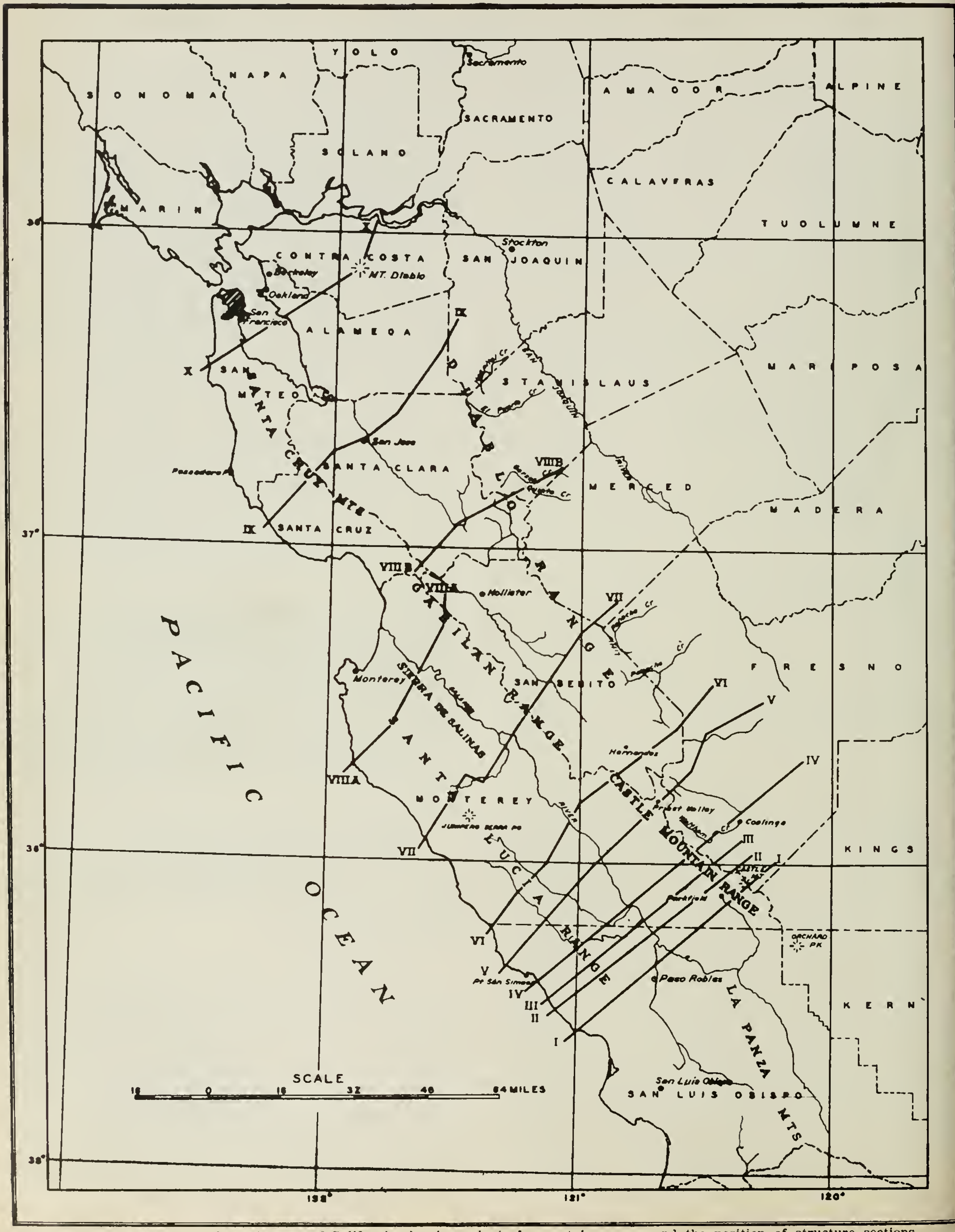

FIG. 56. Map of central Coast Ranges of California showing principal mountain ranges and the position of structure sections.

Sierra de Salinas

Now essentially a part of the Santa Lucia Range but separated from the main range in the Miocene by a seaway. Land-laid Miocene sediments, passing upward into marine beds, occur about its southern end, and there seems to be little doubt that it stood as an island in the Miocene sea. This range, which attains an elevation of nearly 4,000 feet, extends along the west side of the Salinas Valley from a point a few miles south of Salinas almost to the Arroyo Seco, a distance of about 25 miles. The King City fault bounds the east side of this range.

Gabilan Mesa

That broad and somewhat indefinite area, underlain by ancient crystalline rocks, extending northwestward from the La Panza Mountains. Its northeastern boundary is approximately the San Andreas fault; its southwestern boundary is very irregular and indefinite. The hypothetical "Nacimiento fault" was created to serve as the southwestern boundary but this fault exists only on paper and not in the field. This broad feature, faintly outlined in the Upper Cretaceous, was definitely established in the early Eocene as a great southwestward tilted block. Its northeastern side is definite but its downtilted southwestern side is very indefinite and only occasionally marked by faulting. Its southwestern part merges into the Santa Lucia Range. As thus defined it includes that part of the Santa Cruz Mountains west of the San Andreas and Pilarcitos faults.

Gabilan Range

That part of the Gabilan mesa, lying east of the northern end of the Salinas Valley, in which the ancient crystalline rocks are exposed at the surface. It is believed that it first came into existence by upwarping in the Upper Cretaceous; it was further uplifted and accentuated by faulting in the Eocene.

Castle Mountain Range

This is a new geographic term proposed for a definite structural unit usually included in the Diablo Range. It is a comparatively narrow feature approximately 60 miles in length which extends northwestward from Orchard Peak and includes Castle Mountain, Table Mountain, Smith Mountain, and Mustang Ridge. It narrows toward the northwest and ends against the crystalline rocks of the Gabilan mesa. Its position and structure are shown on the accompanying maps and cross-section.

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to the many former students of the University of California who made possible the detailed mapping of so large an area in the central Coast Ranges. He is especially indebted to Charles M. Gilbert, R. E. Turner, and C. E. Van Gundy, without whose assistance the work could not have been accomplished. Many reconnaissance trips have been taken with Dr. Olaf P. Jenkins and acknowledgments are due him for many discussions in the field and constant encouragement in the preparation of this report. H. G. Schenck, S. W. Muller, F. M. Anderson, B. L. Clark, Alex Clark, and W. T. Popenoe have kindly determined many of the fossils collected. A number of geologists and oil companies have supplied well data which have been of great assistance in the preparation of cross-sections. Financial assistance by the Board of Research of the University of California is gratefully acknowledged.

BASEMENT COMPLEX

The term "basement complex" is used to include the Sur series and the Santa Lucia granodiorite, a complex of crystalline rocks on which the later Jurassic, Cretaceous, Tertiary, and Quaternary have been deposited.

The Sur series includes highly metamorphosed sedimentary and volcanic rocks which have been intimately intruded by various types of plutonic igneous rocks (Santa Lucia) and extensively granitized. The sediments have yielded quartzites, various types of mica schists, marble and fine-grained black quartzites derived from cherts; the associated flows and tuffs have been converted into amphibolitic schists of many types. The crystalline schists universally stand at high angles and great difficulty would be encountered in working out their structure. In general the stage of metamorphism is that of the middle and upper mesozone, merging into the extremes of plutonic metamorphism on deep seated igneous contacts. On such contacts widespread granitization is a characteristic feature. The plutonic rocks have a wide range of composition, varying from syenitic types to very basic diorites; granodiorite is probably the prevailing type. Pegmatites are extensively developed and sometimes predominate over rather large areas.

At present these rocks are only exposed along and west of the San Andreas fault. They are typically developed in Santa Cruz, San Benito, Monterey, and San Luis Obispo Counties with minor occurrences in adjacent counties. The largest continuous areas are in the northern Santa Lucia Range, extending southeastward into the northern part of the Cape San Martin quadrangle and the headwaters of the Nacimiento River. They underlie the Gabilan mesa and a part of the La Panza Range. Ordinarily where they are within six or seven thousand feet of the surface they form a rigid basement which has yielded by faulting rather than folding. Where they lie at greater depths the overlying rocks have yielded by complex folding and faulting. Their present exposures are due to diastrophism in the late Cretaceous and at various times in the Tertiary.

There is little or no definite evidence as to the age of these rocks. Several elaborate attempts have been made to correlate the bedded rocks with Sierra Nevada bedrock metamorphics and the granodioritic rocks with the late Jurassic (or early Cretaceous) plutonic invasions. The writer is familiar with the Sierran rocks and can see no reason for such a correlation, especially in the case of the plutonic rocks. Certain of the sediments and volcanics might be equivalent to the lower part of the Sierran Paleozoic catchall, the Calaveras, but they might equally well be correlated with the Colebrooke schists of Oregon or the Abrams and Salmon schists of northern California which are rather certainly pre-Silurian and quite possibly pre-Cambrian. Debris of the Sur series are present in middle Upper Jurassic sediments of the Sierra Nevada, which have been intruded and metamorphosed by the Sierran plutonics. From evidence afforded by pebbles in Jurassic conglomerates in the Sierras these rocks appear to have reached

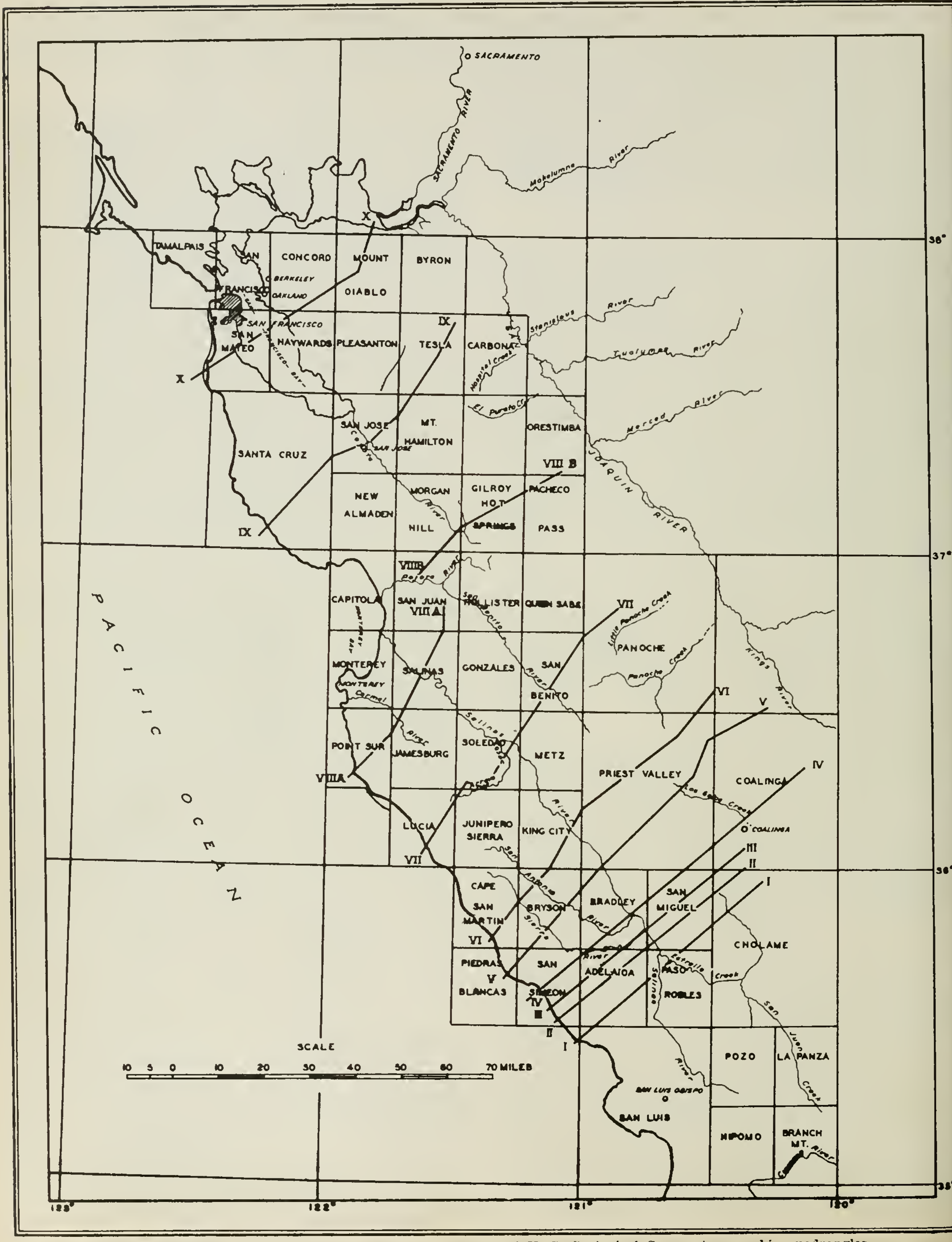

FIG. 57. Map of central Coast Ranges showing location of U. S. Geological Survey topographic quadrangles and position of structure sections.

their present stage of metamorphism long before the close of the Jurassic. They are in a more advanced stage of metamorphism than the Upper Paleozoic rocks of the Sierras.

While no definite statement may be made regarding their age the writer considers that all the available evidence points to their being older than the Upper Paleozoic. They may be Lower Paleozoic or pre-Cambrian or both.

MESOZOIC

FRANCISCAN-UPPER JURASSIC

There are no sediments in the central Coast Ranges older than the Upper Jurassic, other than the crystalline schists previously mentioned. It is possible that sediments older than the Jurassic may have been deposited and subsequently removed by erosion but the writer believes such a supposition extremely unlikely. Metamorphosed Upper Jurassic sediments older than the Franciscan are present in the extreme northern Coast Ranges of California and Triassic sediments are very probably present south of the Transverse Ranges but from regional studies it is believed that the central and much of the northern Coast Ranges as well as a part of the present Pacific Ocean made up a land mass no part of which was submerged below sea level until the deposition of the Franciscan.

The Franciscan consists of a heterogeneous, but rather characteristic, assemblage of shallow marine clastics and chemical and organic sediments of great thickness deposited in a sinking geosynclinal basin which extended the entire length of the Coast Ranges of California and northward into Oregon for an unknown distance. Widespread and extensive volcanism took place, especially in the upper part of the Franciscan, and resulted in the outpouring of pillow basalts and andesites and the intrusion of sills, dikes, and laccoliths of diabase and basalt. At the exposed top of the Franciscan along the west side of the San Joaquin Valley, from the latitude of Tracy almost to Pacheco Pass, there is a very considerable thickness of andesites and dacites with an occasional flow of pillow basalt. These undescribed volcanics, high in the Franciscan, are, as a whole, less basic than the well-known pillow basalts.

Throughout its entire extent the Franciscan may be broadly divided into two parts. The lower part consists largely of arkosic sandstone with very thin and subordinate shale partings with only occasional flows of basalt and few radiolarian cherts. The upper part consists of the same type of sandstone with more numerous dark shale partings and frequent flows of basalt and many lenses of red and green radiolarian chert and an occasional foraminiferal limestone. Thin conglomerates occur in both divisions. The great development of cherts coincides with the beginning of maximum volcanism.

During and after the deposition of the Franciscan there were extensive intrusions of ultrabasic and basic rocks (peridotite, now largely serpentinized, and gabbro and diabase). These were in the form of thick irregular sills, dikes, irregular laccoliths, and plugs. These basic and ultrabasic intrusives caused local pneumatolitic metamorphism and the very erratic development of glaucophane, actinolite and related schists. Such schists are not present in the vicinity of every intrusion; in fact the majority of intrusions produced little or no effect. Furthermore, the size of the intrusion has nothing to do with the extent of the schists formed, as small bodies often caused the formation of more extensive schists than large bodies; only those intrusives having an excess of volatiles caused metamorphism. In practically all cases the schists formed on the roofs of sills, due to the predominant upward movement of the volatiles. Small plugs occasionally caused the development of schist from particular layers, usually sandstone, and schists formed in this manner have been followed for several hundred yards from small plugs; they present the unusual appearance of thoroughly schistose layers interbedded with normal unaltered sediments and having the same dip and strike. Not all of the contact metamorphic rocks of the Franciscan are schistose as many are massive; the degree of schistosity is largely a function of the original bedding. Well-bedded sediments yield recrystallized rocks with marked schistosity and massive rocks such as massive sandstones and basalts yield massive recrystallized rocks. Cherts yield massive quartz-albite-glaucophane rocks in which the constituent minerals have no directional arrangement but the interbedded shales are definitely schistose, the new-formed minerals being parallel to the bedding. Observations in all parts of the Coast Ranges show that the schistosity of the pneumatolitic rocks, when present, is parallel to the original bedding. Although new-formed prismatic minerals, such as glaucophane and actinolite, lie with their long axes in the same general plane they usually have a random arrangement in the plane. These contact schists are not formed in the same manner as the crystalline schists to which the term schist is usually applied. Since these contact rocks are commonly schistose the term may be applied to them without involving the idea of crystallization under shear or pressure. The recrystallization has been brought about by permeation of the original rocks by the volatile and fluid emanations from the ultrabasic magmas and this permeation and the formation of new minerals has been strongly influenced by the bedding planes.

The metamorphism took place in fairly definite stages which may be recognized by careful microscopic work. Different substances were introduced at different times and consequently a fairly definite sequence of new-formed minerals may be recognized. However, sufficient work has not yet been done on the schists as a whole to indicate that there is a definite sequence of introduction of different materials which would hold over wide areas. The substances commonly introduced are Na_2O, MgO, CaO, TiO_2, and Al_2O_3; P_2O_5 and K_2O appear to have been introduced in some cases. A bewildering variety of contact rocks has resulted from the introduction of varying proportions of these substances into a number of different original sedimentary and igneous types.

A large number of occurrences of these contact schists has been seen in which it has been possible to distinguish the original interbeds of sandstone and shale by the nature and particularly the texture of the schist produced. The planes of schistosity have the same attitude as the surrounding unaltered sediments.

The transition along the bedding from unaltered sandstone or shale to a completely recrystallized schist may take place with startling rapidity, sometimes within less than 10 feet. Almost all stages of alteration of sandstones into schists have been seen.

The glaucophane, actinolite and related schists are not evidence of regional metamorphism due to pressure or differential movement but are caused by local pneumatolitic metamorphism brought about by the intrusion of basic and ultrabasic rocks.

The basic and ultrabasic intrusions become thicker and more numerous in the upper part of the Franciscan and in the overlying Upper Jurassic Knoxville owing to the fact that they were intruded during or immediately after the deposition of these beds and that, as they rose, they spread laterally more readily as the weight of the sediments decreased. The serpentine sills experienced all the intricate folding of the Franciscan and Knoxville sediments. Great synclines and broad anticlines of serpentine may be recognized and traced; many of these have been mapped in detail.

The great bulk of the Franciscan sediments is made up of arkosic sandstone of remarkable freshness. More than 200 thin sections of Franciscan sandstone have been examined and, while there are certain broad regional variations recognizable, there is a remarkable similarity in these sandstones throughout the Coast Ranges of California and Oregon. Ordinarily the feldspar content ranges from about 30 to over 60 percent and is predominantly oligoclase-andesine, although more basic varieties are often present. Orthoclase commonly is present, microcline rarely present. Quartz is always present and not infrequently predominates. Many examinations of the heavy minerals have been made and these, like the light minerals, are characteristic of the breakdown of granodiorite and crystalline schists. The individual grains are very angular and universally fresh except in occasional zones of hydrothermal metamorphism. A number of analyses of the sandstones have been made and plotted on various igneous rock diagrams with the result that the sandstone is shown to have the composition of a granodiorite. It is believed that the arkose sandstones were deposited in a shallow marine environment.

The cherts have been adequately described by E. F. Davis. Their constant association with pillow basalts throughout the Coast Ranges as a whole indicates the introduction of silica by volcanism. They are chemical sediments and the radiolaria present are purely accidental inclusions. One of the essential factors for the rapid multiplication of radiolaria was created by the great amount of silica introduced into the sea water.

A regional study of the Franciscan indicates that the clastic material was, for the most part, derived from the west and probably from the same general land mass which contributed to the formation of the Mariposa of the Sierras. No debris of the rock types exposed at present in the Sierras is found in the Franciscan conglomerates. However, it must be remembered that the bedrock complex of the present Sierra Nevada was only exposed after deep denudation and that the unmetamorphosed surface rocks, which probably were shales and sandstones much like those of the Franciscan, could have been removed rapidly. The amount of debris contributed to the Franciscan by the erosion of the unmetamorphosed surface rocks of the rising Sierras is unknown at present and is a question that never may be solved. The evidence at hand, however, indicates that the deeper more metamorphosed rocks, such as those of the present Sierran bedrock complex, were not exposed during the deposition of either the Franciscan or Knoxville. There is, in the central and in the southern part of the northern Coast Ranges a general westward coarsening of the Franciscan sediments and this fact, together with the absence of types now found in the Sierra Nevada, indicates that the chief source lay to the west. Considering all the available evidence the writer believes that much of the Franciscan was derived from a high and rugged terrain, which lay to the west of the present coast line, under rather rigorous climatic conditions, probably heavy precipitation, and a cold climate in the highlands with rather well wooded lower slopes, as shown by the abundance of carbonized wood and plant fragments in the sandstones and shales. Mechanical disintegration clearly predominated over chemical decomposition in the rugged area from which the Franciscan was derived.

The Franciscan was deposited in a sinking geosyncline which formed to the west of the ancient Sierra Nevada, the rocks of which had already been folded and probably intruded by batholitic masses but which was only beginning to rise.

The writer is familiar with the hypothesis of two or more separate basins of deposition for the Franciscan but careful studies have shown a complete lack of evidence for such an hypothesis. There is no coarsening of sediments toward the hypothetical Mesozoic Salinia nor any evidence in the sediments of derivation from such a land mass. The La Panza Mountains may have been an island during the deposition of the Franciscan but there is much evidence against the existence during the Upper Jurassic, of such an hypothetical land mass as Salinia.

There is no foundation for the very general belief that the Franciscan is extensively metamorphosed. As has been pointed out the glaucophane and related schists are due to local pneumatolitic contact action and not to widespread dynamo-thermal metamorphism. They occur in small isolated areas, even smaller than indicated on several published maps. Aside from a few areas which will be mentioned later the Franciscan shows no sign of dynamic alteration. The erroneous belief in the widespread metamorphism of the Franciscan is due to the heterogeneous assemblage which makes up the group and the several periods of comparatively shallow deformation suffered by the rocks. In many places the Franciscan has been intruded by innumerable plugs, sills, dikes and irregular bodies of basic and ultrabasic rocks. During the several periods of folding and faulting that have taken place the sediments have been crushed against these more unyielding masses and an enormous amount of shearing and slickensiding has resulted giving a false impression of metamorphism.

Along the eastern side of the Diablo range the somewhat slaty condition of the shales interbedded with the sandstones is the natural result of the weight of the load of sediments, 25,000 feet of Cretaceous alone, deposited on the Franciscan. Even the Horsetown shales in this region are greatly hardened. Since the bedding of the Franciscan in this region is nearly everywhere parallel to that of the overlying Cretaceous and there is no sign of strong orogeny between the Jurassic and Cretaceous beds in this particular area the slaty nature of the Franciscan shale appears to be the result of simple load metamorphism and depth of burial.

In the northern Coast Ranges there is an area of Franciscan which appears to have been subjected to weak dynamic metamorphism. Folding was strong but far from isoclinal and the slight and imperfect slaty cleavage developed is usually at an angle to the bedding.

There is no justification for the prevailing ideas regarding the widespread metamorphism of the Franciscan.

Another widespread superstition is that there is a lack or great scarcity of Franciscan debris in succeeding formations older than the upper Miocene. It may be stated without question, based on observation and a number of pebble counts, that Franciscan debris is present in varying amounts in all succeeding sediments, with the possible exception of the Eocene.

The age of the Franciscan has been a subject of much debate and much unintentional confusion has been introduced by unjustifiable correlations of the Franciscan with wholly unrelated formations. No discussion of the reported fossils and the various correlations will be presented here as the writer is now engaged in the preparation of a paper on the Franciscan as a whole.

The age of the Mariposa slates has been well established as Kimmeridgian and slightly older (all reported Portlandian and "Tithonian" areas in the Sierras have been studied by the writer and many fossils have been collected, none of which is younger than the Kimmeridgian). In Oregon the Franciscan overlies the Galice unconformably and the Galice, both faunally and lithologically, is the equivalent of the Mariposa. Furthermore the Galice has been converted into slate while the Franciscan is unmetamorphosed. In northern California unmetamorphosed Franciscan occurs in close proximity to Mariposa-Galice slates. The Franciscan is therefore younger than the Kimmeridgian. The writer is convinced that the Franciscan does not extend below Portlandian or at the lowest the upper Kimmeridgian and that it is not a mysterious assemblage of sediments of very uncertain age but may be placed within comparatively narrow age limits. The writer is aware of the implications contained in the above statement with reference to the speed of the late Jurassic Sierran revolution but will discuss this matter more fully in a more appropriate place. The upper limit of the Franciscan will be discussed under the Knoxville.

KNOXVILLE-UPPER JURASSIC

General Statement

The term Knoxville is used here for that part of the old "Knoxville" or "Shasta" group, commonly referred to the Lower Cretaceous, which is now regarded as upper Upper Jurassic and which is separated from the overlying Shasta series by a disconformity which locally becomes a definite angular unconformity.

Perhaps there are few unconformities more frequently mentioned in the literature than that between the Franciscan and the "Knoxville." The writer's early training and a study of the literature strongly impressed on his mind the break between and the great difference in lithology and alteration of these two groups. For 15 years he has searched diligently in the field and has failed to find either the unconformity or the supposed radical difference in character. The only thing which has caused the writer to disregard his early impressions is continued observation in the field and not a preconceived idea or an attempt to fit observations into an hypothesis. The writer's concept of the Franciscan-Knoxville relations, which will be stated here briefly, is based on field observations extending throughout a large part of the Coast Ranges.

The Knoxville, as here defined, and as usually described, consists largely of dark clay shales with abundant gray to black, pure to very impure limestone lenses, numerous thin sandstone beds and an occasional conglomerate. This is an adequate description of the great bulk of the formation but it omits several important elements which are present over wide areas.

Because of its wide distribution on the eastern side of the northern Coast Ranges many of the conclusions reached are based on that area; but fossiliferous Knoxville has been studied at a number of places in the central Coast Ranges and has contributed greatly to an understanding of many obscure relations.

Pillow basalts and volcanic breccias are of widespread occurrence in the lower part of the upper Jurassic Knoxville in both the northern and central Coast Ranges. That the sediments with which the volcanics are interbedded are Knoxville is proved by the presence of typical Knoxville fossils in beds both below and between the pillow basalts and breccias. In a few instances the pillow basalts, which are identical with those in the Franciscan, are associated with radiolarian cherts. Thus, in addition to the ordinary clastics, the Knoxville contains, usually in its lower part, sediments and volcanics which are typical of the Franciscan. Thin sections show that the Knoxville sandstones are identical in character with those of the Franciscan except that they often contain a somewhat greater proportion of clayey material.

In the northern Coast Ranges there is good evidence that the Knoxville may be divided into two parts separated by a disconformity. In places there are lenses of conglomerate in the Knoxville that may be traced for a number of miles that contain debris of both the Franciscan and the underlying lower Knoxville. Upper Jurassic fossils occur in these conglomerates as well as in the beds both above and below. Owing to the intense folding and faulting of the Knoxville in the central Coast Ranges these two divisions have not been recognized, thus far, south of San Francisco. No names have been given to these divisions and it is considered sufficient to refer to them as Lower and Upper Knoxville. When these divisions and their faunas become better known appropriate formational names may be given. It is believed that the slight break observed reflects a mild orogeny to the west. Because of subsequent erosion most, if not all, of the evidence of this orogeny has been removed in the higher parts of the Coast Ranges.

In the Stanley Mountain region, north of the Cuyama River, in the southeastern part of the Nipomo quadrangle a large Knoxville fauna, consisting of a number of genera and species of ammonites, aucellas, and brachiopods, has been obtained from beds which would, without question, be mapped as Franciscan. The Stanley Mountain assemblage consists of dark shales with numerous limestone lenses, typical Franciscan sandstones, more than 1,000 feet of pillow andesites and several hundred feet of red radiolarian cherts. The fossils occur most abundantly in the lower part below the pillow andesite and cherts but a few occur in sediments between flows. These beds are unconformably overlain, with an angular discordance of more than 10 degrees, by conglomerates and sandstones containing a very low Lower Cretaceous fauna. Thus, in this particular locality at least, there is positive evidence that beds having a definite Franciscan lithology, including glaucophane schists, contain a typical Knoxville fauna. This fauna has been called "Tithonian"; if this interpretation is correct the conditions which favored the formation of Franciscan types continued practically to the close of the Jurassic in this region and we have the apparent anomaly of typical upper Knoxville fossils in a distinctive Franciscan lithology. In regions where there were no outpourings of spilitic volcanics at this time the normal fine clastics of the Knoxville were formed.

In the great majority of places the line between what has been called Franciscan and the Knoxville is obscured by the intrusion of serpentine (occasionally passing into a gabbro-diabase-serpentine complex) which ranges up to 2,500 feet and more in thickness. In the few localities thus far observed where this sill is either thin or absent no line can be drawn between the Franciscan and the Knoxville as there are pillow basalts and volcanic breccias in the lower part of fossiliferous Knoxville, and dark shales and sandstones identical with those of the Knoxville well down in what is usually considered to be a distinctive Franciscan assemblage. Thus, only an arbitrary line between the two can be drawn. Should the top of all the beds containing volcanic material be used as the line of division great confusion would be introduced as such a contact would be above typical Knoxville faunas and would, if followed for any distance, transgress time as the volcanic rocks reach various horizons in the Knoxville, being much higher in some places than in others. Neither would it be possible to use the top of the great serpentine sill, referred to previously, as it is very irregular and sometimes rises many thousands of feet into the Knoxville, and as there are a number of other large serpentine sills intrusive into the Knoxville far above the base.

Although the boundary between the Franciscan and the Knoxville is gradational there is a marked difference between the two when both are considered as a whole. The Knoxville is largely made up of shale with lenses of limestone and sandstone and an occasional conglomerate in very different proportions than in the Franciscan. The Franciscan is dominantly coarse clastics and the Knoxville dominantly fine clastics. The essential difference between them, broadly speaking, is not a difference in kind of sediment but in the relative proportion of the different types. Both were deposited in shallow water in the same slowly sinking geosynclinal basin and both were chiefly derived from the same land mass to the west. In a number of regions the Franciscan becomes increasingly shaly in its upper part and, in a few places where the relations may be observed, becomes somewhat finer grained eastward. The writer believes that the gradual wearing down of the source of the detritus making up both the Franciscan and Knoxville resulted in a decrease of coarse clastics and an increase in fine material supplied to the basin of deposition. Broadly speaking, the Franciscan and the Knoxville represent a cycle of deposition in a sinking geosynclinal trough in which not less than 25,000 feet of sediments and volcanics accumulated. Slight interruptions of deposition took place in both the Franciscan and Knoxville as shown by disconformities in both similar to that previously mentioned which separates the lower and upper Knoxville. These disconformities probably reflect uplifts in the source of supply and on the borders of the sinking basin.

The entire sequence may be divided into four parts which merge into each other. There are many local irregularities and overlapping as well as slight breaks within the stages but it is believed that such a division, with all its imperfections and generalizations, will serve a useful purpose and clarify many obscure relationships.

First Stage, Lower Franciscan

Arkose sandstones, representing the rapid, chiefly mechanical, degradation of a recently uplifted rugged land mass to the west, were deposited in a sinking basin between this western land mass and the recently folded ancestral Sierras to the east. That the ancestral Sierras had not yet attained any appreciable elevation is indicated by the absence of any recognizable detritus of eastern origin. Very little volcanism and few chemical or organic sediments.

Second Stage, Upper Franciscan

Beginning of widespread volcanism. Continued deposition of arkose sandstone but with many interdigitations of shale and occasional conglomerates, often containing Franciscan debris and representing minor uplifts in the source of supply and on the borders of the basin. Maximum development of cherts and an occasional foraminiferal limestone. Beginning of the intrusion of basic and ultrabasic rocks.

Third Stage, Upper Franciscan and Lower Knoxville

Continued deposition of coarse and fine clastics with shales becoming more abundant. Waning of volcanism and marked decline in chemical sediments (cherts). Many basic and intermediate flows but chiefly submarine explosions resulting in tuffs and breccias; abundant Knoxville fauna. The third stage is, as a rule, much thinner than the others.

Fourth Stage, Knoxville

Chiefly fine clastics, silts, sandy shales, sandstones, and an occasional conglomerate. Cessation of volcanism and deposition of chemical sediments except in local areas. Continued intrusion of large bodies of ultrabasic and basic rocks which lasted almost to the close of deposition. Abundant Knoxville fauna.

Because of many local variations, such as character of the coast line, elevation of the source of supply, drainage courses, centers of volcanism and slight differences in time of beginning and ending of volcanism in different regions, these divisions cannot be used as definite formations or cartographic units except in local areas. However, it is believed that they give an adequate and comprehensive picture of the usual sequence of events in the Coast Ranges during the closing stages of the Jurassic, in all probability during the Upper Portlandian and "Tithonian" (Aquilonian).

The Knoxville is made up of the same general lithologic types in approximately the same proportions throughout the central and northern Coast Ranges, indicating rather uniform conditions during its deposition. There is nothing in the character or lithology of the Knoxville to indicate deposition in separate basins of deposition. It does not cover large areas in the central Coast Ranges but it is present in a number of widely scattered localities, from the western side of the San Joaquin Valley almost to the Pacific Ocean, including areas within and on the margin of the hypothetical land mass of "Salinia" and throughout this entire region its character and fauna are the same. There is no evidence that "Salinia" had come into existence in the Upper Jurassic. In fact, there is rather definite evidence against this hypothetical land mass until a much later date.

Considering all the available evidence, which has been briefly sketched above, it is believed that both the Franciscan and the Knoxville were deposited in the same general geosynclinal basin and that this basin extended throughout the central and northern Coast Ranges of California and northward into Oregon. This geosyncline lay between a great land mass to the west and the slowly rising Sierran mass to the east. The drainage was chiefly from the west and the bulk of the sediments apparently were derived from that direction. Disturbances occurred in the land mass to the west and on the border of the basin resulting in slight disconformities within both the Franciscan and the Knoxville but no recognizable break occurs between them. Islands or peninsulas may have existed in this sinking basin, especially in the vicinity of the present La Panza Mountains but there is no evidence to support the hypothesis of separate basins of deposition.

The presence of intrusive bodies of serpentine in the Knoxville was first mentioned many years ago but there are still a few who vigorously deny that such intrusive bodies exist and various hypothetical explanations are offered. Such explanations consist in calling the Knoxville sediments, when intruded by serpentine, "Franciscan," or the serpentines, "cold intrusions." Such statements have served only to confuse an already complex problem. The writer has mapped several cold intrusions of serpentine in beds as high as the Miocene but these have no similarity to the great sills and irregular bodies intrusive into Franciscan and Knoxville beds. In a future paper on the Franciscan and Knoxville the writer will present detailed evidence regarding this matter. It is sufficient here to point out the presence of Knoxville fossils below, between, and above folded sills of serpentine, the very irregular sinuous baked contacts and the presence of glaucophane schists clearly derived from fossiliferous Knoxville beds. Such schists have been found in five widely separated localities in the northern and central Coast Ranges, including the type section of the Knoxville. The usual lack of development of glaucophane and related schists on the margins of even large serpentine bodies intruded into the Knoxville is believed to be the result of a loss of volatiles and their utilization as serpentinizing agents during the rise of the ultrabasic magmas high into the thick prism of sediments that had accumulated in the geosyncline.

THE JURASSIC-CRETACEOUS CONTACT: DIABLAN OROGENY

The Jurassic was brought to a close by widespread uplift which affected, in varying degrees of intensity, the entire region of the present Coast Ranges. Along the west side of the Great Valley the emergence was slight but to the west in the central Coast Ranges there are strong overlaps. This disconformity, which locally becomes a distinct unconformity, has been observed in many places in both the northern and central Coast Ranges. Usually the base of the Lower Cretaceous is marked by a basal conglomerate containing debris of the Franciscan and Knoxville, as well as a great variety of older rocks. Granitic debris is only conspicuous in northern California but pebbles of the ubiquitous ancient porphyries so common in most of the conglomerates of Coast Ranges, are abundant. The basal conglomerate is, in some localities, as much as 500 feet in thickness but it is usually much thinner and not uncommonly grades laterally into sandstone or even shale.

In northern California the basal Lower Cretaceous gradually overlaps northward both Knoxville and Franciscan and finally rests on Paleozoic rocks in Tehama County. Because of faulting, there are few normal relations between the Upper Jurassic and Lower Cretaceous along the west side of the San Joaquin Valley but to the west, in the Diablo Range, there are a number of widely scattered localities in which interesting and important relationships may be seen. In the southeastern part of San Benito County, about in the center of the Diablo Range, fossiliferous Lower Cretaceous (Paskenta) sediments rest on typical Franciscan rocks, both igneous and sedimentary, without any intervening Knoxville. However the basal Paskenta conglomerate contains abundant debris of the Knoxville, much of it little rounded, indicating that Knoxville sediments had been present in this region. To the southwest, east of Priest and Waltham Valleys, fossiliferous basal Lower Cretaceous conglomerate rests, without angular discordance, on fossiliferous Knoxville shales, limestones and sandstones. In this region the basal Cretaceous conglomerate usually is thin but in several localities, which appear to have been low headlands extending into the encroaching Lower Cretaceous sea, there are conglomerates, or rather breccias, containing blocks of Knoxville sediments and diabase and gabbro intrusive into the Knoxville, up to 5 feet in diameter. Both the Upper Jurassic Knoxville and the Lower Cretaceous Paskenta sediments are vertical in this region and there is no noticeable angular discordance. Both are abundantly fossiliferous; the fauna in the conglomerate indicates that it represents a very low stage in the Lower Cretaceous.

To the southwest in the Santa Lucia Range, in northern San Luis Obispo County, the Knoxville and Lower Cretaceous, both greatly folded and faulted, lie in a syncline along the crest and west side of the range. On the western side of the syncline basal Lower Cretaceous conglomerates rest on Knoxville shales and on the eastern side on typical Franciscan cherts, sandstones, and basic and ultrabasic intrusives. Thus there is evidence of uplift, resulting in erosion of the Knoxville, in both the Diablo and Santa Lucia Ranges at the close of the Jurassic.

No intrusions of basic and ultrabasic rocks have been found in the Lower Cretaceous above the Upper Jurassic-Lower Cretaceous interval nor are there any contemporaneous flows of pillow lavas such as those in the lower part of the Knoxville. In fact the basal Lower Cretaceous conglomerates contain rather abundant debris of these intrusive and extrusive rocks so common in the Franciscan and Knoxville.

The conclusions reached regarding the nature of the diastrophism which occurred at the close of the Jurassic are necessarily based on relatively small, widely scattered localities. Many periods of diastrophism have occurred in the central Coast Ranges since the deposition of the Lower Cretaceous and much of the evidence has been removed by erosion or by burial beneath younger beds. However since all of the evidence that has been gathered is consistent and points in the same general direction it is believed that the conclusions are reasonable.

In the very late Upper Jurassic the entire Coast Ranges were uplifted and locally warped. No strongly folded mountains were formed, but parts of the Diablo and Santa Lucia Ranges were brought above sea level and eroded. The basins between these warps were only slightly disturbed and probably rose but little above sea level. The upwarping in the Diablo Range may have been in part accomplished by the intrusion of thick sills of ultrabasic rock but the extent to which these thick intrusions caused uplift is difficult to estimate. It is believed that the greater part of the uplift was caused by compressive stresses but the possibility of local uplift by intrusion can not be ignored.

The uplift and broad warping at the end of the Jurassic were more severe and widespread than any of the disturbances during the deposition of the Franciscan and Knoxville. However the geosyncline in which the late Upper Jurassic beds were deposited was not obliterated or even fragmented by the very late Upper Jurassic diastrophism, and widespread deposition and down-sinking continued through the Lower Cretaceous. The Lower Cretaceous sediments are practically identical, lithologically, with those deposited in upper Knoxville time. The major axis of the geosyncline may have been shifted slightly eastward but the evidence is by no means conclusive.

The diastrophism which closed the Jurassic must have occupied a comparatively short interval of time since the upper Knoxville contains a very late Upper Jurassic fauna and the basal Lower Cretaceous conglomerate represents a very low stage in the Lower Cretaceous.

The diastrophism which closed the Jurassic was much stronger and more widespread than has been recognized heretofore. It was especially severe in the Diablo Range and for this reason the writer proposes the name Diablan for this orogenic event.

CRETACEOUS

General Statement

Cretaceous sediments of great thickness and probably representing all known stages from the lowest to the highest were deposited over a very large part of the Coast Ranges and, in the Upper Cretaceous, on the flanks of the Sierra Nevada. More than 50,000 feet of Cretaceous sediments accumulated but because of shifting basins of deposition and unconformities the maximum thickness of any one section rarely exceeds 30,000 feet.

These sediments were deposited in very shallow water in sinking basins. The greatest accumulation in both the northern and central Coast Ranges took place in a long, probably continuous but far from uniform trough which lay along the western border of the Great Valley. Great floods of detritus from an eastern source first appeared during the deposition of this thick prism of shallow-water sediments. The time of the first appearance of large quantities of Sierran detritus is not known with certainty but it seems to have been in the Upper Cretaceous.

The Cretaceous as a whole consists of thick monotonous sequences of arkose sandstones, conglomerates, sandy shales and thin impure limestones; organic shales are abundant only in one formation, the Moreno, high in the Upper Cretaceous. Although there are many local variations the lower part consists predominantly of shale and the upper part of sandstone and sandy shale. Contemporaneous volcanism was practically nonexistent during the accumulation of this thickness of clastics but very minor and unimportant submarine explosions occurred locally in the lower part of the Lower Cretaceous and the upper part of the Upper Cretaceous. As previously reported by the writer there are thin bentonite beds and impure cherts in the Moreno formation in Hospital Canyon in southwestern San Joaquin County and ash beds in the Lower Cretaceous (Paskenta) southwest of Parkfield and to the south of Orchard Peak in western Kings County. As far as is known these thin beds constitute the only record of contemporaneous submarine volcanism during the Cretaceous.

A well-known and very troublesome characteristic of the Cretaceous, particularly of the Upper Cretaceous, is the rapid lateral variation in lithology. This feature, together with a frequent lack or scarcity of fossils, causes difficulty in separating the sediments into cartographic units that may be followed for any distance.

A broad and comprehensive treatment of the Cretaceous as a whole and its division into units, based on physical discontinuities and characterized by distinct faunas, is difficult because there is so little known regarding the faunas and their correlation. The Cretaceous is abundantly fossiliferous in some localities but there are great thicknesses and large areas which have yielded faunas so scanty as to be of little value. So many formational, group, and series names have been used, often with a bewildering variety of meanings that the task of reconciling them seems almost hopeless. From a regional study of the Cretaceous in both the northern and central Coast Ranges it is clear that the Cretaceous is, throughout the Coast Ranges, divisible into two units separated by a major physical break. In parts of the central Coast Ranges there is definite evidence of two major physical breaks but, chiefly because of a lack of positive information in several areas, these breaks in sedimentation have not been recognized everywhere in the region. Evidence obtained in the Santa Lucia Range, in parts of the Diablo Range and on the west side of the San Joaquin Valley indicates that a three-fold division may be made, based on definite physical disturbances. In the Santa Lucia Range these disturbances were strong and resulted in folding and faulting and in angular discordance of as much as 80 degrees; the disturbances decreased in magnitude eastward toward the center of the basin of deposition where they are represented by disconformities only. Unquestionably there were more than two periods of disturbance during the Cretaceous but, from the evidence obtained thus far, most of these were local. The two major diastrophisms, resulting in the three-fold division, seem to have been general and to have affected at least a large part of the central Coast Ranges, and probably the Coast Ranges as a whole, but in varying degree. However since the evidence is not clear in all localities, chiefly because of a lack of definite information, this proposed division may be regarded as chiefly for the purpose of presenting a somewhat simplified account of the many events which resulted in the accumulation of such a great volume of sediments.

During the Cretaceous the extensive Upper Jurassic geosyncline, in which were deposited the Franciscan and Knoxville, became restricted and finally separated into smaller basins of deposition. Also during the Cretaceous the ancient Sierras were deeply eroded and contributed large volumes of sediment to the Upper Cretaceous basins.

The three proposed divisions and the diastrophic events separating them will be discussed and a brief statement made regarding their character and extent.

Lower Cretaceous-Shasta Group

The lowest division of the Cretaceous, the Shasta group, is thickest and best developed in northern California where it lies in a long north-south belt west of the Sacramento Valley and in small areas as far west as the Pacific Ocean. In the central Coast Ranges it is found in many widely scattered localities from the San Joaquin Valley to within less than 3 miles of the Pacific Ocean and from the Berkeley Hills to Santa Barbara County. The writer has collected Shasta fossils in the Santa Cruz Mountains and in the Diablo, Santa Lucia, Mount Hamilton and San Rafael Ranges. The distribution of the Shasta in the central Coast Ranges coincides with the distribution of both the Franciscan and the Knoxville and, notwithstanding the disconformity (locally an unconformity) at the base of the Shasta, it seems to have been deposited in essentially the same geosynclinal trough as the Franciscan and Knoxville and to have had the same wide distribution. Additional evidence for its continuous deposition over a wide area is its rather uniform lithologic character and the nature of its fauna in all of the widely scattered localities in which it is found in the central Coast Ranges. The hypothetical land mass of Salinia had not yet come into existence as there are thick Lower Cretaceous sections over the northwestern part of the area supposed to lie within this land mass and even thicker sections of shales along its eastern border and even on its eastern edge.

The Shasta group in the northern Coast Ranges has a maximum thickness of over 20,000 feet. Because of folding and faulting in the central Coast Ranges its maximum thickness is not known but in some localities it is more than 5,000 feet thick.

The Shasta group consists chiefly of shale but there are frequent interdigitations of sandstone and impure limestone; conglomerates are present at the base and occasionally in higher parts of the section. Lithologically it is practically identical with the sediments of the upper part of the Knoxville but faunally the two are distinct. No basic or ultrabasic rocks, similar to those in the Franciscan and Knoxville have been found intruding the Shasta. In fact the basal Shasta conglomerate contains, in some localities, fairly abundant debris of these igneous rocks.

In northern California the Shasta has been divided into two units, the Paskenta (lower Shasta) and the Horsetown (upper Shasta), each said to be characterized by distinct faunas. Lithologically the two are similar if not identical, the contact is gradational, and it is very difficult to draw a satisfactory contact between them in the field. Until the faunas have been more thoroughly studied and described and the relations between them more fully understood, it seems more appropriate to consider them as faunal stages rather than distinct formations. With our present limited knowledge of these sediments there is no justification in giving either the Paskenta or Horsetown the status of a group.

The Lower Cretaceous (Shasta group) of the central Coast Ranges is chiefly represented by the Paskenta stage, although Horsetown fossils have been found in a few places, especially on the east side of the Diablo Range. No definite conclusion may be reached at present regarding the absence of known Horsetown over large parts of the central Coast Ranges, but the writer is inclined to the belief that it is due to subsequent erosion rather than to nondeposition.

The Shasta has been stated to be the equivalent of the Infravalanginian, Valanginian, Hauterivian, Barremian, Aptian, and a part of the Albian and therefore to represent practically all of Lower Cretaceous time. (There is no general agreement among various authors as to the exact limits of Lower Cretaceous in terms of the European section.) The writer has no reason to question the validity of this correlation but he simply wishes to point out that if this is true very little time is allowed for the marked diastrophic events which ended the Shasta, as the succeeding "Chico series" is supposed to extend continuously from the upper part of the Albian through the Cenomanian and Turonian. The extensive and important diastrophism which ended the Shasta and caused many important changes in basins of deposition therefore would be limited to a small fraction of the Albian. This appears to be another example of the relative rapidity of diastrophism as compared with deposition.

Mid-Cretaceous Disturbance

Although there may be some uncertainty as to the exact time, with reference to the European section, at which the events that ended the Shasta deposition took place there can be no uncertainty regarding the fact that such an event actually occurred or that it was of importance and affected the Coast Ranges as a whole. Everywhere there is either a definite disconformity or a strong unconformity or overlap between the Shasta and the next succeeding Cretaceous sediments. In some localities in the central Coast Ranges, especially in the Santa Lucia Range, there is evidence of deep erosion and profound overlaps. In many places a distinct change in type of sediments naturally resulted and we find a slight general coarsening of the sediments brought about by uplift on the borders of and within the Lower Cretaceous geosyncline. Thus this disturbance not only affected the borders but also resulted in fragmentation of the formerly extensive Lower Cretaceous geosyncline.

As in the case of the Diablan orogeny the mid-Cretaceous disturbance was strongest in the Santa Lucia and Diablo Ranges which were uplifted and partially stripped of their Upper Jurassic and Lower Cretaceous cover. Certain parts of the Lower Cretaceous basin appear to have been little disturbed, as for example along the eastern side of the Diablo Range, in San Joaquin, Stanislaus, and Merced Counties, where lower Upper Cretaceous beds rest disconformably on the Horsetown stage of the Lower Cretaceous. A part of the present Gabilan Range appears to have risen and been extensively stripped at this time. Evidence for this is the character of the Upper Cretaceous beds northeast of Waltham Creek and Priest Valley where heavy Upper Cretaceous conglomerates rest unconformably on Lower Cretaceous shales. These heavy conglomerates rapidly thin and become finer grained eastward. The cobbles and boulders are largely made up of basement complex rocks. Thus a part of "Salinia" emerged at this time but the part that was emergent was only a fraction of the hypothetical "Salinia" as the northwestern part was submerged as shown by thick sections of Upper Cretaceous sediments.

Upper Cretaceous

General Statement

The Upper Cretaceous is divisible into two parts separated by a strong orogenic disturbance. Owing to the lack of satisfactory faunas in many places it is not always possible to distinguish between these divisions everywhere and, consequently, it is not always possible to separate the effects of the mid-Cretaceous disturbance from that which occurred in the Upper Cretaceous, probably between the Turonian and the Coniacian. However, there is sufficient evidence to show that there are two well-defined divisions in the Upper Cretaceous separated by an orogenic period and that the uppermost Cretaceous division is more widely distributed in the central Coast Ranges than the lower.

Although there is much that is yet unknown regarding the distribution and faunas of these two divisions of the Upper Cretaceous, enough is now known to enable us to obtain a reasonable picture of their general distribution. It is believed that a recognition of these two divisions and the events which separated them will be of great value in an interpretation of the complex history of the Coast Ranges. Since they have widely different distributions and since they are separated by an important disturbance each should be distinguished by a definite name. The writer dislikes to add a new group name to an already overburdened literature but when the present confused state of the nomenclature of the Upper Cretaceous and the variety of ways in which many of the names have been used is considered it is believed that the introduction of new terms will serve a useful purpose.

The writer does not intend to trace the history of the nomenclature of the Upper Cretaceous but he wishes to point out certain objections to the current terms. For many years the Upper Cretaceous was known practically everywhere in the Coast Ranges as the Chico although it was frequently recognized that the various occurrences were not always equivalent to the Chico Creek section in Butte County. In many case the symbol Kc on a geologic map included not only what was then recognized as Chico, but Lower Cretaceous as well. In 1915 the term Panoche was introduced for the Cretaceous along the west side of the San Joaquin Valley north of Coalinga. Later work has shown that the Panoche, as mapped at that time, includes Knoxville, Paskenta, and Horsetown, and extends across several disconformities. Recently the term Chico series has been used to include all the Upper Cretaceous and the Panoche as the upper group of this series. This usage is unfortunate, as it makes the Chico include beds separated by a disconformity which locally becomes a pronounced unconformity. Much as the writer would like to continue the use of the old term "Chico" he feels that its use would only be a source of confusion because of the variety of ways in which it has been used.

The writer is greatly indebted to Dr. Willis P. Popenoe for valuable information regarding the faunas of the Upper Cretaceous and wishes to quote from a letter from Dr. Popenoe, dated February 17, 1940.

"To sum up, the evidence on hand suggests that there are probably four and possibly more distinct major faunal divisions in the California Upper Cretaceous, considering the bulk aspects of the complete faunas. It is not yet possible to say if these faunal divisions may be grouped into two larger assemblages corresponding to your middle and upper Cretaceous divisions, but it may be considered likely, in view of the profound unconformities you find in the Santa Lucia range. In regard to the use of Chico as the name for your middle division, your doubts are similar to my own. I had also considered using the term as a stage name, but feel as you do that it has been applied in so many different senses that it would be well to avoid using it if it is practicable to do so. According to my present idea, your middle division in the Coast Ranges probably includes beds considerably older than any found at Chico Creek, and probably also considerably different faunally. A suitable name for your middle division might be taken from the Santa Ana Mountains region or from Redding, but one selected from the central Coast Ranges in which you have been working would under the circumstances probably be more appropriate."

Because of the reasons mentioned above the writer believes it desirable to propose new group terms for the divisions of the Upper Cretaceous and a name for the orogenic event separating them. The proposed divisions of the Cretaceous are as follows:

Upper Cretaceous	Asuncion group
	Santa Lucian orogeny
	Pacheco group
	Mid-Cretaceous disturbance
Lower Cretaceous	Shasta group
	Diablan orogeny
Upper Jurassic	Franciscan and Knoxville

Pacheco Group

The name Pacheco is suggested for the lower division of the Upper Cretaceous because of the development of these beds on the Pacheco Pass quadrangle, especially on Quinto and Garzas Creeks where they are separated from the underlying Horsetown stage of the Lower Cretaceous and the overlying Asuncion group by disconformities. In this region the Pacheco consists of 7,000 to 8,000 feet of gray sandy shales, sandstones, and conglomerates which are either vertical or dip eastward at high angles. .These beds are not confined to the Pacheco Pass quadrangle but extend both to the north and south as a continuous belt. They also occur to the west of this belt on El Puerto Creek in western Stanislaus County in a down-faulted syncline.

The Pacheco group is less widely distributed in the central Coast Ranges than the Asuncion group but the reverse may be the case in the northern Coast Ranges. Beds equivalent to the Pacheco occur in the Santa Lucia Range, in the central part of the Adelaida quadrangle, where they are overlain with an angular unconformity of as much as 80 degrees by beds equivalent to the Asuncion. In the southern part of the Diablo Range, Pacheco beds containing Cenomanian fossils rest directly on the Franciscan southwest of Hernandez, but to the north they rest on Paskenta sediments. To the south, east of Priest Valley and Waltham Creek, thick Pacheco conglomerates, grading upward into sandstones and shales, rest unconformably on Paskenta, Knoxville, and Franciscan in turn. No unconformity between the Pacheco and Asuncion has been discovered in this locality, but one probably exists, as in the eastern part of the Priest Valley quadrangle, in the heart of the Coalinga anticline, Asuncion sediments rest directly on Franciscan sediments and serpentine. Thus the Pacheco sediments which lie on the west flank of the White Creek syncline, east of Priest Valley and Waltham Creek, do not reappear on the east flank of this syncline, which locally forms the west flank of the Coalinga anticline.

In San Luis Obispo County, in the Nipomo and Branch Mountain quadrangles, both divisions of the Upper Cretaceous are represented but thus far the relations between them have not been determined.

In the Orchard Peak quadrangle the meager faunas that have been obtained indicate that the Pacheco is absent and that the Asuncion lies unconformably on the Shasta. To the northwest Pacheco sediments make their appearance.

In the southern part of the Santa Lucia Range beds thought to be equivalent to the Pacheco are widely distributed in comparatively small individual areas and are always unconformably overlain by the Asuncion group; the angular unconformity is as much as 80 degrees. Even where the angular unconformity is not great the Pacheco sediments are overlapped by the Asuncion sediments which have a much wider distribution. In the Santa Lucia Range the Pacheco sediments are similar lithologically to those along the west side of the San Joaquin Valley; they consist of gray and black clay shales, often with lenses of shaly limestone, sandstones, and conglomerate, but the average thickness in the various individual areas is less than 1,000 feet. The maximum original thickness in this region is unknown as the beds were deeply eroded during the Santa Lucian orogeny.

The great bulk of the Pacheco sediments along the west side of the San Joaquin Valley and in the Santa Lucia Range are silty in nature and indicate derivation from a comparatively low land mass. The only very coarse Pacheco sediments occur east of Priest Valley and Waltham Canyon, indicating that the Gabilan mesa may have been above sea level at this time. Shales predominate but there are thick lenses of sandstone and conglomerate. Most of the conglomerates in the Pacheco of the Santa Lucia Range are somewhat unusual as they consist of small well-rounded and highly polished pebbles in a silt matrix. The polish, which is unusually high, is like that ordinarily ascribed to wind action. However the writer regards the polish as the result of abrasion by fine silts on broad tidal flats where the materials were constantly shifted by the tides. In the Santa Lucia Range the maximum exposed thickness of the Pacheco is about 4,000 feet.

Pacheco beds are not known to occur in the northern part of the Santa Lucia Range or in the western part of the Santa Cruz Mountains but it is possible that additional work may show them to be present.

The exact limits of the Pacheco group, in terms of the European divisions are not known with certainty but it is thought to be equivalent to the Upper Albian, the Cenomanian and the Turonian. According to Mr. Allen P. Bennison, Turonian fossils occur in boulders in conglomerates on Quinto Creek which the writer regards as basal Asuncion.

With our present limited knowledge it is impossible to make any very positive statement regarding the basins in which the Pacheco was deposited because so much of the evidence has been removed by erosion, even more than in the case of the Upper Jurassic and Lower Cretaceous. It is certain that a long and probably continuous basin existed along the east side of the Diablo Range and the west side of the San Joaquin Valley. Neither the eastern nor western limits of this basin are known but it probably covered much of the present Diablo Range. The ancestral Coalinga anticline stood either as an island in or a peninsula extending northwestward into this basin; other islands or peninsulas may have existed but of this there is no present evidence. This same basin continued, probably without interruption, into the region on the east flank of the northern Coast Ranges and the west side of the Sacramento Valley. Another basin, probably separated from the long trough just mentioned, extends through northern Santa Barbara, San Luis Obispo, and Monterey Counties. These may have been separated by the present Gabilan Range which rose for the first time at the close of Shasta deposition.

Santa Lucian Orogeny

For the period of folding, uplift, and erosion between the Pacheco and Asuncion groups the writer proposes the name Santa Lucian because of the exposures of the unconformity and the wide overlaps in the Santa Lucia Range. It is not always possible to distinguish between the effects of this orogeny and the mid-Cretaceous disturbance, especially in regions where the Asuncion only is present. It is known that there was strong folding, uplift, and erosion between the Pacheco and the Asuncion but where the Asuncion overlaps onto older rocks, as is frequently the case, it is difficult, if not impossible, to determine which disturbance caused the uplift. Considering the marked unconformity between the two in the southern Santa Lucia Range it is thought that much of the disturbance came in the Upper Cretaceous, after the Pacheco.

The Santa Lucian orogeny was strongest in the Santa Lucia Range and died out eastward until, on the west side of the San Joaquin Valley, there is no angular discordance between the two Upper Cretaceous divisions north of Panoche Creek. However, that there was uplift and erosion is shown by the presence of fossiliferous Pacheco boulders in the basal conglomerate of the Asuncion.

As a result of this orogeny the Gabilan mesa rose for the first time but whether by definite faulting or gentle upwarping is not known. The northern part of the Santa Lucia Range was so strongly uplifted that the Lower Cretaceous and Upper Jurassic beds were stripped off completely in many places and Asuncion sediments frequently rest directly on the basement complex.

Asuncion Group

The name is taken from the Asuncion Grant in the southeastern part of the Adelaida quadrangle where there are good exposures of these Upper Cretaceous sediments, resting unconformably on both Franciscan and Pacheco. Fossils occur in sandstones along the road east of Asuncion school and in Dover Canyon but they are not as abundant as in other parts of the southern Santa Lucia Range. Thicker and more complete sections occur in many other places, especially in the vicinity of Bryson and on the Nacimiento River. Either of these would be more appropriate names, but both are preempted. The Asuncion group consists of over 10,000 feet of coarse conglomerates, sandstones, and shales which, in the Santa Lucia Range, overlie Pacheco sediments with strong unconformity and overlap onto all of the older rocks, Shasta, Knoxville, Franciscan and basement complex. It contains a late Cretaceous fauna equivalent to that found in the restricted Panoche, Moreno, and Garzas on the west side of the San Joaquin Valley. In the central Coast Ranges it attains a far wider distribution than either the Shasta or Pacheco groups; the majority of the beds previously mapped in this region as "Chico" belong to this group. In the southern Santa Lucia Range it has been divided into the Cantinas sandstones, the Godfrey shales and the Piedras Altas formation.

The name Asuncion group is used to include all of the upper Upper Cretaceous beds in the central Coast Ranges above the Pacheco. At present it is not possible to give the exact distribution of these two Upper Cretaceous groups everywhere or to delineate the exact location of the basins in which they were deposited but it is possible to separate them over a fairly large part of the central Coast Ranges. The physical, and easily observable, fact of the pronounced unconformity between them in many places and the difference in their geographic distribution is sufficient justification for their separation. The names here proposed are tentative; other names might be equally suitable and if it is found that any of the older names can be redefined and used without confusion they should be adopted. The two new group names are proposed for convenience of discussion and for the purpose of emphasizing a very important diastrophic episode in the history of the Coast Ranges. Any names proposed in the future must take cognizance of this important event.

The name "Panoche formation" was first used in 1915 as the lower division of the "Chico group" and the type section given as the Panoche Hills in western Fresno County. As originally mapped and defined the Panoche formation includes not only a part of the present Asuncion group and all of the Pacheco group but also Shasta and Knoxville. Hence it is believed that its use as a group name would only lead to confusion. The Panoche formation should be used for the sediments, chiefly sandstones, above the Pacheco and below the Moreno.

On the west side of the San Joaquin Valley, from Coalinga to the Mount Diablo region, the Asuncion group can be divided into three, and possibly four, formations. The lower two-thirds or more, the restricted Panoche formation, consists of conglomerates and arkosic sandstones with thin intercalations of sandy and carbonaceous clay shale grading up into the organic shales of the Moreno which in turn grade upward into the sands and silts of the Garzas. Although there appear to have been local interruptions in sedimentation, especially within the Moreno, the contacts are gradational and the group as a whole seems to have been the result of continuous, or almost continuous, sedimentation. Future work may show the advisability of creating a still higher group in the Upper Cretaceous but thus far the writer has been unable to discover any widespread physical break within the Asuncion group that would justify such a division. Occasional pholas-bored zones occur in the Moreno formation but they appear to be local and are not confined to any one horizon. They could be caused by local basin filling in excess of sinking as well as by uplift.

There is great lateral variation in these sediments and it is not always possible accurately to trace the contacts between the various formations; this is particularly true of the gradational contact between the restricted Panoche and the Moreno. It is probable that this contact, as mapped north of Coalinga, frequently transgresses time from place to place, especially near the mouths of Upper Cretaceous streams where sands, identical with the Panoche, were deposited at the same time as shales identical with the Moreno were being deposited elsewhere. However in spite of such lateral variations Panoche and Moreno are useful lithologic divisions which can be followed from Coalinga northward to the Mount Diablo region. The Garzas may be equally extensive but it is only locally exposed because of overlap by Tertiary sediments and alluvium. When followed westward about the north end of the Coalinga anticline the Moreno becomes sandier and less organic and finally loses its distinctive appearance. The lithologic divisions so distinctive along the west side of the San Joaquin Valley can not be recognized within and to the west of the Diablo Range and new divisions must be made.

The maximum thickness of the Asuncion group on the west side of the San Joaquin Valley north of Coalinga is 17,000 to 18,000 feet but there are noteworthy variations in thickness due both to original thinning and late faulting. The most striking example of local thinning caused by an initial irregularity in the basin of deposition occurs in the vicinity of New Idria, on the northeast flank of the Coalinga anticline which is here made up of Franciscan sediments and volcanics intruded by a thick sill of serpentine. These rocks, which are folded into a broad but steep-sided dome, are overlain on all sides by steeply dipping Asuncion sediments. In the vicinity of New Idria the contact is a thrust fault which dips steeply southwest but along most of the contact, which measures more than 25 miles, the Asuncion sediments rest unconformably either on Franciscan sediments or serpentine, without any intervening Pacheco, and the basal beds frequently contain abundant debris of the underlying rocks. The thinning in the vicinity of New Idria is not due to the faulting but to the presence of a submerged bank in the basin of deposition; all formations are present and all are greatly thinned. This part of the Coalinga anticline was uplifted and broadly arched prior to the deposition of the Pacheco and probably stood out as a low island during that time and the beginning of the deposition of the Asuncion; it was finally submerged and covered with sediments during Asuncion time. In northwestern Stanislaus County, west of Ingram Creek, the Mount Oso anticline causes a local thinning in the Panoche sandstones but not in the Moreno shales. This appears to have been another irregularity in the Upper Cretaceous sea. The buttressing effect of the Cretaceous Mount Oso anticline had a pronounced influence on the structures formed in the late Tertiary.

The exact limits of the Asuncion group, in terms of the European section, are not known but the group is believed to represent all of Cretaceous time after the Turonian. However the Upper Cretaceous faunas will have to be better known before a definite statement can be made. That the Cretaceous section along the west side of the San Joaquin Valley north of Coalinga contains the latest known stages of the Upper Cretaceous is indicated by the faunas of the Garzas beds and especially by the saurian remains. According to Professor C. L. Camp a recently discovered Garzas mososaur shows more advanced features than the Maestrichtian mososaurs of Belgium or a mososaur from the Moreno. Thus it is possible that the Garzas beds represent the Danian. The writer simply offers this as a suggestion as he is aware that the Maestrichtian and Danian are not found in the same locality in Europe and that there has been a long controversy regarding the relation of these two uppermost stages of the Cretaceous and that the inclusion of the Danian in the Cretaceous has been questioned.

It is not certain that the Asuncion group in the Santa Lucia Range and elsewhere is equivalent to all of the time represented by the Asuncion group north of Coalinga. However the faunas of the Santa Lucia Asuncion are known to represent restricted Panoche, Moreno, and Garzas.

In the Orchard Peak region, in the northwestern corner of Kern County, the slight evidence available indicates that Asuncion sediments overlie the Lower Cretaceous Shasta without any intervening Pacheco. However to the northward, in the wide Castle Mountain syncline, it is believed that both the Pacheco and Asuncion are present.

Both divisions of the Upper Cretaceous are represented in the thick and widely distributed sediments which extend northwestward through Santa Barbara and San Luis Obispo Counties, but at present the relative proportions of the two and the relations between them are not known. Southwest of La Panza Mountains about 3,000 feet of Upper Cretaceous sandstones and conglomerates rest unconformably on a much thicker section of Upper Cretaceous sandstones and shales but as the faunas from this region are so meager it is impossible to make any statement regarding the position of this unconformity in the Upper Cretaceous.

Little is known regarding the position in the Upper Cretaceous of the beds in the Santa Cruz Mountains but the meager fauna reported from the sediments extending along the coast from Pescadero Point to Año Nuevo Point indicates that they are to be correlated with the Asuncion group.

The La Panza Mountains-Gabilan Range region was probably partly emergent during the deposition of the Asuncion but the emergent area does not correspond to the hypothetical land mass of Salinia as there are thick Upper Cretaceous sediments along the western part and well into the area supposed to have been included in "Salinia." The very thick Asuncion sections and the fact that so much of the sediments are shales in the latitude of Paso Robles and to the southeast of Parkfield indicate that the southern part of the Gabilan mesa was submerged. The northern part of Gabilan mesa and possibly a part of Diablo Range were emergent and contributed debris both to the east and west.

In the Santa Lucia Range, Asuncion sediments rest unconformably on practically all earlier rocks and frequently overlap onto the basement complex. In the northern part of the Cape San Martin quadrangle, Asuncion fossils have been found close to the base of sandstones and conglomerates resting directly on and containing abundant debris of Sur metamorphics and granodiorite. In the same range, in northern San Luis Obispo and southern Monterey Counties there is a definite westward coarsening of the Asuncion. Near the coast, in the vicinity of San Simeon, Asuncion beds, with a thick basal conglomerate containing abundant boulders of Franciscan sandstones and volcanics up to 5 feet in diameter, rest on the Franciscan with strong (45 degree) unconformity. Eastward near the crest of the range Asuncion sediments rest unconformably on Franciscan, Shasta, and Pacheco with only a thin basal conglomerate and a greater proportion of shales. In the northern part of the Santa Lucia Range there appears to be a slight coarsening toward the northeast and here the Asuncion sediments may have been derived from the emergent northern part of the Gabilan mesa.

In general the Asuncion group has a much wider distribution in the central Coast Ranges than the Pacheco. It is quite possible that the original distribution of the Pacheco was as great as that of the Asuncion and that a large part was removed as a result of the Santa Lucia orogeny.

Thus far it has been impossible to correlate either the Pacheco or Asuncion groups with the sediments at the type section of the Chico, on Chico Creek, Butte County, on the east side of the Sacramento Valley. About 2,000 feet of sediments are exposed on Chico Creek and there are said to be 12 fossiliferous horizons distributed almost from top to bottom. These sediments rest on highly metamorphosed Sierrán bed rock and dip gently westward. Considering the very fossiliferous character of these beds it is strange that a more positive correlation with Upper Cretaceous sediments in other parts of the State has not been made. The faunas seem to be more closely related to the Pacheco than the Asuncion but there are some forms which are characteristic of the latter. This locality is more than 125 miles from any occurrence of either Pacheco or Asuncion sediments, as defined previously, and this might account for the difference in the faunas. Although it is admitted that there is no very positive evidence on the subject the writer is inclined to the belief that the sediments on Chico and adjacent creeks, the type section of the Chico, represent parts of both the Pacheco and the Asuncion groups. The Chico Creek beds were deposited on the margin of the Upper Cretaceous basin, on the rigid Sierran basement, where great thinning of the entire section would be expected, and in a region unaffected by the Santa Lucian orogeny.

SUMMARY OF THE MESOZOIC

The Franciscan and Knoxville sediments were deposited in an almost continuously sinking geosyncline which covered most if not all of the central Coast Ranges. There is no unconformity between Franciscan and Knoxville, and Knoxville fossils have been found in beds having a Franciscan lithologic assemblage. The geosyncline in which these beds accumulated was developed between the rising ancestral Sierra Nevada on the east and a land mass which lay west of the present coast line. Both were chiefly derived from the west. The Franciscan is later than the Mariposa of the Sierra Nevada, the extreme northern Coast Ranges, and Oregon. Franciscan and Mariposa are not in contact in the central Coast Ranges but in northern California and southwestern Oregon unmetamorphosed Franciscan lies unconformably on metamorphosed Galice (Mariposa).

Following the deposition of the Knoxville and occupying but a brief period of geologic time was the Diablan orogeny which affected the Coast Ranges as a whole but which was strongest in the Diablo and Santa Lucia Ranges where the Franciscan and Knoxville were uplifted and eroded prior to the deposition of the Lower Cretaceous. In spite of this uplift, the Lower Cretaceous (Shasta group) was deposited in practically the same geosyncline as the Franciscan and Knoxville and had about the same distribution.

The Lower Cretaceous (Shasta) was brought to a close by the mid-Cretaceous disturbance which fragmented the geosyncline in which the Franciscan, Knoxville, and Shasta were deposited, and formed separate basins of deposition separated by uplifted areas. Like the preceding Diablan orogeny this diastrophism was strongest in the Diablo and Santa Lucia Ranges and in the Gabilan mesa. The sediments deposited after this disturbance are called the Pacheco group from their wide distribution in the quadrangle of that name. Although the evidence is not entirely satisfactory they are thought to represent Cenomanian and Turonian time.

Following the deposition of the Pacheco sediments was another orogenic period which is called Santa Lucian from its development in the range of that name. Strong folding and erosion occurred in the Santa Lucia Range and in the southern part of the Diablo Range. This orogeny was followed by a very general submergence which depressed below sea-level most if not all of both the Santa Lucia and Diablo Ranges. The La Panza Mountains and the Gabilan Range still stood above sea-level but were probably much lower and more restricted than they are at present and, in places, may have been largely submerged, especially toward the close of the Cretaceous.

The Asuncion group was deposited during the period of submergence which followed the Santa Lucian orogeny. Again the evidence is not all that it should be but the Asuncion is thought to represent the Senonian, Maestrichtian, and Danian. This upper division of the Upper Cretaceous has a much wider distribution than the lower division. A very complete and thick section of the Asuncion group is exposed along the west side of the San Joaquin Valley. Although extensively developed in the Santa Lucia Range it is not known whether all of Asuncion time is represented by the sediments of this region.

Table I gives the writer's views on the upper Mesozoic of the central Coast Ranges in outline form.

TABLE I

Generalized Table of the Mesozoic of the Central Coast Ranges

System	European Divisions	Group	Formation, Stage
Upper Cretaceous	Danian	Asuncion group	Garzas sandstone
	Maestrichtian		Moreno shale
	Senonian		Panoche sandstone
	UNCONFORMITY—SANTA LUCIAN OROGENY		
	Turonian	Pacheco group	
	Cenomanian		
	Upper Albian		
UNCONFORMITY—MID-CRETACEOUS DISTURBANCE			
Lower Cretaceous	Lower Albian	Shasta group	
	Aptian		Horsetown stage
	Barrmeian		
	Hauterivian		Paskenta stage
	Valanginian		
UNCONFORMITY—DIABLAN OROGENY			
Upper Jurassic	Aquilonian	Franciscan and Knoxville	
	Portlandian		
	NEVADAN OROGENY—INTENSE FOLDING AND BATHOLITHIC INTRUSION		
	Kimmeridgian	Mariposa group (Sierras)	
	Oxfordian		

TERTIARY

PALEOCENE

The deposition of sediments containing a late Upper Cretaceous fauna was brought to a close by uplift, tilting, and probably folding, but this diastrophism was not as important or severe as either the mid-Cretaceous or Santa Lucian orogenies. As a rule there is comparatively slight angular discordance between the uppermost Upper Cretaceous and the Paleocene and little change in the character of the sediments deposited. The extent of the disturbance which closed the Cretaceous is not known as so little of the Paleocene is preserved in the central Coast Ranges.

In the entire Santa Lucia and Santa Cruz Ranges there are but three definitely proven and one doubtful occurrence of Paleocene sediments and even the largest of these is of small areal extent; all of the unquestioned areas are preserved in synclines.

The most southerly occurrence in the Santa Lucia Range, which is also the thickest, is in the northern part of the Adelaida quadrangle 4 miles south of the north line of San Luis Obispo County but even here the Paleocene sediments are but 1,300 feet thick and cover less than a square mile. Although they are in part covered by Miocene sediments the small areal extent in this particular region is largely due to removal prior to the deposition of the Vaqueros. These beds lie unconformably on the Upper Cretaceous (Asuncion) but the two are almost identical lithologically; fortunately the basal Paleocene conglomerate is usually fossiliferous as otherwise there would be great difficulty in separating them. The writer has mapped this region very carefully and finds, from cross-sections, that the Cretaceous was tilted a maximum of 9 degrees to the southwest and at least 2,500 feet removed before the deposition of the Paleocene. Owing to the limited areal extent of the Paleocene it is impossible to say whether the tilting was due to faulting or folding but it is probable that both took place. The basal Paleocene conglomerate, which is thick and heavy, is largely made up of granite and porphyry cobbles and boulders, probably in large part derived from lithologically identical conglomerates in the Cretaceous but there is also a considerable proportion of debris of the underlying Upper Cretaceous. Martinez sediments have been reported from the Bryson quadrangle to the northwest but the writer has found an abundant Asuncion fauna, including ammonites, in these beds.

About 200 feet of Paleocene sediments are preserved in a syncline near the crest of the Santa Lucia Range, at an elevation of about 3,500 feet, 4 miles east of the Pacific Ocean in the west central part of Monterey County. These rest on Upper Cretaceous (Asuncion) beds and both are so similar lithologically that the exact contact has not been located.

The Carmelo series, which occurs in a very small area on the coast south of Carmel, was first referred to the upper Eocene, then to the Upper Cretaceous, and finally, on meager and uncertain evidence, to the Paleocene. These sediments, which are also lithologically identical with the Upper Cretaceous, rest on the Santa Lucia granodiorite. If these beds are Paleocene the northern part of the Santa Lucia Range must have been uplifted and more deeply eroded than the central and southern parts of the interval between the Upper Cretaceous and the Paleocene. There are other lines of evidence supporting the idea that the northern part of the range was uplifted to a greater extent than the southern part after the deposition of the Asuncion but it is not certain how much of this uplift was accomplished prior to the deposition of the Paleocene. A Paleocene age for the Carmelo beds has not been established with certainty; the available evidence favors an Upper Cretaceous, rather than a Paleocene age for these beds.

In the extreme northern part of the Santa Cruz Mountains, extending some 7 miles southeast of San Pedro Point in San Mateo County, there are dark shales and thin sandstones overlain by conglomerates and sandstones that were originally referred to the Franciscan and subsequently to the Martinez. The greater part of these beds, which rest on the Montara (Santa Lucia) granodiorite, are Cretaceous, as shown by the print of an ammonite found by Dr. Olaf P. Jenkins. Just what part of the Cretaceous is represented by these shales is not known as no fossils, other than the one mentioned above, have been found. The conglomerates and coarse sandstones overlying the dark shales are the only part of the section which contain a Paleocene fauna. These beds have been greatly folded and faulted and have been overridden from the northeast by the Franciscan along the Pilarcitos thrust and crushed against the granodiorite.

There are no known occurrences of Paleocene sediments in the Salinas or Santa Clara Valleys or in the Gabilan Range and few within the Diablo Range. Sediments correlated with the Martinez occur along the west side of the San Joaquin Valley and extend westward into the Diablo Range on both flanks of the Vallecitos syncline. They are overlapped both to the north and south by upper Eocene beds; on the north they extend as far as Ortigalita Creek in Merced County and on the south as far as the crest of the Coalinga anticline.

In the vicinity of San Francisco Bay they occur at the town of Martinez (type section) and southward in Contra Costa County. Although the lower part of the sediments in these two general areas are known to be Paleocene there appears to be faunal evidence that higher Eocene sediments have been included in the areas that have been mapped as Martinez. For this reason the term Martinez no longer can be considered as synonymous with Paleocene.

The Paleocene in both of these widely separated areas is similar lithologically to the Asuncion and was originally mapped as Cretaceous. However, the two are separated by a disconformity which locally becomes a slight unconformity. The unconformity on the west side of the San Joaquin Valley is never as pronounced as that in the Santa Lucia Range.

The actual extent of the Paleocene sea over the central Coast Ranges can not be determined from the small and widely scattered exposures of the sediments. Since there were orogenic movements during the Tertiary which were stronger than those in the Cretaceous most of the Paleocene has been removed by erosion. In the Santa Lucia Range there is positive evidence of the removal of all of the Paleocene except in two small areas, before the deposition of the Vaqueros (lower Miocene). Since the later Tertiary movements were more severe than those prior to the Miocene it is not surprising that so little of the Paleocene remains. The Paleocene sea may have covered a large part of the central Coast Ranges or it may have been confined to two separate basins separated by the Gabilan mesa. The exact extent of this sea is not known at present and never may be known because of an almost complete lack of evidence.

The Paleocene is much more closely related to the Upper Cretaceous both lithologically and faunally than it is to the later Eocene deposits and the disturbance following the Paleocene was greater than that between the Asuncion and the Paleocene. That there were strong movements sometime during the Eocene or Oligocene is clearly demonstrated in northern San Luis Obispo County a few miles northwest of Paso Robles where Vaqueros (lower Miocene) rests directly on granodiorite on one side of a fault and on the other side on at least 6,000 feet of Asuncion and Paleocene which dip into the granodiorite. Although this only dates the fault as pre-Vaqueros and post-Paleocene the faulting must have taken place long before the lower Miocene in order to remove so great a thickness of Upper Cretaceous and Paleocene.

Many statements have been made as to the radical change in fauna between the Cretaceous and Paleocene. It is quite true that a number of species and genera died out and new forms appeared but it is equally true that many genera are common to both. The writer has made a number of collections from both the uppermost Upper Cretaceous and the Paleocene and has found, in many cases, that thoroughly competent paleontologists had great difficulty in distinguishing between them.

It is suggested that the Paleocene represents a final stage in the history of the upper Mesozoic geosyncline in which the Franciscan, Knoxville, and Cretaceous sediments were deposited. As has been pointed out in the preceding pages the upper Upper Jurassic and Cretaceous geosyncline had a far from simple history as there were interruptions in sedimentation and emergence and erosion of ridges during its development. In the Upper Cretaceous, particularly, a number of noteworthy changes took place in this basin; its western margin was uplifted, the Gabilan mesa and the ancestral Coalinga anticline began to rise above sea level, and there were marked differences in the rate of sinking in the northern and central Coast Ranges. Notwithstanding these various interruptions this geosyncline occupied the present central and northern Coast Ranges for a long period of time and received a vast volume of sediments. That part of the geosyncline in the present central Coast Ranges and along the western border of the San Joaquin Valley received sediments throughout the upper Upper Cretaceous; very late Upper Cretaceous sediments, probably as late as anywhere in the world, were deposited in this region. A weak orogeny occurred at the close of the Cretaceous and there was uplift, folding, and erosion in the west but little or none in the central part of the basin. Probably general uplift occurred and the seas retreated completely, or almost completely, from the geosyncline; but in the central part of the trough this uplift appears to have been quickly succeeded by down-sinking, and the Paleocene sea flooded at least parts of the geosyncline. This was the last time deposition took place over rather large areas of this trough. The changes that had taken place previously were of lesser magnitude than the changes that took place after the deposition of the Paleocene. The available evidence indicates that the final fragmentation of the upper Mesozoic geosyncline took place in the Eocene. Great thicknesses of Tertiary sediments accumulated but they formed in comparatively narrow basins, some of which were at a marked angle to the trend of the more extensive and more enduring upper Mesozoic trough.

After the deposition of the Paleocene there appears to have been a widespread, although not complete, withdrawal of the sea from the central Coast Ranges. In restricted areas, deposition seems to have been continuous from the Paleocene into the lower or even into the middle Eocene, but over most of the Coast Ranges there is a marked break at the close of the Paleocene.

EOCENE AND OLIGOCENE

The preceding discussion has been based very largely on field observations made by the writer. No Eocene sediments are present in any of the areas mapped in detail and only casual observations have been made on the Eocene of the central Coast Ranges. Since there is little that the writer can contribute that has not already appeared in the literature, and which is readily available, the discussion of the Eocene and Oligocene will be brief and largely confined to those salient events that appear to be more or less certain.

Although there is, already, an extensive literature on this subject there is still much that is not clear and a great deal of additional field and paleontological information must be accumulated before the details of this important early Tertiary history are thoroughly understood. At present our knowledge of this part of the Tertiary is in a state of flux, and the nomenclature and correlations are constantly changing.

There is a thick and important Eocene section in the central Coast Ranges but as yet there is no universal agreement as to nomenclature and correlation. Several formations have been shifted from upper Eocene to Oligocene and back again a number of times. There are also formations whose lower part is known to be upper Eocene and whose upper part is known to be lower Miocene but which contain no known Oligocene fossils. Whether the Oligocene is a valid division of the Tertiary of California is a subject outside the scope of the present paper, as is the possibility of what we generally consider to be lower Miocene actually being Oligocene of the standard European section. The writer is familiar with the literature on these subjects but feels that, as yet, little approach has been made toward their solution and clarification. The terms that are in common use in California will be followed.

Although there are thick sections of lower Eocene in local areas, more of the California Coast Ranges were emergent than at any time during the upper Jurassic and Cretaceous. The Santa Lucia Range, and probably most of the Santa Cruz Mountains, and much of the Diablo Range stood above sea level, but probably were low. At this time the central Sierras were undergoing continued erosion, which started in the Cretaceous. The warm climate of the Eocene may have been caused in part by the disappearance or great degredation of the western land mass from which the upper Jurassic and Cretaceous sediments were so largely derived. This land mass was no longer a barrier to warm rains and currents. Although much of the Coast Ranges were above sea level, especially during the lower Eocene, they appear to have been comparatively low, as was much of the central Sierra Nevada.

The lower Eocene (Meganos in the northern and central Coast Ranges and Santa Susana in southern California) occurs in comparatively small isolated areas from Mendocino County on the north to Ventura County on the south. Sufficient information is not available to outline the paleogeography of the lower Eocene but there is nothing to indicate that deposition was in a continuous trough. The lower Eocene embayment of southern California was certainly not continuous through the present Coast Ranges with the lower Eocene embayment of northern and central California. The lower Eocene trough may have been continuous through what is now the eastern part of the present northern and central Coast Ranges and the border of the San Joaquin Valley. The Santa Lucia Range, the Santa Cruz Mountains, the Salinas Valley region and most of the Diablo Range appear to have been chiefly above sea level during the lower Eocene but it is possible that there was a sea-way between the San Joaquin Valley and the ocean through San Benito and Santa Cruz Counties.

The middle Eocene sea appears to have had a much wider extent and to have flooded much of the Great Valley and to have encroached onto the flanks of the Sierra Nevada and the northern and central Coast Ranges. As used here the middle Eocene includes the Capay, Domengine and Ione. The rather widespread sinking which permitted the middle Eocene flooding possibly was accompanied by folding and faulting and the post-Paleocene pre-Vaqueros faulting previously mentioned may have occurred at this time, although it may have taken place as late as the Oligocene. The middle Eocene sediments consist chiefly of sandstones, shales, clays, limestones, and coal beds and are usually fine grained except on the margins of the land masses. The middle Eocene sea spread eastward onto the flanks of the Sierra Nevada which, by this time was, in central California, a low, deeply weathered land mass. The Ione, which consists of continental, paludal, and marine sediments, was clearly derived from an eastern source which had undergone extensive chemical decay. The lower gravels of the Ione are made up of resistant materials, such as quartz and andalusite, and rest on deeply weathered bedrock. In some places, especially in Mariposa and Madera Counties, the lower Ione gravels are largely made up of rounded crystals of andalusite.

It was during the middle Eocene that the economically valuable clays, glass sands, and coal accumulated. The glass sands of the Mount Diablo region contain small quantities of andalusite derived from the Sierras. The middle Eocene along the east side of the Diablo Range contains detritus from the Coast Ranges (Franciscan and Cretaceous) as well as detritus from a Sierran source.

The extent of the encroachment of the middle Eocene sea on the Coast Ranges is not yet known but it certainly covered the east flank and northern end of the Diablo Range and probably a part of the Santa Cruz Mountains. It may have covered the northeastern part of the Santa Lucia Range as far south as the latitude of King City as, according to Professor H. G. Schenk, Eocene Foraminifera are found in shales interbedded with massive sandstones below the Vaqueros on Vaquero Creek. These beds rest with a light basal conglomerate on the Santa Lucia granodiorite.

Volcanic activity took place in the Sierra Nevada during the middle Eocene, as the Ione contains both rhyolitic and andesitic material. This volcanic activity did not take place within the basin of deposition of the Ione but to the east in the higher parts of the Sierras and was subaërial rather than submarine. Rhyolite debris is found in the lower part of the Ione in Mariposa and Madera Counties and andesitic material in the upper part of the Ione in Placer and Yuba Counties. There were minor submarine outbursts in the Coast Ranges as bentonite beds occur in the Domengine. This middle Eocene volcanism was of very minor importance in both the Sierra Nevada and the Coast Ranges when compared with the Miocene and Pliocene volcanism.

The upper Eocene (Tejon, Markley, Kreyenhagen, Gaviota, and Wheatland) has a more limited distribution than the middle Eocene. After the maximum flooding of the middle Eocene there was an emergence, accompanied by slight folding and faulting. There is no evidence, however, that mountains of any great elevation or extent were formed. There was no profound disturbance and the same basins and the same sea-ways still persisted but were probably somewhat restricted.

Evidence for local submarine volcanism in the upper Eocene of the central Coast Ranges is found in the Kreyenhagen in which thin beds of bentonite, vitric tuff and vitric crystal tuff are of common occurrence; these have been described previously by the writer. Andesitic explosions occurred in the Sierra Nevada during the deposition of the Wheatland, which has been correlated with the lower part of the Gaviota.

The sediments that have been referred to the Oligocene are less widely distributed than the upper Eocene beds but, where present, occupy in general the same depositional basins. They generally rest unconformably on Eocene sediments and are unconformably overlaid by the Miocene. In general the unconformity between the Miocene and the Oligocene is stronger than that between the Oligocene and the Eocene; however, in the central part of the Santa Cruz Mountains the San Lorenzo (Oligocene?) grades upward into the Vaqueros (lower Miocene). The sediments generally regarded as Oligocene at present are usually called the San Lorenzo group and have been described under the following formational names: San Emigdio and Pleito in the southern end of the San Joaquin Valley; Tumey north of Coalinga; San Juan Bautista and Pinecate in San Benito County; San Lorenzo in the Santa Cruz Mountains; San Ramon and Kirker in the Mount Diablo and San Francisco Bay regions. In addition to these there are certain unnamed beds, generally regarded as Oligocene, at Wagonwheel Mountain, in the La Panza quadrangle, and in the Jamesburg quadrange in the northern part of the Santa Lucia Range. Part of the land-laid Sespe in southern California must be Oligocene. There are red beds lithologically identical with the

Sespe in various parts of the central Coast Ranges; these will be discussed with the lower Miocene. Little is yet known regarding the Oligocene history of the Sierras but it is probable that Oligocene vertebrates will be found in that region.

Volcanism occurred during the Oligocene in the Mount Diablo and San Francisco Bay regions where more than 100 feet of rhyolite tuff is present in the Kirker formation. Some of the Tumey sandstones are said to be "ashy."

The middle Eocene marine embayment which extended across the present San Francisco Bay, Santa Cruz Mountains, and northern Mount Diablo region to the flanks of the central Sierras appears to have been uplifted and partially drained on the east in the upper Eocene and in the Oligocene, although its western part was still submerged. There were probably several advances and retreats of the sea after the middle Eocene. The San Benito trough seems to have been more or less permanent during both the Eocene and Oligocene although it is quite likely that there were brief periods of withdrawal of the sea. This trough probably was the chief sea-way into the San Joaquin basin during the upper Eocene and the Oligocene.

Although there are several exceptions, the beds now called Oligocene are more closely related lithologically and areally to the Eocene than to the Miocene in the central Coast Ranges.

Because of the comparatively limited distribution of the Eocene and Oligocene in the central Coast Ranges it is impossible to give as complete an account of the various diastrophic events and their importance as it is for the preceding and following periods. The disconformities and slight angular unconformities that are known in the Eocene and Oligocene might indicate that these periods were comparatively quiet, in strong contrast to the preceding and succeeding periods. However this seeming lack of important disastrophism may be more apparent than real because of lack of evidence due to the non-deposition of Eocene and Oligocene sediments, over so large a part of the central and northern Coast Ranges. The Upper Jurassic and Cretaceous history shows clearly that the various diastrophisms were strongest in the western coastal region and died out eastward; slight disconformities in the Cretaceous along the edge of the San Joaquin Valley represent strong movements and large angular discordances in the Coast Ranges and the same may be true of the Eocene and Oligocene. In order to appreciate the changes which took place during the Eocene and Oligocene it is necessary to consider the basins of deposition and the distribution of the Miocene sediments. A greater proportion of the central and northern Coast Ranges was submerged during the Miocene than at any time since the Upper Cretaceous but the Miocene basins do not necessarily coincide with those of the Upper Cretaceous. The final collapse of the upper Mesozoic geosyncline seems to have taken place at the close of the Paleocene although there had been earlier fragmentation. That all the changes in basins of deposition took place immediately after the Paleocene is hardly likely but it is impossible as yet accurately to date the known diastrophic events which occurred between the Paleocene and the beginning of the Miocene. It has been stated frequently that the Oligocene was a time of general uplift and withdrawal of the sea. That uplift and folding occurred in some regions during and after the Oligocene is certain but it is probable that the diastrophic effects ascribed to this particular time were in part due to repeated earlier movements. The changes that took place in the central Coast Ranges between the Upper Cretaceous or the Paleocene and the lower Miocene can not be ascribed to any one particular diastrophic event but are probably the general effect of several periods of movement. Profound changes occurred and both folding and faulting took place; many of the faults which became active during the late Tertiary came into existence at this time. Although both folding and faulting took place the evidence available indicates that normal faulting, often of great magnitude, predominated over folding and thrusting. It was during the upper Paleocene-lower Miocene interval that the ancestral San Andreas was formed and the tilting of the Gabilan mesa took place. A part of the stripping of the Franciscan, Knoxville, and Cretaceous from certain areas occurred during this interval. The cumulative effects of the movements during this interval varied greatly from place to place; in the northern part of the Adelaida quadrangle, for example, the Vaqueros lies on a slightly beveled surface of Upper Cretaceous and Paleocene but in the southern part of the same quadrangle the Vaqueros transgresses across more than 5,000 feet of steeply tilted Upper Cretaceous sediments in less than 2 miles.

MIOCENE

The brief discussion of the Miocene that will be given here will be based largely on cartographic units and diastrophic events. Faunally it is possible to divide the Miocene into three parts, lower, middle, and upper, and if these divisions could everywhere be mapped separately this would be the most convenient method of treatment. Frequently a threefold division can be made in the field and the units mapped over wide areas, but unfortunately the contacts between the three units usually transgress time when followed for any great distance. In the Salinas Valley and Huasna regions the appearance of the first sands well up in the shale section forms a convenient lithologic boundary between the Salinas shale and the "Santa Margarita." These sands usually contain a good littoral zone megafauna that may be correlated with the various divisions of the San Pablo. However this is not a time contact, when followed any distance, as the sandstones in one region may represent a lower horizon than those in another. Furthermore the shales immediately below the sandstones frequently contain a microfauna that is usually regarded as upper Miocene. Thus the first appearance of sandstones, creating an excellent cartographic division, did not take place synchronously everywhere even though the detritus was derived from highlands uplifted by a diastrophism which affected most of the Coast Ranges at approximately the same time. Although these sandstones are all upper Miocene, in the paleontological sense, they represent various stages in the upper Miocene from one district to another.

The contact between the lower Miocene (Vaqueros) and the succeeding shales (Temblor, Salinas, etc.) is more nearly a time contact than that ordinarily found between shales and the upper sands but even this transgresses time to a certain extent.

Any uplift that took place during or after the Oligocene was followed by submergence at the beginning of the lower Miocene (as the term is generally used at present). This submergence does not appear to have been accompanied by any noteworthy folding or tilting, except in local areas, and the first flooding spread over the lowlands and gradually covered higher areas as the sinking continued. This lower Miocene sea spread over and into a region of varied topography and relief and the sediments were deposited under a great variety of environmental conditions, such as open coasts, protected bays, estuaries, and straits. Furthermore there were variations of relief under each of these general environments; open coasts might be low and shelving or they might be rugged and precipitous. Because of these varied conditions of deposition a great variety of sediments were deposited. The clastic sediments range from exceedingly coarse conglomerates to fine muds and silts; the organic and chemical deposits range from sandy organic limestones to very pure reef limestones; glauconitic sandstones are not uncommon. Throughout the central Coast Ranges in general the thickness of the Vaqueros rarely exceeds 1,500 feet but in the Caliente basin 6,000 feet of lower Miocene beds are reported, a thickness that cannot be accounted for by simple sinking without downwarping.

In several places in the central Coast Ranges land-laid red beds are found beneath the marine Vaqueros. These varicolored sediments are similar lithologically to the Sespe and were deposited in comparatively small topographic basins under essentially the same conditions. They represent the waste from highlands subjected to chemical weathering during the Eocene and Oligocene. A few fragmentary mammalian remains have been found in these beds by the writer but no correlation with any part of the Sespe has been possible. Since the upper part of the Sespe is known to be lower Miocene these beds are mentioned here rather than under the Eocene and Oligocene even though they may be, in part at least, Oligocene, or even Eocene in age.

The most extensive occurrences known to the writer are in the southern part of the Nipomo quadrangle, in the northern part of the Nipomo and the southern part of the Pozo quadrangles, and in the Bradley and Adelaida quadrangles, where they attain a thickness of 700 feet and cover an area of more than 100 square miles. Another rather extensive area occurs in the Soledad and Jamesburg quadrangles. These land-laid beds rest unconformably on practically all the older formations and contain debris of local origin. They accumulated in local basins, chiefly the broad flood plains of rivers, and were formed both prior to and coincident with the marine Vaqueros. The bulk of the varicolored sediments below the marine Vaqueros are land-laid but some are marine and there are occasional interdigitations of red beds in the marine section.

The Vaqueros sea flooded the areas occupied by these land-laid beds quietly and without folding or noticeable warping as shown by the absence of any angular discordance between them. By the close of the lower Miocene submergence had been sufficient to flood the land areas in which these sediments accumulated and overlap them.

By the end of what is generally called Vaqueros (lower Miocene) time the ocean had spread over the lower part of the present Salinas Valley and had encroached from both sides onto the southern end of the Santa Lucia Range, parts of which were completely covered. A low, island-dotted submarine bank extended southwestward from the Santa Lucia peninsula and connected with an irregular deeply embayed island in the vicinity of San Luis Obispo. The Vaqueros gulf (southern Salinas Valley, the eastern part of the Santa Lucia and the western flank of Gabilan mesa) was open to the southeast between San Luis Obispo and La Panza Island and by a broader seaway northeast of La Panza Island and thence into the southern end of the San Joaquin Valley. Another embayment extended southeastward through the present Santa Cruz Mountains into the northern part of San Benito County and probably occupied a remnant of the Eocene and Oligocene San Benito trough. The western and northern parts of the Santa Lucia Mountains, the western part of the Santa Cruz Mountains, the Sierra de Salinas and the northern end of the Salinas Valley, the Gabilan mesa and the Diablo Range were all above sea level.

In the central Coast Ranges sinking continued without folding or notable warping into the middle Miocene. Unconformities between the Vaqueros and the middle Miocene have been reported in southern California but the writer has never seen an unconformity at this horizon in the central Coast Ranges. In this region the lower Miocene grades upward into the middle Miocene without break. The distribution of the two is not the same, as continued sinking flooded wider and wider areas; the middle Miocene therefore has a much greater distribution than the Vaqueros. Although the middle Miocene overlaps the Vaqueros almost everywhere the contact between them is gradational and not unconformable. In some regions the detrital Vaqueros beds grade upward directly into typical organic and chemical Miocene sediments but in other places there is a sandy and marly transition zone which may be as much as 700 or 800 feet thick.

The Miocene sediments later than the Vaqueros show a great variation in lithology but the prevailing types are foraminiferal shales, marls, limestones, siliceous shales, cherts, and diatomites. Where the "Temblor" sediments overlap the Vaqueros they show all the variations previously mentioned under that formation but the basal sands are usually quickly succeeded by organic and chemical sediments.

Interdigitations of sandstone are common in the shales, especially on the borders of basins of deposition and occasionally the shales are largely replaced by sandstones. In the central part of the Nipomo quadrangle more than 5,000 feet of shales grade laterally into sandstones and these in turn, within a few miles, grade back into shales. This local body of sandstones within the shales represents the delta of a fairly large river which came from La Panza Island to the northeast. Variations from sandstone to shale are common and represent proximity to the edge of the basin or fairly large river deltas.

Shortly after the close of the Vaqueros the simple downsinking which permitted the ingress of the Miocene sea gave place to slow downwarping which accentuated and gradually deepened the basins and permitted the accumulation of great thicknesses of sediments, predominately fine grained, in local areas. No one great and continuous geosyncline existed but deposition took place in separate basins. The interbasin areas, probably originally above sea level, became submerged by the regional downsinking which went on hand in hand with local downwarping. In the early stages of downwarping there was little tendency for the interbasin areas to rise but in the upper Miocene the compressive stresses causing downbowing became stronger and certain of these areas became slightly uparched, even rising above sea level. This gentle downwarping which began in the early middle Miocene appears to have been due to weak compressive stresses which were the first manifestation of the strong and important diastrophism which culminated in the late Pliocene and Pleistocene.

The rapid lateral variation in thickness shown by the Miocene sediments in general is due both to original highlands in the Miocene sea and to the development of steadily deepening basins by local downwarping. Minor faulting may have occurred during the early stages of downwarping, especially in the western part of the present central Coast Ranges, but the writer yet has to see any Miocene basin of deposition that owed its origin to continuous sinking along bounding faults. All of the available evidence indicates slow downwarping rather than faulting.

In some regions Miocene volcanism began in the Vaqueros but over most of the Coast Ranges volcanic action did not begin until after the beginning of middle Miocene sedimentation. Maximum volcanism appears to have begun coincident with or shortly after the beginning of downwarping. Miocene volcanism as a whole will be discussed later.

During the Paleocene-lower Miocene interval the Gabilan mesa was strongly upfaulted along its eastern margin, tilted southwestward and deeply eroded. The greatest uplift took place in the vicinity of the northern part of the present Gabilan Range and decreased both to the northwest and southeast. The western margin of this uplifted and tilted block is less definite than the eastern margin and is not bounded by a continuous zone of faulting. The hypothetical "Nacimiento fault" is not a continuous line of faulting but rather a series of discontinuous en echelon faults separated by apparently unfaulted areas. This hypothetical fault serves no useful purpose and only increases the complexity of an already complex structural and stratigraphic problem. Pre-Vaqueros erosion had removed from this tilted block practically all of the late Mesozoic and early Tertiary sediments and exposed the bedrock complex. The Miocene sea encroached eastward on this area but only the southwestern margin of the southern end was submerged during the Vaqueros. In fact the higher eastern part of this block, in the vicinity of the present Cholame Hills, was not flooded until the upper Miocene. A direct eastward connection from the Vaqueros gulf to the San Joaquin embayment was not established until late in the upper Miocene when practically all of the southern end of the Gabilan mesa was submerged. Much of the northern end of the Gabilan block was never flooded during the Miocene.

The southern end of the Santa Lucia Range, at least as far north as the latitude of San Simeon, was submerged by the close of the Salinas shale phase of deposition. In fact more of the southern end of the Santa Lucia Range was submerged at this time than during the "Santa Margarita."

Breccias of the San Onofre type are an interesting and locally important phase of the early Temblor. All of the occurrences of this breccia are close to the present coast line and all are characterized by a considerable abundance of Franciscan debris, usually angular and unsorted. Two hitherto undescribed occurrences of breccias of this type have been mapped by the writer. One of these is in the southern part of the Adelaida quadrangle a few miles east of the present coast line. This breccia, made up of a heterogeneous assemblage of Franciscan types, lies on the Franciscan and underlies a thick section of typical Miocene shales and volcanics; it was clearly derived from the west and is largely if not wholly marine. Such breccias have frequently been cited as examples of fanglomerates and considered as evidence of an arid climate. In the opinion of the writer they have, at least in the central Coast Ranges, no climatic or diastrophic significance but simply represent the encroachment of the Miocene sea on a rugged coast largely made up of Franciscan rocks. They clearly indicate the presence of a land mass, or at least a series of islands, along the present coast line during the Miocene, features that disappeared at a later time, the date of which is not definitely known except that it was earlier than the Pleistocene. Breccias of this type have no definite time significance but simply represent the time at which the encroaching sea reached a rugged coast underlain by Franciscan rocks. The writer has seen similar breccias in the Paskenta (Lower Cretaceous) and in the upper Upper Cretaceous. Breccias of the San Onofre type have been incorrectly correlated with the Big Blue north of Coalinga; the Big Blue is of a later date and is diastrophic in origin.

Many conflicting statements have been made regarding the relation between the Salinas shale and the Santa Margarita in the Salinas Valley and adjacent regions. For a long time this was regarded as a widespread and profound unconformity but some 15 years ago the idea was advanced that the two are generally conformable and that local unimportant unconformities are the exception rather than the rule. The writer has mapped much of this region in detail and has found that both relations exist but that an unconformable relation, often profound, is present over wider areas than a conformable relation. In the Huasna basin, on the Nacimiento River not far from its junction with the Salinas River, along the west side of the Salinas River north of Bradley, and in Reliz Canyon the relations are gradational and conformable. Along the eastern side of the southern end of the Santa Lucia Range, east of Templeton and in the Cholame Hills, as well as in a number of other places the relations are unconformable.

In many places Santa Margarita sandstones are loaded with debris of the Salinas shale both of the limy foraminiferal "Temblor" type and the siliceous "Monterey" type, and sandstones with a typical Santa Margarita fauna have been found resting with marked angular discordance on both types of the Salinas shale.

This angular discordance becomes more marked as one proceeds westward from the Salinas Valley, and very probably eastward as well, as the Santa Margarita sandstones, below the McLure shale, in the Cholame Hills and in the region east of Templeton, are filled with pebbles of the Salinas shale. There can be no question that these shale pebbles are pre-Salinas shale in age since they contain abundant Salinas shale foraminifera. The acidic volcanic pebbles in the Santa Margarita of the type section, about whose source a question has been raised in the literature, are derived from Temblor volcanics which are abundant along the crest of the southern end of the Santa Lucia Range. Pebbles from this source occur in the Santa Margarita in many other places.

The evidence afforded by the direct visible unconformities between the Salinas shale and the Santa Margarita sandstones and the abundance of Salinas shale debris in the Santa Margarita are clear and convincing proof of important diastrophism, uplift, and erosion prior to the Santa Margarita. The coarse detrital nature of the Santa Margarita, particularly the lower part, is further proof of uplift and renewed erosion. On the other hand, the gradational contact between the Salinas shale and the Santa Margarita sandstone, observed in many places, is equally convincing proof of continuous deposition, even though there is a marked difference in the character of the sediments. These two strongly contrasted relations are not inconsistent or irreconcilable when the nature and extent of the diastrophism are taken into account.

The weak compressive movements which began early in the middle Miocene and which resulted in the development of local downwarped basins became stronger and the pre-existing interbasin areas began to fold and rise above sea level while the deeper parts of the pre-existing basins continued to receive sediments without interruption. This condition was not peculiar to the particular time under discussion but occurred again in the very late Miocene, in the Pliocene, and even in the Pleistocene. Many of the apparently mutually contradictory relations in the later Tertiary of the Coast Ranges of California are due to local diastrophism which deformed, often severely, the interbasin areas, while the central parts of the basins of deposition were relatively undisturbed and were the site of continuous sedimentation.

The Santa Lucia Range was elevated and the sediments folded just prior to the deposition of the Santa Margarita sands; this diastrophism was sufficient to expose beds at least as low as the lower part of the Temblor, since pebbles of this age occur in the Santa Margarita, and it is possible that a considerable part of the shales were removed from what is now the crestal region. On the western side of the Salinas Valley, where the relations have not been obscured by later sediments, there is a gradational contact between the upper siliceous shales and diatomites and the sandstones. The gradation may be rather sudden or there may be a zone of more than 200 feet of interdigitated sandstones and shales. Proceeding westward an unconformable relation appears which becomes more marked as the range is approached. West of the San Antonio River the Salinas shale was folded into an anticline and more than 1,000 feet of shale removed before the deposition of the sandstones across the beveled surface of the shales. The folds established at this time were more acutely folded in the late Pliocene and Pleistocene and greatly accentuated. Neither the maximum deformation of the Salinas shale prior to the deposition of the sandstones nor the maximum western extent of the Santa Margarita can be determined because of the strong later diastrophism and the consequent erosion. The contact between the Salinas shale and the Santa Margarita is not exposed on the Gabilan mesa west of the Salinas Valley except east of Templeton where they are in fault contact. However the little available evidence here indicates that the Salinas shale was folded prior to the deposition of the Santa Margarita In the Cholame Hills, in the eastern part of the Gabilan mesa, the Santa Margarita sandstones are filled with detritus of the Salinas shale. However this debris may have been derived from the Santa Lucia Range rather than from any part of the Gabilan mesa.

In the Diablo Range, north of Coalinga, this diastrophism is possibly represented by the Big Blue, a great lens in the Miocene containing abundant debris of serpentine. The present crest of the Coalinga anticline is made up of a great folded sill of serpentine, emplaced in the Upper Jurassic and an uplift in that region in the late middle or early upper Miocene would result in slides and debris of serpentine. Similar slides and outwash of serpentine, on a smaller scale than the Big Blue, occur at the base of the upper Upper Cretaceous on the north end of the present exposures of the serpentine. The early upper Miocene diastrophism of the Santa Lucia Range and that in the Diablo Range, resulting in the Big Blue, cannot be correlated definitely at the present time but they are thought to be essentially contemporaneous.

How much of the central Coast Ranges were affected by this early upper Miocene diastrophism is not known but it was pronounced and widespread in that part of the Coast Ranges in which the writer has done detailed mapping. It was the result of compressive movements and did not everywhere result in uplift. In the northern part of the Santa Lucia Range it resulted in depression and upper Miocene sands and shales were deposited directly on the bedrock complex. In the Huasna basin downwarping continued and the upper Miocene sea encroached on the west side of La Panza Island to a greater extent than the middle Miocene sea. Since the movements were compressive certain regions rose and were subjected to erosion and certain regions sank and received a continuous supply of sediments. The geographic positions of the uplifts and depressions have not yet been completely outlined; they were not disposed in regular belts for two reasons. First the heterogeneity of the underlying rocks and their various reactions to compressive forces and second the heterogeneity of the topographic features, largely an inheritance from the Paleocene-lower Miocene interval. These two factors must have had a very marked effect on the location and trends of both uplifts and depressions; great irregularities would be caused by these factors even though the compressive movements were uniform.

Late in the Miocene, after the deposition of the Santa Margarita sandstones and just prior to the deposition of the McLure shale, at least a part of the central Coast Ranges were again subjected to compressive movements which were weaker than those early in the upper Miocene but which, nevertheless produced definite and easily recognizable effects. The McLure shale, a siliceous sediment with rather frequent beds of bentonite has a wider distribution than has been reported previously in the literature. In addition to its occurrence in the type section and northward it is present along the west side of Waltham Canyon and in the Castle Mountain Range and Mustang Ridge and thence westward across the San Andreas fault in the Cholame, San Miguel, and Priest Valley quadrangles. In the northern part of the San Miguel quadrangle it reaches a thickness of 700 feet; in the central part of the same quadrangle it is very thin and grades into sandstones. The McLure shale is practically identical lithologically with much of the upper siliceous phase of the Salinas shale but all the evidence indicates that it is later since Santa Margarita sandstones overlie the Salinas shale and the McLure shale overlies the Santa Margarita sandstones. If any sediments representing McLure time were deposited in the Santa Lucia Range they either differ greatly lithologically or have been removed by erosion.

Although the McLure shale is usually unconformable on the Santa Margarita sandstones there are places where the contact is gradational. The greatest angular unconformity ever seen by the writer is 11 degrees, and it is usually less than this. On both sides of Castle Mountain Range to the north and south of Smith Mountain, the shale rests unconformably on sandstones containing a Santa Margarita fauna. Usually there are 20 to 40 feet of sandstone at the base of the shales and even though these sandstones are identical lithologically with the underlying Santa Margarita the unconformity is very apparent and usually well exposed. Both the McLure and the Santa Margarita are folded into overturned and often broken and overthrust anticlines on both flanks of the range, the overturning being away from the range on both flanks with the overturned axial planes or thrusts dipping into the range. The overturning and thrusting took place in the late Pliocene and Pleistocene and not between the Santa Margarita and McLure. The central part of the range is essentially a syncline although complicated by minor folding and faulting. In the central part of the range fossiliferous Santa Margarita sandstones grade upward into the McLure shale without break; this conformable, gradational relationship is well exposed on a ridge which trends eastward from Smith Mountain. The Santa Margarita is thickest in the central part of the range and thins toward each side because of truncation which took place between the Santa Margarita and McLure. In this locality the Santa Margarita was gently and rapidly arched into two low anticlines (now the two sides of the range) and eroded. They may never have been brought above sea level and the erosion may have been marine planation. The relations in this region are clear and unmistakable and are a proof of the rapidity with which folding can take place. These two anticlines, because of weakening by local thinning due to erosion, again folded and finally broke during the severe diastrophism in the late Pliocene and Pleistocene. The range rose along these overturned folds and thrusts. Thus the earlier movement, slight though it appears to have been, was an important factor in the localization of the range.

On the Gabilan mesa, where the relations have been observed by the writer, there is a gradational contact between the Santa Margarita and the McLure.

The extent of this diastrophism is not known at present and may never be known because of the obliteration of evidence by later more severe movements. There is no positive evidence that it affected the Santa Lucia Range but when we consider the undisputable fact that diastrophism always was more severe in the coastal region than in the interior it is reasonable to believe that there was at least slight uplift and folding in the vicinity of the coast at this time.

MIOCENE VOLCANISM

Volcanism was more widespread and severe in the Coast Ranges during the Miocene than at any time since the Franciscan (Upper Jurassic). The great bulk of the igneous activity of the Franciscan, which took place well along in the development of a great and rather long-enduring geosyncline, was basic and ultrabasic in character. That during the Miocene was acidic, intermediate, and basic, with intrusions of semialkaline rocks at about the same time over wide areas. This difference in petrographic character may be purely accidental or it may be a function of geosynclinal development. The Miocene was not deposited in a great, long-enduring, continuous geosyncline, but in separate basins, in few of which were sediments accumulated to a thickness even approaching that of the Mesozoic geosyncline.

Little volcanism took place in the Vaqueros compared with the middle and upper Miocene but there appears to have been local, usually unimportant activity. Flows of andesite and basalt are reported in the lower Miocene in the south end of the San Joaquin Valley but it is possible that they may be Temblor. In Ventura County, south of the South Mountain oil field there is a very shallow sill in the Vaqueros which broke through its shallow cover and flowed on the sea floor during the deposition of the lower Miocene. In the northwestern part of the Nipomo quadrangle, east of Arroyo Grande, there are local breccias of biotite-augite dacite which appear to be in the lower part of the Vaqueros. The explosions producing the breccias were submarine and came up through the Franciscan on submarine banks near the margin of the Vaqueros sea. These are the earliest Miocene volcanics known to the writer in the central Coast Ranges.

Although volcanics, either as ash, flows, or agglomerates are rather widespread in the Miocene of the State there are several centers of volcanism in which they are exceptionally thick. Evidently a long chain of volcanic vents lay in the line formed by the Santa Monica Mountains and the Channel Islands where there are great thicknesses of andesite flows, breccias, and ash, many flows and sills of basalt, and thick sills of thomsonite diabase in the Temblor. These have been named the Conejo volcanics by the writer. Ash beds and flows are present in the Santa Maria district but they are not exceptionally thick or numerous.

Another great center of Miocene volcanism lies in the San Luis Obispo-Huasna basin region where there are several thousand feet of rhyolite tuffs, augite andesite, basalt, and olivine basalt flows; thick sills of analcite diabase and numerous plugs of andesite and rhyolite porphyries occur. In the southern end of the Santa Lucia Range there are rhyolite tuffs and flows and sills, flows of olivine basalt, often having a well-developed pillow structure, and numerous plugs of rhyolite porphyry. Rhyolite ash, basaltic pépérites, flows of basalt and numerous sills of analcite diabase occur in the Santa Cruz Mountains. Thin rhyolite ash, flows and breccias of basalt, and diabase sills are present in the Berkeley Hills, but they are not thick. Basalt flows occur in the Miocene of the Point Arena region. Aside from bentonized ash there are few volcanics in the Miocene in the San Joaquin Valley but there are numerous flows in the Cuyama Valley and the Carrizo Plain. There is abundant evidence that the volcanics were largely submarine; the tuffs and ashy sediments are often fossiliferous and the flows are generally interbedded with sediments containing marine fossils. It is possible that in some instances the volcanics accumulated so rapidly that local evanescent volcanic islands were built up, especially in the immediate vicinity of vents. The only definite subaerial center from which large volumes of volcanics were ejected is on the Gabilan mesa west of Soledad. Here rhyolitic material blasted its way through granodiorite and accumulated near the vent as coarse agglomerates and flows; finer ash was showered into the Miocene sea to the west.

No single description would fit all of the occurrences of Miocene volcanics as the sequence and relative proportions of the various types vary somewhat. However the usual sequence is rhyolite tuffs and flows, flows of andesite and basalt, intrusions of sills of analcite and thomsonite diabase and intrusions of plugs, sills and dikes of soda rhyolite and waning explosive activity. This sequence is not always followed; in the southern end of the Santa Lucia Range the earliest volcanism resulted in thin flows of olivine basalt which lie beneath the rhyolite flows and ash. The most complete sequence studied is in San Luis Obispo County and northern Santa Barbara County where the following types occur in ascending order: first, agglomerates of biotite-augite dacite in the Vaqueros; second, rhyolite tuffs and flows, the tuffs greatly predominating over the flows; third, flows of augite andesite, basalt and olivine basalt which, with the interbedded sediments, are nearly 3,000 feet thick; fourth, sills of analcite diabase, often with syenitic schlieren; fifth, plugs and shallow intrusions of soda rhyolite and occasionally andesite; sixth, waning explosive activity, usually rhyolitic, which continued intermittently well into the upper Miocene and possibly into the lower Pliocene.

The sills of analcite diabase are an important and widespread phase of the Miocene volcanism. The writer has visited practically all the known occurrences of these rocks and has examined many cores of unexposed sills encountered in deep wells. A rough estimate indicates that they have a combined volume of not less than 20 cubic miles. They vary in thickness from less than 50 to more than 500 feet and many may be traced for more than 10 miles. They intrude the early rhyolite tuffs and the andesites and basalts, and appear to be earlier than the later rhyolites. No occurrences of these rocks are known in the upper Miocene; they are confined to a comparatively narrow horizon in the middle Miocene. They were intruded into flat-lying sediments long prior to their uplift and not long after their deposition; the sills are essentially concordant but with occasional transgressive boundaries, causing rather sudden thickenings and thinnings.

Some of the thicker sills show gravitational differentiation and vary from a picrite at the base to a highly feldspathic diabase at the top. Most of them show chilled margins of analcite basalt, usually vesicular. The sediments adjacent to them are hardened and baked for a few feet from the contact. In nearly every case they were intruded into shales but occasionally they are in rhyolite tuffs or andesites.

Analcite is present in practically all of these sills in the central Coast Ranges and sometimes makes up as much as 15 percent of the rock. Although primary it is undoubtedly a late magmatic product. Fairly coarse soda syenitic phases are present in the majority of sills; these represent the last stages of consolidation and the character of the residual magma after the crystallization of most of the minerals. These syenitic phases seem to be due to filter pressing in the last stage of crystallization. The usual texture of the sills is diabasic, with occasional areas of true ophitic texture; the syenitic schlieren are usually hypidiomorphic granular and are often coarser grained than the remainder of the sill.

Analcite is present in most of the sills of the central Coast Ranges but in southern California it is only rarely present, its place being taken by thomsonite, indicating a concentration of calcium rather than sodium in the late magmatic stage.

Near the head of White Creek, southwest of that part of the crest of the Coalinga anticline occupied by the Franciscan (here largely serpentine) is a small stock of barkevikite soda syenite. This intrusion, which is approximately half a mile long and a quarter of a mile wide, is intruded into Upper Cretaceous shales and sandstones which dip southwest at a high angle. Float of a similar rock has been found on the north flank of the range and there are probably one or more intrusions in that rather rough and inaccessible region. The rock making up this stock varies widely in grain size and relative proportions of the minerals from place to place but is usually made up of sodic plagioclase, barkevikite, aegirite-augite, aegirite, and analcite with many minor accessories such as apatite, prehnite, sphene and primary calcite. The chemical and mineralogical characters of this rock more closely resemble those of the analcite diabases than any other igneous rocks of the Coast Ranges and, in the opinion of the writer, the soda syenite is a moderately deep-seated phase of the analcite diabases and was intruded during the Miocene.

The andesite and rhyolite porphyry plugs occur in three general regions: one is in San Luis Obispo Valley where a long line of plugs, forming a chain of conspicuous and rugged hills, extend from Islay Hill on the east to Moro Rock on the west. The easternmost plugs of this line are andesite porphyries but the great majority are of rhyolite porphyry. In the description of the San Luis folio, Fairbanks stated that these plugs were of Lower Cretaceous age but the evidence presented for this statement is not convincing. The plugs in San Luis Valley intrude only the Franciscan and there is no evidence as to the time of the intrusion; the writer has mapped many identical plugs to the north and has found them to intrude the Miocene in a large number of cases. There are a few irregular plugs and sills of rhyolite and andesite porphyry intruded into the Miocene in the western part of the Nipomo quadrangle but none of them approach the size of the larger San Luis intrusions. There is a large group of rather small plugs and sills east of Cambria on the San Simeon quadrangle and a line of large rhyolite porphyry intrusions along the crest of the Santa Lucia Range in the same quadrangle. The latter are intruded into Franciscan and Lower and Upper Cretaceous beds and came in along a fault as plugs and irregular tabular sheets.

The great majority of these intrusions are rhyolite porphyries and are identical mineralogically and chemically in all their occurrences. Two of these plugs, on the flank of the Santa Lucia Range, have been followed upward through the Franciscan, the Vaqueros and well up into the Miocene shales. As they are followed upward they show increasing auto-brecciation, a natural consequence of their intrusion into water-soaked sediments, and finally are found to be completely brecciated. They contributed fragments and blocks to the Miocene sediments, showing clearly that they broke through on the sea floor and were subjected to attack by the waves. Some may have formed temporary volcanic islands in the shallow Miocene sea. They were not all intruded at the same time, as shown by the fact some broke through the sea floor during the deposition of the lower calcareous "Temblor" phase and others during the deposition of the upper siliceous "Monterey" phase of the Miocene. One small plug has been observed to terminate upward in a very shallow sill which burrowed its way under a thin cover of sediments and finally broke through on the sea floor and moved forward as a mass of fragments and blocks. It is unlikely that all of these intrusions reached the surface; many probably consolidated before reaching the sea floor. However, there is little difference in texture in these plugs and all are shallow intrusions.

There can be no doubt that the Miocene volcanism had a pronounced effect on the character of the sediments formed. In practically all regions the sediments, prior to the beginning of volcanism are marls, limestones, and foraminiferal shales, and those formed during and after volcanism are in large part siliceous and often diatomaceous. When examined under the microscope most of these sediments are decidedly ashy and there are frequent layers of ash, often bentonitized. Such sediments are not confined to the great centers of volcanism but are almost universal. Even where there are no flows or intrusions there are beds of ash and ashy sediments indicating many small local centers of explosion.

There appears to be a rather general belief that the siliceous sediments are usually confined to the upper or "Monterey" phase and are usually upper Miocene in age. The writer has used this term in the present paper but without age significance. In some regions the siliceous phase almost immediately follows the Vaqueros and is middle Miocene while in other localities the siliceous sediments do not appear until a higher stratigraphic level is reached.

The writer previously has expressed his views regarding the role played by the Miocene volcanism and additional work has only tended to confirm these opinions.

PLIOCENE

There was no general withdrawal of the sea from the central Coast Ranges at the close of the Miocene, but certain areas were elevated both by folding and faulting and in these areas Pliocene beds rest unconformably on the Miocene. In other areas the two are separated by disconformities, marked by pholas-bored surfaces or light gravels and in some areas by continuous deposition. In the Salinas Valley region the diastrophism between the Miocene and the Pliocene was much like that between the Salinas shale and the Santa Margarita but seems to have affected a wider area. The western part of the Gabilan mesa was little disturbed and, in the few places where the contact may be observed, appears to be gradational. Local faulting and folding occurred in the Cholame Hills, near but not along the eastern border of the Gabilan mesa, and there is an angular unconformity of as much as 40 degrees between the upper Miocene and the lower Pliocene in this region.

In a broad way the chief basins of deposition in the Miocene continued into the Pliocene; in some of these regions the seas were restricted by the upbowing of the margins but in others the Pliocene sea invaded regions not flooded during the Miocene. Land-laid deposits, containing vertebrate remains, are numerous in the Pliocene both within the Coast Range and along the eastern border of the San Joaquin Valley north of Coalinga.

The sediments of the Pliocene vary widely in character but in general they are detrital rather than chemical or organic. Undoubtedly silts are the commonest and most universal types but they do not predominate everywhere. Impure diatomaceous shales and light-colored impure volcanic ash are not uncommon at a number of horizons, particularly in the lower part. Sandy limestones, both marine and lacustrine, occur occasionally; impure coals are present in a few places. In the San Francisco Bay region tuffs, agglomerates, and flows of andesite, basalt, and olivine basalt are interbedded with the land-laid and lacustrine Pliocene sediments and there are a number of rhyolite breccia necks intrusive into them. In general the Pliocene seas were shallow and the land masses comparatively low and well forested.

Weak diastrophism occurred during the Pliocene and there are decided differences in the distribution of the various phases, but strong unconformities do not exist within the Etchegoin, Purisima, or Orinda groups. Overlaps occur but they are due to slow depression and local down-bowing.

Decided faunal changes took place during the Pliocene both among the vertebrates and invertebrates and faunal stages may be recognized. However the contact between them is gradational and they are not satisfactory cartographic units. Locally the various lithologic units may be mapped but because of rather rapid lateral variation such units are not satisfactory for correlation from one region to another. The Etchegoin group may be divided into the Jacalitos and Etchegoin stages but they are not satisfactory mapping units; the contact originally drawn between these two stages in the Coalinga district clearly transgresses time. However, they serve a useful purpose and aid in the interpretation of slowly shifting Pliocene basins.

In this paper a somewhat arbitrary division will be adopted: the Jacalitos stage will be used as synonymous with the lower Pliocene and the Etchegoin for both middle and upper Pliocene. In some parts of the central Coast Ranges the upper Pliocene was a time of strong and active diastrophism but in others it is represented by either marine, lacustrine, or land-laid beds. The upper contact of the Pliocene is, in many places, arbitrarily placed at the top of the marine section; the overlying orogenic sediments such as the Paso Robles, Tulare, Santa Clara, etc., have been arbitrarily placed in the upper Pliocene and the lower Pleistocene.

In many places the basal beds of the Pliocene contain rather abundant debris of the Miocene cherts and siliceous shales. These siliceous pebbles show a type of alteration not seen in similar pebbles in the Santa Margarita, an alteration which may have a bearing on the climatic and physical conditions of deposition of the Pliocene. Siliceous Miocene pebbles and cobbles in the Pliocene commonly have an outer rim of chalky white alteration, a change which must have taken place within the basin of deposition.

In general the Pliocene contains debris of all the older rocks, either Miocene, Cretaceous, Knoxville, Franciscan, or basement complex. Many of the pebbles, cobbles, and boulders in the Pliocene conglomerate were derived from older conglomerates, particularly those in the Cretaceous.

Along the east side of the Santa Lucia Range, in the Adelaida, Bradley, Bryson, Priest Valley, King City, and Soledad quadrangles, the Pliocene is rather thin and is made up of coarse boulder and gravel beds, sandstones, and silts and there is a definite westward thinning of the sediments. In places the conglomerates are thin and are made up chiefly of "rotten-rim" Miocene chert and shale pebbles but in other areas the conglomerates are coarse and thick and made up of well-rounded basement complex cobbles and boulders, largely derived from Cretaceous conglomerates. The coarse conglomerates probably represent deposits near the mouths of streams flowing eastward from the Santa Lucia Range.

The writer has obtained many large collections of Pliocene fossils from the east side of the Santa Lucia Range and the Gabilan mesa; according to Professor B. L. Clark these are all of the Jacalitos stage, the Etchegoin apparently not being represented. This would indicate a broad uplift and an easterly withdrawal of the sea at the close of the lower Pliocene. The paleontological evidence available at present indicates that the western margin of the middle Pliocene sea lay in the vicinity of the western side of Castle Mountain Range and crossed the present San Andreas fault zone diagonally and without interruption.

Along the east side of the Santa Lucia Range, the Jacalitos stage rests unconformably on both the Santa Margarita and various phases of the Salinas shale; this unconformity becomes progressively more pronounced westward but the angular discordance is never large. How much of the Santa Lucia Range was submerged during the Pliocene is not known as subsequent erosion has removed so much of the evidence; but it is thought that much if not all of the range north of the San Luis quadrangle was above sea level as a comparatively low ridge which became higher and more rugged to the north. It was probably well forested, as were most of the highlands during the Pliocene, as carbonized plant remains are abundant in the sediments. The Santa Lucia Range contributed debris to the Pliocene sea at least as far east as the northern end of Castle Mountain Range.

In the Salinas Valley and along the western flank of the Gabilan mesa the contact between the upper Miocene and the lower Pliocene appears to be gradational. In the Cholame Hills there is a local unconformity caused by both folding and faulting; the areal extent of this unconformity is not known because of limited exposures of the contact but it is not thought to be very extensive. There is a very general eastward thickening of the Pliocene west of the Salinas Valley and a marked tendency for the sediments to become finer grained. Pliocene sediments continue across the San Andreas fault without any change in character and thickness except for a continuation of the eastward thickening just mentioned. In this region they attain their greatest thickness, more than 8,000 feet, in Waltham Canyon and southward where both the Jacalitos and Etchegoin stages are present. They again thin and coarsen northward toward the Pliocene Diablo Range which stood above sea level as a low land mass in the southern part but which increased in elevation northward. The southern end of the Diablo Range during the Pliocene was the ancestral Coalinga anticline which extended eastward into the Pliocene sea as a peninsula.

During most of the Pliocene there was a sea-way from the Santa Cruz-Monterey Bay region diagonally across the Coast Ranges through the Priest Valley-Waltham Canyon strait into the San Joaquin basin but it is possible that this connection was not established until late in the lower Pliocene. The northwestern part of this sea-way was approximately the same as the earlier San Benito trough but the southeastern part lay to the south of the older connection. Even though such a connection did exist at the beginning of the Pliocene it must have been narrow and shallow. The principal connection from the open ocean to the southern part of the San Joaquin Valley during the lower Pliocene was into the Santa Maria embayment, around the southern end of the Santa Lucia Range, across most of the central and southern part of the Gabilan mesa, and across the northern end of Castle Mountain Range. In the middle Pliocene (Etchegoin stage) the connection from the ocean around the southern end of the Santa Lucia Range was either greatly restricted or wholly cut off and the chief connection was through the Waltham Canyon-Monterey Bay strait.

From the evidence afforded by surface exposures the Pliocene sea did not extend very far north of Coalinga on the east side of the Diablo Range but, very probably, there was a comparatively narrow embayment which extended northward beneath what is now the west side of the San Joaquin Valley. However there is no indication that this narrow arm of the sea had any northward connection with the ocean.

During the lower Pliocene the Sierra Nevada was a low land mass sloping gently westward toward the San Joaquin basin which, except for its southern part, was largely above sea level (except for a possible narrow northward embayment west of its present center) but which was receiving land-laid sediments derived both from the Sierra Nevada and the Diablo Range. At this time the northern part of the Diablo Range was probably higher and more rugged than any part of the Sierras except the crest region but since it was smaller and narrower it contributed less sediment. The southern end of the Diablo Range, the ancestral Coalinga anticline, extended as a low peninsula into the lower Pliocene sea. Juniper Ridge, to the southwest, was either a very shallow bank or a low island.

West of the southern end of the Diablo Range, in the northwestern part of the Priest Valley quadrangle and northwestward, there was another basin receiving land-laid sediments. This opened northwestward into the marine embayment in which the lower part of the Purisima was being deposited. To the west and south of this was the Santa Lucia Range which was at that time lower than the Diablo Range. The northern end of the Santa Cruz Mountains and the western part of the San Francisco Bay region was a rather rugged recently uplifted land mass separated by an interior basin from the northern end of the Diablo Range; it was in this interior basin that the Orinda was deposited. The upper Miocene sea had not completely withdrawn from this basin as the lowermost beds of the Orinda contain a marine upper Miocene fauna. This basin was either slightly uplifted or rapidly filled above sea level by the flood plain deposits of the continental Orinda.

If the coarseness and thickness of the lower Pliocene sediments on its margins are reliable criteria the northern end of the Diablo Range was the highest and most rugged part of central California during that time.

Slight compressive movements must have been going on during the lower Pliocene as the basins of deposition, both marine and continental, were slowly down-warped, permitting the accumulation of both marine and continental sediments of great thickness. A corresponding upbowing of the land masses probably took place but without any decided increase in elevation because of continuous erosion.

Toward the close of the lower Pliocene (Jacalitos stage), and probably as a result of the slow compressive movements, certain noteworthy changes took place. The Santa Lucia Range and much of the Gabilan mesa were gradually elevated slightly above sea level and the Waltham Canyon-Monterey Bay trough was depressed and expanded, forming a fairly broad and continuous sea-way from the open ocean to the northwest into the San Joaquin basin. These movements were slow and comparatively gentle and deposition was continuous in the basins; overlaps but not unconformities were the result.

Volcanism took place in the Pliocene and was especially noteworthy to the north and south of the San Francisco Bay region where there are thick flows, tuffs, and agglomerates of andesites and basalts and rhyolite breccia necks and thin rhyolite tuffs. Both rhyolitic and andesitic outbursts occurred in the Sierra Nevada and some of the finer material was carried by the streams and air currents into the San Francisco Bay region and the San Joaquin basin. There is no evidence of Pliocene volcanism in the Santa Lucia Range. The subaerial volcanic center at the Pinnacles may have been active during the Pliocene but of this there is no direct evidence.

The slow and continuous sinking of many of the Pliocene basins permitted the accumulation of great thicknesses of both marine and continental sediments. In the Waltham Canyon region the present thickness of the Pliocene is more than 8,000 feet and erosion may have removed a part of the section. The maximum thickness of the Purisima is not less than 9,000 feet and even the continental Orinda (including such related Pliocene beds as the Siesta) is over 5,000 feet in thickness. In the Ventura basin the Pliocene reaches the remarkable thickness of 16,000 feet. However, the Pliocene sinking can not be regarded as exceptionally rapid when the duration of Pliocene time is considered. If that part of the Pliocene represented by the marine sediments mentioned lasted for only 5,000,000 years, a figure probably well below its actual duration, the annual rate of sinking would have been .02 inch for 8,000 feet of sediments.

The land-laid beds of the Pliocene are nearly everywhere tinged with red, especially those in lower Pliocene, indicating oxidation and considerable chemical weathering in the land masses from which they were derived. This is in strong contrast to the land-laid sediments of the late Pliocene and Pleistocene which are largely of coarse and angular material derived by rapid mechanical destruction of recently uplifted highlands.

The weak compressive movements which began in the middle Miocene and continued at intervals throughout the upper Miocene and lower and middle Pliocene were greatly intensified in the upper Pliocene and resulted in strong folding, thrust faulting, and general uplift. This diastrophism was the beginning of the most important orogenesis in California since the Sierran revolution in the Upper Jurassic. It brought into existence or at least accentuated the chief present topographic features of the Coast Ranges although many of these, such as the Santa Lucia and Diablo Ranges, had had well-defined ancestral forms. The very general uplift of the Coast Ranges and the withdrawal of the sea, except from coastal embayments such as the Ventura and Santa Maria basins, was not epeirogenic in nature but orogenic and resulted from compressive diastrophic forces which became very pronounced in the upper Pliocene. Under the compression to which the entire Coast Ranges were subjected the sediments were strongly folded and thrust faulted. Regions which were upbowed during both the Miocene and Pliocene again moved upward; these upwarps or geanticlines had long been interbasin areas, although submerged in part from time to time, and received a thinner cover of Tertiary sediments than the basins. The earliest folding took place along their margins as these were zones of thinning sediments along the sides of the basins. As the folding continued and spread into the basins these first formed marginal folds became accentuated and as the geanticlines continued to rise became overturned and finally thrust, the direction of movement being from the upfolded region toward the basins. Hence the geanticlines rode outward over the basins on either side and characteristic structures produced were ranges with overturned folds and thrust faults dipping inward toward the ranges. The elevation of the present ranges was accomplished by upward movement along overturned folds and thrust faults. The essential structure of the ranges is synclinal, complicated by minor folding and faulting; these uplifted synclines are bordered by zones of intense folding and thrusting. Both the Santa Lucia and Castle Mountain ranges are excellent examples of this type of structure. Again the compressive movements were stronger near the coast and became less pronounced eastward. The Diablo Range rose essentially in this manner but the margins are not overturned except in a few places and thrusts are not as well marked as in the more westerly ranges. Many irregularities and complications were introduced by the nature of the bedrock, whether sedimentary or crystalline, and by the topographic features existing at the beginning of the folding.

A complication exists in the Gabilan mesa, which has a crystalline basement and a relatively thin blanket of Tertiary sediments. This yielded chiefly by faulting, because of the rigid nature of the basement, but the sediments along its margin have been folded. It appears to have been capable of transmitting the stress which was directed from the southwest toward the rigid crystalline block of the Sierras.

Naturally the uplifted ranges were immediately attacked by erosion, resulting in a flood of coarse debris which chiefly accumulated in the basins. These sediments are both uppermost Pliocene and lower Pleistocene in age. However, since they constitute a lithologic unit and are thought to be chiefly Pleistocene, they will be considered under that heading.

QUATERNARY

PLEISTOCENE

Although the Plio-Pleistocene land-laid sediments are the result of strong uplift, they do not everywhere rest on the Pliocene marine beds with marked unconformity. Again there is definite evidence of strong uplift in certain zones and continuous, or almost continuous, deposition in the basins. The strongest uplift took place in the west, adjacent to the coast, and decreased in intensity toward the east.

The Plio-Pleistocene beds consist of gravels, sands, silts, clays, gypsum, and fresh-water marls and limestones. They were deposited on broad flood plains, in interior basins and in temporary, shallow lakes; lacustrine beds are usually confined to the lower part. They are commonly white, gray, tan, buff, and brown in color; only rarely do they show the various shades of pink, red, and green so common in the land-laid Pliocene sediments.

Marine equivalents of these beds are confined to the coastal embayments, such as the Ventura and Santa Maria basins, from which the sea was not completely drained by the late Pliocene diastrophism. These marine beds are similar in character to the marine Pliocene.

The continental Plio-Pleistocene sediments contain debris of all of the older formations. In some places the debris is obviously of local origin and consists largely of one particular type but in others there is a heterogeneous assemblage of many rock types, due either to the diverse nature of the adjacent exposures or to the presence of a larger stream with an extensive drainage area. In some parts of the Salinas Valley the Paso Robles formation is chiefly made up of debris of the Salinas shale, in others largely of Franciscan and Cretaceous debris and in others of debris of the crystalline basement complex. In many places all of these rocks are abundantly represented.

Because of the fact that these Plio-Pleistocene sediments accumulated in basins separated by recently rejuvenated and upfolded highlands, many names have been given them; such deposits have been called Paso Robles, Tulare, Paicines, San Benito, and Santa Clara. It is quite true that no positive statement can be made regarding the exact equivalence of these beds but it is certain that they are due to the same cause, namely strong uplift and folding in the late Pliocene. They may be called orogenic sediments since they are the direct result of the rapid erosion of recently uplifted mountains. This orogeny may not have affected all parts of the central Coast Ranges at exactly the same time but it is essentially one diastrophic event. It is not thought that this orogeny occupied any great period of time or that any important time difference existed from one region to another. If there was any lag in the uplift and folding it probably was from west to east and the possibility exists that the lower part of the Paso Robles might be slightly older than the lower part of the Tulare. At the present time no definite statement can be made regarding this possibility because so little is known regarding the fauna of these beds.

In many localities it is difficult to map the contact between these Plio-Pleistocene continental sediments and marine and land-laid Pliocene beds and it is known that they have been confused many times in the past. On the west side of the San Joaquin Valley the sediments mapped as Tulare north of Orestimba Creek (southern part of Stanislaus County) contain abundant vertebrate remains known to be of lower and middle Pliocene as well as of Pleistocene age. In the Salinas Valley the contact between the Paso Robles and the lower Pliocene (Jacalitos) is very difficult to locate and the writer has found marine Pliocene fossils in several places in beds formerly mapped as Paso Robles. However, both to the east and west of the Salinas Valley the Paso Robles rests with marked unconformity on Pliocene and older sediments. The contact between the Paso Robles and the marine Pliocene is only difficult to locate in those basin areas, or in regions underlain by rigid crystalline rocks, which were not folded during the late Pliocene diastrophism.

West of the Salinas Valley the Paso Robles rests unconformably on the Pliocene and Miocene and the unconformity becomes progressively greater westward toward the Santa Lucia Range. West of the San Antonio River the Paso Robles rests on highly folded Miocene beds and in one place transgresses across the Miocene onto the Cretaceous. Although the Paso Robles is often steeply folded along the east side of the Santa Lucia Range the angular discordance between it and the older beds is everywhere apparent. Furthermore, the Paso Robles frequently contains debris of the marine Pliocene.

Lacustrine sediments are rather common at several horizons in the lower part of the Paso Robles, in the Tulare in the Priest Valley quadrangle and probably elsewhere, and in the San Benito formation. These are usually confined to the lower half of these continental formations but it is possible that lakes existed throughout the time represented by their deposition, especially in the San Joaquin Valley. Evidence for the existence of these lakes is the presence of marls and limestones and thin-bedded, almost gritless clays, containing fresh-water fossils. There are many possible origins for these lakes; they may have been formed by original slight diastrophic warping of the basins, which is not considered likely, by irregularities of sedimentation; or by the interference with natural longitudinal basin drainage by the rapidly growing deltas at the mouths of streams from the highlands bordering the basins. As these deltas grew and coalesced into broad alluvial aprons the lakes would be confined to the central parts of the basins and, with continued basin-filling, would be obliterated. They also may have been due to a lack of well-established longitudinal drainage in the early history of the basins. These lakes, especially those that existed in the Salinas Valley region, seem to have been rather temporary, shallow-water bodies.

The thickness of these Plio-Pleistocene deposits varies but is usually less than 2,000 feet. The present maximum thickness of the Paso Robles is about 1,100 feet, of the San Benito the same and of the Tulare in the Priest Valley quadrangle about 1,800 feet. The Tulare in the San Joaquin Valley has been reported to be 2,000 to 3,000 feet in thickness but older beds may have been included.

It is highly improbable that even these comparatively small thicknesses were the result of simple basin-filling without downsinking. The rather violent movements in the late Pliocene, which brought about basin-filling, probably gave way to less violent but none the less important and continuous sinking of the basins. The highlands probably continued to rise as there is no tendency for the continental sediments to become finer upward, indicating a reduction in elevation of the source with the passage of time. The upper part of the Paso Robles, the Priest Valley quadrangle phase of the Tulare, and the San Benito beds is quite as coarse as the lower part.

It has been stated in the literature that the rather rapid sinking of the Pliocene gave way to slow sinking in the Pleistocene but there is nothing to substantiate this. Even granting that the continental Plio-Pleistocene sediments may have accumulated more rapidly than the marine Pliocene, the time involved for their deposition could have been only a small part of that represented by the lower and middle (and probably part of the upper) Pliocene. There is nothing to indicate that the late Pliocene and early Pleistocene downwarping was not as rapid, if not more rapid, than that during the Pliocene.

The deposition of these late Pliocene and early Pleistocene beds was brought to a close by an even more important and widespread diastrophic event than that through which they originated, an event which affected not only the Coast Ranges as a whole but also the Sierra Nevada. The late Pliocene folds and faults were greatly accentuated, the highlands formed at that time were again uplifted and new folds were formed. The orogenic sediments, Paso Robles, Tulare, etc., were folded, in some places so strongly as to be locally overturned. The exact time during the Pleistocene at which this event took place is not known with certainty but in view of the many subsequent Pleistocene events it was probably about mid-Pleistocene. The great fans which border the Sierra de Salinas west of the northern part of the Salinas Valley and which are later than the Paso Robles contain upper Pleistocene vertebrates.

The Santa Lucia, Diablo, Castle Mountain, and Gabilan Ranges were greatly elevated and the present main drainage lines firmly established. Changes in the coast line have taken place since that time but the major configuration was much the same.

The compressive movements that produced this orogeny were much the same as those that took place in the late Pliocene. In fact, the orogeny which formed the Coast Ranges as we know them today was a two-phase diastrophism, each phase being stronger than any previous Tertiary movements but of the same general character. The mid-Pleistocene diastrophism was the culmination of the compressive movements which began in the middle Miocene and continued through the Miocene and Pliocene with gradually increasing severity. Subsequent Pleistocene movements appear to have been of a different character.

The mid-Pleistocene diastrophism accentuated the late Pliocene folds and faults and formed new folds and faults which affected the Plio-Pleistocene sediments. The uplift of the ranges along the inward-dipping marginal faults and folds continued and the ranges were widened as well as uplifted.

The nature of the underlying bedrock naturally controlled the effects produced by the late Pliocene and Pleistocene orogenies. Those areas underlain by thick sedimentary prisms yielded by folding and ultimately by thrust faulting but those underlain by a crystalline basement with a relatively thin cover of sediments yielded chiefly by faulting although in some cases faulting in the bedrock resulted in folding in the overlying sediments. Where there is a gradual thickening of the sediments resting on a rigid basement no sharp line can be drawn between the two types of yielding. At present it is impossible exactly to define "thick-blanketed" and "thin-blanketed" areas in terms of thickness of sediments.

That part of the Gabilan mesa which lies to the north of Paso Robles is an excellent example of the yielding of gradually thickening sediments resting on a crystalline basement. From the Cholame Hills, on the northeastern side, to the San Antonio River, on the southwestern side, there is a gradual thickening of the Tertiary sediments, known from wells, from 3,500 feet to 9,000 feet. On the southwest, where the thickness is 9,000 feet, the beds are folded, often acutely, and the yielding was approximately the same as that observed to the west where there is known to be more than twice this thickness of Mesozoic and Tertiary sediments. East of the Salinas River there are such folds as the Vineyard Canyon anticline and the San Miguel dome but both of these seem to be connected with bedrock faulting. The shortening of the crust brought about by the Pliocene and Pleistocene orogenies in the Santa Lucia Range and that part of the Gabilan mesa covered by more than

6,000 or 7,000 feet of sediments is more than 20 percent, but the shortening on that part of the Gabilan mesa underlain by less than 6,000 or 7,000 feet of beds is less than 3 percent. The transition from one region to the other is not sharp and there is a gradual dying out of the folds eastward. However, the figure of 6,000 to 7,000 feet cannot be taken as a dividing line between thin- and thick-blanketed areas. Proceeding northward in the Santa Lucia Range, the crystalline basement gradually emerges and the Mesozoic and Tertiary sediments thin, and the yield is chiefly by faulting. However, the beds are acutely folded even where they are but a few thousand feet thick. The writer has no intention of implying that the crystalline basement was folded; folding in thin overlying sediments resulted from movement over the bedrock and faulting.

The cores of the uplifted ranges, consisting of Mesozoic sediments or basement complex, were uplifted above and thrust over soft Tertiary sediments. The rapid uplift and the great oversteepening of the mountain fronts resulted in slides, frequently of great magnitude. Although any type of rock might slide under such conditions, the Franciscan, because of its heterogeneous character, and the clay shales of the Knoxville and Cretaceous were especially favorable for the development of the gigantic slides which took place coincident with the uplift of the ranges. That these slides were very early features is shown by the fact that many of them have been dissected by subsequent erosion. It is not uncommon to find hills and ridges along the mountain fronts, but separated from them, covered by thick slide remnants isolated from the main slide by erosion. Naturally sliding of this type was not confined to the middle and late Pleistocene but has been a continuous process. In places there is a definite sequence of slides observable; in general the magnitude of the sliding decreased with the passage of time. These great slides and rock streams often obscure the structure of the mountain fronts; a very erroneous picture of the structure and areal distribution of the rock units appears on several published maps because the nature of the slides was not recognized. Fortunately the later uplift of the Coast Ranges, which resulted in the widespread terraces, enabled many of the small streams to cut through the slides; a careful study of practically all of the small, steep-walled stream courses is essential to an understanding of the complex structure of the mountain fronts. It is not unlikely that the late Pliocene orogeny caused the development of similar slides but the erosion which resulted in the Plio-Pleistocene sediments removed all traces of such possible earlier features.

Notwithstanding the recency of the mid-Pleistocene faulting there is little direct physiographic evidence of the individual faults although many of them were of great magnitude and brought about the elevation of the ranges. Erosion and reduction of the surface was so rapid that all original surface, physiographic effect of the faulting, was quickly obliterated.

In the late Pleistocene in the Los Angeles, Ventura, and San Joaquin basins there was comparatively gentle folding which formed low folds so recently that they have been little modified by erosion. This period of folding has not been detected thus far to the west of the San Joaquin Valley. Its relation to the period of terrace formation is not known, but it may coincide with the late warping of terraces.

TERRACES

The terraces so well developed along the coast and in the interior valleys are later than the mid-Pleistocene diastrophism as, in places, they are cut on the beveled edges of folded Plio-Pleistocene sediments. The marine terraces have been reported to occur at elevations of 2,000 feet or more, but the writer has never seen any above 1,500 feet. In many places well-developed terraces may be seen at various intervals from sea level to elevations of 1,000 or 1,500 feet. Individual terraces are difficult if not impossible to follow from one region to another and there is little definite correspondence of the various terrace levels over wide areas. Over limited areas there may be very definite intervals between terraces; a few miles away the terraces may be equally well developed but the interval may be very different, indicating either initial irregularities in uplift or warping between various uplifts. Furthermore the marine terraces along the coast cannot be correlated definitely with the terraces of the interior valleys. There is strong evidence that the coastal region has, in general, been uplifted to a greater extent than the interior. If the uplift had been uniform throughout the Coast Ranges the interior valleys would have been well below sea level at the time the higher marine terraces were formed, a condition contrary to the known facts. When a longitudinal profile of the coast is considered it is clear that uplift was not the same everywhere and that there were areas, such as San Francisco Bay, that were depressed rather than uplifted. It is, of course, impossible to state at present how much of this apparent irregularity is original and how much is due to later tilting and warping but it is believed that at least a part of the present irregularities observable were caused by inequalities of the original movements responsible for the terraces. More quantitative data must be assembled before a definite statement can be made regarding the type of movement responsible for terrace development. These terraces have been cited as evidence of widespread epeirogenic uplift but when both the longitudinal and transverse irregularities are considered doubt is cast on this hypothesis. They might equally well have resulted from late, relatively weak orogeny and a broad gentle upbowing of the ranges.

Little definite evidence of the warping of earlier and higher terraces can be obtained because they are so frequently obliterated. The best example of a tilted terrace, known to the writer, is in the vicinity of Half Moon Bay. Five miles south of the town the base of the terrace sediments is at an elevation of over 150 feet; this pholas-bored surface, cut in Purisima shales and sandstones, slopes gently northward and disappears beneath the present beach at the town of Half Moon Bay. In other regions there is fairly definite evidence of the warping of the terraces into low broad anticlines and synclines.

PLEISTOCENE VOLCANISM

There was little volcanic activity in the central Coast Ranges during the Pleistocene when compared with the extensive and important volcanism in the Sierra Nevada and in northern California. Pleistocene olivine basalt flows and agglomerates occur in the Santa Lucia and Diablo Ranges and along the east side of Santa Clara Valley but no detailed study has been made of these volcanics and little is known regarding them. The olivine basalts along the east side of the Santa Clara Valley have been referred to the Miocene but, from their relation to the present surface, the writer has no hesitancy in placing them in the Pleistocene.

The writer has seen but one occurrence in the Santa Lucia Range but there may be other undiscovered localities. In the Bryson quadrangle a short distance east of the main crest of the range and at an elevation of 2,000 feet olivine basalt flows, breccias, and tuffs occur in a structural and topographic basin. The basalt was erupted through serpentine and large blocks of serpentine are common in the agglomerates. The flows and fragmental volcanics, which have been folded into a syncline, occupy an almost circular area about half a mile in diameter. The fragmental beds are soft and unconsolidated and obviously have never been buried beneath any appreciable thickness of volcanics or sediments. The flows are usually glomeroporphyritic, with clots of granular olivine up to 4 or 5 inches in diameter. The only evidence for a Pleistocene age for these volcanics is the completely unconsolidated nature of the pyroclastics, identity of petrographic character with volcanics of known Pleistocene age, and dissimilarity to any of the Miocene volcanics. Although the evidence is far from conclusive it is believed that they were erupted during the Pleistocene.

East of Gilroy there are identical volcanics which are unquestionably Pleistocene because of their relation to a very late surface, because they are unfolded while nearby Santa Clara gravels are strongly folded, and because no debris of the volcanics occurs in the Santa Clara gravels. The olivine basalts, flows and pyroclastics near the edge of the San Joaquin Valley south of Pacheco Pass are late Pleistocene since they are interbedded with flat-lying terrace gravels. The nearby volcanics resting on the Franciscan and the more extensive areas to the south along the crest of the Diablo Range are identical in every respect and are, without doubt, late Pleistocene.

TABLE II

Periods of Igneous Activity in the Central Coast Ranges

Age	Formation, Group or Series in Which Volcanics Occur	Geographic Distribution	Petrographic and Petrologic Character	Remarks
Age unknown but either pre-Cambrian or lower Paleozoic	Sur series	Widespread	Intermediate and basic volcanics now represented by chloritic and amphibolitic schists	
Age unknown, pre-Cambrian or lower Paleozoic	Santa Lucia granodiorite intrusive into Sur series	Widespread	Granodiorites, pegmatites, and related plutonics	
Upper Jurassic	Franciscan and Knoxville groups	Widespread throughout Coast Ranges	Chiefly basaltic and andesitic flows, tuffs and agglomerates. Basic and ultrabasic intrusives	Largely submarine tuffs, flows and agglomerates in Franciscan and lower Knoxville. Intrusions in Franciscan and throughout the Knoxville
Lower Cretaceous	Shasta group	Very local. Southeast of Parkfield and in Orchard Peak Region	Rhyolitic? tuffs	Thin and unimportant tuffs probably submarine
Upper Cretaceous	Moreno formation	Very local. Alameda and Stanislaus counties	Bentonitized volcanics	Thin and unimportant tuffs—submarine
Middle Eocene	Ione and Domengine	Sierra Nevada and San Francisco Bay region	Rhyolitic and andesitic tuffs and agglomerates	Chiefly explosive. Possibly flows in Sierra Nevada
Upper Eocene	Kreyenhagen formation	West side of San Joaquin Valley	Dacitic or rhyolitic ash, often bentonitized	Submarine explosive activity
Lower Miocene	Vaqueros formation	Southern end of San Joaquin Valley (may be Temblor). Nipomo quadrangle. Very local	Andesitic and basaltic flows. Dacite breccias	Probably subaerial explosions
Middle and upper Miocene	Temblor, Salinas, and Maricopa shales, "Monterey," San Pablo, Santa Margarita, McLure, etc.	Widespread and important, practically throughout the Coast Ranges	Rhyolitic tuffs and flows, andesitic and basaltic flows, and agglomerates. Analcite diabase sills. Soda syenite plugs. Quartz porphyry plugs	Largely submarine but with at least one large and important subaerial volcano
Lower Pliocene	Orindan	San Francisco Bay region	Andesites, basalts, olivine basalt. Flows, tuffs, and agglomerates. Rhyolite breccia necks and tuffs	Subaerial and sublacustrine
Lower and middle Pliocene	Etchegoin	San Joaquin Valley	Andesitic tuffs	May have been a few unimportant submarine explosions. Much of the ash may have come from the Sierra Nevada
Pleistocene	Later than Santa Clara and Tulare	Santa Lucia and Diablo Ranges	Olivine basalts, often glomeroporphyritic. Flows and agglomerates	Entirely subaerial

DIASTROPHIC HISTORY AND STRUCTURE

Almost every assertion regarding the fundamental control of Coast Range structure has been met with a contradiction. Folds are the result of faulting and die out away from fault zones; they are independent of and unrelated to faulting. Faulting is ancient and some faults go back to the earliest decipherable geologic history; faults are young, that is, formed during the last orogeny, and disappear when sections across them are unraveled and reconstructed for an immediately preceding period. The San Andreas fault is ancient and the horizontal movement is measurable in scores of miles; it is very young and the movement is measurable in thousands of feet rather than in miles.

The Coast Ranges have been referred to as a "heterogeneous mobile belt" in which blocks of the crust have behaved independently and have moved up and down on faults almost at will. Lateral variations in thickness, so common in the Coast Ranges, have been ascribed to deposition in sinking "blocks", bounded by faults which were active during the deposition of the sediments and which limited the sediments deposited during any particular time to these sinking "blocks". This well-presented and ably defended concept has been opposed by Reed and others who have given a more logical picture of folding, faulting, and deposition.

Anyone unfamiliar with the Coast Ranges of California who attempted to read and reconcile all that has been written regarding their structure either would resign the task in utter bewilderment or would be forced to accept one or the other of the opposed points of view. This would be unfortunate since no one concept is either wholly correct or wholly erroneous.

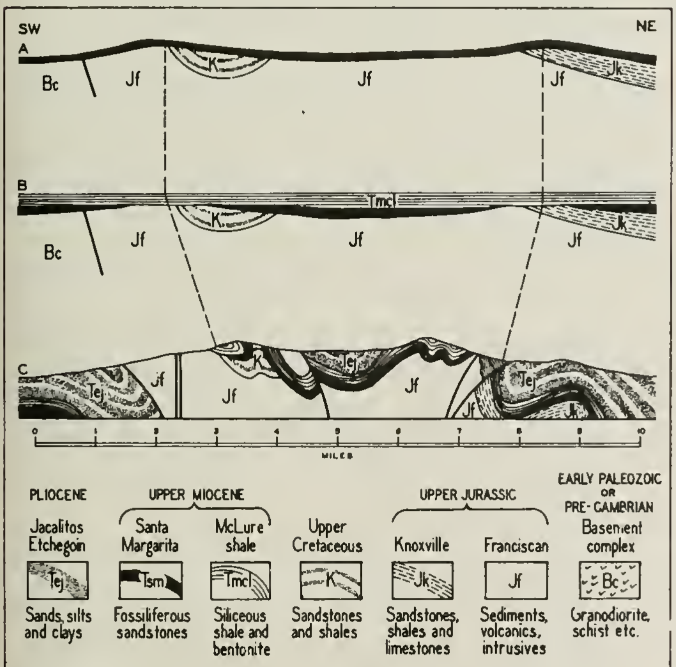

Fig. 58. Ideal section, showing the effect of late upper Miocene anticlinal warping on the localization of the marginal overturned folds and thrusts on the two sides of Castle Mountain Range. A. Santa Margarita sands were gently folded in two parallel anticlines which were beveled before the deposition of the McLure shale. B. McLure shale deposited across area; rests on Santa Margarita sands except along beveled crests of parallel anticlines where it rests on older rocks, either Franciscan, Knoxville, or Cretaceous. C. Present section across Castle Mountain Range, between Smith and Charley Mountains, showing development of the marginal thrusts along the general lines of the upper Miocene anticlines, which were accentuated, overturned, and finally broken and overthrust in the late Pliocene; thrusting again took place along the same general lines in mid-Pleistocene.

Broad tectonic syntheses, of the type so commonly advanced by Continental geologists, too frequently omit those seemingly minor details which are in apparent disagreement with the particular concept. So many things are ignored that the picture tends to become too perfect and the pattern too greatly simplified. Many syntheses confuse several orogenic episodes and fail to note the effect of earlier or later diastrophisms. The writer believes that the structures, and even the topography, formed by an earlier important orogeny leave their imprint on a later and even stronger diastrophism, and that many of the current opinions regarding Coast Range structure are erroneous because they have confused the effect of two or more diastrophisms; this is particularly true of the San Andreas fault.

In order to give a background for the complex structure of the Coast Ranges as we see it today, it will be necessary to recapitulate the diastrophic history previously presented.

Too little is known of the history of the ancient crystalline rocks to make any statement regarding the many pre-Franciscan diastrophisms they probably experienced. All that is known is that they were folded, dynamically metamorphosed, intruded by plutonic and hypabyssal rocks, uplifted and deeply eroded prior to the deposition of the Franciscan. They contributed debris to the Upper Jurassic sediments of the Sierra Nevada and were sufficiently denuded to expose the plutonics. The fine-grained nature of the upper part of the Mariposa indicates that they had been reduced to a comparatively low land mass just prior to the Nevadan revolution. The first readily decipherable history of the central Coast Ranges begins with the formation of the geosyncline in which the upper Upper Jurassic Franciscan and Knoxville and the Cretaceous sediments were deposited. This long geosynclinal trough was formed between the embryonic Sierras on the east and a rejuvenated land mass west of the present coast line. The extent to which the Sierra Nevada was upwarped is not known but it is certain that representatives of the present exposed crystalline rocks of the Sierras are not found as detritus in Franciscan, Knoxville, or Shasta sediments. However the higher, little-metamorphosed sediments of the Sierra Nevada may have been largely removed at this time. The late Jurassic Nevadan orogeny must have occupied a comparatively brief interval of geologic time, since beds of known Kimmeridgian age were folded and converted into slates. At the same time the western land mass was greately uplifted, and in the trough between the two land masses, Portlandian sediments were deposited.

During the upper Upper Jurassic (Portlandian and Aquilonian) at least 25,000 feet of shallow-water sediments and volcanics accumulated. Minor and apparently local diastrophisms (which may have been severe in the unknown region west of the present coast line) caused local interruptions in sedimentation and produced local disconformities in both the Franciscan and Knoxville. The strongest of these movements occurred during the deposition of the Knoxville and is recorded in mid-Knoxville conglomerates containing debris of both Franciscan and lower Knoxville rocks. This mid-Knoxville disturbance, so easily seen in the northern Coast Ranges, has not yet been recognized to the south. These diastrophisms were not sufficiently severe to leave any imprint on features produced at a later time.

The widespread break between the Upper Jurassic and the Lower Cretaceous was caused by diastrophism which was most severe in the west and died out eastward. It is represented by a strong overlap in the Santa Lucia and northern Diablo Ranges and by a disconformity to the east. Because of the complex subsequent history, deep erosion in some places and burial beneath later sediments in others, the evidence for this diastrophism, here called the Diablan orogeny, can only be found in a comparatively few localities. Nevertheless, these regions are so widely scattered over the central and northern Coast Ranges that it must have affected practically all of the California coast. There is evidence that this orogeny was most active in the Santa Lucia Range along a line, the Las Tables fault zone, which yielded by faulting in the Upper Cretaceous, the Eocene, the late Pliocene, and probably in the mid-Pleistocene. Preserved in synclines along this zone, which goes through the Adelaida and San Simeon quadrangles, are coarse Lower Cretaceous (Paskenta) breccias. Elsewhere than along this particular line the Paskenta stage of the Shasta is made up of the usual dark clay shales and thin sandstones. Whether these breccias, which contain abundant angular blocks of the Franciscan up to 12 feet in diameter, represent uplift by folding or faulting is not known but since the breccias are so coarse along the Las Tables zone and become finer so rapidly away from it, it is thought that they represent uplift by local faulting. If this undoubted uplift within the Santa Lucia Range was accompanied by faulting along the Las Tables line, this is the earliest movement, known to the writer, along any fault active during later orogenies. The effect of the Diablan orogeny on later diastrophisms must have been slight in general, but at least it is known to have been most severe in regions such as the Diablo and Santa Lucia Ranges which were afterwards strongly deformed. There is some evidence that faulting took place along a line which was active during several succeeding periods.

In the late Upper Jurassic sills, laccoliths, and irregular bodies of ultrabasic rock, now largely serpentinized, were intruded into both Franciscan and Knoxville prior to the deformation of either, as the sills are folded with the enclosing sediments. The higher of these sills and irregular bodies reached, in some places, almost to the top of the Knoxville. In a few places they were exposed by erosion between the Knoxville and Lower Cretaceous, as shown by serpentine debris in the Paskenta. A few miles southeast of Wilbur Springs, in Colusa County, there are thick and extensive serpentine mud flows in Paskenta shales. Some of these intrusions are locally more than 5,000 feet thick, and it is only reasonable to believe that they caused local uplift. West of Paskenta, in Tehama County, a very thick and irregular body of serpentinized peridotite clearly caused a local uplift in the Knoxville prior to the deposition of the Paskenta. The thick serpentine sill or laccolith now exposed in the crest of the Coalinga anticline in southern San Benito and Fresno Counties may very well have caused local uplift and may have been the fundamental cause of the localization of the Coalinga anticline. The general belief has been that the Coalinga anticline was first folded in the Upper Cretaceous; but the intrusion of a body of serpentine at least 4,000 feet thick in this locality may have been more effective in producing the observed results. Folding in the Upper Cretaceous may have accentuated the effect, but the possibility of uplift by intrusion can not be ignored.

Notwithstanding the widespread nature of the Diablan orogeny there is no evidence that the Franciscan-Knoxville geosyncline was separated into two or more basins of deposition. It may have been somewhat narrowed in an east-west direction and local islands may have been formed which stood above sea level for a short time, but deposition continued after a very brief interval in at least a large part of the original basin. Again the rapidity of diastrophism is demonstrated; the Knoxville immediately below the Diablan unconformity represents a very late stage in the Jurassic and the Shasta immediately above a very early stage in the Lower Cretaceous.

There is no evidence for and much against the existence of the hypothetical land mass of Salinia during the Upper Jurassic and Lower Cretaceous. It is possible that the present La Panza Mountains extended a short distance northward as a peninsula and a low but submerged bank continued to the north causing a local thinning of the Franciscan and Knoxville.

At least 5,000 feet of predominantly fine-grained shallow-water marine clastics accumulated during the Lower Cretaceous, which appears to have been a time of quiet deposition uninterrupted by diastrophism.

Widespread uplift and erosion occurred after the deposition of the Shasta and again in the Upper Cretaceous. The Upper Cretaceous has been divided by the writer into the Pacheco below and the Asuncion above, separated by the Santa Lucian orogeny; the Pacheco is separated from the Shasta by the mid-Cretaceous disturbance. It is not always possible to separate the effects of these two Cretaceous diastrophisms, but each appears to have been stronger and more extensive than any movements during the Upper Jurassic and Lower Cretaceous. The effects of both were greater in the west and died out eastward. In the Santa Lucia Range both are represented by profound unconformities which, on the west side of the San Joaquin Valley, are simply disconformities. Since these two orogenies and the distribution of the Pacheco and Asuncion groups have been discussed previously, only their combined effect will be considered here.

The combined effect of these diastrophisms was profound and marked the beginning of the break-up of the Mesozoic geosyncline. As a result of the mid-Cretaceous disturbance, a broad area roughly corresponding to the hypothetical land mass of Salinia was uplifted and stripped of its cover of Franciscan, Knoxville, and Shasta. The uplift was accomplished either by broad arching or faulting or both; local faulting is known to have taken place, but it is thought that the uplift was chiefly due to broad warping which was greatest in the vicinity of the present Gabilan and northern Santa Lucia Range. The wide exposures of crystalline basement rocks in these areas are an inheritance from the Upper Cretaceous orogenies, accentuated by faulting and tilting in the Eocene.

The southern part of the Gabilan mesa and practically all of the Santa Lucia Range as well as the Santa Cruz Mountains were submerged during Asuncion time and buried under an unknown thickness of sediments. These were in part removed as a result of uplift and erosion in the Eocene. The only part of "Salinia" that was emergent during the deposition of the Asuncion was the Gabilan Range, which forms the northern part of the more extensive feature known as the Gabilan mesa.

Although the Upper Cretaceous orogenies were of great importance and affected a large part of the central Coast Ranges they did not split the Mesozoic geosyncline into completely separated basins. By the close of the Upper Cretaceous most of the original trough in the central Coast Ranges was flooded, with the exception of the Gabilan Range, which probably stood as an island in the late Upper Cretaceous sea. The Upper Cretaceous movements appear to have been essentially parallel to the main axis of the trough, in marked contrast to the Eocene faulting which finally fragmented the Mesozoic geosyncline and cut across its trend at an angle.

The mid-Cretaceous and Santa Lucian diastrophisms had a profound effect upon the subsequent history of the central Coast Ranges, as they resulted in the removal of a thick prism of Upper Jurassic and Lower Cretaceous sediments from a central block, the Gabilan mesa. Eocene faulting, tilting, and stripping accentuated this effect and firmly established the three-fold division of the central Coast Ranges south of Monterey Bay into two "thick-blanketed" belts separated by a belt with a comparatively thin prism of sediments resting on a rigid crystalline basement.

There was slight folding, uplift, and erosion between the Cretaceous and Paleocene, but these movements were not comparable with those in the Upper Cretaceous. In the Santa Lucia Range the Cretaceous was slightly folded and eroded before the deposition of the Paleocene but there are no overlaps of Paleocene across the Cretaceous. Occurrences of Paleocene sediments in the central Coast Ranges are so few in number, except along the west side of the San Joaquin Valley, that little can be said regarding the original basins of deposition. However it is believed that the uplift and slight folding at the close of the Cretaceous was quickly followed by depression and local submergence of restricted troughs which were essentially parallel to the axis of the main Mesozoic geosyncline. Although less widely distributed and thinner than the Upper Cretaceous, the Paleocene sediments have the same geographic distribution and are lithologically similar, and there is nothing to indicate that any great uplift or widespread erosion occurred between them. There was no reshaping of the Coast Ranges at this time, and the movements had little effect in guiding subsequent diastrophisms.

As pointed out previously, the almost complete absence of Eocene and Oligocene beds over much of the central Coast Ranges does not permit a separation of the various movements which took place during this time; it is only possible to determine the net effects of the movements that occurred between the Paleocene and the lower Miocene. That several important movements took place during this long period of time is shown by the unconformities and disconformities along the west side of the San Joaquin Valley. Since it is known that all preceding and practically all succeeding diastrophisms were strongest in the west and decreased in severity eastward to the present western border of the San Joaquin Valley north of Coalinga, it is only reasonable to believe that movements resulting in slight disconformities in the east probably produced much greater effects in the west. Although it is impossible to distinguish between the various movements it is known that the sum of these movements was of profound effect in the shaping of the Coast Ranges.

The fragmentation of the long-enduring Mesozoic geosyncline, begun in the Upper Cretaceous, was completed in the Eocene. Deposition no longer took place in a long, practically continuous basin of deposition, but in basins which lay at a marked angle to the trend of the former geosyncline. It is clear that folding took place during the Eocene but the available evidence indicates that more important effects were accomplished by profound normal faulting, a type of movement which is in marked contrast to the later severe compression which resulted in folding, overturning, and thrusting.

Perhaps the most important result of Eocene diastrophism was the uplift and southwestward tilting of the Gabilan mesa along a line which roughly corresponds to the present San Andreas fault. Throughout that part of the central Coast Ranges northwest of Parkfield, in southeastern Monterey County, the northeastern side of this block is rather well defined even where covered with Miocene and Pliocene sediments, but the downtilted southwestern side is very irregular and only occasionally bounded by faults. The theoretical Nacimiento fault was created to serve as the western boundary of the hypothetical land mass of "Salinia," which would roughly correspond to the tilted Gabilan mesa. Although there are numerous faults in this region, some of which date from the Eocene, there are none which could, by any stretch of the imagination, correspond to the Nacimiento fault. In the tilting of the Gabilan mesa the southwestern margin was not everywhere faulted, and hence this border is very irregular and often indefinite.

The faulting which caused the tilting of the Gabilan mesa can be dated fairly closely both along the northeastern margin and on faults which appear to have developed within the tilted block. Many of these faults became active during the late Pliocene and Pleistocene but usually no difficulty is encountered in separating the effects produced in the two widely separated periods. Along the northwest side Franciscan, Knoxville, Shasta, and Asuncion sediments, usually of great thickness, are in contact with the crystalline rocks; sediments as old as the Temblor rest on the Mesozoic sediments on the northeast side and on the crystalline rocks on the southwest side, dating the movements as post-Asuncion (upper Upper Cretaceous) and pre-Temblor. Along the San Marcos fault, 5 miles northwest of Paso Robles, at least 6,000 feet of Asuncion and Paleocene sediments dip northeast into granodiorite; on one side of this fault Vaqueros (lower Miocene) sediments rest on granodiorite and on the other on a great thickness of Upper Cretaceous and Paleocene, dating the fault as post-Paleocene and pre-Vaqueros. Since the removal of this great thickness of Upper Cretaceous and Paleocene rocks would have required a very appreciable time, it is believed that the faulting occurred fairly early in the Eocene. The San Marcos fault, which can be traced for about 15 miles, lies somewhere near the very indefinite, irregular southwestern margin of the Gabilan mesa and is thought to have formed at approximately the same time as the parallel ancestral San Andreas, 20 miles to the northeast. The first discernible movement on the San Marcos fault was post-Paleocene and pre-Vaqueros but the more continuous fault to the northeast can only be dated as post-Asuncion and pre-Temblor because of the complete absence of Paleocene and Vaqueros sediments along its course. Both faults are connected with the uplift of the Gabilan mesa and it is believed that both originated in the Eocene.

Along the ancestral Eocene San Andreas fault the movement was largely vertical, the downthrow being on the northeast. Faulting may have been preceded by broad upwarping in the Eocene, but of this there is no positive evidence. Broad upwarping undoubtedly occurred in the Upper Cretaceous but strong faulting at that time is unlikely as there are thick sections of late Upper Cretaceous sediments, containing no coarse angular debris of the crystalline rocks, immediately adjacent to or but a short distance from the fault. Even during the Eocene it is probable that the northern end of the Gabilan mesa, the present Gabilan Range, stood higher than the southern part, a result of upbowing during the Upper Cretaceous, accentuated by uplift and faulting in the Eocene.

The writer believes that there is good evidence of profound faulting during the Eocene along the northeastern side of the Gabilan mesa at least from Parkfield to the latitude of Hollister, a distance of 90 miles. Movement undoubtedly continued beyond these limits but it is probable that the magnitude decreased in both directions. The greatest apparent uplift occurred along the east side of the present Gabilan Range but it is probable that a part, and perhaps a large part, of this movement was caused by upbowing in the Upper Cretaceous.

Movement took place along at least a part of the Las Tables fault zone, in the Adelaida and San Simeon quadrangles, during the Eocene, as the Vaqueros lies on the Franciscan on the northeast side and on Asuncion on the southwest side along a part of its course. Although it is certain that the Las Tables zone was active in places in pre-Vaqueros and post-Asuncion time, the full extent of this movement is not known because so much of the evidence has been removed by uplift and northeastward thrusting in the late Pliocene and probably in the Pleistocene. A very considerable part of the late uplift of the southern part of the Santa Lucia Range was accomplished by overfolding and thrusting along the Las Tables fault zone.

Along the coast, in the southeastern part of the San Simeon quadrangle and the northwestern part of the San Luis quadrangle there is a zone of pre-Vaqueros and post-Asuncion faulting which appears to have been tilted, and probably slightly folded, by later movements. Folded Franciscan sediments and volcanics, overlain by Vaqueros, lie on the northeast and Asuncion sediments, which dip into the Franciscan at an average angle of 30 degrees, on the southwest. The relations appear to indicate faulting in the Eocene with the downthrown side on the southwest. Other faults in the Santa Lucia Range may have been active in the Eocene but because of the absence of Tertiary sediments in the higher parts of the range there is no positive evidence of such movements.

The downthrown side of the profound Eocene fault on the northeast border of the Gabilan mesa was on the northeast; in the Santa Lucia Range the downthrow was on the southwest. Even though the southwestern downdropping in the Santa Lucia Range was of great magnitude there is no evidence that the region was depressed beneath sea level during the Eocene. This apparent anomaly may be due to upbowing prior to faulting in the early Eocene, similar to that in the Upper Cretaceous, or to continuous uplift, coincident with normal faulting, during the Eocene.

The Santa Cruz-San Benito trough developed after the early Eocene faulting, as it crosses the ancestral San Andreas at a marked angle. The causes of its development and localization are not clear, but it appears to have developed by downwarping at a marked angle to previously established structural lines. Its localization may have been greatly influenced by the presence of a rigid crystalline buttress in the northern part of the Gabilan mesa and the Santa Lucia Range, an inheritance from Upper Cretaceous and early Eocene diastrophisms, and by the ancestral Coalinga anticline, also a relic of earlier movements. By middle and late Eocene time an arm of the Santa Cruz-San Benito trough probably extended southwestward between the Santa Lucia Range and the Gabilan mesa but there is no evidence that this arm extended any farther south than the latitude of King City or that it ever connected with the San Benito trough across the central part of the present Gabilan Range.

It is, of course, possible that Eocene sediments may have been widely distributed in the central Coast Ranges and removed before the deposition of the Miocene. If this were the case the widespread removal must have been accomplished by general uplift without folding for, if folding had taken place, Eocene sediments should somewhere be preserved in the deep synclines in the region. It is believed that certain paleographic maps of the Eocene have indicated a much wider extent of the sea than is justified by the evidence even though the Eocene was followed by a long period of erosion. The upwarping, which accompanied the faulting in the early Eocene, is thought to have been sufficient to have kept much of the central Coast Ranges above sea level.

There is no evidence that the early Eocene fault along the northeastern margin of the Gabilan mesa experienced any movement, except where crossed by late Pliocene and Pleistocene faults, until the late Pleistocene when the present San Andreas fault was formed. The region traversed by this fault was eroded and much of it submerged and covered with sediments in the Miocene, Pliocene, and Pleistocene before a very different type of movement took place along it. It did not act as a barrier to marine invasions during the Miocene and Pliocene.

Over most of the central Coast Ranges the Miocene began with rather quiet and comparatively uniform sinking and the topographic depressions formed during the late Eocene and Oligocene were first flooded; as sinking continued the seas expanded and covered greater and greater areas. The early movement appears to have been chiefly widespread sinking with only minor downwarping except in local troughs, such as the Caliente basin, where an abnormal thickness of Vaqueros is reported. Early in the middle Miocene simple sinking gave way to slow downwarping of the basins, permitting the local accumulation of great thicknesses of Miocene sediments. It is believed that the downwarping was caused by compressive movements and that interbasin areas were actually upbowed at the same time. This slow and gentle, but rather continuous, warping of the Coast Ranges was the first manifestation of the compressive movements which reached their culmination in the late Pliocene and mid-Pleistocene. That there was upbowing as well as downwarping is shown by the relations in the southern part of Monterey County. On the east flank of the Santa Lucia Range, east of the San Antonio River, there are at least 12,000 feet of Miocene sediments. In this region the Santa Lucia Range was not completely covered by the Miocene sea (although it was not far to the south) and the sediments thin and become slightly coarser westward toward the range. At the beginning of the Miocene the ancestral Santa Lucia Range stood above sea level as a low land mass which increased in elevation northward; there is nothing in the character of the sediments to indicate that it was either high or rugged. It was subjected to erosion and contributed sediments to the sinking trough to the east (and very probably to a trough to the west) throughout the Miocene. There is no evidence that the margin of this trough was faulted at any time during the deposition of the Miocene sediments and it is unreasonable to postulate an abrupt strong marginal flexure to account for the sinking. Less than a quarter of the downwarping of the closely adjacent trough during the lower and middle Miocene would have carried the Santa Lucia Range well below sea level, hence it is believed that the sinking of the trough was accompanied by upwarping of the range. There is definite evidence, which has been presented previously, that the range was rather suddenly elevated in the late Miocene; it is believed that this uplift simply represents an accentuation of the rather continuous upwarping which had been going on since the beginning of the middle Miocene.

The compressive forces that produced the Miocene troughs and upwarps may have been applied rather uniformly over the central Coast Ranges but they did not result in evenly spaced troughs and uplifts because of heterogeneities of basement and topography brought about by previous diastrophisms. An important and rather long-enduring trough developed along the western down-tilted side of the Gabilan mesa, west of the Santa Lucia Range. The southern end of the Santa Lucia Range was flooded but it did not sink to the same extent as the basin to the west. Remnants of Miocene sediments occur along the west side of the range as far north as the Cape San Martin quadrangle and again in the Point Sur quadrangle to the north indicating a possible trough west of the Santa Lucia Range. The trough east of the range continued to sink and expand until the southern part of the Gabilan mesa, except for a few islands of crystalline rocks northwest of Parkfield, was covered. This trough also expanded toward the northwest between the Santa Lucia Range proper and the Sierra de Salinas (now essentially a part of the Santa Lucia Range) and a connection with the present Monterey Bay region was established in the upper Miocene. The upper Miocene diastrophism, which has been discussed previously, uplifted and folded the Santa Lucia Range and at least a part of the Diablo Range but deposition was continuous in the central parts of the basins which continued to sink.

The present crest of the Coalinga anticline, now occupied by Franciscan, stood above sea level throughout the Miocene. Lower and middle Miocene sediments in the Vallecitos syncline contain characteristic Franciscan debris, such as benitoite, showing clearly that the Franciscan was exposed to the south at that time. A peninsula of Cretaceous rocks extended southeastward from this island at least as far south as Curry Mountain. The southwest side of this island roughly followed, but did not necessarily exactly coincide with, a zone of faulting, the ancestral Waltham Canyon fault. The writer is well aware that many conflicting statements have been made regarding the Waltham Canyon fault, that it has been regarded as of recent origin, and that cross-sections have been published showing its disappearance in the Miocene. He has mapped those parts of the Priest Valley and Coalinga quadrangles adjacent to this fault and the relations can only be explained by sharp folding and faulting in the pre-Miocene. Space does not permit the presentation of the maps, cross-sections and explanations necessary to prove this statement; the briefest statement that can be made is that it would be necessary to believe that over 11,000 feet of Upper Jurassic and Cretaceous sediments thinned to nothing in a distance of approximately 15,000 feet unless it is admitted that faulting occurred. The date of the faulting is not definitely known but it is believed to have been early Eocene.

At the close of the Miocene that part of the Santa Lucia Range between the latitude of Bryson on the southeast and Point Sur on the northwest stood above sea level as a low, long, narrow island. The Sierra de Salinas, most of the Gabilan Range, and the northern part of the Gabilan mesa stood as a large island, probably higher than the Santa Lucia island. A peninsula extended to the southeast at least as far as Lonoak; southeast of this peninsula and along the same trend were a few small rather rugged islands made up of crystalline rocks. East of this peninsula lay the island marking the crest of the Coalinga anticline. To the northwest lay the long narrow Diablo island. This was smaller than usually shown on paleographic maps, as the writer has found middle and upper Miocene sediments at an elevation of nearly 3,000 feet in eastern Santa Clara County. In the troughs between these islands a variable, but usually great thickness of Miocene sediments had accumulated. These sediments, thick in the basins, thinned toward these islands, a condition which aided in localizing overturns and thrusts later. These islands were in part due to slight but continuous upbowing during the Miocene and in part were inheritances from earlier diastrophisms. The thickest accumulation of Miocene sediments in Monterey and northern San Luis Obispo Counties took place along the western down-tilted margin of the Gabilan mesa, which was constantly downwarped by the compressive movements which began early in the Miocene.

The effect of movements during the late upper Miocene cannot always be evaluated because of removal of evidence by later more severe diatrophisms; this is especially true in the Santa Lucia Range. However, in the northern part of the Castle Mountain Range and in its northern continuation, Mustang Ridge, the evidence is clear and unmistakable and has been preserved for many miles on both sides and within the range, notwithstanding the severity of the later diastrophisms. Middle Miocene sediments (with a characteristic Temblor fauna) are present in this region but their distribution is very limited, either because of small narrow original basins of deposition or removal in the early upper Miocene. Santa Margarita sands were deposited over the region on a basement consisting chiefly of Franciscan but with remnants of Knoxville, Shasta, and Upper Cretaceous sediments. These were deposited on a surface of moderate relief and their original thickness varies somewhat from place to place, but they are usually from 100 to 300 feet in thickness. After, or perhaps even during, the deposition of these sands, there was gentle anticlinal folding along two more or less parallel lines, 6 or 8 miles apart, which roughly correspond with the present margins of the range; the maximum observed tilt is 11 degrees. These two anticlinal ridges, formed within the basin of deposition of the Santa Margarita sandstones, were planed off, possibly almost as rapidly as they were formed by marine planation. The McLure shale, usually with a thin basal sandstone, was then deposited over the entire region. Where it crosses the two anticlines it lies unconformably on the Santa Margarita sands and on the Franciscan. Elsewhere the Santa Margarita sands and the McLure are conformable and in many places appear to be gradational. This local thinning, due to gentle folding before the deposition of the McLure, had a marked influence on the localization of the overturning and thrusting on the two sides of the range, by which action the range was uplifted in the late Pliocene and mid-Pleistocene. The accompanying figure indicates the stages in this process: **A** shows the gently folded Santa Margarita sands; **B** the McLure shale transgressing across the beveled edges of the sands and locally resting on the Franciscan across the anticlinal crests; **C** is an actual section across the present northern end of Castle Mountain Range between Smith and Charley Mountains. The localization of the late Pliocene and mid-Pleistocene marginal overturning and thrusting was only in part caused by the two late Miocene anticlinal ridges. East of this range is the Waltham Canyon trough which gradually subsided during the Pliocene and in which fully 8,000 feet of Pliocene sands and silts accumulated. Pliocene sediments are preserved within the range in synclines but they are thinner across the range than on either side. Much of this thinning may be due to erosion after uplift but rather meager paleontological evidence indicates that there is a definite thinning of the Jacalitos phase across the range. Although this part of the Castle Mountain Range was not emergent during the deposition of the Jacalitos and Etchegoin phases of the Pliocene, it did not sink to the same extent as the regions on either side. There is no evidence in the character and distribution of the sediments that the two sides of the range were active faults during the deposition of the Pliocene. It is believed that the gentle and rather continuous downwarping of the Priest Valley-Waltham Canyon basin was accompanied by upbowing of the adjacent range, upbowing so slight that it did not keep pace with the general sinking of the region but caused a general thinning of the sediments across the range. This local thinning also influenced the localization of the overturning and thrusting in the late Pliocene and mid-Pleistocene. This range is a good example of the influence of earlier movements on the localization of later and more powerful diastrophisms.

The movements which closed the Miocene have been described previously; in the west, and possibly over much of the central Coast Ranges, they were much like those in the upper Miocene in that many of the former uplifts were accentuated but deposition was continuous in the basins. The Santa Cruz-Priest Valley-Waltham Canyon trough was greatly deepened and thick accumulations of silty sediments took place, especially in the northwest and southeast. Sediments did not accumulate to as great a thickness in the central part of this trough in central and southern San Benito County. The northern part of this trough corresponded with the earlier San Benito Eocene trough but the southern part lay to the southwest, rather than to the north of the crest of the ancestral Coalinga anticline. The southeast end of the Eocene San Benito trough was still a slightly depressed area but it received continental rather than marine sediments during the Pliocene. The thick accumulation of sediments in sinking troughs and their marginward thinning, begun in the Miocene, was accentuated in general by lower and middle Pliocene deposition.

The gentle compressive movements which began early in the Miocene reached their first great peak in the late Pliocene and their second peak in the mid-Pleistocene. Opinions have differed as to the relative importance of these two closely related diastrophisms and in many instances only one has been recognized. In general it may be said that those who have worked in the western part of the Coast Ranges have emphasized the importance of the earlier and those whose experience has been chiefly limited to the eastern part have stressed the importance of the later movements. Both were of great importance and deformed most, if not all of the Coast Ranges; the late Pliocene folding and thrusting was especially strong in the Santa Lucia Range, somewhat less so in the Castle Mountain Range and comparatively weak eastward. In that part of the Diablo Range lying in central and northern San Benito County the earlier movements were much stronger than the later as the Plio-Pleistocene San Benito orogenic sediments are only gently folded and occasionally pass across strong late Pliocene thrusts without interruption. The mid-Pleistocene deformation, judged by the degree of folding of the Plio-Pleistocene orogenic sediments, was equally strong from the coast to Waltham Canyon, dying out eastward but less rapidly than the late Pliocene movements. These are broad generalizations only and there are local exceptions caused by variation in resistance of bed rock and by the presence of earlier folds and faults.

The late Pliocene diastrophism not only uplifted the ranges by folding and thrusting of their margins but also brought about uplift of the Coast Ranges, causing a very general retreat of the seas from the entire region, except from certain coastal embayments. The rapid folding and uplift of the ranges and the erosion which ensued formed thick flood plain and lacustrine deposits (Paso Robles, Santa Clara, San Benito, restricted Tulare, etc.) in the basins which in general were already filled with thick Tertiary sediments.

Since the late Pliocene and mid-Pleistocene diastrophisms were of the same general character and were produced by compressive forces, and since the later movements only served to accentuate major features formed by the earlier, the effects of the two will be treated as a whole. The writer will leave a discussion of the ultimate causes of the forces which produced the results we see to those who are not satisfied with the observation and presentation of known facts but must indulge in speculations regarding deep convection currents, isostatic adjustments, shifting continents and the like. Such speculations, while valuable, all too often ignore the array of surface evidence already available. It is sufficient to say that observations in the Coast Ranges indicate that since the Eocene, at least, there has been a constant pressure of the oceanic segment against the continent. The compressive forces which were brought to bear on the continental margin and which culminated in two peaks in the late Pliocene and mid-Pleistocene acted on a region of diversified topography and bedrock and variable thicknesses of sediments. Much of the diversity in the nature of the bedrock was an inheritance from the Upper Cretaceous and the Eocene. The three-fold division south of Monterey Bay into two belts underlain by a thick prism of pliable sediments separated by a central belt underlain by a crystalline basement came into existence in the early Eocene; diversities within this central belt also were an early feature. The wide exposures of crystalline rocks in the northern Santa Lucia Range and in the Gabilan Range essentially are due to upwarping in the Upper Cretaceous and to block faulting and tilting in the Eocene. The thick accumulation of Miocene and Pliocene sediments in basins and their marginal thinning across interbasin upwarps, although greatly influenced by earlier-formed features, was largely a result of the widespread sinking which began in the lower Miocene and the compressive forces which began, over most of the region, in the early middle Miocene and which deepened the basins almost continuously, and gently arched the interbasin areas. Our present major topographic and structural features clearly show the imprint of Upper Cretaceous and Eocene movements but their general direction and localization came into existence in the early middle Miocene; the strong Plio-Pleistocene diastrophisms followed the major trends established at that time. The upwarped areas, originally rather simple, in some cases at least, became compound during the various minor upper Miocene peaks and developed parallel marginal folds along which later overturning and thrusting were localized.

It is realized that the idea here outlined, if followed to its logical conclusion, is contrary to many current beliefs regarding the continued sinking of a basin by constant additions of load and its final collapse from the same cause. It is believed that the available evidence does not favor such a concept but indicates that basin sinking and interbasin upwarp was a long continued process due to forces which originated outside of the local province of deposition and erosion. The final collapse was not due to deep basin filling but to one of many strong orogenic pulses which affected the continental margin. The localization of the major overturning and thrusting toward the basins was a result of basin-filling and marginal thinning but the compressive forces which were the cause of the orogeny were not brought into play by local erosion and deposition.

The effect of the late Pliocene and mid-Pleistocene orogenies naturally differed with the type of bedrock undergoing deformation. The regions underlain at comparatively shallow depths by crystalline rocks, or those where the crystalline rocks were exposed, yielded by faulting, while those underlain by thick sedimentary prisms yielded by folding and ultimately by thrusting. However, as pointed out previously, it is difficult to draw the line between thin- and thick-blanketed areas. Regions with a crystalline basement at present depths of 8,000 or 9,000 feet (known from deep wells) yielded in a manner very similar to those underlain by at least twice this thickness of sediments.

Under the strong Plio-Pleistocene compressive forces the areas underlain by thick prisms of sediments first began to rise along the pre-existing upwarps. These were rapidly folded, most strongly along regions of marginal thinning which corresponded to the margins of the upwarps which began to form in the early Miocene and were accentuated in the upper Miocene. These areas first rose by folding which increased until the marginal folds were overturned away from the rising ridges toward the deeper basins. Finally the stretched limbs of the overturned folds yielded by thrusting, and as the ranges rose they were thrust outward over the adjacent basins. Thus the areas between the original downwarps rose as ridges whose flanks were thrust outward over the thick sediments of the basins. Along the present ranges, formed in thick, yielding sedimentary prisms, the thrusts dip inward toward the ranges and, except where guided by pre-existing faults, represent the stretched and broken limbs of anticlines developed on the thinning edges of Miocene and Pliocene basins of deposition.

In the central Coast Ranges the central belt of crystalline rock transmitted the forces to the more easterly belt of thick sediments, and these were folded in the same way as those to the west.

On the accompanying cross-sections these marginal folds, along which the ranges rose, are shown as steepening downward and hence with a basinward concavity. It is admitted that the actual visible evidence for this can be seen only occasionally. In following certain thrusts from deep canyons to ridges there is, in some cases, an actual decrease in angle. Also the thrusts developed within the ranges are always steeper than the outer marginal thrusts, except where there have been complications introduced by previous structures. It is believed that there are adequate grounds, both observational and inferential, for the downward steepening of the thrust along which the ranges rose. These marginal thrusts were the result of the breaking of overturned folds and are essentially parallel with the fold axes; it is hardly possible that the axial planes of the folds are concave toward the centers of the ranges. The most perfect examples of the formation of ranges by upbowing, folding, and rising along outward-dipping thrusts are the central and southern Santa Lucia Range and the central and northern parts of the Castle Mountain Range. The northern part of the Santa Lucia Range exhibits the same type of structure but it is compound and consists of at least two units. It is further complicated by the presence of crystalline basement rocks at the surface.

Although the ranges are practically always bordered by marginal thrusts the individual faults rarely can be traced for more than 20 or 25 miles. As a thrust dies out its place is taken by one or more en echelon faults. Frequently the thrusts steepen as they die out in a bundle of folds. Occasionally the larger thrusts die out by branching, as the great Oceanic thrust zone on the west side of the Santa Lucia Range. This thrust, along which Franciscan is moved westward over the Miocene, branches at San Simeon Creek and the branches gradually diverge and die out; each branch can be traced by discontinuous belts of overturned Miocene sediments and volcanics overriden by Franciscan.

The angle of inclination of the thrusts varies from less than 20 to over 80 degrees. The outer marginal thrusts average between 40 and 50 degrees; the faults within the ranges are somewhat steeper and usually increase in angle as the center is approached. The beds on the under sides of the thrusts are practically always overturned through stratigraphic thicknesses of less than 100 to more than 2,000 feet.

In addition to the thrusts there are transverse faults, some of which cut almost completely across the range. These are especially numerous in the Santa Lucia Range, where they have had a marked effect on the amount of uplift attained. In the southern part of the Adelaida quadrangle the southerly decrease in the elevation of the range is definitely related to a series of transverse faults, each having the down-throw on the south.

Some of the individual ranges of the Coast Ranges are similar to mountains that have been described by Continental and American geologists, but they are smaller than most of the examples that have been cited. The Castle Mountain Range, with its overturned marginal folds and thrusts and its central synclinal area, modified by minor warps and faults, is very similar to the larger picture given by Kober of "Randketten" riding out over bordering rigid plates, and separated by gently folded, essentially synclinal "Zwischengebirgen". Here, however, the likeness ends, as the explanations given by Kober and the writer differ fundamentally. The Santa Lucia Range is much more complex and, while essentially due to the same causes as the Castle Mountain Range, differs from it in many respects. In fact the Santa Lucia Range is compound north of the latitude of Bradley and consists of at least two imperfectly developed units bordered by marginal faults, a condition due to the development of basins on a crystalline basement, much of which stood above sea level during the Miocene. The type of ranges developed in the Coast Ranges is not due to the crushing of a deep geosyncline between two rigid plates, as are some of the examples cited by Kober and others, but are features which developed between comparatively small basins.

Some of the faults which were formed during the Eocene as profound normal faults became active during the Plio-Pleistocene diastrophisms as thrusts. This was only natural since they were lines of weakness, usually between two very different types of rocks. On some of these there was a definite reversal of movement and the former downthrown side was thrust upward and over the former upthrown block. Concrete examples of this reversal of movement are to be found in the San Marcos fault and in some places along the eastern side of the Gabilan mesa; both of these faults have been described previously and both are shown on some of the accompanying cross-sections. The writer does not believe that such movement along older faults can be considered as a renewal of growth on that particular fault. The types of forces causing the two movements were very different and they were separated by a long interval of time during which the fault was inactive and was covered by a great thickness of sediments. The older faults, usually because they were between such diverse rock types as granodiorite and sediments, merely localized the later movements. Other old faults which are known to have moved during the severe Plio-Pleistocene diastrophisms were the Las Tables, Waltham Canyon, and Pescadero. Probably many older faults again broke, but most of the thrusts appear to have been newly formed features. It is sometimes possible to distinguish a newly formed thrust from breaking along an older line by the type of movement which took place. In general the newly formed thrust is a cleaner, more continuous break that can be related definitely to the breaking of an overturned fold. Movement along older lines sometimes has a tendency to be very complex, with a number of parallel lines of movement, or with a series of small discontinuous en echelon breaks. Furthermore, they may exhibit what appear to be very profound displacements which die out with great rapidity. Newly formed thrusts usually bear a closer relation to basin margins than movements along old faults, which may take place either within the range or within the basins. However these can only be considered as generalizations, as there are many exceptions.

Many different opinions have been expressed as to the importance of the King City fault; some have held that it is one of the major features of central California and others have expressed doubt as to its existence. Although the evidence for a fault along the east side of the Sierra de Salinas is largely physiographic there is some direct evidence of its presence. Physiographic evidence for the King City fault is the steep, straight eastern front of the Sierra de Salinas which attains an elevation of over 3,800 feet above the Salinas Valley within 2 miles, and which is cut by sharp steep-walled, high-gradient canyons. Alluvial fans, formed at the mouths of these canyons, have coalesced into a continuous apron along the range front, burying practically all direct evidence of faulting. The streams causing the fans are consequent streams resulting from recent uplift. Deep water wells along this front have not encountered the crystalline rocks which make up the

Sierra de Salinas at depths of as much as 1,300 feet below sea level. Wells along the east side of Salinas Valley, at the foot of the Gabilan Range, reach the crystalline basement rocks at comparatively shallow depths and indicate that the Gabilan Range surface slopes gently westward beneath the Salinas Valley. Shear zones have been reported in the crystalline rocks along the east front of the Sierra de Salinas; these are parallel to the front and may represent movements along minor faults west of the King City fault.

The Sierra de Salinas and its wide alluvial apron end just north of Arroyo Seco, and a mile east of Paraiso Springs a fault emerges from beneath the alluvial apron. This trends due south for about 2 miles and then turns to the southeast, crossing both Arroyo Seco and Reliz Canyon and dying out in Miocene sediments. This is a high-angle thrust fault, dipping southwest into the range, between Miocene shales on the west and Santa Margarita and Paso Robles on the east. This is thought to be a branch of the King City fault, although it may be its southern end, as the Salinas Valley is no longer bordered by a steep front flanked by an alluvial apron. The King City fault may extend to the southeast along the edge of the valley either as a fault in the bedrock or as a zone of sharp flexing in the Tertiary sediments. In the King City, Priest Valley, and Bradley quadrangles there is a zone of steepening and occasional overturning toward the northeast along the hill front which may represent the southeastern continuation of the King City zone. Even this dies out a short distance south of San Ardo. There is no surface evidence of any kind that the King City fault extends even as far south as King City. However there is good evidence that it has a length of about 25 miles, which is as long or longer than most of the marginal faults of the Santa Lucia Range. It is not a major feature of central California but merely one of the system of faults developed in the late Pliocene and mid-Pleistocene. The coarse detritus of crystalline rocks and the abundant Miocene shale pebbles in the Paso Robles in the vicinity indicate that there was movement in the late Pliocene, and the high dips in the Paso Robles indicate renewed faulting in the mid-Pleistocene. Movement may have taken place at an earlier date, but of this there is no evidence. The present elevation of the Sierra de Salinas is only in part due to the faulting, as this range stood above sea level in both the Miocene and Pliocene.

Although greatly influenced by earlier movements the present major structural and topographic features of the central Coast Ranges were developed by the late Pliocene and mid-Pleistocene diastrophisms. The movements since the mid-Pleistocene have been important but they have not obliterated or greatly modified the features established at the close of the mid-Pleistocene orogeny. Great slides resulted from the mid-Pleistocene uplift of the ranges and these have somewhat obscured the marginal thrusts; but subsequent erosion has dissected these early slides and the Plio-Pleistocene structures are exposed in the gullies and canyons.

Although the Plio-Pleistocene diastrophisms acted on a somewhat heterogeneous area of strongly contrasted types of bedrock, the writer can see nothing that is not orderly and comparatively simple either in the Miocene and Pliocene events which preceded and strongly influenced the localization of these movements or in the diastrophisms and their results. There is nothing strange or abnormal in the filling of basins which sank by simple downwarping accompanied by the gentle upwarping of interbasin areas and a thinning of the sediments across them. The compressive forces causing warping reached minor peaks in the upper Miocene and Pliocene and caused local marginal unconformities through the uplift of the interbasin areas, but with continuous deposition in the sinking basins. These comparatively minor and easily understood complications, together with structures inherited from earlier diastrophisms and great differences in rigidity of bedrock resulted in many apparent complexities when the entire region was subjected to the strong late Pliocene and mid-Pleistocene diastrophisms. Other minor complexities arose from the presence of islands of rigid crystalline rocks in the Miocene and Pliocene seas, against which the sediments were crushed, and which often caused great divergences in fold trends. A concrete example of this type of complexity is found in the Arroyo Seco region, northwest of King City, where the folds in the Miocene and Pliocene sediments curve from their normal northwest trend to east-west and even east-northeast because of the buttressing effect of the crystalline rocks of the Sierra de Salinas, toward which the sediments thin, and which stood as an island in the Miocene sea. When we consider the many possible causes of complexities it is surprising that the pattern is not even more irregular. Since there is a reasonably logical sequence of events and since it is possible to observe comparatively orderly progression from cause to effect, the writer can see no reason for calling the Coast Ranges a heterogeneous mobile belt. Heterogeneities exist, but when understood they become part of a related series of events.

SAN ANDREAS RIFT

Perhaps the most important, and certainly the most discussed and widely known structural feature of central California developed since the mid-Pleistocene orogeny is the San Andreas rift, regarding which so many conflicting statements have been made. The writer is well aware that the conclusions presented here will be contrary to many of the current views regarding this feature. These conclusions, however, are not based on hypothetical reasoning, on a preconceived idea, or on any of the conflicting statements that have been made, but have developed gradually as field observations have accumulated during many years mapping over a wide belt from the Pacific Ocean to the San Joaquin Valley. The statements made at this time apply only to that part of the San Andreas north of Parkfield, but it is believed that ultimately they may be extended to the zone as a whole.

The chief difficulty in the way of a study and interpretation of the San Andreas rift is the disentanglement of this line of movement from earlier faults. It is probable that many of the misconceptions that have arisen have been due to a confusion of the San Andreas with earlier movements of a very different type. It is impossible to discuss and interpret the San Andreas line of movement without considering the major structural features of the central Coast Ranges as a whole. As has been stated a number of times previously, a profound normal fault developed in the early Eocene along the eastern side of the Gabilan mesa, by which the southwestern side was elevated with respect to the northeastern side and stripped of its cover of Mesozoic rocks. Southwest of this fault is the crystalline basement complex and northeast is a thick prism of sediments. Many of the inequalities of relief caused by this fault were obliterated by erosion prior to the middle Miocene, when it was again partially flooded and sediments deposited across it. It did not act as a barrier to either the upper Miocene or Pliocene seas, and there is no sign of any general movement along it until the late Pleistocene. This has been referred to previously as the ancestral San Andreas, chiefly for brevity of reference rather than as an implication that it was related in origin to the present San Andreas. When the forces which caused the formation of the San Andreas rift came into being this important but long inactive line was in existence, and it probably aided in localizing a new type of movement. In the more than 50 miles of the San Andreas fault that have been followed and mapped by the writer, the San Andreas fault is close to but rarely exactly coincident with this earlier line. The earlier line is always the boundary between crystalline basement complex and Mesozoic sediments (Franciscan, Knoxville, Shasta, and Upper Crustaceous). The San Andreas fault however is rarely the boundary between these two very diverse types, but usually is either wholly within crystalline rocks or Mesozoic rocks, except where it cuts through either Miocene, Pliocene, or Pleistocene sediments. It might be argued that it forms the boundary between crystalline basement and sediments in depth, but when we consider the eastward dip of the Eocene fault and the fact that the San Andreas is often west of the crystalline boundary, this is hardly likely. As has been stated previously the present major structural and topographic features were formed by the Plio-Pleistocene diastrophism. The late mid-Pleistocene thrusts and all the features of overturning and the positive evidence of uplift associated with them are cut by the San Andreas and actually may be traced across the latter; even the early slides are traversed by the San Andreas. Nearly everywhere along the San Andreas there is abundant physiographic evidence of recent faulting, such as true sag ponds and offset ridge and drainage lines. However, along the earlier mid-Pleistocene faults there is no similar direct physiographic evidence of faulting. Late as they are, erosion has obliterated any such features originally present. Of course the ranges themselves are visible evidence of their effect, but of such direct physiographic evidence as exists along so much of the San Andreas rift there is no trace.

As a concrete example may be mentioned a thrust which has brought Franciscan and Cretaceous rocks above overturned Miocene and Pliocene sediments in an eastward-dipping fault which is the main inward-dipping thrust on the west flank of Castle Mountain Range. This thrust lies nearly 3 miles east of the San Andreas fault in the latitude of Parkfield, from which point it may be traced northwestward as a continuous zone of thrusting and overturning. About 12 miles northwest of Parkfield it becomes entangled with the San Andreas zone and, for a distance of about 3 or 4 miles the two can not be separated because of the very acute angle of intersection. However, 15 to 16 miles north of Parkfield it emerges, with all its characteristics of uplift, thrusting, and overturning on the opposite, or west, side of the San Andreas zone, and may be traced northward for 15 miles before it is lost. To the southeast of the intersection the San Andreas lies wholly within the crystalline basement and its Tertiary cover, and to the northwest wholly within Franciscan, Knoxville, and Shasta beds. There is abundant undestroyed evidence of recent movement everywhere along the San Andreas, but none along the thrust, except where the two coincide.

The opposite, or southwestward-dipping zone of thrusting which marks the eastern margin of Castle Mountain Range lies 12 miles east of the San Andreas in the latitude of Castle Mountain. This, and identical en echelon zones having the same effect, continue northwestward for 40 miles before being cut by the San Andreas. Thus, the more recent San Andreas movement cuts across the older Plio-Pleistocene structures at an angle. Many of these earlier thrusts have been regarded as branches of the San Andreas but they are earlier features formed by a very different type of movement and may be traced across the later line. Everywhere along the earlier thrusts are found the usual features of broken overturned folds, of uplift on one side and the overturning of beds on the other, features which are everywhere characteristic of the margins of the uplifted ranges. These effects are never found along the San Andreas except where it coincides with the thrusts for short distances.

Mustang Ridge forms the northwestern end of Castle Mountain Range and was formed at the same time and in the same manner, that is, in the mid-Pleistocene by outward thrusting on both sides. The San Andreas zone enters the southwestern corner of Mustang Ridge, crosses the ridge and emerges on the east side and continues northwestward along the east side of Bitterwater Valley, having completely cut across a definite topographic and structural unit. Throughout its course across Mustang Ridge, the San Andreas rift lies wholly within Franciscan, Knoxville, and Shasta, and is nearly everywhere, whether on the flanks or crest of the ridge, marked by sag ponds, trenches, and other familiar physiographic features indicating recent movement.

The Pilarcitos thrust, which cuts diagonally across the southwestern part of the San Mateo quadrangle and continues to the southeast across the Santa Cruz quadrangle, appears to be another example of the truncation of a late Pliocene fault by the San Andreas. At its northwestern end the Pilarcitos thrust is almost 4 miles southwest of the San Andreas; to the southeast it gradually approaches and finally crosses the San Andreas in the Santa Cruz quadrangle. The region to the southeast has not been mapped and its continuation in that direction is not known. The Pilarcitos thrust is not a branch of the San Andreas as has been suggested but is a fault formed first in the Eocene, after the deposition of the Paleocene and before the deposition of the Vaqueros. It is in fact the same Eocene zone of normal faulting which marks the northeast side of the Gabilan mesa to the southeast. This became active again in the late Pliocene, and possibly in the mid-Pleistocene, and experienced a reversal of movement, the Franciscan being thrust to the southwest over Cretaceous and Paleocene and the basement complex (here largely granodiorite) on which they rest. Kober was correct in stating that the Pilarcitos thrust is not a subordinate feature, but his statement that it is an allochthonous nappe is entirely without any supporting evidence.

The San Andreas has produced no important structural modification of features formed by the Plio-Pleistocene diastrophism throughout its course from Parkfield to the Pacific Ocean. All of the thrusting and overturning in the vicinity of the San Andreas are definitely related to similar structures which resulted from strong compression in the late Pliocene and mid-Pleistocene and which produced the dominant type of structure and topography from the Pacific Ocean to the San Joaquin Valley; these are universal in the Coast Ranges and are not features peculiar to the San Andreas zone. Statements that the San Andreas zone is several miles in width are the result of failure to separate the effects of earlier orogenics from later movement. Unless such a distinction is made the San Andreas becomes a zone of fantastic width.

The compressive forces which resulted in the late Pliocene and mid-Pleistocene diastrophisms not only produced characteristic structural features that are cut by the San Andreas, but the present major topographic features as well. These also are cut indiscriminately by the San Andreas, which, north of Parkfield at least, cuts across both ridges and valleys. Rift features, which as a rule can be readily followed, are not confined either to ridges or valleys but cross both.

The greatest apparent complexity and width of the San Andreas zone known to the writer are shown on cross-sections II and III on Plate II. Most of these features antedate the San Andreas movements and are the result of the effect of pre-existing topography and the Plio-Pleistocene diastrophisms. In this region, largely in the northeastern part of the San Miguel quadrangle and extending into the Priest Valley quadrangle, there were islands of ancient crystalline rocks in the upper Miocene and lower Pliocene sea. Both the upper Miocene and lower Pliocene in this region consist of coarse arkose and breccias deposited about the islands which may have been completely covered during the Pliocene. The soft sediments were faulted and crushed against the rigid crystalline rocks, which had a very irregular surface, and very complex structures resulted. It has been necessary to omit many of the minor details from the cross-sections because of the scale. The apparent width and complexity in this region are the result of the Plio-Pleistocene diastrophisms acting on unconsolidated sediments resting on a very irregular surface rather than movement along the San Andreas rift.

That there has been horizontal movement along the San Andreas rift is clearly shown by offsetting of ridge and drainage lines as well as by the visible movement in 1906. The same type of movement has taken place along the Hayward fault, which may be a branch of the San Andreas, although a definite connection has never been established. The writer is aware that there are many who believe that great horizontal movement has taken place along the San Andreas rift, movements measurable in miles, or even scores of miles. Shifts of this magnitude may have occurred south of the region studied by the writer but along that part of the rift north of Parkfield there is no evidence for, and much against, great horizontal movement. Thus far it has been impossible to obtain definite evidence of the exact amount of movement because of the rather acute angle of intersection of the rift and the structural and topographic features formed by the Plio-Pleistocene diastrophisms, but there is reasonable evidence that the horizontal movement has been less than a mile; had a shift of greater magnitude taken place the offsetting of mid-Pleistocene structural and topographic features would be clearly shown. The maximum offsetting of drainage lines, caused by repeated movements along parallel breaks, is less than 3,000 feet.

As a result of field evidence accumulated over a long period of time and from a large area in the central Coast Ranges, the following conclusions regarding the San Andreas fault have been reached:

1) The San Andreas zone roughly coincides with a zone of profound Eocene faulting which marks the boundary between the ancient crystalline basement and Mesozoic rocks. However, the two do not always agree, and the later zone may be wholly within either the crystalline basement or the Mesozoic rocks.
2) The movement has been chiefly horizontal but in that part of the rift north of Parkfield the horizontal shift has been small, and has not been greater than 1 mile and probably even less.
3) The horizontal shifting along the San Andreas zone is a very late feature, as it cuts across structures and topography developed in the late Pliocene and mid-Pleistocene. Although a major structural feature, the effects produced by all of the late Pleistocene and Recent movements along it have not been comparable with those which resulted from the Plio-Pleistocene diastrophisms. It has produced no important modification of either the structures or topography formed by these diastrophisms.
4) The supposed branches or "barbs" are actually earlier faults which were formed by a very different type of movement, and which may be traced across the San Andreas. No important faults branch off from the San Andreas north of Parkfield, with the possible exception of the Hayward; even in this case a direct connection between the two has not been established.

EXPLANATION OF GEOLOGIC STRUCTURE SECTIONS—PLATE II

Ten structure sections of the central Coast Ranges, extending from the Pacific Ocean to the San Joaquin Valley have been prepared. These range from 50 to 86 miles in length and are believed to give a fairly accurate picture of the structure of the central Coast Ranges over a distance of 170 miles, from San Luis Obispo County on the south to Mount Diablo on the north. All but one of these are continuous sections but because of lack of information in critical areas it was necessary to break section VIII into two disconnected parts. Sections I to VI inclusive and section VIII B are based on field work done by the writer, except for the extreme northeastern ends of sections IV, V, and VI which are taken from the literature. The remaining sections are based on published material and on unpublished theses of graduate students of the University of California and Stanford University; the source of the information is given below each section. Occasionally the sections have been slightly changed from the originals, the modifications being based on actual field observations made by the writer.

Section VIII B is obviously incomplete and is based on reconnaissance work only. The writer expects to publish more complete and accurate sections, in this and other localities, in the future. Incomplete and inaccurate as is section VIII B, especially immediately east of the Santa Clara Valley, it has been included to show the great thickness of Knoxville (Upper Jurassic) and Shasta (Lower Cretaceous) sediments, folded into a syncline, and to contrast the conditions on the two sides of the Diablo Range in this region.

Sections I to VI inclusive are not built up from traverses but are based on detailed mapping over a large area (with the exception of that part of section VI which crosses the King City quadrangle) and are thus believed to be more accurate than sections based on traverses alone. Subsurface relations which might be considered obscure from the sections alone would be clear if a geological map were available. Because of the scale on which the sections are published it has been necessary to omit much detail in areas of complex structure. Since the sections are in black and white it has been impossible to show lithologic variations within any single unit: this is unfortunate as such lithologic variations often indicate shore lines and the source of the sediments. More than 40 units have been recognized and mapped in the field; these have been condensed to 20 units on the sections.

Since the sections have been carried to depths of 7,000 to 9,000 feet below sea level it is obvious that a large element of interpretation has entered into their construction. However, a number of deep wells have materially aided in the construction of several of the sections; this is especially true of the Gabilan mesa where deep wells have given valuable information regarding the depth to the crystalline basement.

The structure of the Franciscan has been generalized but in the majority of the sections the positions of the major folds are accurately located. Minor crumplings and minor igneous bodies in the Franciscan necessarily have been omitted.

The interpretation given to the serpentine body in the heart of the Coalinga anticline in sections V and VI is new and may be startling. Obviously, direct observation along the line of section is impossible but from indirect evidence, such as folded leaves of Franciscan sediments along the crest of the fold (one of which is shown in section VI) and many parallel leaves about the margins, it is believed this is a folded sill which swells into an irregular laccolith in the Coalinga anticline and which thins westward toward Laguna Mountain and Hepsidam Peak. The bottom of the thin westward continuation may be seen south of the line of section VI. Both the bottoms and tops of the folded serpentine sills shown in the Santa Lucia Ranges and in Table Mountain may be seen in many places.

The field evidence for the inward dipping thrusts along the margins of the Santa Lucia Range and Castle Mountain is clear and convincing. The positions and inclinations of these thrust planes are based on surface observations, checked in two cases by subsurface information from mines.

The westward dipping thrust on the east side of the Diablo Range as shown on sections VI to X inclusive, has never been mentioned in the literature. In fact much of the evidence for this thrust has been obtained since the accompanying paper was written. It is especially impressive in the New Idria mine (section VI) where the average dip in a vertical distance of over 1,500 feet is 54 degrees, and in the vicinity of Ortigalita Creek (section VII) where the dip varies from less than 30 to 45 degrees in a vertical distance of nearly 1,000 feet. This thrust, which is definitely late Pliocene and was not active in the mid-Pleistocene, was responsible for a large part of the uplift of the Diablo Range.

The sections illustrate the description of the structure given in the accompanying paper. They also clearly indicate the important orogenies mentioned. It is regretted that space does not permit a detailed discussion of each section.

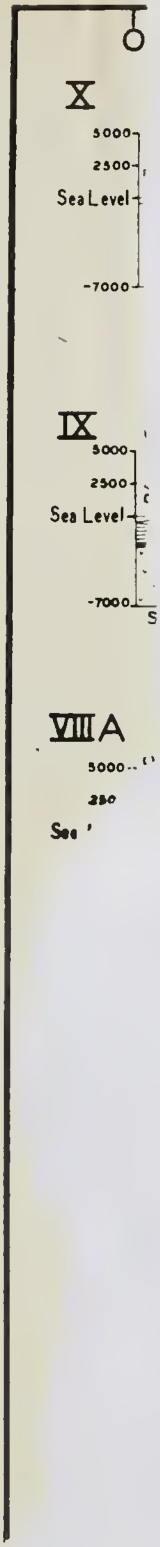
X
5000
2500
Sea Level
-7000
IX
5000
2500
Sea Level
-7000
VIII A
5000

Fig. 59A. A well exposed anticline in the northern Coast Ranges, with an oil derrick on its crest. Looking northwest toward Point Arena. *Photograph by Olaf P. Jenkins.*

Fig. 59B. A typical view in the central Coast Ranges, showing landslide topography of the Franciscan in the foreground. Looking south across Peachtree Valley. *Photograph by Olaf P. Jenkins.*

Chapter VI

Paleontology and Stratigraphy

CONTENTS OF CHAPTER VI

CHARACTERISTIC FOSSILS OF CALIFORNIA*

By G. Dallas Hanna** and Leo George Hertlein***

OUTLINE OF REPORT

INTRODUCTION

Because of the special interest in the sedimentary formations of Tertiary age, in relation to the exploration for petroleum in California, most of the fossil specimens illustrated in the following eight plates have been selected from beds of that geologic period. One plate of Cretaceous and one plate of pre-Cretaceous fossils, however, have also been included.

In choosing the fossils for these plates, an endeavor has been made to select forms which are usually common, and which are confined to narrow stratigraphic ranges. Unfortunately, however, space is limited, and it has been impossible to include all of even the most familiar species. It is desirable here to call attention to a recent publication that contains marker fossils, "California Fossils for the Field Geologist", by H. G. Schenck and A. M. Keen (40).

ACKNOWLEDGMENTS

The specimens from the Cretaceous have been selected by Dr. F. M. Anderson. Those of the pre-Cretaceous were furnished by Dr. S. W. Muller of the Department of Geology of Stanford University. Mr. C. C. Church has assisted with the Foraminifera. Messrs. C. M. Carson and J. B. Stevens cooperated in numerous ways particularly in the assembling of specimens. These contributors, together with Dr. H. G. Schenck of the Department of Geology at Stanford University, have helped with the determination of species, and to all of them we extend our thanks.

Photographs of the specimens (except the diatoms) were made by Frank L. Rogers; typing was done by Alta Holton, as a part of work accomplished by Federal Works Progress Administration, Project No. 10996.

All the specimens illustrated, except those furnished by Dr. Muller and Dr. Schenck, are preserved in the series of type specimens of the Department of Paleontology, California Academy of Sciences. The pre-Cretaceous specimens illustrated are in the Department of Geology at Stanford University. Casts of these are in the type series of the California Academy of Sciences.

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GENERAL FEATURES

A brief explanation of the significance of fossils may be pertinent for those who are not familiar with the nomenclature and occurrence. Certain genera have a very restricted range, for example, the sand dollar, *Astrodapsis*, occurs in the upper Miocene and lower Pliocene, and, in the very southern part of the State and in Lower California, in the middle Pliocene. The species of the genus, however, are restricted to certain narrow stratigraphic zones; *Astrodapsis tumidus*, for instance, occurs only in a zone of that name in the upper Miocene. Such a zone is extremely useful for field mapping of geologic formations.

The ideal index fossil is one which is easily identified and which occurs abundantly over wide geographic extent but in a limited stratigraphic range. Some periods are characterized by certain classes or genera. For example, ammonites are not known to occur later than the Cretaceous. The same is true of *Inoceramus* which can often be recognized in well cores by fragments of the shell which are composed of layers of prisms. In certain genera or species, characteristic ornamentation of fossils can be used by field geologists. For instance, species of *Aucella* with strong radial striae ornamenting the shell are usually upper Jurassic in age, while those of the Lower Cretaceous are usually without such radial striae or if these are present they are much less conspicuous. Large species of *Venericardia* occur in the Eocene but those with nearly obsolete ribs or nearly smooth shells such as *Venericardia ionensis* are characteristic of the middle Eocene. The genus *Tejonia* occurs only in the middle and upper Eocene. With the exception of a couple of species, giant thick-shelled pectens occur from Miocene to Recent. The same appears to be true of *Dosinia*. Giant species of *Turritella* are common in the lower and especially in the middle Miocene of California, and giant oysters occur commonly in the Miocene, and lower Pliocene. Specimens from the upper Miocene are reported to attain a length of 18 inches. Strongly plicated oysters occur in the lower Miocene and commonly in the middle and upper Pliocene where *Ostrea vespertina* occurs. *Dendraster*, the genus to which the common living sand dollar belongs, is known only from Pliocene to Recent.

Recent species are unknown in the Eocene of California, but beginning with the Oligocene, Recent forms appear. In the lower and middle Miocene about 20 species have been cited as identical with Recent species and nearly a dozen others have been cited questionably as identical with Recent forms while many others are closely related. The number increases in the upper Miocene, while in the Pliocene at least a hundred Recent species appear, and in the late Pleistocene about 95 percent of the species are to be found at the present time in waters of the adjacent regions.

The climatic significance of the Tertiary faunas of California is interesting and important. This feature has been ably discussed by J. P. Smith (19) in his classic work on this subject.

A gradual cooling of the temperature is indicated by the Tertiary marine faunas. This becomes very pronounced in the late Pliocene and early Pleistocene but then is followed by decidedly warmer temperature in the upper Pleistocene. This is well illustrated at San Pedro, California, where *Pecten caurinus* and *Borcotrophon stuarti*, cool-water forms, occur in the lower Pleistocene, while in the upper Pleistocene of San Pedro and San Diego, such species as *Dosinia ponderosa*, *Chione gnidia* and *Pecten vogdesi* are an element of the fauna. These species now are not found living north of Cedros Island, Lower California. Following the Pleistocene a slight cooling of the climate occurred, resulting in the climate of today.

Field geologists can encourage the progress of paleontological studies by making careful collections of specimens which together with exact locality data should be deposited in an institutional collection where the specimens may be studied and the results published. A useful volume on the technique used in the preparation of specimens is given by Camp and Hanna (37).

PALEOZOIC, TRIASSIC, AND JURASSIC FOSSILS

Explanation of Figure 60 (1-25)

FIG. 60-1. *Weyla alata* von Buch. Left valve. From south side of Mount Jura, Plumas County, California. W. Pratt, coll. Hardgrave sandstone, lower Jurassic. Length approximately 59.3 mm; height approximately 45.8 mm.

FIG. 60-2. *Halobia superba* Mojsisovics. Left valve. From Brock Mountain, Shasta County, California. J. P. Smith, coll. Hosselkus limestone, upper Triassic. Length 36.2 mm; height 21.5 mm.

FIG. 60-3. *Pseudomonotis subcircularis* Gabb. Right valve. From Indian Valley, Plumas County, California. J. P. Smith, coll. Noric stage, upper Triassic. Length approximately 51 mm; height 42 mm.

FIG. 60-4. *Trachyceras lecontei* Hyatt and Smith. Front view of specimen shown in figure 60-12. Upper Triassic.

FIG. 60-5. *Owenites koeneni* Hyatt and Smith. Right side. From Loc. 894 (L. S. J. U.), Union Wash, Inyo Mountains, Inyo County, California. J. P. Smith, coll. Lower Triassic. Greatest diameter 31.4 mm.

FIG. 60-6. *Anoria lodensis* Clark. Reproduction of figure given by J. F. Mason (35, p. 109, pl. 15, fig. 11). From Marble Mountains, San Bernardino County, California. Cadiz formation, Middle Cambrian.

FIG. 60-7. *Juvavites subinterruptus* Mojsisovics. Left side. From Loc. 1765 (L. S. J. U.), Brock Mountain, Shasta County, California. J. P. Smith, coll. Hosselkus limestone, upper Triassic. Greatest diameter 41 mm.

FIG. 60-8. *Meekoceras newberryi* Smith. Front view of specimen shown in figure 60-20. Lower Triassic.

FIG. 60-9. *Owenites koeneni* Hyatt and Smith. Front view of specimen shown in figure 60-5. Lower Triassic.

FIG. 60-10. *Juvavites subinterruptus* Mojsisovics. Front view of the specimen shown in figure 60-7. Upper Triassic.

FIG. 60-11. *Tropites subbullatus* Hauer. Right side. From the same locality as the specimen shown in figure 60-7. Upper Triassic. Greatest diameter 29.5 mm.

FIG. 60-12. *Trachyceras lecontei* Hyatt and Smith. Left side. From the same locality as the specimen shown in figure 60-7. Upper Triassic. Greatest diameter approximately 95 mm.

FIG. 60-13. *Pseudosageceras multilobatum* Hyatt and Smith. Front view of specimen shown in figure 60-14. Lower Triassic.

FIG. 60-14. *Pseudosageceras multilobatum* Hyatt and Smith. Left side. From the same locality as the specimen shown in figure 60-5. Lower Triassic. Greatest diameter approximately 108.8 mm.

FIG. 60-15. *Aucella erringtoni* Gabb. Right valve. From Texas Charlie's ranch[1], 6 miles east of Copperopolis, Calaveras County, California. J. P. Smith, coll. Mariposa formation, upper Jurassic. Height, beak to base, approximately 29.2 mm; length approximately 14 mm. Specimen somewhat distorted.

The elongate shape and radial striae ornamenting the shell are characteristic of this species.

FIG. 60-16. *Parapopanoceras haugi* Hyatt and Smith. Right side. From Loc. 884 (L. S. J. U.), Union Wash, Inyo Mountains, Inyo County, California. S. W. Muller, coll. Middle Triassic. Greatest diameter 21.8 mm.

FIG. 60-17. *Schizodus deparcus* Walcott. From Baird, Shasta County, California. Baird shale, lower Carboniferous. Dimensions of right valve, length (incomplete) 32.8 mm; height (incomplete) 27 mm.

FIG. 60-18. *Gigantella gigantea* Martin. Posterior view of specimen shown in figure 60-19. Lower Carboniferous.

FIG. 60-19. *Gigantella gigantea* Martin. Exterior view of dorsal valve. From the west bank of McCloud River, immediately above the Baird fishery, Shasta County, California. Baird formation, lower Carboniferous. Length (incomplete) 109.6 mm; height (incomplete) 67.6 mm; thickness approximately 29.5 mm.

FIG. 60-20. *Meekoceras newberryi* Smith. Right side. From Union Wash, Inyo Mountains, Inyo County, California. J. P. Smith, coll. Lower Triassic. Greatest diameter 60.5 mm.

FIG. 60-21. *Griffithides nosoniensis* Wheeler. Holotype[2], No. 778 (L. S. J. U.). From dark shale on the south side of the ridge south of Potter Creek, about 250 feet stratigraphically above the McCloud-Nosoni contact, elevation 1,800 feet, in NE¼SW¼ Sec. 24, T. 34 N., R. 4 W., M. D., Redding quadrangle, Shasta County, California. S. W. Muller and H. E. Wheeler, colls. Lower Nosoni formation, Permian. Length (incomplete) approximately 26.4 mm; width approximately 18 mm.

The dark areas on either side of the anterior half of the specimen represent the cavities remaining after the dissolution of the marginal border and genal spines of the cephalon (Wheeler). (*See* Wheeler, H. E. 35, pp. 51-52, pl. 6, figs. 6 and 7.)

FIG. 60-22. *Tropites subbullatus* Hauer. Back of specimen shown in figure 60-11. Upper Triassic.

FIG. 60-23. *Amoeboceras dubius* Hyatt. Holotype, No. 1762 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 556 (C. A. S.) (original No. 11953 Calif. State Mining Bureau), the Mariposa slates (middle Upper Jurassic) at Texas Charlie's ranch[1], 6 miles north of Copperopolis, Calaveras County, California. Mariposa formation, upper Jurassic. Greatest diameter approximately 26.8 mm.

FIG. 60-24. *Weyla alata* von Buch. Right valve. From the same locality as the specimen shown in figure 60-1. Lower Jurassic. Height (incomplete) approximately 46 mm.

FIG. 60-25. *Parapopanoceras haugi* Hyatt and Smith. Front view of specimen shown in figure 60-16. Middle Triassic.

[1] Place shown on the Copperopolis quadrangle as "Texas Gulch," tributary to Angels Creek, is approximately 6 miles northeast of Copperopolis in Secs. 28 and 29, T. 2 N., R. 13 E., M. D., Calaveras County, California.

[2] Holotype: a single secimen (or fragment) upon which a species is based. (Frizzell, D. L. 33).

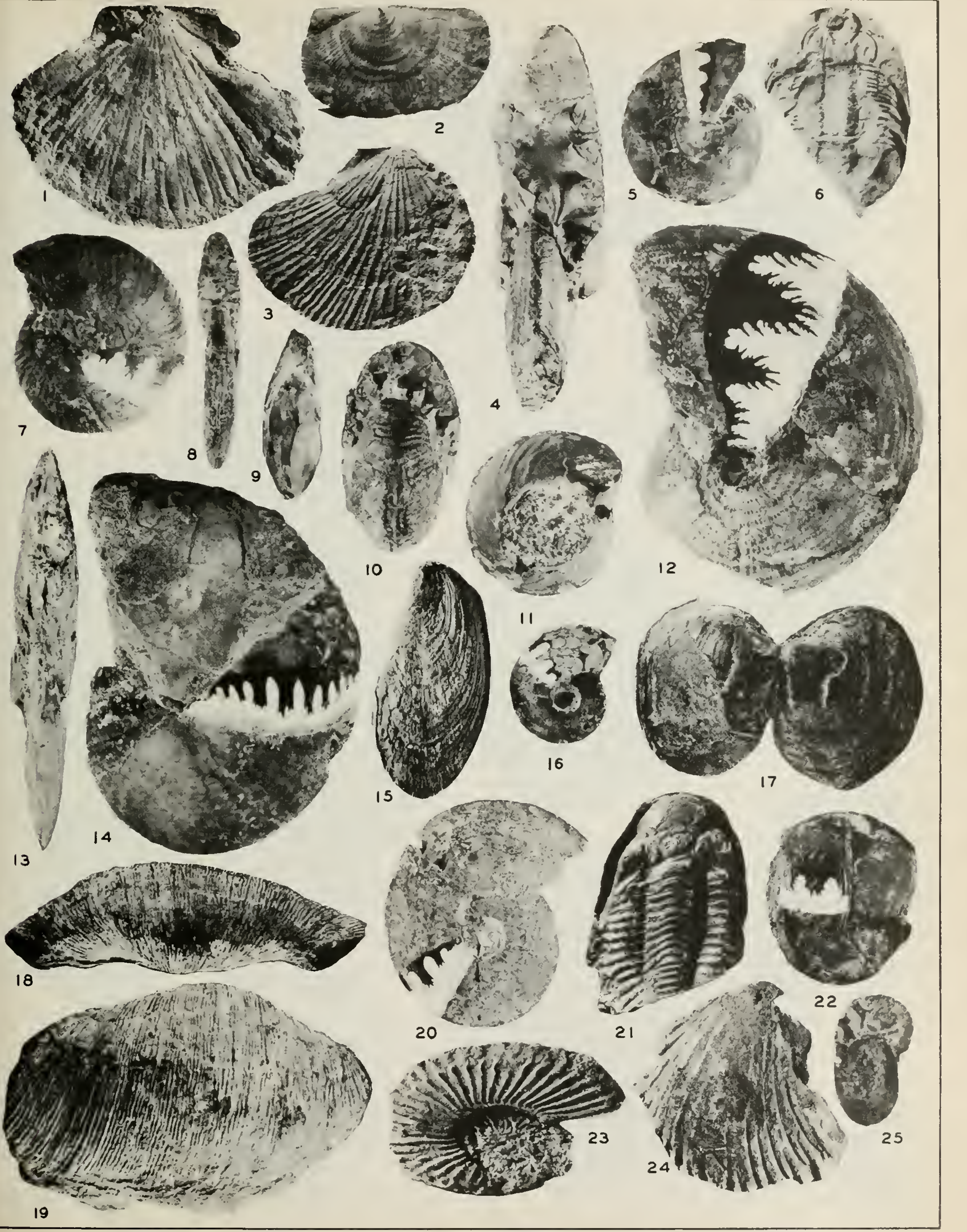

FIG. 60 (1 to 25). Paleozoic, Triassic, and Jurassic fossils of California.

CRETACEOUS AND UPPER JURASSIC FOSSILS

Explanation of Figure 61 (1-22)

FIG. 61-1. *Aucella crassa* Pavlov. Hypotype,[3] No. 5970 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 27 (C. A. S.), on the north bank of Myrtle Creek, about 1¾ miles north of the town of Myrtle Creek, Douglas County, Oregon. Myrtle formation, lower Cretaceous. Height 36.8 mm; width 36.2 mm.

This species occurs in the lower Cretaceous of California.

FIG. 61-2. *Aucella crassicolis* Keyserling. Hypotype, No. 5971 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1349 (C. A. S.), half a mile south of ranch house, Wilcox Ranch, 5 miles northeast of Paskenta, Tehama County, California. F. M. Anderson and G. D. Hanna, colls. Shasta series, lower Cretaceous. Height 52.6 mm; width 35.9 mm.

FIG. 61-3. *Aucella mosquensis* von Buch. Hypotype, No. 5967 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 28624 (C. A. S.), near Cushman's place, 1¼ miles southwest of Chrome, near northeast corner of SE¼ Sec. 31, T. 22 N., R. 6 W., M. D., Glenn County, California. J. A. Taff, F. M. Anderson, and C. M. Cross, colls. Knoxville, upper Jurassic. Altitude 29.0 mm; width 18.2 mm.

FIG. 61-4. *Aucella piochii* Gabb. Hypotype, No. 5966 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 155 (C. A. S.) Secs. 34 and 35, T. 25 N., R. 7 W., 3± miles southwest of Lowry's house on Elder Creek drainage, Tehama County, California. F. M. Anderson, coll. Base of Knoxville series, upper Jurassic. Height 26 mm; width 16.4 mm.

FIG. 61-5. *Aucella piochii* Gabb. Side view of specimen in figure 61-4.

FIG. 61-6. *Neocomites (Steueroceras) jenkinsi* Anderson. Hypotype, No. 7735 (Calif. Acad. Sci. Paleo. Type Coll.). From 1,200 feet southeast of Burt's ranch house, McCarthy Creek, Tehama County, California. F. M. Anderson, coll. Fifteen hundred feet above base of Shasta series, lower Cretaceous. Greatest diameter approximately 36 mm.

FIG. 61-7. *Gabbioceras angulatum* Anderson. Hypotype, No. 5972 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1347 (C. A. S.), north of Roaring River, 5 miles south of Ono, California, on road to Millsap, Shasta County, California. F. M. Anderson, coll. Horsetown formation, lower Cretaceous. Greatest diameter 36.9 mm.

FIG. 61-8. *Desmoceras haydeni* Gabb. Hypotype, No. 5944 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1344 (C. A. S.), Horsetown, Shasta County, California. F. M. Anderson, coll. Lower Cretaceous. Greatest diameter 66.9 mm.

FIG. 61-9. *Metaplacenticeras pacificum* J. P. Smith. Reproduction (Anderson, F. M. 02, figure 162 on plate 8). From Arroyo del Vallé, Alameda County, California. Upper Cretaceous. Diameter 20.5 mm.

FIG. 61-10. *Metaplacenticeras pacificum* J. P. Smith. Reproduction (Anderson, F. M. 02, figure 164 on plate 8). From Henley, California. Upper Cretaceous. Diameter 47 mm.

FIG. 61-11. *Neocomites* sp. cf. *N. neocomiensis* d'Orbigny. Hypotype, No. 5969 (Calif. Acad. Sci. Paleo. Type Coll.). From Waltham Creek Valley, SW¼ Sec. 17, T. 20 S., R. 13 E., M. D., north of the Coalinga-Priest Valley road, Priest Valley quadrangle, Fresno County, California. N. L. Taliaferro, coll. Lower Cretaceous. Greatest diameter 21 mm.

FIG. 61-12. *Kossmatia tehamaensis* Anderson. Hypotype, (Univ. Calif.), and plasto-hypotype, No. 5956 (Calif. Acad. Sci. Paleo. Type Coll.). Dorsal view of specimen shown in figure 61-16. From Loc. A2921 (Univ. Calif.), south fork of Elder Creek, Sec. 13, T. 24 N., R. 7 W., M. D., Tehama County, California. R. Rist, coll. Lower Knoxville, upper Jurassic, Knoxville series. Greatest diameter 47.2 mm.

FIG. 61-13. *Submortoniceras chicoensis* Trask. Hypotype, No. 5952 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 27838 (C. A. S.), from sandstone along southeast bank of Big Chico Creek 3.1 miles by road south of bridge at Mickey's ranch, or 3.6 miles by road from Ten-Mile House on the Humboldt road east of the town of Chico, Butte County, California. J. A. Taff, G. D. Hanna, and C. M. Cross, colls. Type Chico formation, lower upper Cretaceous. Greatest diameter 58 mm.

FIG. 61-14. *Submortoniceras chicoensis* Trask. Side view of the specimen shown in figure 61-13.

FIG. 61-15. *Dichotomites tehamaensis* Anderson. Holotype, No. 5943 (Calif. Acad. Sci. Paleo. Type Coll.). From Wilcox ranch, 5 miles north of Paskenta, Tehama County, California. Lower Cretaceous. Greatest diameter 71.9 mm.

FIG. 61-16. *Kossmatia tehamaensis* Anderson. Side view of specimen shown in figure 61-12.

FIG. 61-17. *Berriasella crassiplicata* Stanton. Hypotype, No. 5958 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 2925 (C. A. S.), Paskenta beds on McCarthy Creek, Tehama County, California. R. Rist, coll. Lower Cretaceous. Greatest diameter 31.6 mm.

FIG. 61-18. *Hamiticeras aequicostatus* Gabb. Hypotype, No. 5950 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1348 (C. A. S.), Alderson Gulch, on north fork of Cottonwood Creek, 2 miles south of Ono, Shasta County, California. F. M. Anderson and G. D. Hanna, colls. Horsetown beds, lower Cretaceous. Height 58 mm.

FIG. 61-19. *Phylloceras onoense* Stanton. Hypotype, No. 7736 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 153 (C. A. S.), head of Bee Creek, 3 miles south of Ono, on Shoup ranch, Shasta County, California. F. M. Anderson, coll. Horsetown beds, lower Cretaceous. Greatest diameter 114 mm.

FIG. 61-20. *Hibolites* sp. Hypotype, No. 5960 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 28607 (C. A. S.), lower beds of Knoxville series 3 miles north of old Knoxville (Reddington Mine) northern Napa County, California. N. L. Taliaferro, coll. Knoxville, upper Jurassic. Length 47 mm.

FIG. 61-21. *Baculites chicoensis* Trask. Hypotype, No. 5951 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 61-13. Type Chico formation, lower upper Cretaceous. Height 82.3 mm.

FIG. 61-22. *Bochianites* sp. Hypotype, No. 5959 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 28037 (C. A. S.), 6½ miles north of Winslow bridge, SE¼SW¼ Sec. 10, T. 21 N., R. 6 W., M. D., western Glenn County, California. F. M. Anderson and H. O. Jenkins, colls. Knoxville series, upper Jurassic. Height (incomplete) 45 mm.

[3] Hypotype: a described or figured specimen, used in publication in extending or correcting the knowledge of a previously defined species (Frizzell, D. L. 33).

EOCENE, OLIGOCENE, AND MIOCENE FOSSILS

Explanation of Figure 62 (1-33)

FIG. 62-1. *Brachysphingus gabbi* Stewart. Hypotype, No. 5700 (Calif. Acad. Sci. Paleo. Type Coll.). Apertural view. From Loc. 27174 (C. A. S.), a quarter of a mile east and 200 feet north of SW. corner of Sec. 8, T. 1 N., R. 1 E., M. D., Contra Costa County, California. J. A. Taff and C. M. Cross, colls. Martinez formation, lower Eocene. Height 28.3 mm.

FIG. 62-2. *Brachysphingus gabbi* Stewart. Another view of the specimen shown in figure 61-1.

FIG. 62-3. *Cardium (Schedocardia) brewerii* Gabb. Hypotype No. 5701 (Calif. Acad. Sci. Paleo. Type Coll.). Left valve. From Loc. 244 (C. A. S.), on east branch of Live Oak Creek about three-quarters of a mile from its mouth or from the edge of San Joaquin Valley. This locality is about 3 miles due east of the mouth of Grapevine Canyon, Kern County, California. Bruce G. Martin, coll. Tejon formation, upper Eocene. Altitude 25.3 mm; length 26.2 mm.

FIG. 62-4. *Spiroglyphus tejonensis* Arnold. Hypotype, No. 5941 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 31222 (C. A. S.), 600 feet north and 4,400 feet east of southwest corner of Sec. 27, T. 23 S., R. 17 E., M. D., south of Big Tar Canyon,

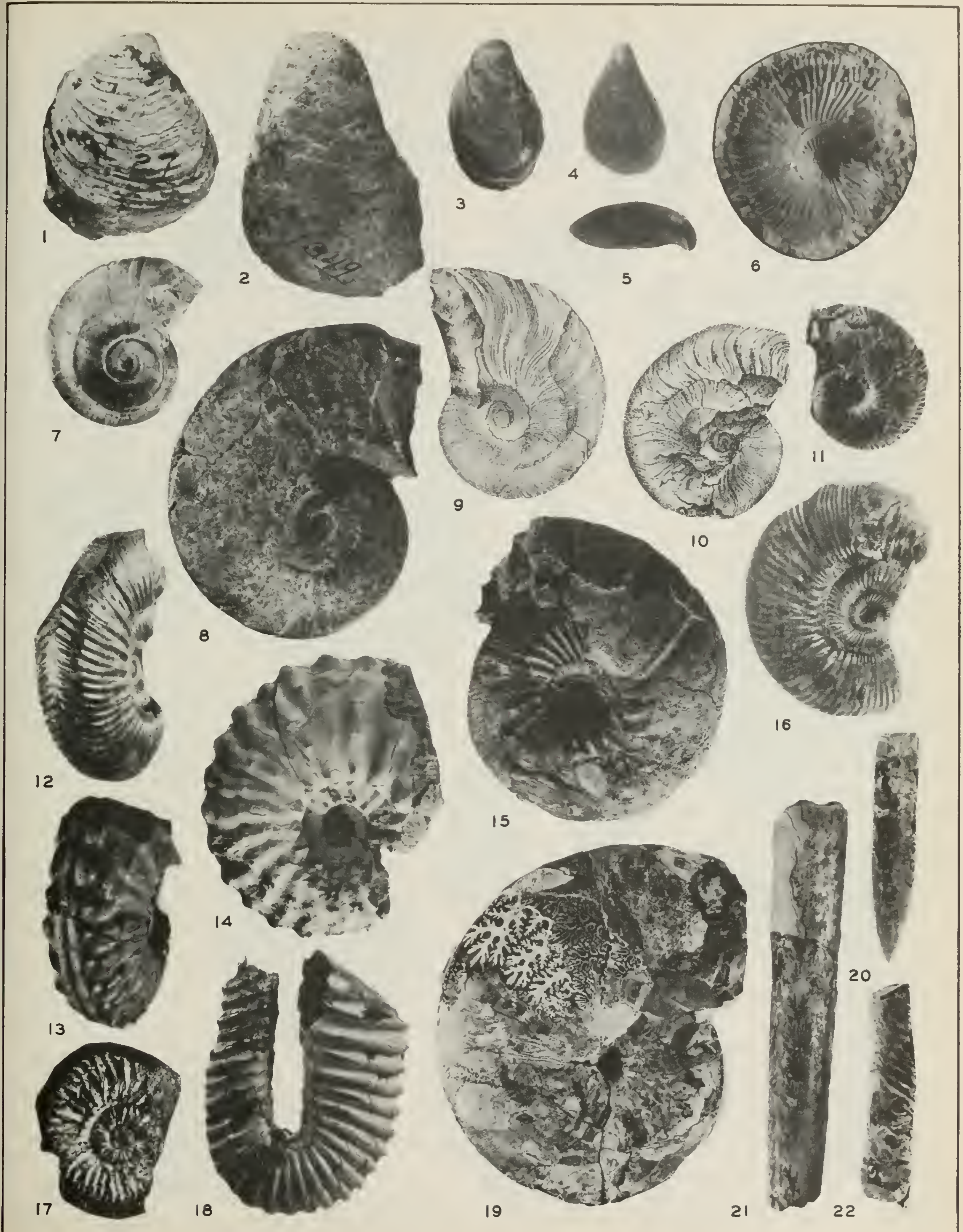

FIG. 61 (1 to 22). Cretaceous and Upper Jurassic fossils of California.

Kings County, California. Type locality of the species. Earl Dillon, coll. "Avenal Sand," upper Eocene. Cross-section of a typical specimen, diameter 10 mm.

A large number of specimens of this species from the type locality have been sectioned and they show very great variation in details. However, all of them show that the so-called spiral threads, grooves, or ridges are really sharp spiral plaits, usually three or four to the body whorl. These are very obscure and may be misleading on many weathered individuals. The apex or center of the whorls is ordinarily concealed in weathered specimens but the sections show uniformly, a mass of irregular twisting of the tubule.

FIG. 62-5. *Spiroglyphus tinajasensis* Hanna and Hertlein, n. sp. Paratype,[4] No. 5975 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 31218 (C. A. S.), Sec. 20, T. 25 S., R. 18 E., M. D., Devils Den, Kern County, California. Cross-section, diameter 9 mm.

FIG. 62-6. *Turritella andersoni* Dickerson. Hypotype, No. 5621 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 316 (C. A. S.), Sec. 15, T. 18 S., R. 14 E., M. D., Lillis ranch on Salt Creek, Fresno County, California. F. M. Anderson, coll. Domengine, upper Eocene. Altitude 32.8 mm.

FIG. 62-7. *Turritella andersoni* Dickerson. Hypotype, No. 5622 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 62-6. Domengine, upper Eocene. Altitude 36 mm.

FIG. 62-8. *Nuculana temblorensis* Anderson and Martin. Hypotype, No. 5704 (Calif. Acad. Sci. Paleo. Type Coll.). Right valve. From Loc. 26064 (C. A. S.), Clyde De Lano well No. 1, Sec. 34, T. 28 S., R. 28 E., M. D., Kern County, California, depth, 833-835 feet. Temblor, middle Miocene. Length 20.6 mm; height 9.9 mm.

FIG. 62-9. *Nuculana washingtonensis* Weaver. Syntype,[5] No. 450b (Calif. Acad. Sci. Paleo Type Coll.). Left valve. From Loc. 256 (Univ. Washington Paleo. Coll.), in railway cuts on the O.-W. R. R. & N. Co., a quarter of a mile west and north of Lincoln Creek Station in Sec. 27, T. 15 N., R. 3 W., W., Lewis County, Washington. In this region the bluffs extend above and below the railway track and for a distance along the track of about a mile. Lower Oligocene.

This species has been reported to occur in beds referred to the Oligocene in California.

FIG. 62-10. *Galeodea sutterensis* Dickerson. Hypotype, No. 5711 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 248 (C. A. S.), 2 miles north and 80 degrees west of South Butte in the Marysville Buttes quadrangle, in a small gulch locally known as Fig Tree Gulch, an eighth of a mile east of the road, Sutter County, California. R. E. Dickerson, coll. Middle Eocene. Altitude 30 mm.

FIG. 62-11. *Pseudoperissolax blakei* Gabb. Hypotype, No. 5934 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 711 (C. A. S.), on the east side of Grapevine Creek near the point where the stream flows out upon the valley floor; the fossils were collected near the center of Sec. 20, T. 10 N., R. 20 W., S. B., Kern County, California. G. D. Hanna and M. A. Hanna, colls. Tejon, upper Eocene. Altitude (incomplete) 29.5 mm.

FIG. 62-12. *Spiroglyphus tinajasensis* Hanna and Hertlein, n. sp. Holotype, No. 5974 (Calif. Acad. Sci. Paleo. Type Coll.). (Paratypes, Nos. 5933, A-F, and 5975). From Loc. 31218 (C. A. S.), Sec. 20, T. 25 S., R. 18 E., M. D., Devils Den, Kern County, California. Upper Eocene. Greatest diameter 12.9 mm.

Shell coiled, sharply keeled and with two shallow concentric grooves on the body whorl; in cross-section body cavities round and symmetrical.

This species is named for "Las Tinajas de Los Indios" (Tanks of the Indians) by which name the nearby locality was known.

Species very similar to *tejonensis* and *tinajasensis* occur in the Eocene of the Gulf Coast region of Alabama, Texas, and Mexico. These have been discussed by Gardner (39, pp. 17-20, pl. 6), who placed them under the genus *Tubulostium*.

FIG. 62-13. *Macrocallista pittsburgensis* Dall. Plasto-hypotype (from impression) No. 5667 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 2267 (C. A. S.), diatomaceous shale with shell impressions from the 100-foot *Leda* zone 50 to 60 feet below the top, SE¼ Sec. 25, T. 16 S., R. 13 E., M. D., in the first deep canyon north of Arroyo Ciervo, south side, just below old Ciervo Mountain road, Fresno County, California. C. C. Church, coll. Kreyenhagen shale, Oligocene. Length 17.4 mm; height 10.0 mm.

FIG. 62-14. *Macrocallista conradiana* Gabb. Hypotype, No. 5623 (Calif. Acad. Sci. Paleo. Type Coll.). From the same location as the specimen shown in figure 62-3. Tejon, upper Eocene. Length 28 mm; height 19.3 mm.

FIG. 62-15. *Turritella lawsoni* Dickerson. Hypotype, No. 5916 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 549 (C. A. S.), west of Aliso Canyon (west), south side of Santa Susana Mountains, near point where east boundary of Simi land grant crosses hogback ridge south of 3,384-foot hill not far above base of the "Tejon," Los Angeles County, California. W. S. W. Kew and C. Wagner, colls. Las Llajas formation, lower upper Eocene. Height 46.5 mm.

FIG. 62-16. *Turritella andersoni* Dickerson. Hypotype, No. 7737 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimens shown in figures 62-6 and 62-7. Domengine, upper Eocene. Altitude of slab 132 mm.

This view shows a slab of Domengine sandstone filled with specimens of *Turritella andersoni*. These characteristic *Turritella* beds appear for several miles along the west side of the San Joaquin Valley in Fresno County.

FIG. 62-17. *Eocernina hannibali* Dickerson. Hypotype, No. 5962 (Calif. Acad. Sci. Paleo. Type Coll.). Apertural view, aperture incomplete. From Loc. 393 (C. A. S.), near southeast corner, NE¼ Sec. 26 (near east line), T. 3 N., R. 17 W., S.B., in west bank of Aliso Canyon of Devil Creek, due west of Andrew Janglin's ranch in Sec. 25, Santa Susana quadrangle, Los Angeles County, California. R. G. Stoner and R. E. Dickerson, colls. Las Llajas formation, lower upper Eocene. Altitude 41.4 mm; width 38.6 mm.

A very similar species has been described from the Eocene of Chiapas, Mexico (*Cernina (Eocernina) chiapasensis* Gardner and Bowles; 34, p. 243, figures 2 and 3 on p. 246. From "about 12 miles east-south-east of Sayula, Chiapas, Mexico. Eocene.")

FIG. 62-18. *Turritella sargeanti* Anderson and Hanna. Hypotype, No. 5903 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimens shown in figures 62-3 and 62-14. Tejon, upper Eocene. Altitude 69.8 mm; diameter of penultimate whorl 17 mm.

FIG. 62-19. *Turritella variata* Conrad. Hypotype (Univ. Calif.). Plasto-hypotype, No. 5665 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. "A889" (Univ. Calif.) [from A887 (Univ. Calif.), Lompoc quadrangle, U. S. G. S. Topo. map, Santa Ynez Mountains, Santa Barbara County, California. Coarse-grained sandstone beds, outcropping in Nojoqui Creek an eighth of a mile east of coast highway bridge, 1.2 miles north of Gaviota Pass. W. L. Effinger, coll. (Loc. 4)]. Gaviota formation, upper Eocene. Altitude 56 mm; diameter of body whorl 22.6 mm.

FIG. 62-20. *Spiroglyphus tejonensis* Arnold. Hypotype, No. 5940 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 62-4. "Avenal Sand", upper Eocene. Greatest length approximately 13 mm.

FIG. 62-21. *Lyria andersoni* Waring. Hypotype, No. 5712 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 364 (C. A. S.), Aliso Creek, Sec. 25, T. 3 N., R. 17 W., S. B., in canyon below Andrew Janglin's ranch house near Chatsworth, Los Angeles County, California. R. G. Stoner, coll. Las Llajas formation, lower upper Eocene. Altitude 24.6 mm.

FIG. 62-22. *Whitneya ficus* Gabb. Hypotype, No. 5713 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimens shown in figures 62-3, 62-14, and 62-18. Type Tejon, upper Eocene. Altitude 22 mm.

FIG. 62-23. *Retipirula crassitesta* Gabb. Hypotype, No. 5915 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 396 (C. A. S.), 1⅜ miles S. 45° W., from B.M. 961, strike N. 50° W., dip 40° N., Santa Susana Mountains, Los Angeles County, California. R. E. Dickerson, coll. Martinez, lower Eocene. Altitude 18.8 mm.

FIG. 62-24. *Retipirula crassitesta* Gabb. Hypotype, No. 5915A (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 62-23. Martinez, lower Eocene. Altitude 21 mm.

FIG. 62-25. *Turritella merriami* Dickerson. Hypotype, No. 5709 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 29138

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[4] Paratype: a specimen, other than the holotype, upon which an original specific description is based (Frizzell, D. L. 33).

[5] Syntype: any specimen of the author's original material when no holotype was designated; or any of a series of specimens described as "cotypes" of equal rank (Frizzell, D. L. 33).

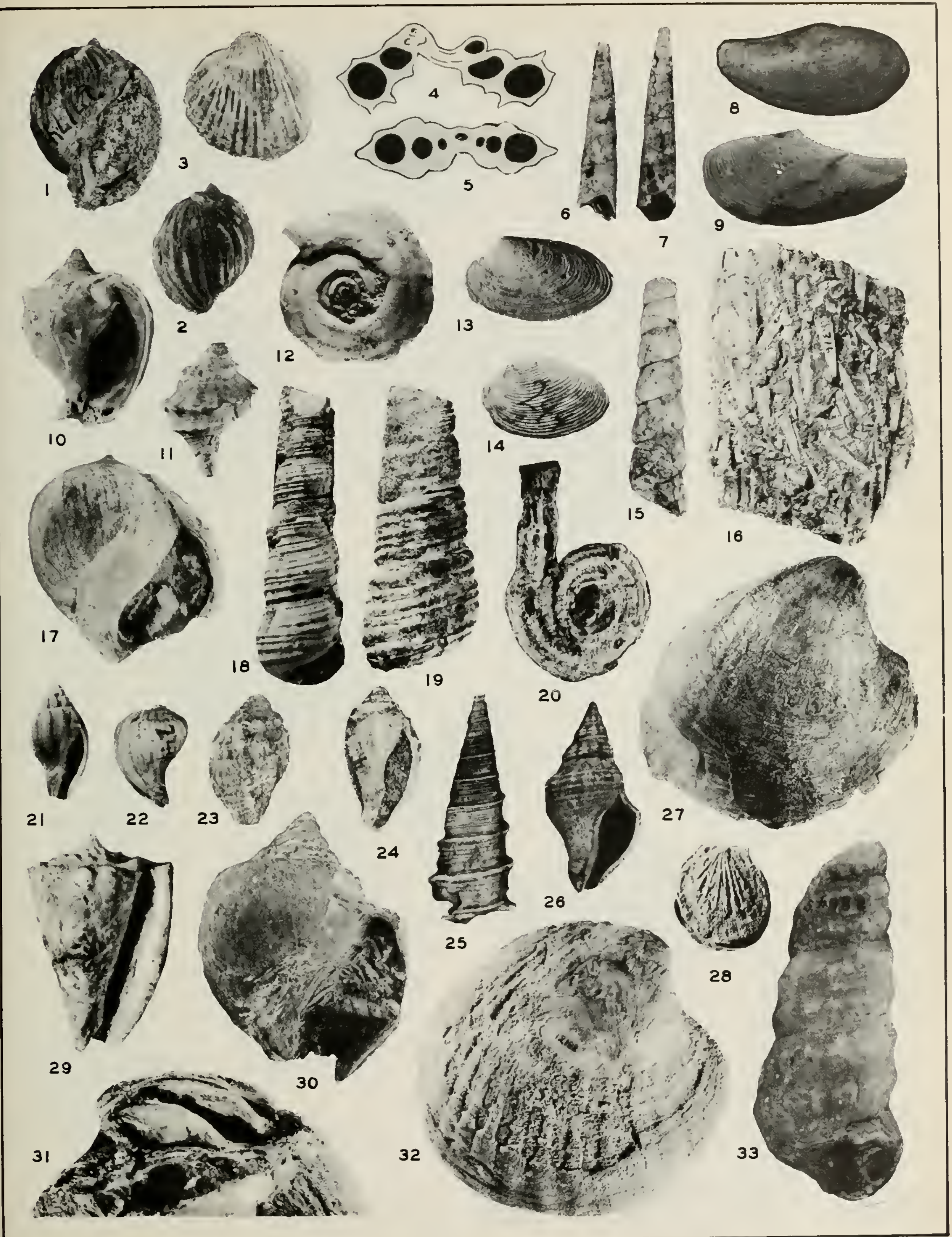

Fig. 62 (1 to 33). Eocene, Oligocene, and Miocene fossils of California.

(C. A. S.), Buttes well No. 4 at a depth of about 2,800 feet, about 3 miles west and 1½ miles north of Sutter City, Sutter County, California. E. R. Leach, coll. Middle Eocene. Altitude 38.8 mm.

FIG. 62-26. *Siphonalia sutterensis* Dickerson. Hypotype, No. 5710 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 62-10. Middle Eocene. Altitude 15.4 mm.

FIG. 62-27. *Venericardia ionensis* Waring. Hypotype, right valve, No. 7738 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1930 (C. A. S.), Sec. 17, T. 23 S., R. 17 E., M. D., half a mile south of Big Tar Canyon, Eocene sandstone reef, Kings County, California. O. P. Jenkins, coll. Upper Eocene. Altitude (beak to base) 103 mm; length 101.5 mm.

FIG. 62-28. *Pecten (Propeamusium) interradiatus* Gabb. Hypotype, left valve, No. 5733 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 899 (C. A. S.), from type locality of Kreyenhagen shale on Canoas Creek, Kreyenhagen ranch, Kings County, California. G. D. Hanna, coll. Upper Eocene. Altitude 11.8 mm.

FIG. 62-29. *Volutocristata lajollaensis* M. A. Hanna. Hypotype No. 5714 (Calif. Acad. Sci. Paleo. Type Coll.), from the same locality as the specimen shown in figure 62-21. Las Llajas formation, lower upper Eocene. Altitude 44 mm; greatest diameter 29.2 mm.

Regarding the genus *Volutocristata* and related genera, see Gardner and Bowles (34, pp. 245-248).

FIG. 62-30. *Tejonia lajollaensis* Stewart. Hypotype, No. 5666 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 393 (C. A. S.), near the southeast corner of NE¼ Sec. 26 (near east line), T. 3 N., R. 17 W., S. B., in west bank of Aliso Canyon of Devil Creek due west of Andrew Janglin's ranch in Sec. 25, Santa Susana quadrangle, Los Angeles County, California. R. G. Stoner and R. E. Dickerson, colls. Las Llajas formation, lower upper Eocene. Altitude (incomplete) 57.2 mm; greatest diameter 44.6 mm.

This and allied species have been placed by writers in various genera, none of which seem entirely satisfactory for this well-known group. (*See* Woodring, 31a, p. 385.) We therefore propose the genus *Tejonia* with the type *Natica alveata* Conrad (Blake, W. P. 55a, p. 10, Ap. to Rep. of W. P. Blake. "Locality. ______ Cañada de las Uvas." *See* Anderson and Hanna 25, p. 119, pl. 6, fig. 2; pl. 7, fig. 1; pl. 15, fig. 17. Type locality). Due to a prior use of the name *Natica alveata* by Troschel in 1852, Conrad's species was renamed *Amaurellina moragai* by Stewart (26, p. 334, pl. 28, fig. 3. Tejon, Eocene). Cox (31, p. 38) has given a brief review of the Ampullospiridae.

A species very similar to *Tejonia lajollaensis* has been described from the Eocene of Chiapas, Mexico (See *Amaurellina cortezi* Gardner and Bowles (34, p. 244, figs. 7 and 9 on p. 246. "About 12 miles east-north-east of Sayula, Chiapas, Mexico. Eocene.").

FIG. 62-31. *Venericardia hornii* Gabb var. Hypotype, No. 5982 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 12122 H. H. (C. A. S.), Rose Canyon, San Diego, California. Henry Hemphill, coll. Rose Canyon formation, lower upper Eocene. Altitude 103.2 mm; length 108 mm.

View showing hinge of right valve.

FIG. 62-32. *Venericardia hornii* Gabb var. View of exterior of right valve of the specimen shown in figure 62-31.

FIG. 62-33. *Turritella pachecoensis* Stanton. Hypotype, No. 5670 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 28645 (C. A. S.), in gully 5,300 feet south along coast and 9,200 feet east of Kinton Point, Santa Cruz Island, Santa Barbara County, California. C. St. John Bremner, coll. Martinez, lower Eocene. Altitude (incomplete) 75.8 mm.

MIOCENE FOSSILS

Explanation of Figure 63 (1-24)

FIG. 63-1. *Pecten andersoni* Arnold. Hypotype, right valve, No. 5739 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 2023 (C. A. S.), zone B along Kern River, Kern County, California. F. M. Anderson, coll. Temblor, middle Miocene. Length 44 mm; height 40.5 mm.

FIG. 63-2. *Pecten andersoni* Arnold. Hypotype, left valve, No. 5739A (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 63-1. Temblor, middle Miocene. Length 42.4 mm; height 40.8 mm.

FIG. 63-3. *Astrodapsis whitneyi* Rémond. Hypotype, No. 5923 (Calif. Acad. Sci. Paleo. Type Coll.), from Loc. 137 (C. A. S.) 1 to 1¼ miles north of the road along Quailwater Creek, San Luis Obispo County, California. Santa Margarita formation, upper Miocene. Greatest diameter 56.9 mm; lesser diameter 54 mm.

The genus *Astrodapsis* occurs commonly in the upper Miocene and lower Pliocene of California.

FIG. 63-4. *Turritella temblorís* Wiedey. Paratype, No. 2984 (C. A. S.). From Loc. 567 (C. A. S.), from Dry Canyon, Topanga Canyon Road, about 3 miles south of Calabasas, Los Angeles County, California. J. O. Nomland, coll. Topanga formation, middle Miocene. Height 51.2 mm; diameter of body whorl 28 mm.

FIG. 63-5. *Cancellaria posunculensis* Anderson and Martin. Hypotype, No. 5725 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 65 (C. A. S.), hills just north of Kern River and northeast of Barker's ranch house, Kern County, California. Bruce G. Martin, coll. Temblor, middle Miocene. Height 24.3 mm; diameter 10.8 mm.

FIG. 63-6. *Turritella ocoyana* Conrad. Hypotype, No. 5963 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 66 (C. A. S.), near the top of a prominent hill on the west side of Cottonwood Creek and about a mile southeast of the Rio Bravo ranch house about 12 miles east of Bakersfield, Kern County, California. F. M. Anderson, coll. Temblor formation, middle Miocene. Height 54.2 mm; diameter of body whorl 16.6 mm.

FIG. 63-7. *Pecten (Lyropecten) estrellanus* Conrad. Hypotype, right valve, No. 5900 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 28473 (C. A. S.), west central part of SW¼ SE¼ Sec. 16, T. 23 S., R. 13 E., M. D., Monterey County, California. N. L. Taliaferro, coll. Santa Margarita formation, upper Miocene. Length 92.8 mm; height 84.6 mm.

FIG. 63-8. *Pecten (Lyropecten) crassicardo* Conrad. Hypotype, right valve, No. 5979 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 2036 (C. A. S.), Sec. 29, T. 18 S., R. 14 E., M. D., Fresno County, California. F. M. Anderson, coll. Santa Margarita formation, upper Miocene. Length 113 mm; height 103 mm.

FIG. 63-9. *Astrodapsis tumidus* Rémond. Hypotype, No. 5706 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 2379 (C. A. S.), "Shell Ridge" about 100 yards northeast of quarry 1¾ miles east (S. 76° E.) of Walnut Creek, Contra Costa County, California. J. L. Nicholson, coll. *Astrodapsis tumidus* zone, Neroly formation of the upper San Pablo, upper Miocene. Greatest diameter 31 mm.

FIG. 63-10. *Conus owenianus* Arnold. Hypotype, No. 5708 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 63-5. Temblor, middle Miocene. Height 26 mm; greatest diameter 25.9 mm.

FIG. 63-11. *Echinarachnius fairbanksi* Arnold. Hypotype, No. 5738 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 251 (C. A. S.), in Sespe Canyon, between Sespe and Piedra Blanca Creeks, about 18 miles north of Nordhoff (Ojai), Ventura County, California. B. W. Evermann, coll. Vaqueros, lower Miocene. Greatest diameter 51.5 mm.

FIG. 63-12. *Trochita filosa* Gabb. Hypotype, No. 5731 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 63-5. Temblor, middle Miocene. Greatest diameter (incomplete) 16.8 mm; height approximately 10.4 mm.

FIG. 63-13. *Lucina richthofeni* Gabb. Hypotype, No. 5737 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 63-5. Temblor, middle Miocene. Length 15 mm; height 15 mm.

FIG. 63-14. *Ostrea titan* Conrad. Hypotype, left valve, No. 5961 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1282 (C. A. S.), Sec. 20, T. 18 N., R. 15 E., M. D., 2 miles north of Domengine ranch house, Fresno County, California. G. D. Hanna, coll. Santa Margarita formation, upper Miocene. Height (beak to base) approximately 150 mm.

FIG. 63-15. *Ocenebra topangensis* Arnold. Hypotype, No. 5719 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 567 (C. A. S.), Dry Canyon-Topanga Canyon road, about 3 miles south of Calabasas, Los Angeles County, California. J. O. Nom-

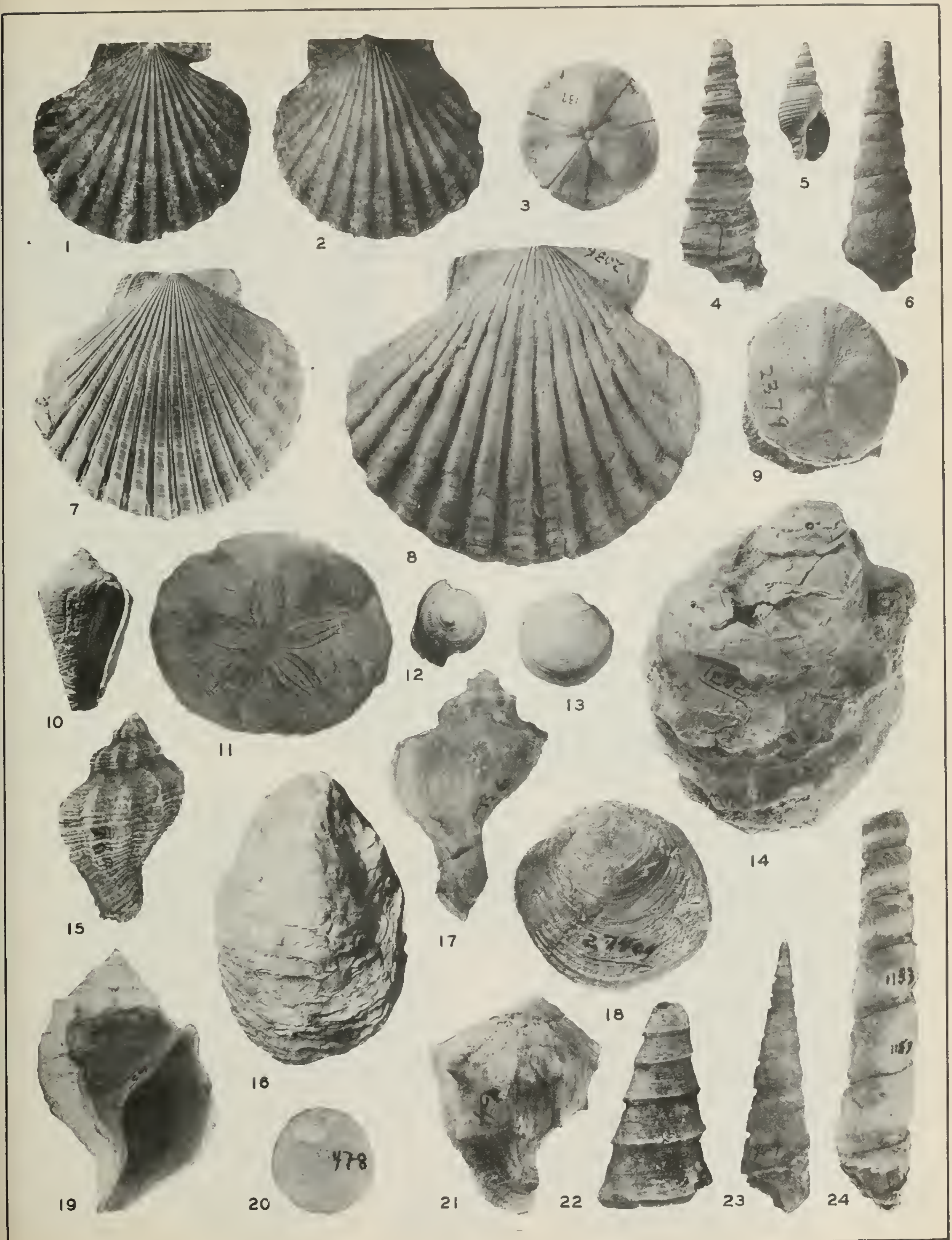

FIG. 63 (1 to 24). Miocene fossils of California land, coll. Topanga formation, middle Miocene. Altitude 42.5 mm; diameter 26 mm.

FIG. 63-16. *Ostrea eldridgei* Arnold. Hypotype, left valve, No. 5964 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 27409 (C. A. S.), 3,100 feet east and 1,600 feet north of the southwest corner of Sec. 31, T. 4 N., R. 18 W., S. B., Ventura County, California. C. E. Leach, coll. Vaqueros, lower Miocene. Height (beak to base) 128.5 mm; width 88.4 mm; thickness (both valves) 69.8 mm.

FIG. 63-17. *Trophon kernensis* Anderson. Hypotype, No. 5718 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 126 (C. A. S.), from rock in bed of a small creek running southeast and emptying into Shell Creek near the center of Sec. 34, T. 28 S., R. 15 E., M. D., San Luis Obispo County, California. Bruce G. Martin, coll. Temblor, middle Miocene. Altitude 49.3 mm; diameter 32.5 mm.

FIG. 63-18. *Miltha sanctaecrucis* Arnold. Hypotype, left valve, No. 5740 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 63-16. Vaqueros, lower Miocene. Height 42.5 mm.

FIG. 63-19. *Bruclarkia barkeriana* Cooper. Hypotype No. 5741 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 65, (C. A. S.), hills just north of Kern River and northeast of Barker's ranch house, Kern County, California. Bruce G. Martin, coll. Temblor, middle Miocene. Height 54.3 mm; diameter 36.5 mm.

FIG. 63-20. *Echinarachnius merriami* Anderson. Hypotype, No. 5707 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 478 (C. A. S.), Temblor beds north of Cantua Creek, Fresno County, California. Temblor, middle Miocene. Greatest diameter 12 mm. Abactinal view.

FIG. 63-21. *Trophosycon kernianum* Cooper. Hypotype, No. 5717 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 64 (C. A. S.), in the bed of a small gulch about 1¼ miles northeast of Barker's ranch house on Kern River, Kern County, California. Bruce G. Martin, coll. Temblor, middle Miocene. Height 48.5 mm; diameter 37.8 mm.

FIG. 63-22. *Turritella ocoyana bösei* Hertlein and E. K. Jordan. Hypotype, No. 5702 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 146 (C. A. S.), 3 miles south of bridge on San Juan River, in southwest corner of SE¼ Sec. 34, T. 29 S., R. 17 E., M. D., San Luis Obispo County, California. Temblor, middle Miocene. Altitude 43.4 mm.

FIG. 63-23. *Turritella ocoyana bösei* Hertlein and E. K. Jordan. Hypotype, No. 5669 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1929 (C. A. S.), Miocene sandstone on Garzas Creek, Sec. 10, T. 23 S., R. 16 E., M. D., Kings County, California. Temblor, middle Miocene. O. P. Jenkins, coll. Altitude 55 mm.

FIG. 63-24. *Turritella inezana* Conrad. Hypotype, No. 5543 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1153 (C. A. S.), San Augustine Canyon, in bed of creek about ¾ to 1 mile from mouth of canyon. Santa Rosa Island, Santa Barbara County, California. L. G. Hertlein and E. Rixford, colls. Vaqueros, lower Miocene. Altitude (incomplete) 109 mm.

MIOCENE, PLIOCENE, AND PLEISTOCENE FOSSILS

Explanation of Figure 64 (1-20)

FIG. 64-1. *Cardium* (*Mexicardia*) *procerum* Sowerby. Hypotype, right valve, No. 5948 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 110 (C. A. S.), at the foot of 26th Street, San Diego, California. Upper Pleistocene. Length 77.5 mm; height 82 mm.

FIG. 64-2. *Turritella jewettii* Carpenter. Hypotype No. 5668 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 93 (C. A. S.), from loose sand immediately underlying the upper San Pedro series, Deadman Island, San Pedro, Los Angeles County, California. Lower San Pedro formation, lower Pleistocene. Height 64 mm; diameter of body whorl 18.2 mm.

FIG. 64-3. *Crepidula princeps* Conrad. Hypotype, No. 5937 (Calif. Acad. Sci. Paleo. Type Coll.). (Original Calif. State Min. Bur. No. 14639). Collected from Rincon Asphalt Mine, Santa Barbara County, California, November 12, 1895. Upper Pliocene. Length 100.5 mm; width 65.5 mm; thickness 49 mm.

FIG. 64-4. *Ostrea vespertina* Conrad. Hypotype, left valve, No. 5912 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 725 (C. A. S.), from coarse conglomerate 1 mile north of Camulos, Ventura County, California. W. L. Watts, coll. (No. 4, Calif. State Min. Bur. Coll.). Upper Pliocene. Height (beak to base) 91 mm; width 79 mm.

FIG. 64-5. *Dendraster venturaensis* Kew. Hypotype, No. 5938 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 28461 (C. A. S.), 2½ miles N. 2° W. from B. M. 313 above the *Crepidula* and *Chrysodomus* zone in Las Posas Valley, Santa Paula quadrangle, Ventura County, California. C. M. Carson and M. McDivitt, colls. Upper Pliocene. Greatest diameter 95.9 mm; lesser diameter 89 mm; thickness 17.5 mm.

FIG. 64-6. *Dendraster venturaensis* Carson. View of profile of the specimen shown in figure 64-5.

FIG. 64-7. *Olivella biplicata* Sowerby. Hypotype, No. 5732 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 546 (C. A. S.), from Wilson's Ranch, near Russian River about 1½ to 2 miles south of the intersection of the road running west from Windsor with the north-south road, Sonoma County, California. R. E. Dickerson, coll. Merced, lower upper Pliocene. Height 18.5 mm; diameter 9.5 mm.

FIG. 64-8. *Forreria belcheri* Hinds. Hypotype, No. 5723 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 2364 (C. A. S.), North Dome of Kettleman Hills, Kings County, California. *Pecten coalingaënsis* zone, middle Pliocene. Altitude 44.6 mm; diameter 31.5 mm.

FIG. 64-9. *Acila castrensis* Hinds. Hypotype, right valve, No. 5727 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 710 (C. A. S.), oil sand in Elsmere Canyon, first large creek to left above Standard Oil pumping plant, about 1½ miles from plant. Strata 75 feet thick, dip 15° SW. Overlain by 2,000-3,000 feet of conglomerate. Los Angeles County, California. G. D. Hanna, coll. Middle Pliocene. Height (beak to base) approximately 12.5 mm.

FIG. 64-10. *Lucina* (*Luciniscа*) *nuttalli* Conrad. Hypotype, right valve, No. 5735 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 64-2. Lower Pleistocene. Length 27.2 mm; height 25 mm.

FIG. 64-11. *Pecten* (*Delectopecten*) *pedroanus* Trask. Hypotype, right valve, No. 5734 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1894 (C. A. S.), from diatomaceous shale, 220 yards east of the breakwater at San Pedro, Los Angeles County, California. L. G. Hertlein, coll. Upper Miocene. Length 15.4 mm; height 14.5 mm.

This specimen is from sediments occurring in the area originally indicated as the type locality of this species.

FIG. 64-12. *Cantharus fortis* Carpenter. Hypotype, No. 5742 (Calif. Acad. Sci. Paleo. Type Coll.). (Original No. 14637, Calif. State Min. Bur.) From the same locality as the specimen shown in figure 64-3. Upper Pliocene. Height 58.8 mm; diameter 35 mm.

FIG. 64-13. *Gonidea coalingensis* Arnold. Hypotype, left valve, No. 5947 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 2371 (C. A. S.), east flank of North Dome, Kettleman Hills, Kings County, California. F. M. Anderson, coll. Basal Tulare, upper Pliocene. Length 74 mm; height 36 mm; thickness (two valves) 17.4 mm.

FIG. 64-14. *Molopophorus anglonana* Anderson. Hypotype, No. 5724 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 65 (C. A. S.), in the hills just north of Kern River and northeast-east of Barker's ranch house, Kern County, California. Temblor, middle Miocene. Bruce G. Martin, coll. Height 33 mm; diameter 20 mm.

FIG. 64-15. *Bittium asperum* Gabb. Hypotype, No. 5729 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 82 (C. A. S.), sea cliff near bath house immediately southwest of the Porter Hotel, Santa Barbara, California. Pleistocene. Altitude 13 mm.

FIG. 64-16. *Lucina* (*Lucinoma*) *acutilineata* Conrad. Hypotype, right valve, No. 5730 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 27276 (C. A. S.), Temblor Reef in west center of Sec. 21, T. 19 S., R. 15 E., M. D., south of Oil City, Fresno County, California. Temblor, middle Miocene. Length 28.5 mm; height 26.6 mm.

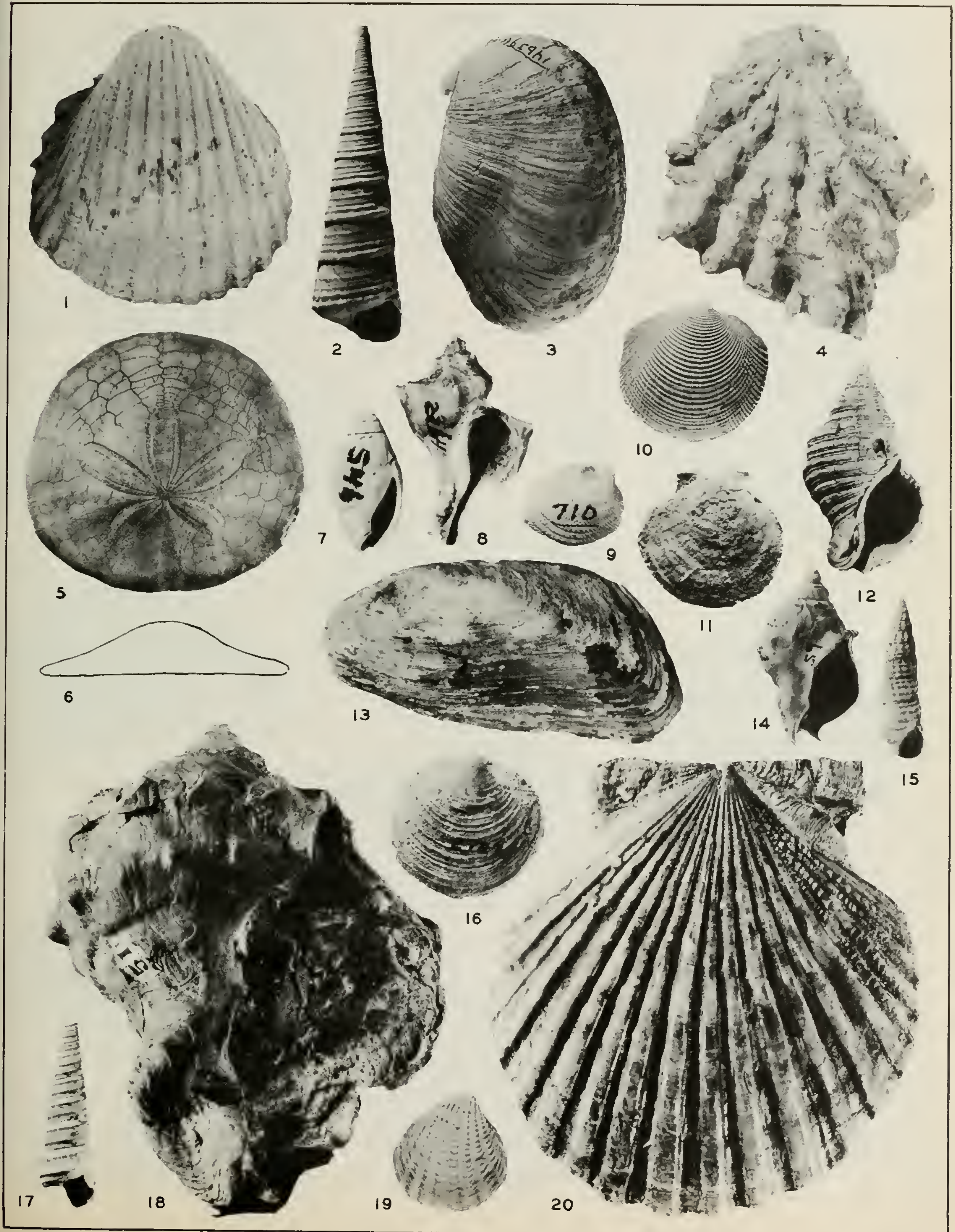

Fig. 64 (1 to 20). Miocene, Pliocene, and Pleistocene fossils of California.

FIG. 64-17. *Turritella cooperi* Carpenter. Hypotype, No. 5703 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 28484 (C. A. S.), south flank of South Mountain in road cut in west bank of unnamed canyon 2¾ miles N. 21° W. from B. M. 313, Santa Paula quadrangle, U. S. Geol. Survey, Topo. sheet, Ventura County, California. C. M. Carson, coll. Upper Pliocene. Height 35.5 mm; diameter of body whorl 11 mm.

FIG. 64-18. *Rapana vaquerosensis imperialis* Hertlein and E. K. Jordan. Hypotype, No. 2841 (C. A. S.) (Original No. 12322 Calif. State Min. Bur.). From Santa Rosa Island, Santa Barbara County, California. Vaqueros, lower Miocene. Height 102.2 mm; diameter 84 mm.

FIG. 64-19. *Cardita californica* Dall. Hypotype, right valve, No. 5736 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 77 (C. A. S.), in railroad cut 1 mile north of Schumann Station, about 6 or 7 miles south of Guadalupe, Santa Barbara County, California. Middle Pliocene. Altitude 21.9 mm. View of exterior.

FIG. 64-20. *Pecten (Vertipecten) bowersi* Arnold. Hypotype, right valve, No. 7739 (Calif. Acad. Sci. Paleo. Type Coll.). From SW¼ Sec. 36, T. 26 S., R. 17 E., M. D., Temblor Range, Kern County, California. 250-500 feet above basal Miocene. E. J. Roche, coll. Vaqueros, lower Miocene. Length 170 mm; height 185 mm.

On the left valve of this species every second or third rib is raised above the intervening ones. The species occurs in the upper Vaqueros and lower Temblor.

PLIOCENE FOSSILS

Explanation of Figure 65 (1-18)

FIG. 65-1. *Pecten (Patinopecten) lohri* Hertlein. Hypotype, right valve, No. 7734 (Calif. Acad. Sci. Paleo. Type Coll.). From beds at railroad bridge across Waltham Creek, about 2 miles southwest of Coalinga, Fresno County, California (F. M. Anderson). Jacalitos formation, lower Pliocene. Height (beak to base) 123 mm; length 124 mm.

This species was formerly known as *Pecten oweni* Arnold (not *Pecten oweni* Sowerby).

FIG. 65-2. *Littorina mariana* Arnold. Hypotype, No. 5722 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 26811 (C. A. S.), south center of Sec. 17, T. 23 S., R. 19 E., M. D., Kettleman Hills, Kings County, California. Etchegoin, upper Pliocene. Height 13.3 mm; diameter 11.4 mm.

FIG. 65-3. *Pecten (Patinopecten) healeyi* Arnold. Hypotype, right valve, No. 5920 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 105 (C. A. S.), Pacific Beach, San Diego, California. San Diego formation, middle Pliocene. Height 72 mm; length 78 mm.

FIG. 65-4. *Scalez petrolia* Hanna and Gaylord. Hypotype, No. 5901 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 885 (C. A. S.), at a depth of 3,208 feet in well No. 55 Pacific Oil Co., Sec. 27, T. 30 S., R. 24 E., M. D., Elk Hills, Kern County, California. J. H. Menke, coll. Etchegoin formation, upper Pliocene. Diameter of core 46 mm.

Left of the central figure of *Scalez petrolia* the impression of a freshwater gastropod is visible. *Scalez petrolia* is believed to be the operculum of this or a similar gastropod. MacNeil (39, p. 357) has cited the genus from beds of Cretaceous age in Montana.

FIG. 65-5. *Clothrodrillia mercedensis* Martin. Hypotype, No. 5716 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 28617 (C. A. S.), on southeast slope of hill about 2½ miles south and a little west of the intersection of lines of Lat. 37° 25′ N. and Long. 122° 10′ W., M. D., Palo Alto quadrangle, U. S. Geol. Surv. Topo. sheet. About 3¼-3½ miles south of the Stanford University quadrangle, Santa Clara County, California. L. G. Hertlein and S. French, colls. Merced formation, lower upper Pliocene. Height 20.8 mm.

This species occurs commonly in the Merced formation in the region about San Francisco Bay.

FIG. 65-6. *Mulinia densata* Conrad. Hypotype, left valve, No. 5743 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 26820 (C. A. S.), NW¼ Sec. 19, T. 23 S., R. 19 E., M. D., Kettleman Hills, Kings County, California. *Mulinia* zone. Etchegoin formation, upper Pliocene. Length 32.5 mm; height 30 mm. View of interior.

FIG. 65-7. *Mulinia densata* Conrad. Hypotype, right valve, No. 5743A (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 65-6. Length 45.5 mm; height 41 mm.

FIG. 65-8. *Nassorius californianus* Conrad. Hypotype, No. 5720 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1397 (C. A. S.), Federal Exploration Company, well Kinsella No. 1, northeast corner of SE¼ Sec. 15, T. 22 S., R. 24 E., M. D., Tulare County, California. Depth 2,760 feet. Etchegoin formation, upper Pliocene. Height 12 mm; diameter 7 mm.

FIG. 65-9. *Nassorius californianus* Conrad. Hypotype, No. 5721 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 65-8. Etchegoin formation, upper Pliocene. Height 15 mm; diameter 8 mm.

FIG. 65-10. *Pecten coalingaënsis* Arnold. Hypotype, right valve, No. 5946 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 698 (C. A. S.), northwest corner of Sec. 35, T. 21 S., R. 17 E., M. D., North Dome, Kettleman Hills, Kings County, California. *Pecten coalingaënsis* zone. Etchegoin formation, upper Pliocene. Length 58.2 mm; height 55.9 mm; thickness 21 mm.

FIG. 65-11. *Arca trilineata* Conrad. Hypotype, right valve, No. 5922A (Calif. Acad. Sci. Paleo. Type Coll.). From Loc 26805 (C. A. S.), center SE¼ Sec. 30, T. 21 S., R. 17 E., M. D. Kettleman Hills, Fresno County, California. *Arca* zone. Etchegoin formation, upper Pliocene. Length 68.4 mm; height 55 mm.

FIG. 65-12. *Mya japonica* Jay. Hypotype, right valve, No. 5925 (Calif. Acad. Sci. Paleo. Type Coll.). From 600 feet west and 600 feet south of northeast corner of Sec. 31, T. 21 S., R. 17 E., M. D., North Dome, Kettleman Hills, Fresno County, California. *Mya* zone. Etchegoin formation, upper Pliocene. Length 76 mm; height 49 mm.

FIG. 65-13. *Mya japonica* Jay. Hypotype, left valve, No. 5925A (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 65-12. *Mya* zone. Etchegoin formation, upper Pliocene. View of inside of left valve. Length 89.7 mm; height 52.7 mm.

FIG. 65-14. *Pecten bellus* Conrad. Hypotype, right valve, No. 5919 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 28559 (C. A. S.), at base of Santa Barbara sands and marls on trail on northeast slope of Packard's Hill, Santa Barbara, California. T. W. Dibblee, Jr., coll. Upper Pliocene. Length 95 mm; height 81.6 mm. (Specimen slightly distorted.)

FIG. 65-15. *Amphissa versicolor* Dall var. Hypotype, No. 5728 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 568 (C. A. S.), from railroad cut ¾ mile northeast of Schumann, Santa Barbara County, California. R. E. Dickerson, coll. Pliocene, probably upper. Height 10.6 mm; diameter 4.8 mm.

FIG. 65-16. *Kelletia kettlemanensis* Arnold. Hypotype, No. 5902 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 27072 (C. A. S.), center of Sec. 16, T. 22 S., R. 18 E., M. D., Kettleman Hills, Kings County, California. Upper *Mulinia* zone. Etchegoin formation, upper Pliocene. Height 85.2 mm; diameter 63.3 mm.

FIG. 65-17. *Arca trilineata* Conrad. Hypotype, left valve, No. 5922 (Calif. Acad. Sci. Paleo. Type Coll.). From the same locality as the specimen shown in figure 65-11. *Arca* zone. Etchegoin formation, upper Pliocene. Exterior of left valve. Length 68 mm; height 55 mm.

FIG. 65-18. *Pecten etchegoini* Anderson. Hypotype, left valve, No. 5945 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 2032 (C. A. S.), NE¼ Sec. 26, T. 22 S., R. 16 E., M. D., Fresno County, California. Etchegoin formation, middle Pliocene.

The type specimen of *Pecten wattsi* Arnold was apparently lost in the San Francisco fire and earthquake in 1906; it came from approximately the same locality as our No. 5945 which is here designated lectotype of this species. Length 57 mm; height 62 mm.

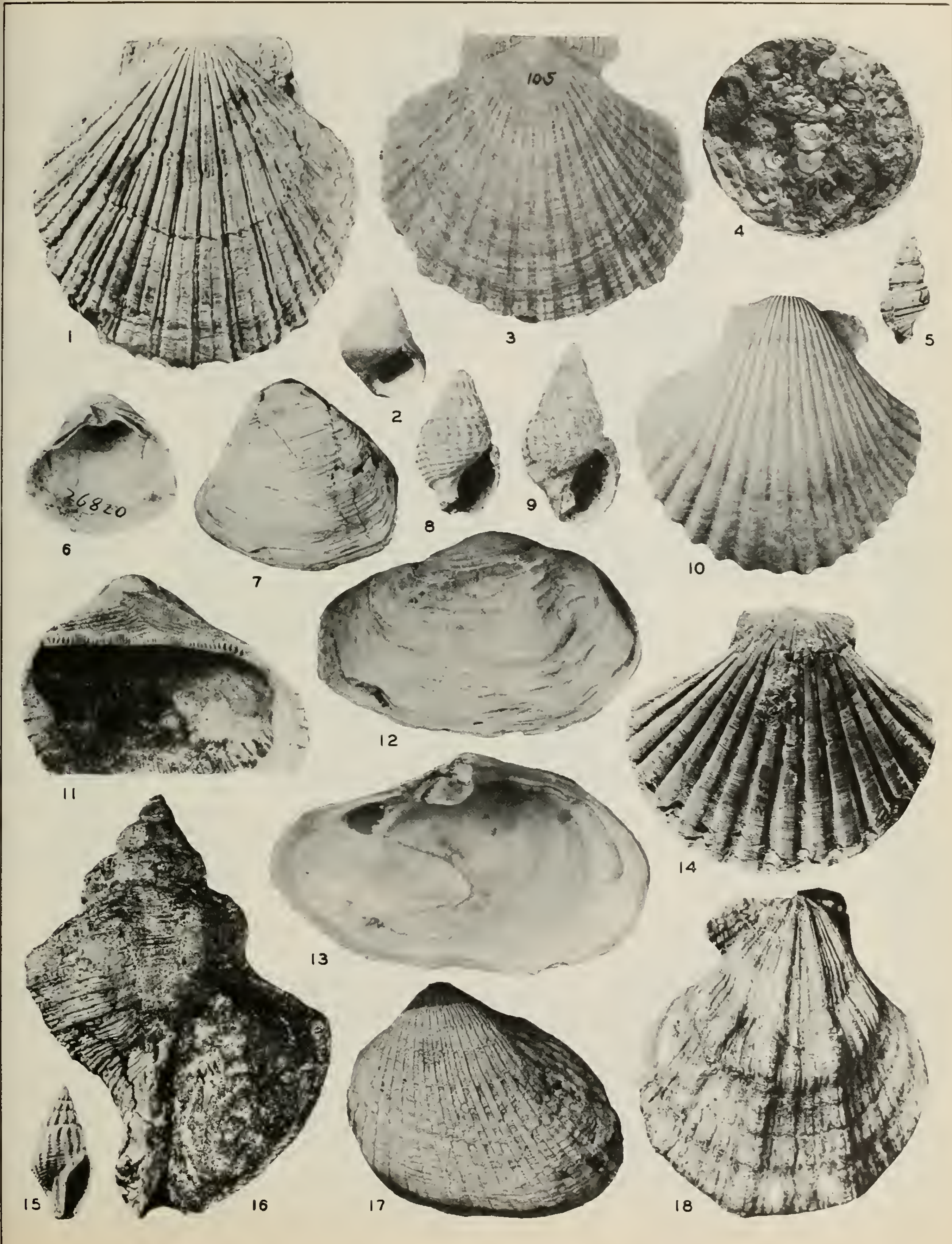

FIG. 65 (11 to 18). Pliocene fossils of California.

DIATOMS (CRETACEOUS TO RECENT)

Explanation of Figure 66 (1-21)

FIG. 66-1. *Hemiaulus claviger* Schmidt. Hypotype, No. 3053 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 894 (C. A. S.), Phoenix Canyon, 7 miles north of Coalinga, Fresno County, California. Kreyenhagen shale. Oligocene or upper Eocene. Length 0.10 mm; width 0.044 mm. (Hanna, G. D. 27, p. 113, pl. 18, fig. 8.)

FIG. 66-2. *Diploneis exempta* Schmidt. Hypotype, No. 3354 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 866 (C. A. S.), 4 miles east of Del Monte, Monterey County, California. Upper Monterey shale, upper Miocene. Length 0.1152 mm; width 0.0372 mm.

FIG. 66-3. *Diploneis ornata* Schmidt. Hypotype, No. 3355 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 866 (C. A. S.), 4 miles east of Del Monte, Monterey County, California. Upper Monterey shale, upper Miocene. Length 0.1440 mm; width 0.0550 mm.

FIG. 66-4. *Meretrosulus gracilis* Hanna. Paratype, No. 2020 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 943 (C. A. S.), Moreno Gulch, Panoche Hills, Fresno County, California. Upper Moreno shale, Upper Cretaceous. Length 0.0590 mm. (Hanna, G. D. 27a, p. 24, pl. 3, fig. 10.)

FIG. 66-5. *Rhaphoneis rhombus* Ehrenberg. Hypotype, No. 3352 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 26482 (C. A. S.), Sec. 11, T. 25 S., R. 19 E., M. D., South Dome, Kettleman Hills, Kern County, California; about 100 feet below *Mulinia* zone. H. M. Horton, coll. Etchegoin, Pliocene. Length 0.0554 mm; width 0.0220 mm.

FIG. 66-6. *Rhaphoneis rhombus* Ehrenberg. Hypotype, No. 3352a (Calif. Acad. Sci. Paleo. Type Coll.). From same locality as figure 66-5. Length 0.0836 mm; width 0.020 mm.

FIG. 66-7. *Gephyria gigantea* Greville. Hypotype, No. 3356 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 866 (C. A. S.), 4 miles east of Del Monte, Monterey County, California. Upper Monterey shale, upper Miocene. Length 0.1440 mm; width 0.0290 mm.

FIG. 66-8. *Triceratium montereyi* Brightwell. Hypotype, No. 3360 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 866 (C. A. S.), 4 miles east of Del Monte, Monterey County, California. Upper Monterey shale, upper Miocene. Length of one side 0.140 mm.

FIG. 66-9. *Cymatogonia amblyoceras* Ehrenberg. Hypotype, No. 3178 (Calif. Acad. Sci. Paleo. Type Coll.). From. Loc. 1068 (C. A. S.), Sharktooth Hill, Kern County, California. Temblor, middle Miocene. Length of one side 0.090 mm. (Hanna, G. D. 32, p. 186, pl. 10, fig. 5. Snyder, L. C. 32, p. 219, fig. 77-3.)

FIG. 66-10. *Auliscus californicus* Grunow. Hypotype, No. 3353a (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1277 (C. A. S.), 3.7 miles north of Carmel River on road from Salinas-Monterey highway to Tassajara Springs, Monterey County, California, near granite contact. Monterey shale, upper Miocene. Diameter 0.0782 mm. (Hanna, G. D. 30a, p. 7.)

FIG. 66-11. *Xanthiopyxis umbonatus* Greville. Hypotype, No. 3361 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 866 (C. A. S.), 4 miles east of Del Monte, Monterey County, California. Upper Monterey shale, upper Miocene. Diameter 0.080 mm.

FIG. 66-12. *Lithodesmium cornigerum* Brun. Hypotype, No. 3136 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1220 (C. A. S.), 4 miles west of Casmalia, Santa Barbara County, California. Pliocene. Distance between tips of two arms 0.0636 mm. (Hanna, G. D. 30b, pp. 189-191, pl. 14, fig. 10.)

FIG. 66-13. *Rutilaria epsilon* Greville. Hypotype, No. 3095 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 866 (C. A. S.), 4 miles east of Del Monte, Monterey County, California. Upper Monterey shale, upper Miocene. Length 0.1516 mm; width 0.0250 mm. (Hanna, G. D. 28, pl. 8, fig. 3.)

FIG. 66-14. *Melosira clavigera* Grunow. Hypotype, No. 3358 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 866 (C. A. S.), 4 miles east of Del Monte, Monterey County, California. Upper Monterey shale, upper Miocene. Diameter 0.0665 mm. (L. C. Snyder 32, p. 219, fig. 77-5.)

FIG. 66-15. *Cocconeis baldjikiana* Grunow. Hypotype, No. 3349 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 26482 (C. A. S.), Sec. 11, T. 25 S., R. 19 E., M. D., South Dome Kettleman Hills, Kern County, California; about 100 feet below *Mulinia* zone. H. M. Horton, coll. Etchegoin, Pliocene. Length 0.0720 mm; width 0.0380 mm.

FIG. 66-16. *Glyphodiscus stellatus* Greville. Hypotype, No. 3357 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 866 (C. A. S.), 4 miles east of Del Monte, Monterey County, California. Upper Monterey shale, upper Miocene. Diameter 0.0747 mm.

FIG. 66-17. *Frustulia lewisiana* Greville. Hypotype, No. 3351 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 26482 (C. A. S.), Sec. 11, T. 25 S., R. 19 E., M. D., South Dome, Kettleman Hills, Kern County, California; about 100 feet below *Mulinia* zone; Etchegoin, Pliocene. H. M. Horton, coll. Length 0.2568 mm; width 0.0436 mm.

FIG. 66-18. *Frustulia lewisiana* Greville. Hypotype, No. 3353 (Calif. Acad. Sci. Paleo. Type Coll.). A living specimen from Bolinas Bay, Marin County, California, to show characteristic markings. Length 0.1264 mm; width 0.0286 mm.

FIG. 66-19. *Coscinodiscus asteromphalus* Ehrenberg. Hypotype, No. 3350 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 26482 (C. A. S.), Sec. 11, T. 25 S., R. 19 E., M. D., South Dome Kettleman Hills, Kern County, California; about 100 feet below *Mulinia* zone. Etchegoin, Pliocene. Diameter 0.2728 mm.

FIG. 66-20. *Stictodiscus californicus* Greville. Hypotype, No. 3359 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 866 (C. A. S.), 4 miles east of Del Monte, Monterey County, California. Upper Monterey shale, upper Miocene. Diameter 0.0508 mm.

FIG. 66-21. *Melosira granulata* Ehrenberg. Hypotype, No. 3362 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 26863 (C. A. S.), depth 349-375 feet in Prospect well No. 10, Sec. 14, T. 12 S., R. 11 E., M. D., Laguna Seca district, Fresno County, California. Upper Pliocene. Length 0.1142 mm; width 0.0170 mm.

FORAMINIFERA (CRETACEOUS TO PLIOCENE)

Explanation of Figure 67 (1-49)

FIG. 67-1. *Elphidium hannai* Cushman and Grant. Hypotype, No. 7740 (Calif. Acad. Sci. Paleo. Type Coll.). From Superior Oil Co., Hansen well No. 1, Sec. 26, T. 21 S., R. 17 E., M. D., Fresno County, California; depth 1,345 feet. San Joaquin formation, upper Pliocene. Width 0.65 mm; height 0.76 mm. Side view.

FIG. 67-2. *Elphidium hannai* Cushman and Grant. Same specimen as figure 67-1. Apertural view.

FIG. 67-3. *Elphidium hughesi* Cushman and Grant. Hypotype, No. 7741 (Calif. Acad. Sci. Paleo. Type Coll.). From General Petroleum Corp., K. C. L. well No. 25-1, Sec. 25, T. 26 S., R. 25 E., M. D., MacFarland district, Kern County, California; depth 2,624 feet. San Joaquin formation, upper Pliocene. Width 0.26 mm; height 0.30 mm. Side view.

FIG. 67-4. *Elphidium hughesi* Cushman and Grant. Same specimen as figure 67-3. Apertural view.

FIG. 67-5. *Buliminella elegantissima* d'Orbigny. Hypotype, No. 7742 (Calif. Acad. Sci. Paleo. Type Coll.). From King Tulare Syndicate Palmer well No. 1, Sec. 19, T. 21 S., R. 23 E., M. D., Tulare County, California; depth 5,282 feet. San Joaquin formation, upper Pliocene. Width 0.12 mm; height 0.32 mm. Side view.

FIG. 67-6. *Buliminella elegantissima* d'Orbigny. Hypotype, No. 7743 (Calif. Acad. Sci. Paleo. Type Coll.). From same well and depth as figure 67-5. Width 0.11 mm; height 0.25 mm. Side view.

FIG. 67-7. *Buliminella elegantissima* d'Orbigny. Same specimen as figure 67-6. Apertural view.

FIG. 67-8. *Eponides exigua* H. B. Brady. Hypotype, No. 7744 (Calif. Acad. Sci. Paleo. Type Coll.). From King Tulare Syndicate, Palmer well No. 1, Sec. 19, T. 21 S., R. 23 E., M. D., Tulare County, California; depth 5,282 feet. San Joaquin forma-

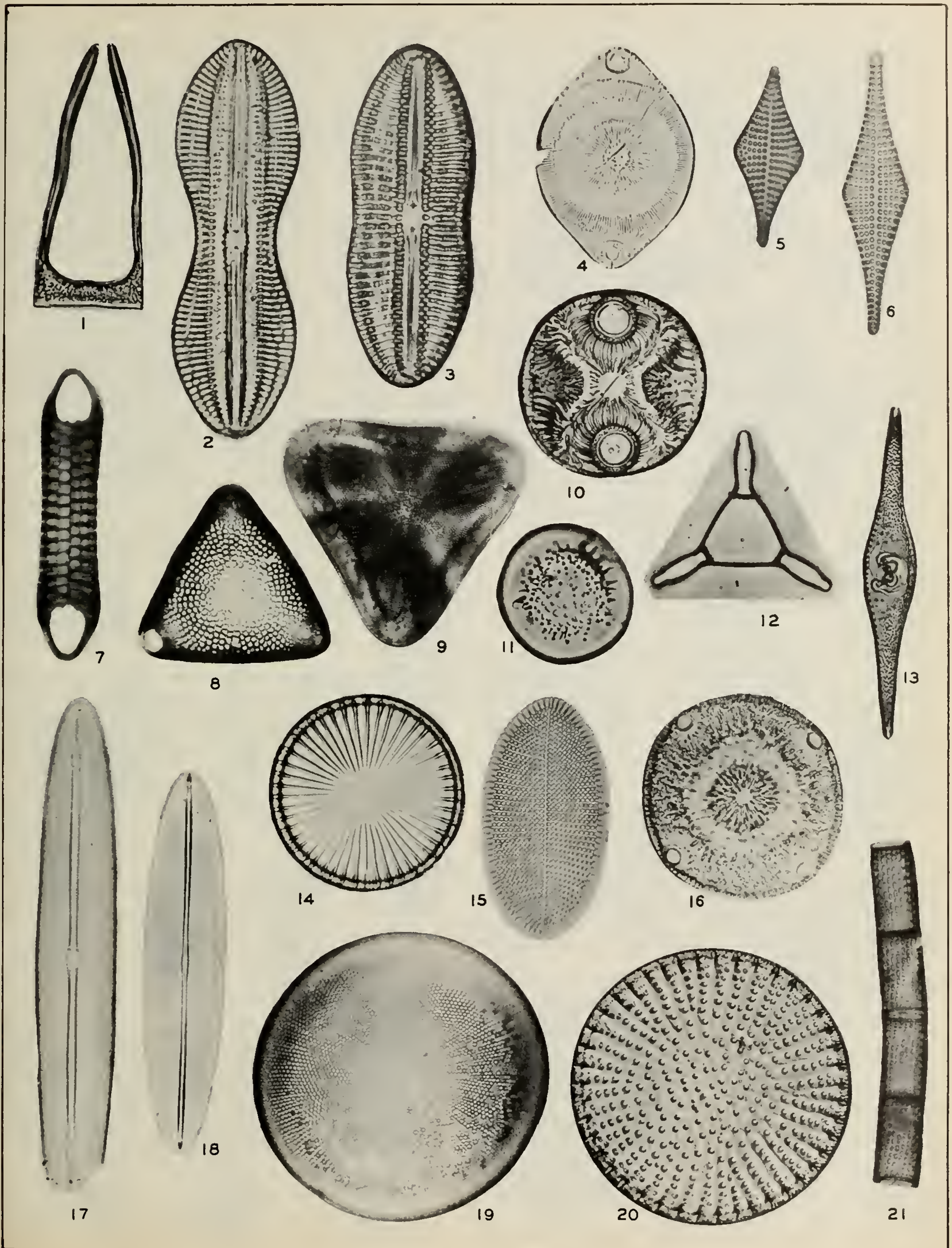

Fig. 66 (1 to 21). Diatoms (Cretaceous to Recent) of California. (Microscopic fossil plants with siliceous tests).

tion, upper Pliocene. Width 0.25 mm; height 0.29 mm. Dorsal view.

FIG. 67-9. *Eponides exigua* H. B. Brady. Same specimen as figure 67-8. Ventral view.

FIG. 67-10. *Eponides exigua* H. B. Brady. Same specimen as figure 67-8. Apertural view.

FIG. 67-11. *Rotalia beccarii tepida* Cushman. Hypotype, No. 7745 (Calif. Acad. Sci. Paleo. Type Coll.). From Graham and Young, McAdams well No. 1, Sec. 26, T. 29 S., R. 23 E., M. D., Kern County, California; depth 5,812 feet. San Joaquin formation, upper Pliocene. Width 0.22 mm; height 0.24 mm. Dorsal view.

FIG. 67-12. *Rotalia beccarii tepida* Cushman. Same specimen as figure 67-11. Ventral view.

FIG. 67-13. *Rotalia beccarii tepida* Cushman. Same specimen as figure 67-11. Peripheral view.

FIG. 67-14. *Elphidium hannai* Cushman and Grant. Hypotype, No. 7746 (Calif. Acad. Sci. Paleo. Type Coll.). From Superior Oil Co., Hansen well No. 1, Sec. 26, T. 21 S., R. 17 E., M. D., Fresno County, California; depth 1,345 feet. San Joaquin formation, upper Pliocene. Width 0.60 mm; height 0.70 mm. Side view.

FIG. 67-15. *Elphidium hannai* Cushman and Grant. Same specimen as figure 67-14. Apertural view.

FIG. 67-16. *Bolivina brevior* Cushman. Hypotype, No. 7747 (Calif. Acad. Sci. Paleo. Type Coll.). From Associated Oil Co., Whepley well No. 1, Sec. 35, T. 21 S., R. 17 E., M. D., Kettleman Hills, Fresno County, California; depth 5,465-5,484 feet. Reef Ridge shale, upper Miocene. Width 0.15 mm; height 0.31 mm. Side view.

FIG. 67-17. *Bolivina brevior* Cushman. Same specimen as shown in figure 67-16. Apertural view.

FIG. 67-18. *Virgulina subplana* Barbat and Johnson. Hypotype, No. 7748 (Calif. Acad. Sci. Paleo. Type Coll.). From Associated Oil Co., Whepley well No. 1, Sec. 35, T. 21 S., R. 17 E., M. D., Kettleman Hills, Fresno County, California; depth 5,465-5,484 feet. Reef Ridge shale, upper Miocene. Width 0.13 mm; height 0.36 mm. Side view.

FIG. 67-19. *Virgulina californiensis* Cushman. Hypotype, No. 7749 (Calif. Acad. Sci. Paleo. Type Coll.). From Associated Oil Co., Whepley well No. 1, Sec. 35, T. 21 S., R. 17 E., M. D., Kettleman Hills, Fresno County, California; depth 5,465-5,484 feet. Reef Ridge shale, upper Miocene. Width 0.18 mm; height 0.54 mm. Side view.

FIG. 67-20. *Bolivina obliqua* Barbat and Johnson. Hypotype, No. 7750 (Calif. Acad. Sci. Paleo. Type Coll.). From Associated Oil Co., Watson well No. 1, Sec. 34, T. 22 S., R. 18 E, M. D., Kings County, California; depth 5,745-5,750 feet. Reef Ridge shale, upper Miocene. Width 0.21 mm; height 0.54 mm. Side view.

FIG. 67-21. *Bolivina obliqua* Barbat and Johnson. Same specimen as figure 67-20. Apertural view.

FIG. 67-22. *Buliminella brevior* Cushman. Hypotype, No. 7751 (Calif. Acad. Sci. Paleo. Type Coll.). From Associated Oil Co., Whepley well No. 1, Sec. 35, T. 21 S., R. 17 E., M. D., Kettleman Hills, Fresno County, California; depth 5,465-5,484 feet. Reef Ridge shale, upper Miocene. Width 0.18 mm; height 0.30 mm. Ventral view.

FIG. 67-23. *Valvulineria miocenica* Cushman. Hypotype, No. 7752 (Calif. Acad. Sci. Paleo. Type Coll.). From Clyde De Lano well No. 1, Sec. 34, T. 28 S., R. 28 E., M. D., Kern County, California; depth 750-770 feet. Temblor formation, middle Miocene. Width 0.62 mm; height 0.76 mm. Ventral view.

FIG. 67-24. *Bolivina* sp. Hypotype, No. 7753 (Calif. Acad. Sci. Paleo. Type Coll.). From Associated Oil Co., Whepley well No. 1, Sec. 35, T. 21 S., R. 17 E., M. D. Kettleman Hills, Kern County, California; depth 5,465-5,484 feet. Reef Ridge shale, upper Miocene. Width 0.23 mm; height 0.37 mm. Side view.

FIG. 67-25. *Bolivina* sp. Same specimen as figure 67-24. Apertural view.

FIG. 67-26. *Nonionella miocenica* Cushman. Hypotype, No. 7754 (Calif. Acad. Sci. Paleo. Type Coll.). From Associated Oil Co., Watson well No. 1, Sec. 34, T. 22 S., R. 18 E., M. D., Kings County, California; depth 5,805-5,818 feet. Reef Ridge shale, upper Miocene. Width 0.24 mm; height 0.32 mm. Ventral view.

FIG. 67-27. *Nonionella miocenica* Cushman. Same specimen as figure 67-26. Apertural view.

FIG. 67-28. *Nonionella miocenica* Cushman. Same specimen as figure 67-26. Dorsal view.

FIG. 67-29. *Nonion*, sp. Hypotype, No. 7755 (Calif. Acad. Sci. Paleo. Type Coll.). From Associated Oil Co., Watson well No. 1, Sec. 34, T. 22 S., R. 18 E., M. D., Kings County, California; depth 5,805-5,818 feet. Reef Ridge shale, upper Miocene. Width 0.36 mm; height 0.53 mm. Apertural view.

FIG. 67-30. *Nonion*, sp. Same specimen as figure 67-29. Side view.

FIG. 67-31. *Bulimina ovula* d'Orbigny. Hypotype, No. 7756 (Calif. Acad. Sci. Paleo. Type Coll.). From Associated Oil Co., Whepley well No. 1, Sec. 35, T. 21 S., R. 17 E., M. D., Fresno County, California; depth 5,465-5,484 feet. Reef Ridge shale, upper Miocene. Width 0.30 mm; height 0.48 mm. Side view.

FIG. 67-32. *Uvigerina* cf. *senticosa* Cushman. Hypotype, No. 7757 (Calif. Acad. Sci. Paleo. Type Coll.). From Aliso Canyon, Ventura County, California. Pliocene. Length 0.55 mm; width 0.35 mm. Side view.

FIG. 67-33. *Discocyclina clarki* Cushman. Hypotype, No. 7758 (Calif. Acad. Sci. Paleo. Type Coll.). From Domengine Reef on Domengine Creek, near center of Sec. 30, T. 18 S., R. 15 E., M. D., Fresno County, California. Eocene. Greatest diameter 3.9 mm.

FIG. 67-34. *Bolivina interjuncta* Cushman. Hypotype, No. 7759 (Calif. Acad. Sci. Paleo. Type Coll.). From Lomita quarry, Palos Verdes Hills, Los Angeles County, California. Pleistocene. Length 0.95 mm; width 0.35 mm. Side view.

FIG. 67-35. *Bolivina spissa* Galloway and Wissler. Hypotype, No. 7760 (Calif. Acad. Sci. Paleo. Type Coll.). From Pacific Western Oil Co., Rubel well No. 16, Sec. 8, T. 2 S., R. 14 W., S. B., Los Angeles County, California; depth 1,125 feet. Pico formation, lower Pliocene. Length 0.85 mm; width 0.30 mm. Side view.

FIG. 67-36. *Siphogenerina transversa* Cushman. Hypotype, No. 7761 (Calif. Acad. Sci. Paleo. Type Coll.). From east side of Adobe Canyon, a quarter of a mile north and an eighth of a mile east of the southwest corner, Sec. 30, T. 27 S., R. 29 E., M. D., Kern County, California. Lower Temblor formation, Miocene.

FIG. 67-37. *Siphogenerinoides whitei* Church, n. sp. Holotype, No. 7762 (Calif. Acad. Sci. Paleo. Type Coll.). From near center of Sec. 6, T. 15 S., R. 12 E., M. D., Panoche Hills, Fresno County, California. R. T. White, coll. Eight hundred feet below top of Moreno shale, upper Cretaceous. Length 2.25 mm; width 0.75 mm. Side view. (For description of this form, *see* accompanying paper by C. C. Church.)

FIG. 67-38. *Bolivina angelica* Church. Hypotype, No. 7763 (Calif. Acad. Sci. Paleo. Type Coll.). From Petroleum Securities Co., Mills well No. 1, Sec. 13, T. 6 S., R. 11 W., S. B., Huntington Beach, Los Angeles County, California; depth 2,820 feet. Repetto formation, lower Pliocene. From type lot. Length 1.05 mm; width 0.40 mm. Side view.

FIG. 67-39. *Bulimina subacuminata* Cushman and Stewart. Hypotype, No. 7764 (Calif. Acad. Sci. Paleo. Type Coll.). From Aliso Canyon, Ventura County, California. Pliocene. Length 0.40 mm; width 0.25 mm. Side view.

FIG. 67-40. *Bulimina rostrata* H. B. Brady. Hypotype, No. 7765 (Calif. Acad. Sci. Paleo. Type Coll.). From Aliso Canyon, Ventura County, California. Pliocene. Length 0.40 mm; width 0.25 mm. Side view. (*See* Cushman, Stewart, and Stewart 30a, p. 65, pl. 5, fig. 1.)

FIG. 67-41. *Valvulineria californica* Cushman. Hypotype, No. 7766 (Calif. Acad. Sci. Paleo. Type Coll.). From Quailwater Creek, Sec. 24, T. 28 S., R. 14 E., M. D., 7.8 miles east of Creston, San Luis Obispo County, California. Lower Monterey shale, Miocene. Greatest diameter 1.45 mm. Dorsal view.

FIG. 67-42. *Marginulina vacavillensis* Hanna. Hypotype, No. 7767 (Calif. Acad. Sci. Paleo. Type Coll.). From 3 miles north of Vacaville, California, in bed of Ulatis Creek, southwest side of Dunn Peak. Capay or Domengine, Eocene. Length 1.10 mm; width 0.70 mm. Side view.

FIG. 67-43. *Uvigerina perigrina latalata* Stewart and Stewart. Hypotype, No. 7768 (Calif. Acad. Sci. Paleo. Type Coll.). From Aliso Canyon, Ventura County, California. Pliocene. Length 0.75 mm; width 0.45 mm. Side view.

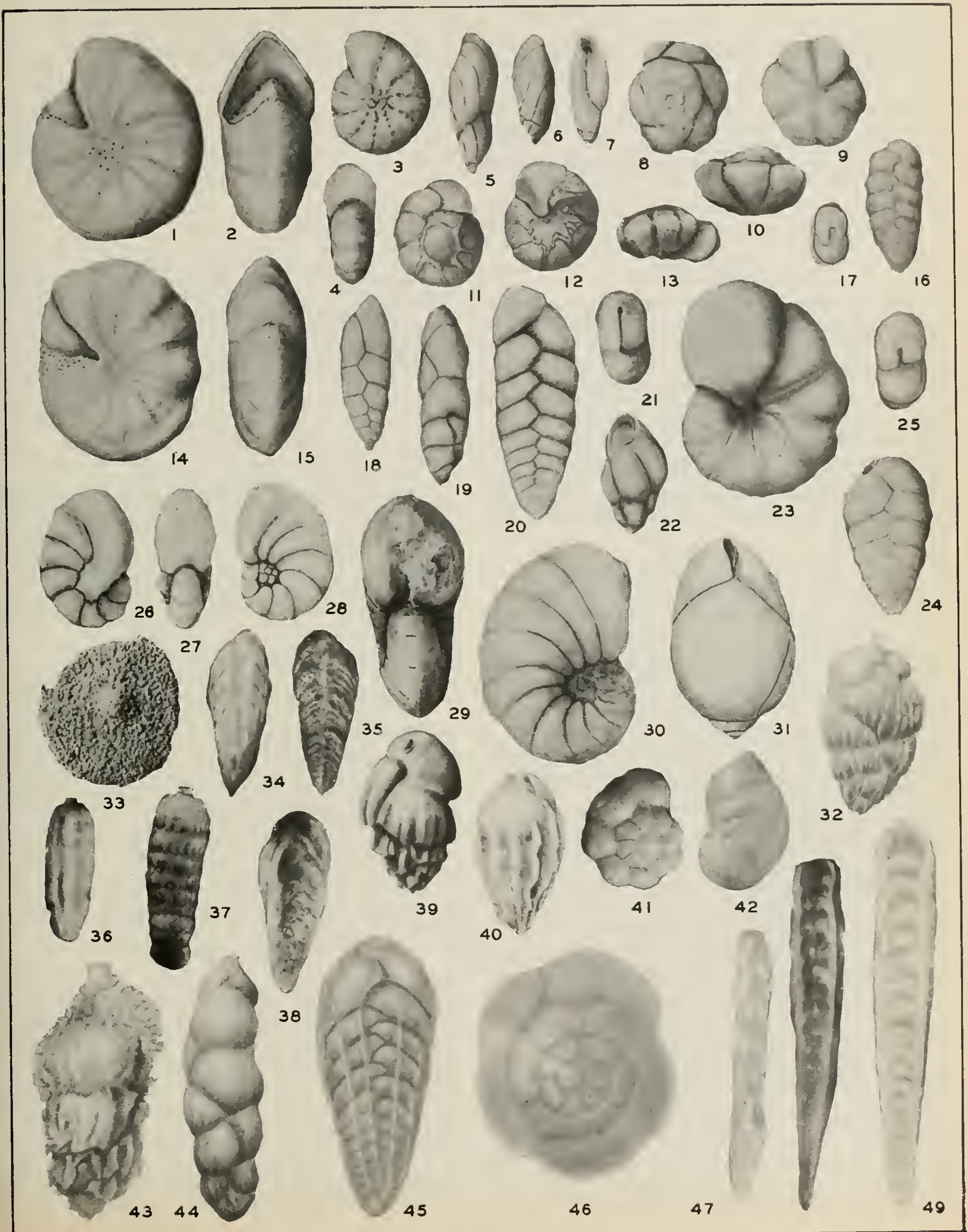

FIG. 67 (1 to 49). Foraminifera (Cretaceous to Pliocene) of California. (Microscopic fossil animals with calcareous tests).

FIG. 67-44. *Uvigerina tenuistriata* Reuss. Hypotype, No. 7769 (Calif. Acad. Sci. Paleo. Type Coll.). From Aliso Canyon, Ventura County, California. Pliocene. Length 0.85 mm; width 0.30 mm. Side view.

FIG. 67-45. *Bolivina interjuncta* Cushman. Hyoptype, No. 7770 (Calif. Acad. Sci. Paleo. Type Coll.). From Aliso Canyon, Ventura County, California. Pliocene. Length 0.80 mm; width 0.30 mm. Side view.

FIG. 67-46. *Eponides tenera* H. B. Brady. Hypotype, No. 7771 (Calif. Acad. Sci. Paleo. Type Coll.). From Aliso Canyon, Ventura County, California. Pliocene. Width 0.55 mm. Dorsal view.

FIG. 67-47. *Plectofrondicularia jenkinsi* Church. Hypotype, No. 7772 (Calif. Acad. Sci. Paleo. Type Coll.). From Markley Canyon (old quarry) NE¼ Sec. 2, T. 1 N., R. 1 E., M. D., Contra Costa County, California. Kreyenhagen shale, Eocene. Part of type lot. Length 1.50 mm; width 0.25 mm. Side view.

FIG. 67-48. *Plectofrondicularia californica* Cushman. Hypotype, No. 7773 (Calif. Acad. Sci. Paleo. Type Coll.). From Lomita quarry, Palos Verdes Hills, Los Angeles County, California. Repetto formation, lower Pliocene. Length 4.10 mm; width 0.65 mm. Side view.

FIG. 67-49. *Plectofrondicularia californica* Cushman. Hypotype, No. 7774 (Calif. Acad. Sci. Paleo. Type Coll.). From Lomita quarry, Palos Verdes Hills, Los Angeles County, California. Repetto formation, lower Pliocene. Length 2.10 mm; width 0.35 mm. Side view.

DESCRIPTIONS OF FORAMINIFERA

By C. C. CHURCH*

INTRODUCTION

In connection with a series of papers on the Kreyenhagen formation published by the California State Division of Mines in 1931 (Jenkins, O. P. 31), the present writer included (Church, C. C. 31b), among others, figures of four characteristic Foraminifera which were believed then to have been undescribed, for which new names were supplied in the explanations of the plates. Formal descriptions of these forms, prepared at that time, are given below. In addition to these there is included a formal description of *Siphogenerinoides whitei;* the illustration of this form appears on the plate of Foraminifera supplied by Messrs. Hanna and Hertlein herewith.

DESCRIPTIONS

Plectofrondicularia jenkinsi Church, n. sp.
Fig. 67-47

Plectofrondicularia jenkinsi Church, n. sp. Rept. Calif. State Mineral., Vol. 27, no. 2, April, 1931, p. 208, pl. A, figs. 5, 7-9.

This very distinctive species is elongate, compressed and rather uniformly narrow; edges smooth, rounded and slightly irregular; early arrangement of chambers gives the initial end a bluntly rounded aspect with a slight tendency to coiling; first four or five chambers biserial, then regularly uniserial becoming inflated in the later stages, often growing rounded, triangular or square; ten chambers comprise the uniserial portion of the type which is a fair average; sutures somewhat depressed, visible as opaque lines outlining the more translucent chambers, regularly curving downward to the sides in inverted "V's"; wall relatively thin, calcareous, translucent to glassy, finely perforate, polished, with minute striations running longitudinally; aperture terminal, oval to rounded, smooth outwardly but serrated with fine marginal teeth inside. Length 1.3 mm., width 0.18 mm. Named for Olaf P. Jenkins, Chief Geologist, California State Division of Mines.

The tendency of this species to change from the compressed to the inflated round, triangular or square form in growth led the writer to classify it at first as an *Amphimorphina*. It is considered to be an excellent marker fossil for the Kreyenhagen.

Holotype, No. 5502 (Calif. Acad. Sci. Paleo. Type Coll.). From an old quarry 2½ miles south of Antioch, Contra Costa County, California, NE¼ Sec. 2, T. 1 N., R. 1 E., M. D.

Planularia markleyana Church, n. sp.

Planularia markleyana Church, n. sp., Rept. Calif. State Mineral., Vol. 27, no. 2, April, 1931, p. 208, pl. A, fig. 6; pl. B, figs. 1, 10.

Test large, compressed laterally, chambers twelve or more, periphery smoothly rounded with only slight inflation of the chambers; the initial chamber unusually large in the megalospheric form, standing out as a central nob; the smaller initial chambers of the microspheric form result in a greater number of chambers, a narrower test and a consequent elongation in the later uncoiled stage; chambers only slightly inflated over test, sutures plain, limbate in the initial stages, depressed somewhat in the later, wall thin, polished and smooth, very finely perforate, aperture a rounded opening with a short, cylindrical neck at the peripheral angle of the apertural face, short tooth-like irregularities serrate the edge suggesting a degenerate radiate opening. Length of type 1.2 mm, width .85 mm. Megalospheric form.

Holotype, No. 5500 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1832 (C. A. S.), Markley (Kreyenhagen) formation, 2½ miles south of Antioch, Contra Costa County, California, in an old quarry; NE¼ Sec. 2, T. 1 N., R. 1 E., M. D. A good marker fossil.

Pullenia lillisi Church, n. sp.

Pullenia lillisi Church, n. sp., Rept. Calif. State Mineral., Vol. 27, no. 2, April, 1931, p. 208, pl. A, fig. 10.

Test very small and compressed, five chambers visible, increasing enormously as they advance, the last three making up most of test, moderately inflated, close coiled, involute, sutures plain, depressed, slightly curved, wall smooth, finely perforate, calcareous, aperture a low arched opening at the base of the apertural face. Length 0.3 mm; width 0.22 mm.

Holotype, No. 5503 (Calif. Acad. Sci. Paleo. Type Coll.). From Loc. 1832 (C. A. S.), Markley (Kreyenhagen) formation, 2½ miles south of Antioch, Contra Costa County, California, in an old quarry; NE¼, Sec. 2, T. 1 N., R. 1 E., M. D.

Robulus welchi Church, n. sp.

Robulus welchi Church, n. sp., Rept. Calif. State Mineral., Vol. 27, no. 2, April, 1931, p. 212, pl. C, figs. 13, 14.

Test small, close coiled, with thin, narrow keel, chambers increase normally with growth but become more inflated and develop a distinct angular offset where they meet the earlier coil, sutures indistinct in early part of coil but become pronounced depressed lines with increasing curvature, in the later chambers, wall calcareous, fairly thin, polished, finely perforate, no surface ornamentation, aperture radiate with facial opening larger and elongate, apertural face flattened and forming distinct angle with side, often continuous to two previous chambers. Rarely abundant but persistent and widespread; a good marker for the lower 125 to 150 feet of the Kreyenhagen.

Holotype, No. 5522 (Calif. Acad. Sci. Paleo. Type Coll.). From Salt Creek, Fresno County, California, 125 to 150 feet above the base of the Kreyenhagen. Length 0.5 mm; width 0.3 mm.

Siphogenerinoides whitei Church, n. sp.
Fig. 67-37

Test elongate, slightly tapering; circular in cross section, widest at apertural end, early stages triserial in microspheric form, biserial in megalospheric form, uniserial in adult. Chambers distinct but only slightly inflated, somewhat overlapping; sutures well marked, slightly indented scalloped lines in upper two-thirds of test, becoming faint dots in initial portion. Megalospheric form sides nearly parallel, initial end rounded and blunt; microspheric form pointed and tapering; wall minutely perforate. Aperture terminal with distinct lip, one side convex, the other concave, ending in two inwardly projecting tooth-like prominences. Length 2.25 mm; width .75 mm. Named for R. T. White.

Holotype, No. 7762 (Calif. Acad. Sci. Paleo. Type Coll.). From near center Sec. 6, T. 15 S., R. 12 E., M. D., Panoche Hills, Fresno County, California, about 800 feet below top of Moreno shale, Upper Cretaceous; R. T. White, coll.

* Paleontologist, Tide Water Associated Oil Company. Manuscript submitted for publication December 2, 1940.

SYNOPSIS OF THE LATER MESOZOIC IN CALIFORNIA

By Frank M. Anderson *

OUTLINE OF REPORT

INTRODUCTION

The following outline of the later Mesozoic series in California has been prepared chiefly because of the interest now felt in these terrains for their possible content of economic deposits in certain districts of their occurrence. This interest is not entirely of recent origin, but its recent revival calls for some consideration of the subject, which can be given better now than in the past. Interest now, as in the past, has come partly from the economic aspects of correlative deposits in other west coast regions outside of California, rather than from evidences of their value found in their environs here. Since correlations are best based either upon stratigraphic or faunal evidences, these features are stressed in the following notes and tables. By these means later Mesozoic strata may be traced from one area to another within the limits of the State itself, or far beyond these limits in other regions.

The Moreno formation is of interest in all parts of the State, wherever it can be traced, even beyond the limits of California if it can be traced so far, because of the oil measures it contains in Fresno County. The usefulness and value of such correlations should be evident to all, and when they can be made to yield practical results, the academic aspects of stratigraphic correlations become translated into values to the State of another order, and are seen to be instruments of utility for searchers for mineral wealth.

Since paleontological criteria for correlation are not commonly understood, these have been reduced to the minimum in the following tables, and only the more important, or better known molluscan types are given for each of the faunal zones. These are of use to those who know them, and they can be learned readily by all.

THE KNOXVILLE SERIES

The Knoxville series constitutes the highest sequence of Jurassic age known in California, or on the Pacific coast. It is best developed on the western side of the Sacramento Valley between Shasta and Napa counties, but it extends farther south in scattered tracts in the Coast Ranges as far as Santa Barbara County. It is almost wholly detrital in character, and consists of shales, sandstones, and conglomerates, the shales forming much of its lower and higher divisions; and sandstones and conglomerates, its middle division. Its thickest sections are found in western Tehama County, where it attains a thickness of more than 16,000 ft.

Farther south it diminishes to 15,000 ft., 14,000 ft., 12,000 ft., and 9,000 ft., due largely to the drop of the sediments by their transporting currents, or to the overlap of the Shasta series along the eastern margin of the Knoxville.

The series is divisible into three somewhat equal groups of strata—lower, middle, and upper—each with its characteristic faunal assemblage.[1]

The series contains characteristic marine fossils of three dominant invertebrate types: ammonoids, belemnoids, and Aucellae, the latter being the more abundant in each of the three groups of strata, although each group of strata has its appropriate cephalopod types.

The Knoxville series contains little of present known economic value, although small amounts of petroleum have been found in its lower beds, and scattered bodies of limestone and other rocks capable of being utilized for structural purposes, or for road building. Its conglomerates are usually of hard, resistant rock types, and are readily accessible in many localities.

THE SHASTA SERIES

In California the Shasta series constitutes a great sequence of strata (sandstones, conglomerates and shales), that have an aggregate thickness varying locally from 2,000 ft. or less to more than 25,000 ft. It is well developed along the west border of the Great Valley, and in the Coast Ranges to the west, as far south as Santa Barbara County.

Where it is in contact with the Knoxville series, it is generally unconformable, but in various places it overlaps the latter and rests directly upon pre-Knoxville formations (earlier Mesozoic and Paleozoic).

The Shasta series is divisible into two groups of strata, the Paskenta group below, and the Horsetown group above, each with its characteristic faunal assemblages of marine invertebrates, including ammonoids, belemnoids, and other classes.

Many of these have already been described and illustrated (Anderson, F.M. 38a), but other species, and even genera, remain to be described.

No economic features of present importance are attached to either group of the Shasta series, although the lower group contains deposits of limestone that may sometime be utilized for structural purposes. Prospect wells have been drilled into the lower group in search of petroleum, but so far drilling has been without commercial results.

THE CHICO SERIES

The Chico series constitutes the latest sequence of Cretaceous deposits in California, and has the widest surface distribution of any of them. Within its known geographic spread it covers not less than 20,000 sq. mi. of surface, and much larger areas under cover of later terrains. In California its aggregate thickness exceeds 28,000 ft., though not in any single section. It is divided into three distinct groups of strata, not of equal thickness, or of equal surface exposure, as follows:

The lowest, or Pioneer group, is restricted in its occurrence, but outcrops along the west side of the Sacramento Valley in a belt of considerable width, and

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[1] Anderson, Frank M. The Knoxville series in the California Mesozoic: *in press* Geological Society of America.

Series	Group	Stage	Zone	Fossils	Fossils	Lithology
SHASTA SERIES (LOWER CRETACEOUS) 13,000 FEET	HORSETOWN GROUP	ALBIAN	HULEN BEDS	Oxytropidoceras packardi Anderson Beaudanticeras breweri Gabb Desmoceras merriami Anderson Sonneratia stantoni Anderson Cleoniceras lecontei Anderson	Acanthoplites perrini Anderson Douvilleiceras mammilatum var. Schlotheim Cheloniceras stoliczkanum Gabb Puzosia dilleri Anderson	
		APTIAN	ALDERSON ZONE	Lytoceras batesi Trask Desmoceras voyi Anderson Melchiorites shastensis Anderson	Phylloceras aldersoni Anderson Hamiticeras aequicostatum Gabb	
				Acroteuthis aboriginalis Anderson Gabbioceras angulatum Anderson	Parahoplitoides shoupi Anderson Shastoceras shastense Anderson	
		BARREM.	MITCHELL ZONE	Ancyloceras elephas Anderson Ancyloceras ajax Anderson Shasticrioceras poniente Anderson	Shasticrioceras hesperum Anderson Pulchellia popenoei Anderson Hemibaculites sp.	
		HAUTERIV.	ONO ZONE	Neocraspedites aguila Anderson Hoplocrioceras remondi Gabb	Acroteuthis sp. Phylloceras occidentale Anderson	
				DEPOSITIONAL HIATUS	Local conglomerates.	
	PASKENTA GROUP	VALANGINIAN	HAMLIN-BROAD ZONE	Polyptychites lecontei Anderson Simbirskites broadi Anderson Lytoceras aulaeum Anderson Crioceras latum Gabb	Subastieria sp. Acroteuthis impressa Gabb Acroteuthis shastensis Anderson	
			SYLVESTER ZONE	Inoceramus ovatus Stanton	Hoplocrioceras sp.	
			DUNCAN ZONE	Neocomites russelli Anderson Neocomites sp. Spiticeras duncanense Anderson	Lytoceras sp. Crioceras aff. latum Gabb Lytoceras saturnale Anderson	
KNOXVILLE SERIES (UPPER JURASSIC) 14,200 FEET	NEWVILLE GROUP	TITHONIAN		Phylloceras sp. Berriasella storrsi Stanton Aulacosphinctes sp. Substeueroceras sp.	Cylindroteuthis tehamaensis Stanton Cylindroteuthis sp. Inoceramus sp. Pecten sp.	Dark clay shales.
						Dark sandy shales.
	GRINDSTONE GROUP	MIDDLE AND UPPER PORTLANDIAN		Many beds of sandstone with occasional conglomerates; few fossils.		
				Phylloceras sp. Rhynchonella schucherti Stanton	Kossmatia dilleri Stanton Aucella terebratuloides Lahusen	
				Heavy beds of conglomerate and sandstone with few fossils.		
	ELDER CREEK GROUP			Sandy shales with few fossils.		
				Kossmatia sp. Aucella piochii Gabb Aucella mosquensis von Buch	Aucella sp. Belemnopsis sp.	Dark concretionary shales; small amounts of gas, oil, tar.

NEVADAN OROGENY

MARIPOSA – MOUNT JURA SUCCESSION

FIG. 68. Columnar section of the Knoxville series (Upper Jurassic) and the Shasta series (Lower Cretaceous) of California.

CHICO SERIES (UPPER CRETACEOUS) 28,000 FEET ±	MORENO GROUP	DANIAN	GARZAS	Turritella sp. Pseudogaleodea sp. Glycymeris sp.	Garzasaurus sp. Trigonarca sp.	
		MAESTRICHTIAN	QUINTO	Diplomoceras sp. Numerous diatoms and foraminifera Helicoceras	Baculites occidentalis Meek Solenoceras Plesiosaurs	Oil and gas in Fresno County.
			MORENO	Bostrychoceras aff. polyplocum Roemer	Inoceramus aff. impressus d'Orbigny	
	PANOCHE GROUP ("UPPER CHICO")	SENONIAN — CAMPANIAN	LOS GATOS STAGE	Parapachydiscus catarinae Anderson and Hanna Parapachydiscus pensularis Anderson and Hanna Desmoceras (Kotôceras) fresnoense Anderson	Lytoceras coalingense Anderson "Hamites"vancouverensis Gabb Nostoceras sp. Bostrychoceras sp. Tessarolax sp. Nemodon vancouverensis Meek	
			JOAQUIN STAGE	Phylloceras gargantuum Anderson Parapachydiscus panochensis Anderson Canadoceras aff. multicostatum Whiteaves Parapachydiscus sp.	Inoceramus aff. sachalinensis Sokolow Inoceramus pacificus Anderson and Hanna Inoceramus aff. regularis d'Orbigny	
		SENONIAN — SANTONIAN	BUTTE STAGE	Canadoceras fraternum Gabb Trigonia hemphilli Anderson Mortoniceras aff. delawarense Morton Submortoniceras gabbi Anderson	Submortoniceras buttense Anderson Submortoniceras chicoensis Trask Baculites chicoensis Trask Helicoceras breweri Gabb Muniericeras pentzanum Anderson	
		CONIACIAN	YOLO STAGE	Nowakites aff. carezi Grossouvre Canadoceras newberryanum Meek Parapachydiscus arbucklensis Anderson Inoceramus aff. digitatus Sowerby Inoceramus aff. undulatoplicatus Roemer	Inoceramus pembertoni Waring Desmoceras aff. pyrenaicum Grossouvre Desmoceras yoloense Anderson Prionocycloceras crenulatum Anderson Placenticeras pacificum Smith Peroniceras tehamaense Gabb Peroniceras sp.	Possible oil-bearing beds.
				Conglomerates with Bellavista fossils.		
	PIONEER GROUP	TURONIAN	BELLAVISTA STAGE	Prionotropis bakeri Anderson Prionotropis branneri Anderson Gaudryceras tenuiliratum Yabe Oregoniceras oregonense Anderson Oregoniceras knighteni Anderson	Scaphites condoni Anderson Scaphites roguensis Anderson Fagesia californica Anderson Fagesia siskiyouensis Anderson	
		CENOMANIAN	GAINES STAGE	Phylloceras velledae Michelin Lyelliceras lyelli d'Orbigny Cyrtochilus aff. baculoides d'Orbigny Pervinquieria inflata var. Sowerby	Puzosia aff. planulata Sowerby Acanthoceras turneri White Stoliczkaia aff. clavigera Neumayr Puzosia sp.	Lignitic veins with conchoidal fracture.
				Conglomerates with Albian fossils.		
				DEPOSITIONAL HIATUS		

FIG. 69. Columnar section of the Chico series (Upper Cretaceous) of California.

farther north in Siskiyou County; it is not known to exceed 7,000 ft. in thickness at any place. This group constitutes the "lower Chico" division of earlier papers, and is characterized by an assemblage of marine fossils, gastropods, pelecypods and cephalopods, not all of which are yet well known, although they are now being described.

The second division of the series, in stratigraphic order, is the Panoche group. In thickness and in surface exposures this group far exceeds the preceding, and in its surface spread overlaps all older Cretaceous deposits unconformably. The Panoche is more than twice as thick as the Pioneer group, which in many areas is entirely covered by it. It embraces most of the "upper Chico" of earlier works, and includes all of the Cretaceous outcrops known on the east side of the Great Valley south of Shasta County (Chico Creek, Butte Creek, Pentz, Folsom, etc.), and most of the upper Cretaceous deposits exposed on the west side of the valley south of Tehama County. On the west side of the San Joaquin Valley, and in many other areas in the Coast Ranges west and south of this valley (Salinas Valley, Santa Maria Valley, Santa Ynez Valley, Santa Monica Mountains, Santa Ana Mountains, and San Diego County), this group of the Chico series is extensively spread, and assumes a major importance.

Throughout its geographic extent the Panoche group contains its own assemblage of marine fossils, mostly distinct from those of the Pioneer group. Most of the larger ammonoids of the Pacific coast Cretaceous are found in the upper part of the Panoche group. Most of the coal mined on Vancouver and adjacent islands is from strata of this group, and in northern California (Siskiyou and Shasta counties) coal is found in rocks of this age, but not always in commercial quantities. Gas has also been obtained from strata of this group in many places (Siskiyou, Tehama, Sutter and Glenn counties).

The highest division of the Chico series, the Moreno group, is more restricted in its occurrence, and is much less thick. Its greatest development is on the west side of the San Joaquin Valley, where it attains a thickness of 5,000 ft. or more, including three distinct stages (Moreno, Quinto, Garzas).

The lowest of these stages, the Moreno shale, is traceable from Coalinga northward to near Martinez, but it is not known to outcrop farther north. It is noted for having been the source of commercial quantities of petroleum a few miles north of Coalinga, and under suitable structural conditions it may also prove productive at other points. The upper part of the Moreno shale is highly organic in character, containing foraminifera, diatomaceae, many forms of mollusks, and, in addition, bones of plesiosaurs and shore dinosaurs. In age it may be classed as uppermost Cretaceous, correlative with the Maestrichtian of southwest France or western Germany. This stage is overlaid by the Quinto member of the group, chiefly noted for its distinctive molluscan fauna. This member has been traced at intervals from Los Banos Creek northward to Brentwood, Contra Costa County.

The highest part of the Moreno group, the Garzas member, is notable chiefly as being near the top of the Cretaceous succession, and the near equivalent of the Danian division of the upper Cretaceous in western Europe, and therefore, as constituting the highest beds of the Cretaceous system found on the west coast.

It has yielded a distinctive fauna of marine mollusks, including species of *Glycymeris*, *Trigonarca*, *Inoceramus*, *Exogyra*, *Turritella*, *Pseudogaleodea*, and various cephalopods.

This member has a thickness limited to a few hundred feet, and is chiefly composed of fine or coarse sandstone, and of thin beds of conglomerate. It is unconformably overlain by marine Eocene beds that cover the Mesozoic sequence in many parts of California within, and outside the Great Valley. Among the fossil remains that have been found in this member is a species of saurian to which the name *Garzasaurus* has been given by C. L. Camp of the University of California.

The Moreno group contains oil and gas measures of economic consequence, that, under structural conditions suitable for accumulation and retention, have yielded these products in the past, and are still capable of doing so.

The gas fields near Tracy, on McDonald Island, and at other places, seem to derive their gas supply from some part of the Moreno group.

FIG. 70. Basal conglomerate of the Lower Cretaceous Shasta series. In the matrix are fossils characteristic of these rocks. The large, white, irregular limestone boulders carry fossils of the underlying Knoxville (Upper Jurassic). Location: Glenn County, near road between Chrome and Newville. *Photo by Olaf P. Jenkins.*

FIG. 71. Typical Knoxville (Upper Jurassic) shales. Blue Canyon, north of Paskenta, Tehama County. *Photo by Olaf P. Jenkins.*

NOTES ON CALIFORNIA TERTIARY CORRELATION

By Bruce L. Clark *

OUTLINE OF REPORT

INTRODUCTION

This paper presents a brief outline of the divisions of the marine Cenozoic series of California, based upon the megafossils. Accompanying the report is a tentative correlation chart for some of the more important general areas; lack of space prohibits the discussion of details of the sections. There are several debatable points in this chart; some of these pertain to nomenclature, others to local and general correlations. For example, the writer is not certain where the lines of division should come between the Eocene and Oligocene or the Oligocene and the Miocene. R. M. Kleinpell (38) places the Vaqueros and the lower portion of the Temblor (as here used) in the Oligocene. R. A. Stirton (37, 39) considers that the upper portion of the San Pablo group is lower Pliocene; Kleinpell (38), the writer, and others place it in the upper Miocene.

PALEOCENE

Martinez Stage

The deposits here referred to the Paleocene are designated generally as the Martinez formation, and have been placed in the Martinez stage by Clark and Vokes (36). The stage may be referred to as the *Turritella pachecoensis* zone.

H. G. Schenck has pointed out, in an unpublished paper read before the meetings of the Pan American Scientific Societies at Berkeley in 1939, that the type section of the Martinez includes deposits which represent at least a portion of the Meganos, Capay, and Domengine stages. The writer favors the restriction of the name Martinez to the lower part of this section; it is the fauna from these beds that has been referred by paleontologists to the Martinez.

Important papers that deal with the faunas of the Martinez stage are those by R. E. Dickerson (14) and R. N. Nelson (25). Undoubtedly, however, only a small portion of the Martinez faunas is known and described.

* Associate Professor of Paleontology, University of California, Berkeley, California. Manuscript submitted for publication July 28, 1940. The writer is indebted to Miss Herdis Bentson of the Museum of Paleontology, University of California, for aid in editing the paper. Assistance in the preparation of this manuscript was furnished also by the personnel of Works Projects Administration, Official Projects No. 665-08, 3-30, Unit A-1.

Dickerson (14) recognized three faunal zones in the "Martinez" formation; the *Meretrix dalli* zone, the *Trochocyathus zittelli* zone and the *Solen stantoni* zone. The first two only belong to the Martinez in the restricted sense, and their relative importance is still to be determined.

EOCENE

The Eocene series of California, on the basis of megafossils, is divided into four major zones or stages. These may be referred to as the Meganos, Capay, Domengine, and Tejon stages. A fifth division, the "Transition Zone" of Clark and Vokes (36), possibly should be included as a major zone.

Meganos Stage

The Meganos was differentiated and described first from a section north of Mt. Diablo, California (Clark, B.L. 18a). The fauna and stratigraphy of the formation were described by Clark and Woodford (27), who recognized five divisions: A, B, C, D, and E, with a maximum thickness of about 3,000 ft. for the series. The megafauna described from Division D came from a sandstone 300 ft. thick, about 1,000 ft. above the base of the section.

On the basis of foraminifera, micropaleontologists consider that Division E of the type section of the Meganos belongs to the Capay stage (lower middle Eocene). In so far as the writer is aware, good foraminiferal faunas have not been obtained from the lower portion of Division E. If there is a stratigraphic break between the deposits of Division E and those of Division D, it comes probably in the lower part of Division E.

The fauna from Division D of the Meganos is correlated with that found in the upper portion of the Santa Susana formation of Simi Valley, Ventura County, California. The same zone has been recognized in Round Valley, Lake County, by Merriam and Turner (37).

MIDDLE EOCENE

Clark and Vokes (36) have pointed out that there has been some confusion in the past as to the divisions here referred to the middle Eocene. For the history of the development of the concepts held at the present time, the reader is referred to their paper.

Capay Stage

The type section of the Capay formation lies on the west side of Capay Valley, several miles north of the town of Capay, Yolo County. These deposits contain the fauna of the *Siphonalia sutterensis* zone of R. E. Dickerson (14a, 16). This fauna, referred to the Capay stage (Clark and Vokes 36), has a wide geographic distribution on the West Coast, and in places is divisible into several subzones (see Vokes, H.E. 39). Three of the most distinctive species of the *Siphonalia sutterensis* zone are *Galeodea sutterensis* Dickerson, *Turritella merriami* Dickerson and *Turritella andersoni* Dickerson. At the present time a greater number of molluscan species are known from strata of this zone than from any other portion of the Eocene and Paleocene on the Pacific Coast.[1]

Domengine Stage

The deposits of the Domengine stage have a distribution similar to those of the Capay. At a number of localities the Domengine deposits rest unconformably upon Capay strata. This is the case north of Mount Diablo and north of the town of Coalinga. The fauna of the Domengine is distinct from that of the Capay, but the two are fairly closely related, and many of the distinctive species of the former have ancestral species in the older beds. A number of more generalized types are common to the two zones.

Transition Zone

The fauna referred by Clark and Vokes (36), to the "Transition Zone" should possibly be considered to belong to a subzone of the Domengine stage. The Rose Canyon shales, which form the upper portion of the La Jolla formation described by M. A. Hanna (27), are taken as the type section of this zone. The deposits may be referred to the *Rimella supraplicata* zone. *Rimella supraplicata* (Gabb) is ancestral to *Rimella canalifera*, a distinctive species of the Tejon stage. The fauna of this zone has been recognized at a number of localities from the Mount Diablo area to southern California. There is no doubt as to its stratigraphic position between the deposits of the typical Domengine and those of the Tejon. The fauna of the "Transition Zone" has many more species in common with that of the typical Domengine than with the fauna of the overlying Tejon.

Tejon Stage

Until a comparatively few years ago, all the Eocene deposits of the West Coast (exclusive of those of the Martinez stage, here referred to the Paleocene) were referred to as Tejon. It was pointed out by Clark (Clark, B.L. 21, 26) that the type section of the Tejon formation came stratigraphically and unconformably above beds referable to the Domengine and Capay stages, and that the name Tejon should be restricted to these upper deposits, which contain a fauna distinct from that found in the underlying beds. Clark and Vokes (36) proposed the use of the term "Tejon stage" as a general designation for these deposits and faunas which can be correlated with the typical Tejon. The fauna of the type Tejon has been monographed by Anderson and Hanna (25).

The deposits referable to the Tejon stage have a much more restricted distribution than do those of the Capay and Domengine stages. Clark and Vokes (36) have shown that three subzones are to be recognized in the type Tejon; these are based upon subspecies of *Turritella uvasana* Conrad. The *Turritella uvasana* group has been one of the most useful of all the gastropod species in the zoning of the Eocene strata. Species of the group appear first in deposits of the Martinez stage, and each zone of the Eocene has its distinctive subspecies.

OLIGOCENE

The Oligocene of western North America presents many unsolved problems. There is a possibility that certain deposits considered to be Oligocene, for example, the lower portion of the Gaviota formation of the Santa Ynez Mountains of California, should be referred to the upper Eocene.

The faunal divisions of the marine Oligocene of the West Coast are best known from Oregon and Washington. At least four major faunal zones are determinable. These are, from base to top: the Keasey (Schenck, H.G. 27); Gries Ranch (Effinger, W.L. 38); Lincoln restricted (Weaver, C.E. 37); and Blakeley (Tegland, N.M. 33). All these zones have been recognized at one place or another in California. Thus the lower portion of the Gaviota formation and possibly the lower portion of the San Emigdio (Wagner and Schilling. 23) appear to be the equivalent of the Keasey, while the Gries Ranch zone is represented probably by the upper San Emigdio and a portion of the Gaviota.

The megafossils from the lower portion of the Pleito formation (Wagner and Schilling. 23) show a close relationship to those of the Lincoln formation (in the restricted sense)—*i.e.*, the *Molopophorus lincolnensis* zone of Weaver. The fauna from the upper portion of the Pleito formation is equivalent to that found in the San Ramon formation (Clark, B.L. 18). The latter fauna in turn appears to be close to that of the Blakeley of Washington. Kleinpell (38) on the basis of the foraminifera, has expressed the belief that the Blakeley of Washington is the equivalent of the Vaqueros of California, and has placed it in the lower part of his Zemorrian zone. The writer does not agree with this correlation. The megafaunas of the San Ramon and the Blakeley are more closely related to the fauna of the underlying Lincoln than to that of the overlying Vaqueros. In the San Emigdio Mountains the San Ramon fauna is found in the upper part of the Pleito formation, which lies unconformably below the Vaqueros. Thus, if the correlation of the San Ramon of California with the Blakeley of Washington is correct, it is difficult to see how the latter fauna can be the equivalent of that of the California Vaqueros.

LOWER AND MIDDLE MIOCENE

In the correlation table, the writer has followed general usage and has placed the Vaqueros in the lower Miocene and the Temblor in the middle Miocene, although the use of "Temblor" for middle Miocene is questionable. Much work remains to be done on the molluscan faunas of the "Temblor" before the zones can be adequately differentiated.

The megafauna of the Vaqueros has been described by Loel and Corey (32). It is more closely related to that of the overlying "Temblor" than to the fauna of the underlying San Ramon. Remington Kellogg[2]

[1] In the area north of Coalinga, deposits referable to the Capay stage were described by Vokes (39) and were referred by him to the Arroyo Hondo formation. Robert T. White (38) had already applied the name Lodo formation to these same deposits. White used the name Arroyo Hondo for one of the shale members in his Lodo formation. It should be noted, however, that the type section of the Lodo formation is north of the area studied by Vokes, and includes deposits referable to the Martinez stage as well as the Capay stage. In that area, Mr. White finds no evidence of a break between the deposits of these two stages. The Martinez deposits apparently are not present in the section studied by Vokes. White's names are used in the correlation chart accompanying this paper. It is the writer's opinion, however, that further stratigraphic and faunal work may show that the Martinez deposits should be included in a separate formation. (*See* Vokes, H. E. 39; White, R. T. 38, 40.)

[2] Written communication.

GENERAL TIME SCALE		COAST RANGES OF CALIFORNIA							
		BERKELEY HILLS	NORTH OF MT. DIABLO	SOUTH & WEST OF MT. DIABLO	COALINGA AREA	SOUTHERN SAN JOAQUIN VAL.	VENTURA CO. SIMI VAL. AREA	LOS ANGELES BASIN	SAN DIEGO COUNTY
PLEISTOCENE		River terraces			Terraces Tulare	Terraces Tulare	Terraces Las Posas Saugus	Palos Verdes = Upper San Pedro Lower San Pedro Timms Point zone "San Pedro Pliocene"	"San Pedro"
PLIOCENE	UPPER				San Joaquin clays	Etchegoin (including San Joaquin clays)	Pico: Santa Barbara zone	3rd St. Tunnel at 4th & Brdwy	
	MIDDLE	Tassajara		Tassajara	Etchegoin ss.		Pico: San Diego zone	San Diego zone	San Diego zone
	LOWER	Bald Peak lavas Siestan Moraga vol.	Los Medanos "Lawler tuff"	Green Valley Alamo formation	Jacalitos Reef Ridge shales	Jacalitos	Repetto	Repetto	
MIOCENE	UPPER	Orinda - Neroly Cierbo Briones Hercules	Neroly Cierbo	Neroly formation Cierbo ss. Briones ss.	? ? Santa Margarita formation = McLure shale	Maricopa	"Modelo"	Puente	
	MIDDLE	Rodeo sh Hambre ss Tice sh Oursan ss Claremont sh Sobrante ss		"Monterey" formation	"Big Blue" "Temblor"	"Temblor"	Topanga	Topanga	
	LOWER					Vaqueros Tecuya	Vaqueros Sespe	Vaqueros	
OLIGOCENE	UPPER	Concord ss Kirker tuff San Ramon ss	Kirker tuff	San Ramon formation		Pleito	Sespe		
	MIDDLE		Kirker ss		Tumey formation	San Emigdio			
	LOWER								
EOCENE	UPPER		? ? Markley fm. Upper Radiolarian zone		"Kreyenhagen" proper	Tejon	Lower Sespe	Tejon ?	Poway congl.
	MIDDLE	Undiff. Eocene	"Nortonville sh" Lower Radiolarian zone "Domengine" Division E Capay	Undifferentiated Eocene: Domengine fauna Capay fauna	Canoas silt Domengine: "Cibicides Coalingensis zone", Domengine sands Yokut ss Arroyo Hondo sh. Cantua ss Cerros sh	Undifferentiated: Domengine Capay	Llajas fm.: Transition zone Domengine Capay	Middle Eocene Undifferentiated	La Jolla fm.: Rose Canyon sh Torrey sand Delmar sand
	LOWER		Meganos Gr.: Division D Division C Division B Division A		Lodo formation		Santa Susana		
PALEOCENE			Martinez		Lodo formation; Martinez		Martinez	Martinez (in Santa Ana and Santa Monica Mts.)	

FIG. 72. General correlation chart of the Cenozoic of California.

believes that the sirenian material in the Vaqueros indicates a Burdigalian age, rather than Aquitanian and Rupelian, as shown in Kleinpell's (38) correlation table.

UPPER MIOCENE

The faunas of the upper Miocene from the vicinity of San Francisco Bay and Mount Diablo have been studied in detail. Here three major stratigraphic and paleontologic zones have been recognized. These are: (1) the Briones formation, or the *Astrodapsis brewerianus* zone; (2) the Cierbo formation, or the *Echinarachnius gabbi* zone; (3) the Neroly formation, or the *Astrodapsis tumidus* zone. These make up the San Pablo group. J. C. Merriam (98) and Clark (Clark, B.L. 15) did not include the Briones in their definition of the San Pablo. Parker Trask (22) has shown that stratigraphically and faunally the Briones formation is more closely related to the overlying Cierbo and Neroly than to the underlying *Arca devincta* zone of the "Monterey," and later work seems to bear out this conclusion.

In the San Joaquin Valley and farther to the west, beds equivalent to the San Pablo are known as the Santa Margarita and McClure shales. According to R. M. Kleinpell (38), the type section of the Monterey includes beds equivalent to all of the San Pablo. For that reason, the term "Monterey group" can not be used as a general name for the lower and middle Miocene of California, as was proposed by Louderback (Louderback, G.D. 13) and Lawson (Lawson, A.C. 14).

There has been considerable confusion in the naming of the Miocene deposits of southern California. The name "Modelo" was applied by Kew (Kew, W.S.W. 24) and English (English, W.A. 26) to beds of upper Miocene age in that area. Later work has shown conclusively that the lower portion of the type section of the Modelo is equivalent to the "Temblor" and may even include beds of Vaqueros age. In the Santa Monica Mountains, the "Modelo" rests unconformably upon the Topanga formation, which is in part at least equivalent to the "Temblor."

The Puente formation of the Los Angeles Basin area has yielded few megafossils. Kew (24) and English (26) have used the name "Modelo" for this series of beds. According to R. M. Kleinpell (38), the lowest beds of the "Modelo" of that area are approximately equivalent to the Briones formation of the San Francisco Bay area, and are placed in his Mohnian stage.

PLIOCENE

The Pliocene series of California may be divided roughly on the basis of megafossils into three major zones, lower, middle, and upper. One of the most complete and best-known marine Pliocene sections in California is in the San Joaquin Valley, south and southwest of the town of Coalinga, and in the general area of the Salinas Valley.

The marine lower Pliocene of the San Joaquin Valley area may be referred to as the Jacalitos stage. This is the lower portion of the Etchegoin formation as redefined by J. O. Nomland (16, 16a). Nomland recognized two faunal zones in the deposits referred originally by Arnold and Anderson (10) to the Jacalitos, the *Chione elsmerensis* zone and the *Turritella nova* zone. The fauna of the Jacalitos is very different from that of the overlying Etchegoin sands.

One of the best sections of the lower Pliocene of California is that found along the west side of the Salinas Valley south of King City. Here two distinct formations are recognizable; the lower of these is the King City formation (Clark, B.L. 40), the upper the Poncho Rico (Reed, R.D. 25).

The deposits of the King City formation have previously been incorrectly referred by the writer and others to the Santa Margarita formation (upper Miocene). Later work has shown that they are referable to the *Astrodapsis antiselli* zone of Clark (Clark, B.L. 32). Two other distinctive species of echinoids in this zone are *Astrodapsis spatiosus* Kew and *Astrodapsis arnoldi* Pack. In the Salinas Valley area southeast of King City, the beds of this zone rest unconformably upon the basal complex. The fauna is found in the basal arkosic sands which in places are more than 100 ft. thick. Overlying is a series of white shales, in turn overlain by the basal sands of the Poncho Rico formation, the type section of which is in the vicinity of Poncho Rico Creek. The Poncho Rico formation may be referred to as the *Astrodapsis peltoides* zone. *Astrodapsis peltoides* Anderson and Martin and its varieties are very common in the middle and upper portions of the "Jacalitos" formation in Waltham Valley west of Coalinga. The King City and the Poncho Rico formations taken together are apparently the equivalent of the Jacalitos formation of Arnold and Anderson.

Recognition of the fact that the King City deposits are of Pliocene rather than upper Miocene age changes considerably the previously held concepts of Pliocene paleogeography. Thus, at least in middle California, the beginning of the Pliocene is marked by a transgressing sea. A large portion of the old positive area, Salinia of Reed (Reed, R.D. 33), which was probably land during most of the Tertiary, was covered by water during lower Pliocene times.

No marine middle or upper Pliocene deposits have been found, as far as the writer is aware, in the Salinas Valley area. In general the marine deposits of that portion of Pliocene times have a more restricted range than those of the lower Pliocene.

The marine middle Pliocene of the San Joaquin Valley area is best represented in the general vicinity of the town of Coalinga. The Etchegoin sands as now recognized include only the lower portion of the Etchegoin of Arnold and Anderson (10); the upper portion of their Etchegoin is now referred to the San Joaquin clay. The Tulare formation, which overlies the San Joaquin clay and may be lower Pleistocene in age, is chiefly continental in origin.

In southern California the deposits referred to generally as the Repetto formation are considered to be the equivalent of the Jacalitos. The megafauna from Elsmere Canyon, Ventura County, described by English (English, W.A. 14), appears to be approximately equivalent to the Jacalitos.

The Etchegoin sands of the Coalinga area, on the basis of the molluscan fauna, are about equivalent to the San Diego zone as recognized by Grant and Gale (31). The same fauna is found also in the Foxen formation of the Santa Maria area, in the upper sands of the

Purisima formation of the Santa Cruz quadrangle, and in at least a part of the type Merced. Just how much Pliocene is represented in the latter section is still to be determined, and more work needs to be done before detailed correlations can be made. The same holds true for the Pliocene deposits known as the Wildcat formation in the northern part of the State. The deposits of the Merced formation in the Santa Rosa quadrangle are intercalated with the Sonoma volcanics, and contain a fauna equivalent to that found in the Etchegoin sands and the San Diego formation. The San Joaquin clays in the San Joaquin Valley area overlie the Etchegoin sands and are considered to be upper Pliocene in age. The fauna from these beds is probably equivalent to that of the Santa Barbara zone of Santa Barbara and Ventura counties. The faunal facies from these two general areas, however, are very different and there is little with which to establish a correlation, on the basis of the molluscan faunas.

The Pliocene deposits of the Berkeley Hills and the Mount Diablo area have a maximum thickness of more than 5,000 ft. The type section of the Orinda formation of the Berkeley Hills area was referred originally to the Pliocene by Lawson and Palache (02) and Merriam (Merriam, J.C. 13). K. A. Richey,[3] a graduate student at the University of Califorina, has shown conclusively that intercalated with the deposits of lower Orinda are lenses of marine beds which contain a typical Neroly (upper Miocene) fauna. The Orinda formation is overlain by the Moraga volcanics, which in turn are overlain by the Siesta formation. The Siesta is considered to be lower Pliocene in age on the basis of vertebrate fossils.

A great series of continental beds, younger in age than the Orinda, is found in the Berkeley Hills east of the type section of the Orinda formation, and is best seen in the vicinity of Moraga Valley. Here the deposits are more than 5,000 ft. thick, and have been considered incorrectly by Lawson (Lawson, A.C. 14) and others to belong to the Orinda formation. These deposits include beds from lower to at least middle Pliocene age, and are equivalent to the Green Valley and the Tassajara formations found on the south and west sides of Mount Diablo.

The best and most complete Pliocene section found in this general area is the one to which reference has just been made. At the base are about 1,000 ft. of marine beds, the Alamo formation, which contain a fairly large megafauna. The most distinctive species in these beds is *Astrodapsis major* (Kew), a species very close to some of the varieties of *A. peltoides* Anderson and Martin in the Jacalitos. On that basis the beds are correlated tentatively with the Jacalitos formation of the Coalinga area. The Alamo rests unconformably upon the Neroly (upper Miocene). Above the Alamo are between 2,000 and 3,000 ft. of continental beds, the Green Valley formation. The name Green Valley is used here for the first time. It is equivalent to the "Orinda formation," the name used by Clark (Clark, B.L. 35) for the continental deposits which immediately overlie the Alamo formation in the section to the west and southwest of Mount Diablo. As has already been pointed out, the type section of the Orinda is now considered equivalent to the upper San Pablo, that is, the Neroly formation. Above the Green Valley deposits are more than 1,000 ft. of silts, sands and gravels, a large proportion of which are lacustrine in origin. These deposits belong to the Tassajara formation. A large, well-preserved collection of vertebrates has been obtained from the basal beds of the Green Valley formation. This fauna is being studied by K. A. Richey, who considers it lower Pliocene (Richey, K.A. 38) in age. The Tassajara formation overlies the Green Valley, and is separated from it by a series of tuffaceous deposits, the "Moraga" tuffs of Clark (Clark, B.L. 35).

No fossils have been found in the continental deposits which overlie unconformably the Neroly formation north of Mount Diablo. The names here applied—Lawler tuff and Los Medanos formation—previously referred to as the Pinole tuff and Orinda formation, are used by C. E. Weaver[4] for this series of beds as found in the Napa quadrangle a little to the northwest.

PLEISTOCENE

In the Coast Ranges the problem of the boundary between the Pliocene and Pleistocene epochs is debatable. Earlier investigators have placed the latest folded beds in the upper Pliocene, and the oldest unfolded deposits found on the marine and river terraces in the lower Pleistocene. However, it was recognized that in the Ventura and Los Angeles basins the highest folded beds contained an invertebrate fauna with a Pleistocene percentage of recent species. The discovery by Pressler (Pressler, E.D. 29) of the Pleistocene *Equus occidentalis* in these highest folded beds shows that it is a very late deposit. At the present time these highest folded beds are referred to the Pleistocene. The name Las Posas formation was given to these deposits by Pressler (29). As he has pointed out, they overlie a series of beds which are considered generally to belong to the Santa Barbara zone. The invertebrates of this zone indicate cool water conditions while those of the Las Posas formation represent a much warmer climate. From the above evidence the conclusion gained is that a large proportion of the folding in the Coast Ranges took place during Pleistocene time. For additional details of the Pleistocene sequence the reader is referred to the monograph by Grant and Gale (31).

Bibliography: Anderson, F. M. 05; Anderson and Hanna 25; Arnold, R. 06a; Arnold and Anderson 08b; 10; Atwill, E. R. 35; Bailey, T. L. 31; Barbat and Galloway 34; Barbat and Johnson 34a; Clark, B. L. 15; 18; 18a; 21; 24; 26; 32; 35; 38a; 40; Clark and Stewart 25; Clark and Woodford 27; Clark and Vokes 36; Clark and Anderson 38; Crook and Kirby 35; Dickerson, R. E. 14; 14a; 16; 22; Effinger, W. L. 38; English, W. A. 14; 26; Grant and Gale 31; Hanna, G. D. 23a; Hanna, M. A. 27; Jenkins, O. P. 31; Kew, W. S. W. 20a; 24; Kleinpell, R. M. 38; Lawson, A. C. 14; Lawson and Palache 02; Loel and Corey 32; Louderback, G. D. 13; McMasters, J. H. 33; Merriam, J. C. 98; 13; Merriam and Turner 37; Nelson, R. N. 25; Nomland, J. O. 16; 16a; Pressler, E. D. 29; Reed, R. D. 25; 33; Richey, K. A. 38; Schenck, H. G. 27; 35a; Siegfus, S. S. 39; Stirton, R. A. 37; 39; Stock, C. 32; 32a; Tegland, N. M. 33; Trask, P. D. 22; Turner, F. E. 38; Vokes, H. E. 39; Wagner and Schilling 23; Weaver, C. E. 37; White, R. T. 38; 40; Woodring, Bramlette, and Kleinpell 36.

[3] Oral communication.

[4] Paper to be published in the near future.

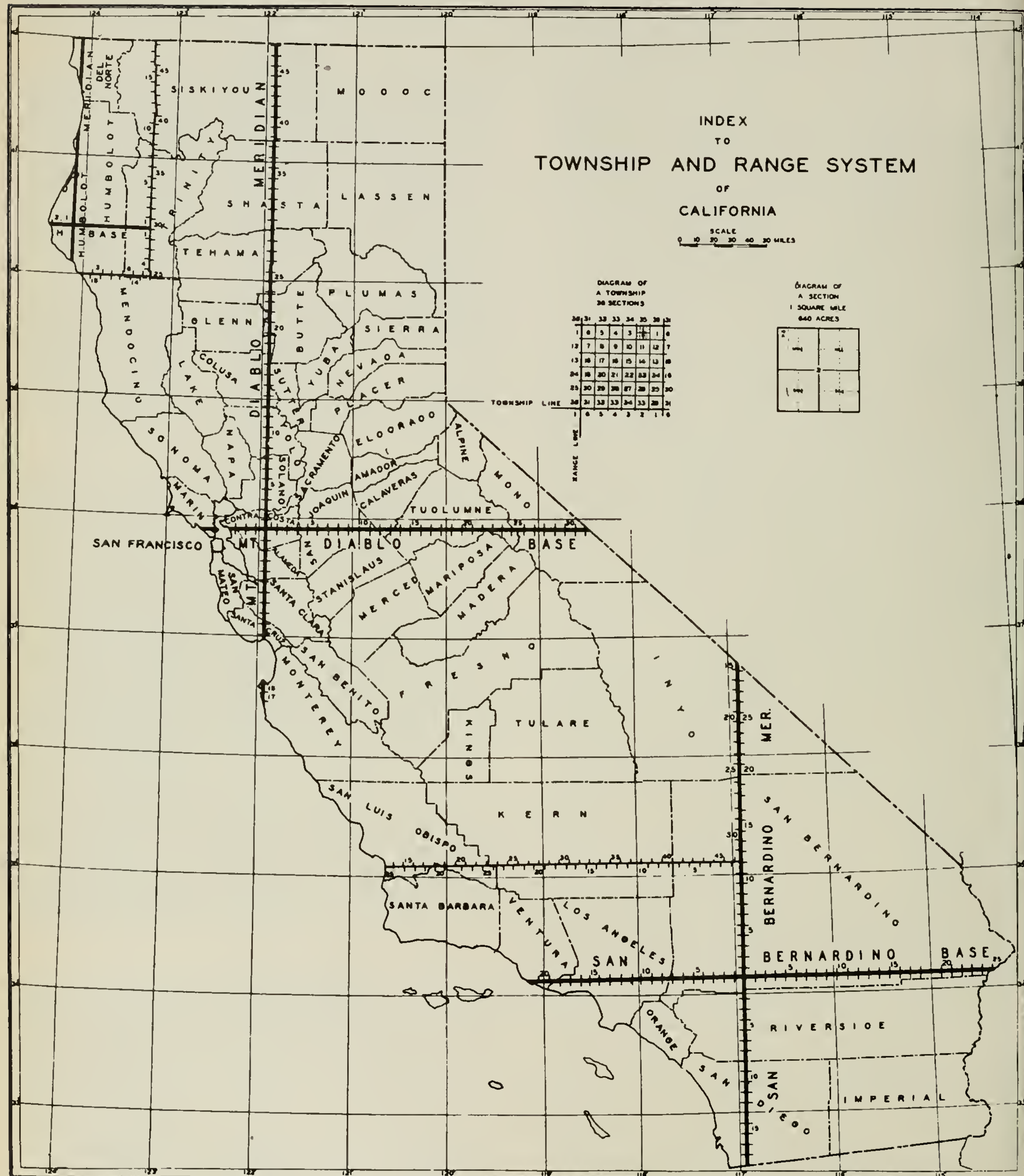

FIG. 73. Outline map of California showing the meridians and base lines, together with the numbering of townships and ranges. *Republished from Sheet V, Geologic Map of California, 1938*

EOCENE FORAMINIFERAL CORRELATIONS IN CALIFORNIA*

By Boris Laiming**

OUTLINE OF REPORT

SIGNIFICANCE OF THE EOCENE

Since the recent discoveries of important productive horizons of oil and gas in the Eocene of California, the correlation of these strata has acquired considerable economic importance.

Eocene shales of Tejon and Meganos age have for some time been considered the source of oil produced from younger Tertiary formations in California, principally in the Coalinga region of the west border of the San Joaquin Valley, and in the Santa Clara Valley and Simi Valley regions in Ventura County. However, only a small amount of production had been obtained from the Eocene itself.

The development of gas production from Eocene strata in the Rio Vista gas field in Solano County in 1936, followed by the discovery of the East Coalinga (Coalinga Nose) oil field in 1938, and the North-East Coalinga oil field in 1939, both with large initial output of oil from middle Eocene formations, stimulated great interest in the Eocene stratigraphy of California. Active drilling for Eocene objectives emphasized the need of an adequate and uniform basis for correlation of heterogeneous members of the Eocene stratigraphic column.

BASIS FOR CORRELATION

The lithologic diversity of Eocene formations in California, attended by marked lateral facies changes and by lenticularity of the producing horizons or members of these formations, increases the difficulty in correlation by ordinary lithologic methods and by electrical logs.

Therefore, in determining the stratigraphic position of producing horizons in various areas, a basis for correlation must be provided which transgresses lithologic boundaries. Detailed foraminiferal zonation of the Eocene can supply such a basis for correlation.

Widespread distribution of the foraminifera and the comparative ease with which they may be recovered from the rocks, afford a distinct advantage in the study of nearly continuous sequences of strata, and the establishment of a greater number of stratigraphic units over a wider area than can be accomplished by means of the molluscan fossils.

The object of this investigation has been to determine the character of distribution of the smaller foraminifera in the marine Eocene deposits of California, and to establish foraminiferal zones for correlation of the Eocene strata within the California province.

This investigation has included the study of 16 detailed control sections of Eocene strata, the geographical locations of which are shown in figure 76. Additional study of numerous well sections served to corroborate and amplify the evidence relating to the stratigraphic distribution of the foraminiferal zones in the type sections.

None of these sections furnished a complete faunal sequence throughout the Eocene column, and more than one section was used in establishing the order of superposition of each zone. However, the finding of analogous sequences in numerous well sections from widely separated areas has given assurance of the validity of the sequences thus established. The correlations of faunal zones in various sections were made by direct comparison of mounted assemblages of foraminifera rather than by scrutinizing faunal lists. The general

* Abstract from paper titled "Some Foraminiferal Correlations in the Eocene of the San Joaquin Valley, California" (Laiming, B. 39). The figures submitted with this manuscript and published herewith (figures 74 to 82, inclusive) are the same as those published in the paper from which the abstract was made.

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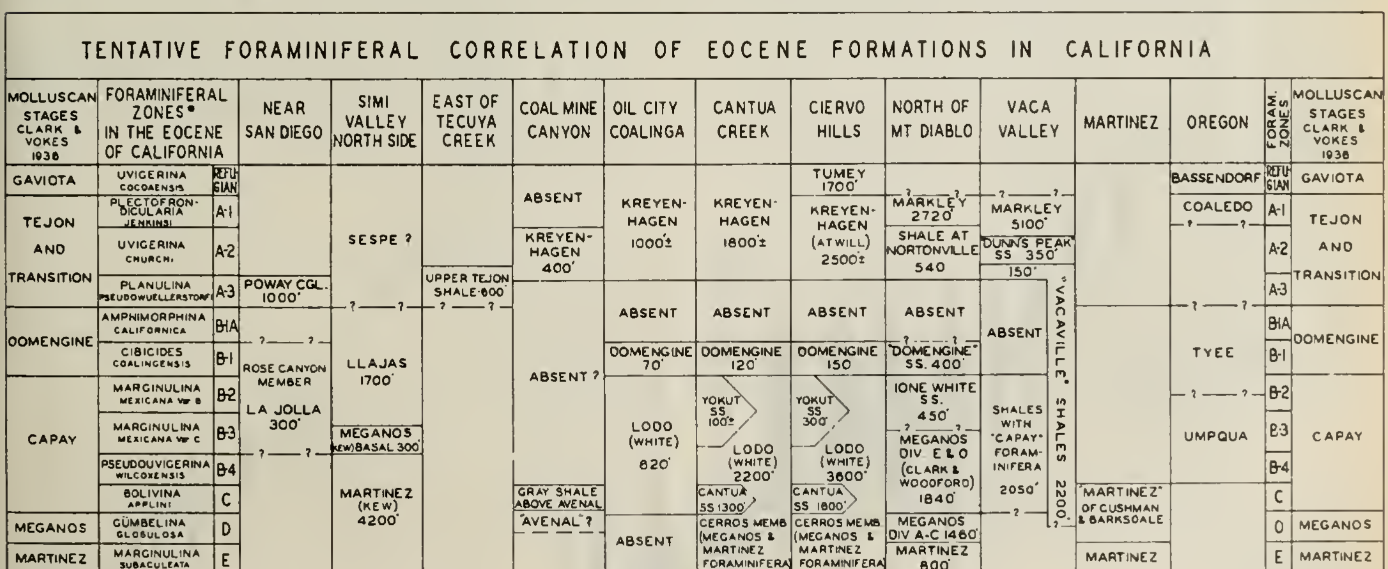


* THE BIOLOGICAL DESIGNATION OF THE ZONES IS HERE PROPOSED INFORMALLY PENDING THEIR MONOGRAPHIC TREATMENT.

Fig. 74. General correlation chart of the Eocene.

order of superposition of those assemblages and their components has remained remarkably constant throughout the major portion of the area studied.

In defining the limits of each zone, emphasis was placed upon continued occurrence of a given assemblage rather than upon the presence or absence of individual markers. However, the distribution of the markers was noted, and a range chart containing some of the most important ones was included in figure 75.

For the purpose of clarity, the record of distribution of each foraminiferal assemblage in the stratigraphic column is presented in graphic summary form in figure 75. This clearly shows that the majority of the zones can be differentiated on the basis of assemblage characteristics, and only the middle Eocene zones B-1, B-2, and B-3 can not be distinguished in any other way than by means of marker fossils.

The effect of ecologic factors on correlation and the importance of taking faunal provinces into account in biostratigraphic studies deserve serious consideration. This investigation has led the writer to the conclusion that, within the area considered in this report, one is dealing with the same faunal province. Therefore, correlations within this province on the basis of foraminiferal zones set forth in figure 75 are believed to be reliable, allowing for local limitations.

A comparison of the faunal sequence presented in figure 75 with that of the Gulf Coastal area of the United States and Mexico points to the same order of superposition of the main faunal groupings, although the California microfaunal zones could not be correlated individually with these areas.

FORAMINIFERAL ZONES

Departing from the conventional method of presentation, the foraminiferal zones are described in descending order in this paper, with the thought in mind that this order will afford greater convenience for study of the foraminifera to the largest group of foraminiferal workers who are dealing with subsurface sections in drilling wells.

The uppermost zone here described and designated zone "R" is characterized by the group of foraminifera figured by Cushman and Schenck (Cushman, J. A. 28) from the Bassendorf shale of Oregon, typical of the Refugian stage of the California Tertiary.

Most characteristic for this zone are the occurrences of *Uvigerina cocoaensis*, *"Planulina" haydoni*, *Plectofrondicularia packardi* and *Bulimina sculptilis*, the first two being confined to this zone.

The succession of strata which underlie the Refugian stage, and which comprise that portion of the Eocene section assigned to the Unnamed stage by Schenck and Kleinpell (Schenck, H. G. 36), have here been divided into three zones on the basis of foraminifera. In descending order these are zones A-1, A-2, and A-3.

The fauna of zone A-1 was described by Church (Church, C. C. 31b) from the Kreyenhagen shale, but it is confined to the middle and upper-lower portion of the Kreyenhagen shale as mapped by Anderson and Pack (Anderson, R. 15) north of the town of Coalinga.

Zone A-1 is characterized by the common occurrence of *Plectofrondicularia jenkinsi* restricted to this zone, and associated with *Planularia markleyana*, *Eponides pygmea* and *Robulus welchi*.

Zone A-2 is characterized by the restricted occurrence of *Uvigerina churchi*, associated with *Uvigerina garzaensis*, *Bulimina corrugata*, *Gyroidina orbicularis* var. *planata*, and *Plectofrondicularia packardi*. The lower portion of zone A-2 is locally marked by the presence of several characteristic species including *Globorotalia* cf. *palmarealensis*, *Bulimina lirata* and *Bulimina instabilis*, and an undescribed species of *Plectofrondicularia*, ornamented with four prominent peripheral ridges and one to three short costae over the initial chamber.

Near the base of zone A-2, and occasionally recurrent at points within this zone, are found in some areas numerous species

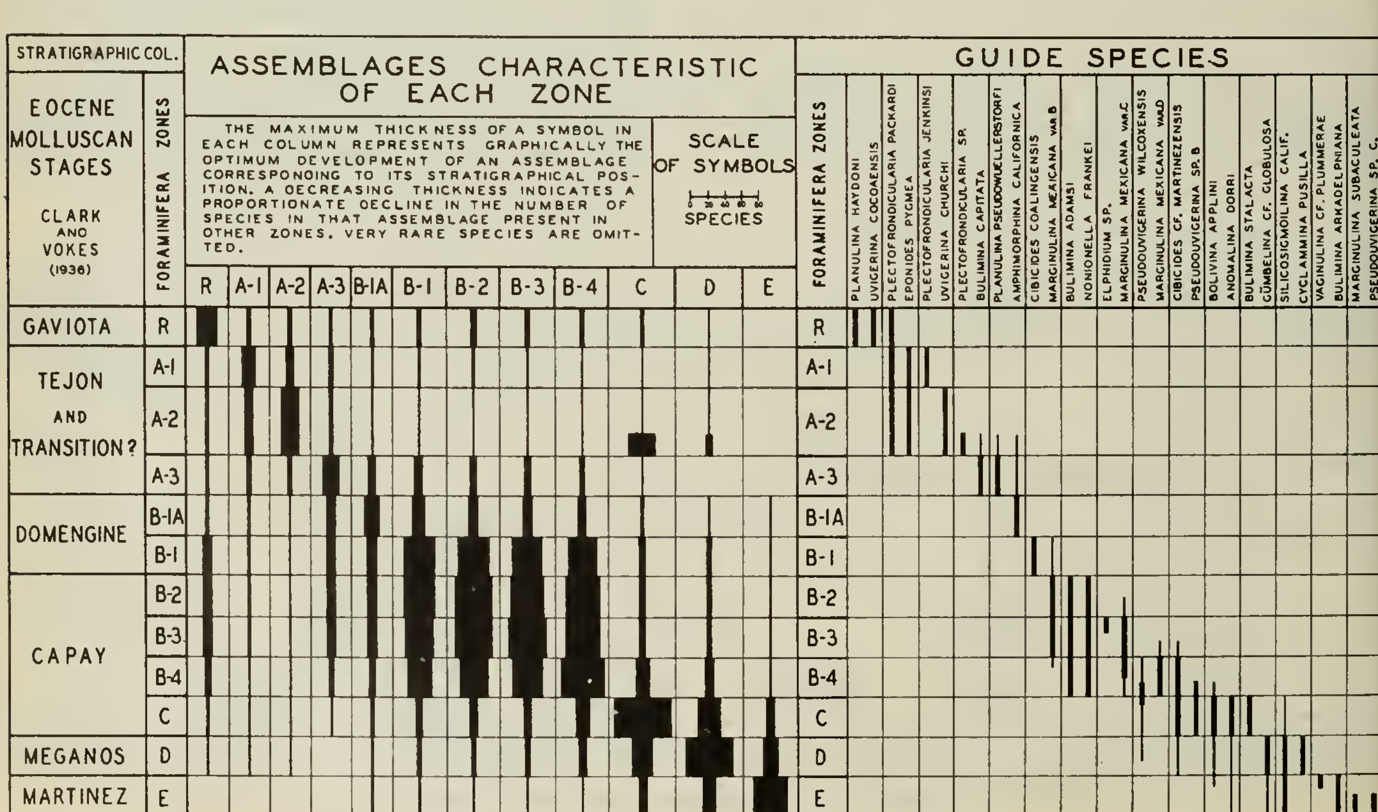


FIG. 75. Chart showing distribution of Eocene foraminiferal assemblages.

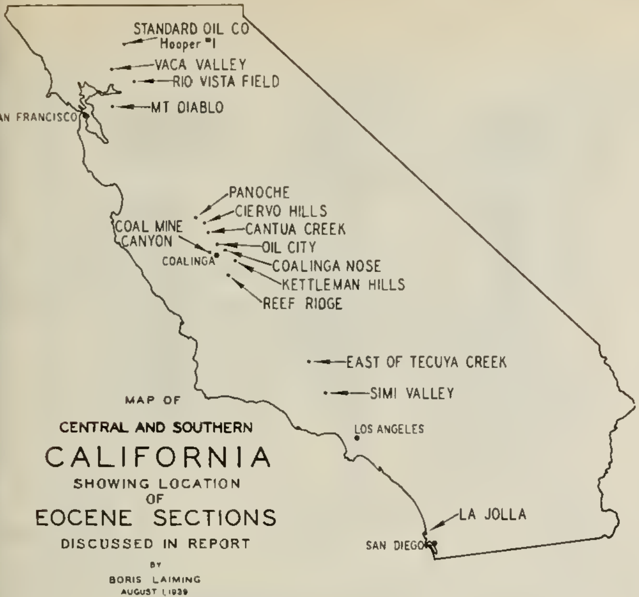


FIG. 76. Index map showing location of Eocene sections.

which show a marked affinity for the fauna of the C zone. Whether ecologic conditions or redeposition are responsible for the recurrence of this fauna in zone A-2 can not be established at this time, but redeposition appears to be the more likely explanation.

Zone A-3 has been recognized in a few sections only, and is believed to have been overlapped by the superjacent Kreyenhagen formation along the western border of the San Joaquin Valley. Many of the species in this zone have been figured by Cushman and Dusenbury (Cushman, J. A. 34) from the Poway conglomerate of California. Additional species have been figured by G. D. Hanna and M. A. Hanna (Hanna, G. D. 24a) from the Eocene of Cowlitz River, Washington.

A notable change in foraminiferal assemblage occurs at the base of zone A-3. The faunas of the subjacent five zones are all closely related to each other, differing mainly in assemblage characteristics and preponderance of certain species or varieties in one zone over another, and containing a limited number of forms restricted to any one zone. This group, comprising the zones B-1A, B-1, B-2, B-3, and B-4, in descending order, bears marked affinity for the Claiborne group of the Gulf Coastal area of the southern United States, and the Tantoyuca formation (upper Eocene) of Mexico. The fauna of zone B-1A was described by Cushman and McMasters (Cushman, J. A. 36) from the upper portion of the Llajas formation. It is characterized principally by the common occurrence of *Amphimorphina californica*. In the Sacramento Valley, zone B-1A is directly underlain by a foraminiferal fauna identical to that found in the Domengine formation at its type locality north of Coalinga, California, carrying abundant *Cibicides* (*Truncatulina*) *coalingensis* which marks zone B-1.

The assemblage of foraminifera in the portion of the stratigraphic column comprising the microfaunal zones B-1, B-2, B-3, and B-4 remains rather constant. These zones may be differentiated only on the basis of a few short-range species, a gradational change in the characters of certain species, as for example *Marginulina mexicana*, and a local predominance of other forms not wholly restricted to any one zone. A considerable number of species found in this group of zones have been described by Cushman and G. D. Hanna (27a) from the Eocene near Coalinga, by G. D. Hanna (23) from the Eocene near Vacaville, by Cushman and M. A. Hanna (Cushman, J. A. 27) from the Eocene near San Diego, and by Cushman and McMasters (Cushman, J. A. 36) from the Llajas formation.

The first appearance of *Goudryina jacksonensis coalingensis*, and *Discocyclina* sp. (cf. *D. Cloptani* of Cushman and McMasters (Cushman, J. A. 36), associated with an abundance of *Cibicides coalingensis* mark the top of zone B-1. A variety of *Marginulina mexicana*, similar to the form figured by Cushman and McMasters (Cushman, J. A. 36, Pl. 74, Fig. 16) from the Llajas formation is abundant in this zone.

The first appearance of *Bulimina adamsi*, *Nonionella* cf. *frankei*, *Nonion halkyardi*, and *Marginulina truncana* mark the top of the next zone B-2. A variety of *Marginulina mexicana nudicostata*, broader in its latter portion and similar to the form figured by Cushman and McMasters (Cushman, J. A. 36, Pl. 74, Fig. 15) from the Llajas formation designated as var. B, is common in zone B-2. This form, in association with another variety of that species designated var. C, distinguished by a longer uncoiled portion and an inflated terminal chamber, is also common in zone B-3. The occurrence of *Elphidium* sp. near the top of zone B-3 was noted in many of the sections studied, while *Bulimina* cf. *inflata* was common near the bottom of that zone. *Discocyclina* cf. *clarki* is found abundant in zones B-2 and B-3, and *Marginulina subbullata* makes its first appearance in zone B-3.

Zone B-4 is characterized by the common occurrence of another variety of *Marginulina mexicana* ornamented with spines (var. D), in association with *Cibicides* cf. *martinezensis* and the first occurrences of *Marginulina mexicana* var. *alticostata*, *Pseudouvigerina* cf. *wilcoxensis*, *Siphonina* cf. *wilcoxensis*, and *Valvulineria* cf. *wilcoxensis*. Characteristic of the base of zone B-4 is the appearance of many forms ranging up from the "lower Eocene" and the Cretaceous, and the disappearance of a fauna dominated by *Marginulina mexicana* var. *nudicostata*, *Eponides guayabalensis*, *Gaudryina jacksonensis coalingensis*, and *Marginulina truncana*. A marked faunal change takes place at the base of zone B-4, as shown in figure 75.

The assemblage of the underlying zone C exhibits great diversity of species, a large proportion of which do not extend higher in the section, except in zone A-2, where they are believed to be redeposited. Many of the species of zone C have been reported from the lower Eocene (Aragon) of Mexico, from the Midway formation of Texas, from the Eocene of Cuba, and the late Cretaceous from Tabasco, Mexico. Some species of the C zone have also been figured from Martinez, California, by Cushman and Barksdale (Cushman, J. A. 30) and from the lower Kreyenhagen, by Cushman and Siegfus (39).

Characteristically common in the C zone are *Bolivina applini*, a large form of *Anomalina dorri* var. *aragonensis*, *Marginulina asperuliformis*, *Clavulina* cf. *parisiensis*, *Gyroidina* cf. *florealis*, and *Bulimina stalacta*. Associated with these are *Coleitis* cf. *reticulosus*, *Bulimina denticulata*, *Pseudouvigerina* sp. B, a species of "*Plectofrondicularia*" with two apertures, *Nodosaria* cf. *velascoensis*, *Nodosaria* cf. *pseudoobliquestriata*, *Pulvinulinella* cf. *culter*, *Amphimorphina ignota*, *Gümbelitria* sp., *Ganatosphaera alternicostata*, *Bulimina* cf. *declivis*, and *Spiroplectoides directa*.

The foraminifera which appear most characteristic of zone D include *Gümbelina* cf. *globulosa*, *Loxostomum* cf. *wilcoxensis*, *Marginulina mexicana* var. *alticostata*, *Discorbis* sp. (small form), *Bulimina excavata*, *Silicosigmoilina californica* (large form), *Lenticulina* cf. *nuda*, *Spiroplectoides clotho*, *Ammodiscus* cf. *turbinatus*, *Saccammina* cf. *rhumbleri*, *Cyclammina* cf. *pusilla*, *Glomospira charoides*, and *Cribrostaminoides* cf. *trinitatensis*. Many of the species listed in the D zone have been described from lower Eocene and Cretaceous strata.

Zone E is stratigraphically the lowest in the section, ascribed to the Eocene in California. Particularly notable in the E zone is the presence of a large number of species described from the Midway formation of Texas, the Moreno (upper Cretaceous) shale of California, the upper Cretaceous of Trinidad, and other Cretaceous localities.

The most characteristic foraminifera of the E zone are *Marginulina subaculeata* var. *tuberculata*, *Lenticulina midwayensis*, *Bulimina arkadelphiana* var. *midwayensis*, associated with *Silicosigmoilina californica*, *Spiroplectaides clotho*, *Cibicides* cf. *ungeriana* var., *Vaginulina* cf. *simondsi*, and rare occurrences of *Flabellina reticulata*. Typical for the upper portion of this zone is the occurrence of *Bulimina* cf. *exigua*, *Marginulina* (*Vaginulina*) cf. *plummerae*, and *Bolivinoides* sp. (thick cross-section). In the lower portion of the zone, *Pseudouvigerina* sp. C, a large triangular form, is abundantly present, associated with *Bolivina incrassata*, and rare *Frondicularia frankei*.

CORRELATIONS

The distribution of foraminiferal zones in 14 key sections from widely separated areas in California, presented in figures 77 to 82,[1] shows that the order of

[1] In a recent article, Robert T. White (40) has defined the Yokut sandstone as a separate formation, distinct from either the Lodo or the Domengine formations. Therefore, the Yokut should not have been included in the Lodo formation, as it is shown in figures 74 and 78.

superposition of these zones in the Eocene column remains constant. The validity of the microfaunal sequence illustrated in these figures finds confirmation in well sections studied from areas adjacent to, or intermediate between the key sections.

Further evidence of the reliability of the microfaunal sequence here described as a basis for establishing time stratigraphic units is obtained from a comparison with other remote basins of deposition, such as western Oregon, the Gulf Coastal area of the southern United States, and Mexico. Several authors who have described Eocene foraminifera from California, have pointed out the similarity between the California faunas and those collected from the areas just mentioned, where these faunas occupied a position in the local stratigraphic column similar to that assigned to them in California.

The position of the lithologic members of the Eocene succession in the various sections shows that comparable microfaunal assemblages have been found in the same stratigraphic position, irrespective of the predominating character of the sediments in which they were contained. Only coarse sandstone members which totally lacked interstratified finer sediments failed to yield a foraminiferal fauna. The foraminiferal zones have been found to transcend formational and lithologic boundaries in many localities, as for example in Vaca Valley at the top of the "Vacaville" shales, in the Simi Valley at the base of the Llajas formation, and in Coal Mine Canyon at the base of the Kreyenhagen formation. However, in most places where a faunal hiatus was recognized within a formational unit, as for example in the Kreyenhagen at Coal Mine Canyon and Oil City, in the Vacaville shale, in the Hooper well above zone B-1A, and other localities, a change in sedimentation was indicated by the presence of a glauconite bed, or a difference in the character of the underlying and the overlying sediments.

A tentative foraminiferal correlation of Eocene formations in California is presented in figure 74. The localities shown in this correlation chart have been purposely selected from the areas referred to by Clark and Vokes (Clark, B. L. 36) in their tentative correlation of Eocene marine formations on page 856 of their summary of the Eocene sequence of western North America. By this method it has been possible to correlate tentatively the foraminiferal zones of this report with the molluscan stages defined by Clark and Vokes on the basis of those sections in which a good sequence of both the molluscan stages and the foraminiferal zones could be found.

A comparison of figure 74 with the correlation chart published by Clark and Vokes shows that with the aid of foraminifera greater detail in the correlations is accomplished.

A difference between the two correlation charts may be noted in the assignment of a portion of the strata underlying the Llajas formation in Simi Valley to foraminiferal zones correlative with the Capay stage in other areas, instead of the Meganos, as shown by Clark and Vokes. An absence of mollusca in Division E of the type Meganos where these foraminiferal zones are rep-

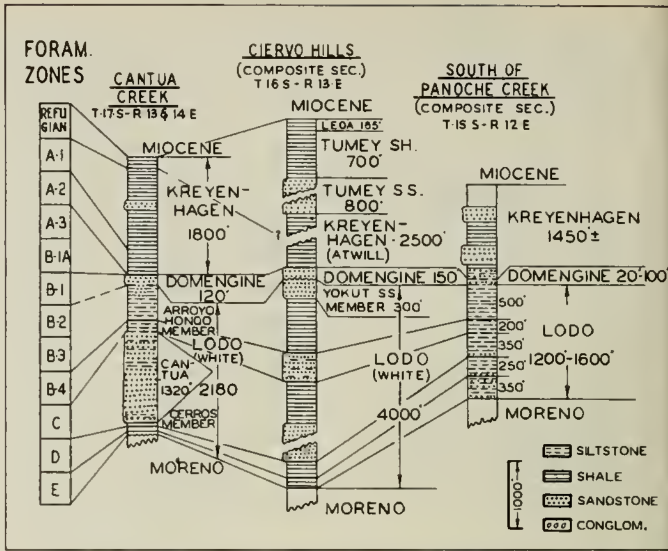


FIG. 78. Columnar correlations: Cantua Creek, Ciervo Hills, and south of Panoche Creek.

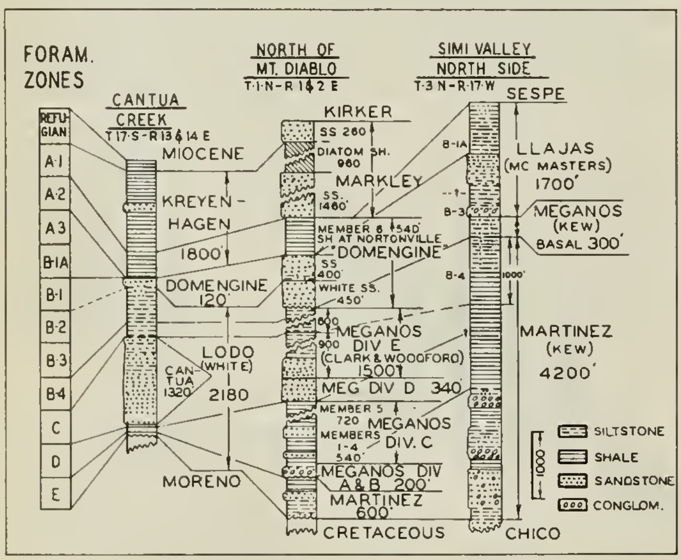


FIG. 77. Columnar correlations: Cantua Creek, north of Mt. Diablo, and Simi Valley.

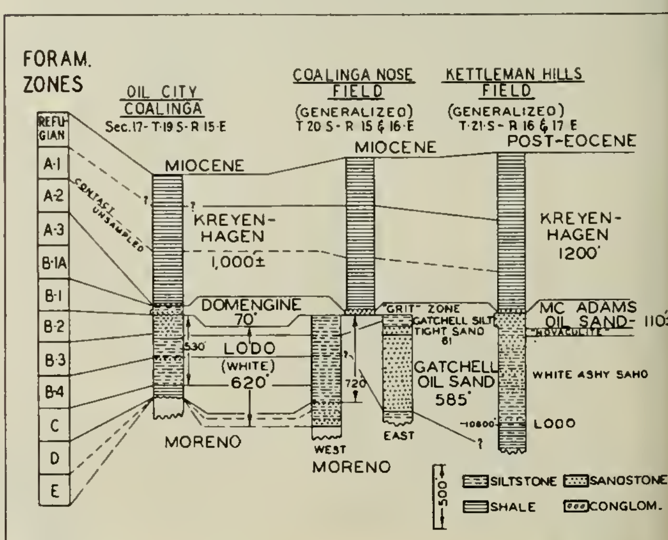


FIG. 79. Columnar correlations: Oil City Coalinga, Coalinga Nose field, and Kettleman Hills field.

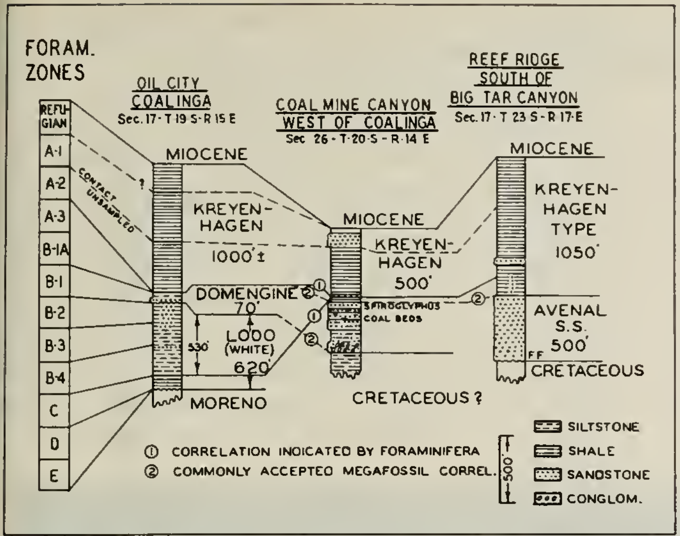


Fig. 80. Columnar correlations: Oil City Coalinga, Coal Mine Canyon west of Coalinga, and Reef Ridge south of Big Tar Canyon.

resented (figure 77) may explain the discrepancy in correlations.

A faunal hiatus marked by the absence of zones A-3 and B-1A at the base of the Kreyenhagen formation suggests an unconformity at this point in the section, in the Coalinga Nose field, at Oil City, and in the area to the north (figures 78 and 79). A marked difference in the section between the eastern producing and the western non-productive portion of the Coalinga Nose field has been observed in the underlying Lodo formation. It is accounted for by the presence of a thick body of Gatchell oil sand within zone B-3 in the eastern area. This sand body, as well as the Cantua sandstone contained within zone C in the area adjacent to Cantua Creek (figure 78) are absent in the western portion of the Coalinga Nose field.

The age assignment of the Avenal (?) sandstones at Coal Mine Canyon (figure 80), as indicated by foraminifera, differs from the commonly accepted megafaunal correlation. A glauconitic bed at the base of zone A-2 in Coal Mine Canyon directly overlies a 20-ft. member of a clay shale containing abundant foraminifera and resting on the *Spiroglyphus*-carrying sandstones assigned to the Domegine formation by Vokes (Vokes, H. E. 39). The Foraminiferal fauna found in that gray clay shale in Coal Mine Canyon is decidedly different from the fauna of the type Domengine, and is almost indistinguishable from the fauna of zone C of the present paper. At this locality the C zone appears to be in contact with zone A-2, and the entire succession represented by the zones A-3, B-1A, B-1, B-2, B-3, and B-4 is missing. While the megascopic evidence of Domengine age of these sandstones is inconclusive, the foraminifera suggest an older Eocene age for the beds directly overlying the sandstones.

The occurrence of the fauna of the C zone at the base of the Kreyenhagen formation in the Reef Ridge area implies an age older than Domengine for the underlying Avenal sandstone. However, some doubt is cast upon this correlation by the reported presence of Domengine mollusca in the Avenal sandstone, by insufficient foraminiferal evidence for dating the Avenal sandstone, and by possible redeposition of the foraminiferal fauna of the C zone into the basal gray shale member of the Kreyenhagen formation.

A microfauna characteristic of zone A-2 collected near the mouth of Grapevine Creek from the uppermost part of the Tejon shale indicates a correlation with the lower Kreyenhagen south of Panoche Creek (figure 81). This fauna is believed to overlie the fauna of zone A-3 developed in a shale section of the Tejon one-half mile east of Tecuya Creek, as shown in figure 81. However, somewhat obscure field relationships in the type Tejon area and insufficient material available from zone A-3 in other areas, leave some doubt as to the exact stratigraphic position of that zone in the upper Eocene sequence.

A section in Vaca Valley (figure 82) shows that the uppermost 150 ft. of "Vacaville" shales are sepa-

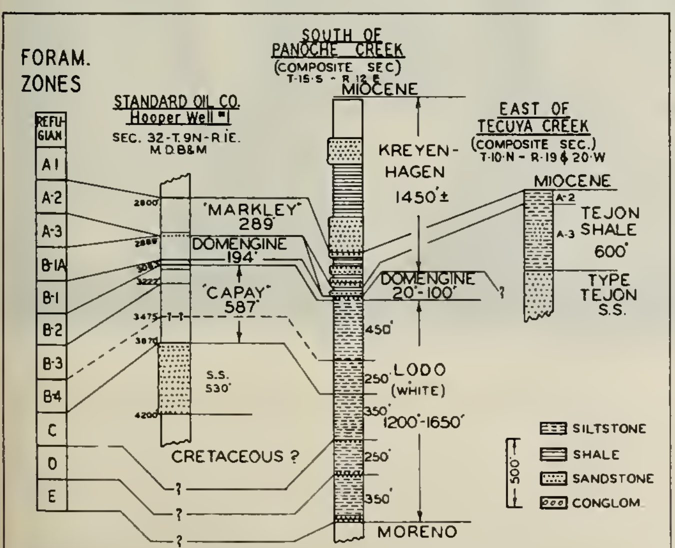


Fig. 81. Columnar correlations: Standard Oil Co. Hooper Well No. 1, south of Panoche Creek, and east of Tecuya Creek.

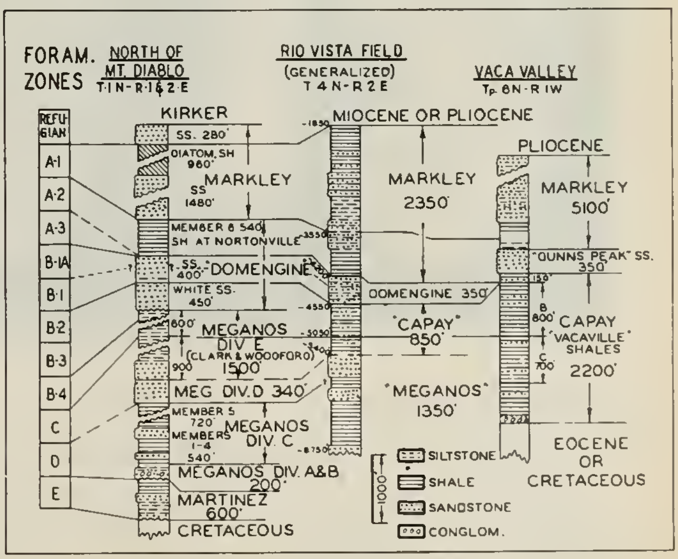


Fig. 82. Columnar correlations: north of Mt. Diablo, Rio Vista field, and Vaca Valley.

rated from the underlying succession of Eocene strata by a glauconite bed, and that a faunal hiatus exists at this point in the section in which the zones A-3, B-1A, and B-1 are missing. A microfauna assignable to zone A-2 was found both above and below the sandstone member at Dunns Peak, which overlies the "Vacaville" shales. This portion of the Vaca Valley section is correlative with Member 6 of Clark and Woodford's Domengine formation (Clark, B. L. 27) north of Mount Diablo designated by Reed and Hollister (Reed, R. D. 36) as the shale at Nortonville (figure 82).

The most profound faunal change in the entire Eocene column, between zones C and B-4, occurs within a shale member in most of the sections. An absence of diagnostic megascopic faunas in the majority of the shale members of the Eocene precluded a detailed zonation of these shale members until foraminifera furnished the missing links in the sequence. For this reason, wherever the megafaunal stage boundaries have been locally drawn to include unfossiliferous portions of lithologically similar strata, they may have to be revised with the aid of foraminiferal evidence.

The correlation tables accompanying this report present an attempt to interpret the Eocene succession in California on the basis of foraminiferal evidence, and to fit this evidence, as far as possible, into the divisions of the California Eocene established previously by means of megafossils. Some of these foraminiferal correlations will be found in disagreement with other lines of evidence, and are here presented tentatively with the primary purpose of pointing out where the discrepancies in the application of various lines of evidence for correlation do occur. Additional detailed work on the foraminifera can contribute a great deal toward a more satisfactory interpretation of the Eocene succession in California.

FIG. 83. (1 to 7). Some characteristic Eocene Foraminifera from California. *Photographed by Manley L. Natland. Plate prepared by Genevieve E. Estes.*

1. *Pseudouvigerina* sp. A, x50; a, front; b, apertural view. Middle part of Llajas fm., Loc. No. 266 in type section, NW of Las Llajas Canyon, Ventura Co.

2. *Pseudouvigerina* sp. B, x50; a, front; b, apertural view. Zone C, Eocene; Lodo fm., Loc. No. 199, SW slope 1200-ft. hill, SW¼SE¼ Sec. 8, T. 15 S., R. 12 E., M.D.

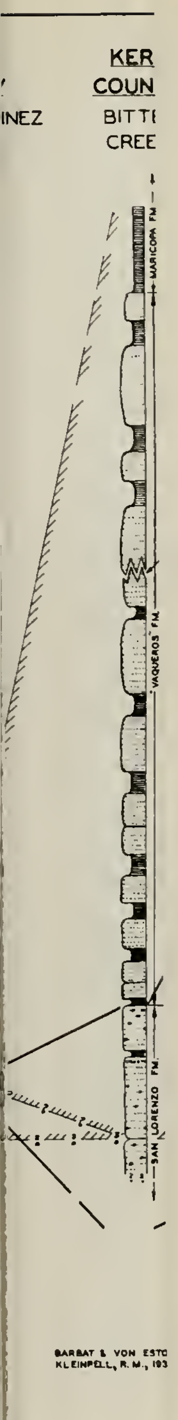
3. *Pseudouvigerina* sp. C, x50; a, front; b, apertural view. Zone E, Eocene; from Martinez fm., Loc. No. 571 in type section, 50 ft. W of E end of first large ss. cut NE of highway on N side Vine Hill, Carquinez quad.

4. *Marginulina mexicana* (Cushman) var. A, x45; a, side; b, apertural view. Zone B-1, Eocene; Oil City section, Coalinga, Loc. No. 2; 10 ft. below top of Domengine fm.

5. *Marginulina mexicana* (Cushman) var. B, x40; a, c, side; b, d, apertural view. Zone B-3, Eocene; Oil City section, Coalinga. Loc. No. 6; 190 ft. below base of Domengine fm. in Lodo fm.

6. *Marginulina mexicana* (Cushman) var. C, x35; a, side; b, apertural view. Zone B-3, Eocene; Oil City section, Coalinga, Loc. No. 12; 290 ft. below base of Domengine fm. in Lodo fm.

7. *Marginulina mexicana* (Cushman) var. D, x40; a, c, side; b, apertural view. Zone B-4, Eocene; Oil City section, Coalinga, Loc. No. 19; 430 ft. below base of Domengine fm. in Lodo fm.



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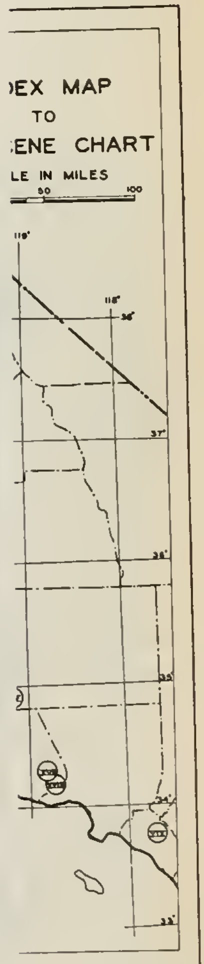

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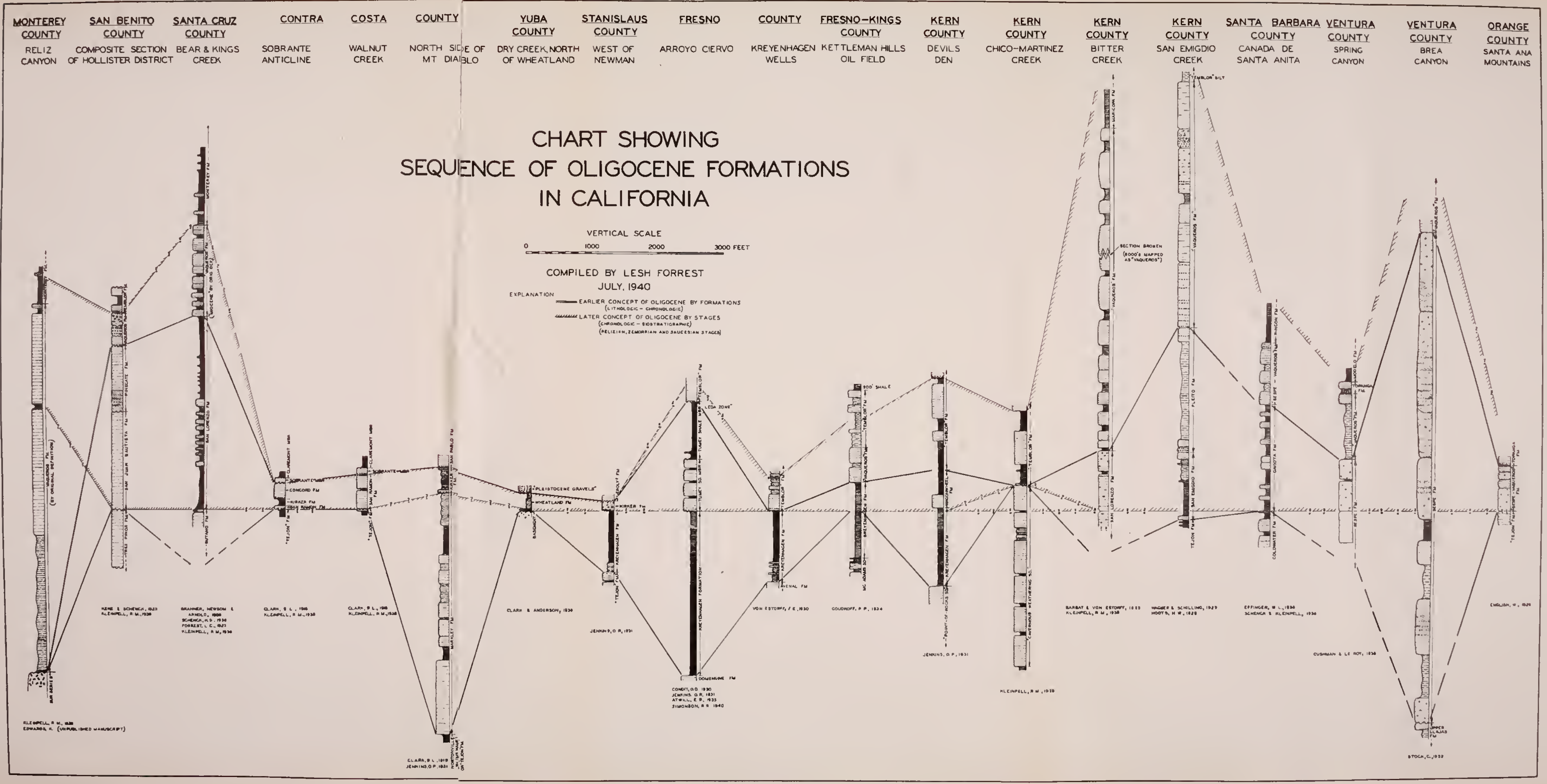
CHART SHOWING
SEQUENCE OF OLIGOCENE FORMATIONS
IN CALIFORNIA
VERTICAL SCALE
0 1000 2000 3000 FEET
COMPILED BY LESH FORREST
JULY, 1940
EXPLANATION
EARLIER CONCEPT OF OLIGOCENE BY FORMATIONS (LITHOLOGIC - CHRONOLOGIC)
LATER CONCEPT OF OLIGOCENE BY STAGES (CHRONOLOGIC - BIOSTRATIGRAPHIC) (REFUGIAN, ZEMORRIAN AND SAUCESIAN STAGES)
MONTEREY COUNTY
RELIZ CANYON
SAN BENITO COUNTY
COMPOSITE SECTION OF HOLLISTER DISTRICT
SANTA CRUZ COUNTY
BEAR & KINGS CREEK
CONTRA COSTA COUNTY
SOBRANTE ANTICLINE
WALNUT CREEK
NORTH SIDE OF MT DIABLO
YUBA COUNTY
DRY CREEK, NORTH OF WHEATLAND
STANISLAUS COUNTY
WEST OF NEWMAN
FRESNO COUNTY
ARROYO CIERVO
KREYENHAGEN WELLS
FRESNO-KINGS COUNTY
KETTLEMAN HILLS OIL FIELD
KERN COUNTY
DEVILS DEN
KERN COUNTY
CHICO-MARTINEZ CREEK
KERN COUNTY
BITTER CREEK
KERN COUNTY
SAN EMIGDIO CREEK
SANTA BARBARA COUNTY
CANADA DE SANTA ANITA
VENTURA COUNTY
SPRING CANYON
VENTURA COUNTY
BREA CANYON
ORANGE COUNTY
SANTA ANA MOUNTAINS
PLEISTOCENE GRAVELS
WHEATLAND FM
KREYENHAGEN FORMATION
SECTION BROKEN
CLARK & ANDERSON, 1938
JENKINS, O. P., 1931
VON ESTORFF, F. E., 1930
JENKINS, O. P., 1931
KLEINPELL, R. M., 1938
CUSHMAN & LE ROY, 1938
STOCK, C., 1932

SEQUENCE OF OLIGOCENE FORMATIONS OF CALIFORNIA

By Lesh C. Forrest *

OUTLINE OF REPORT

INTRODUCTION

The sequence of the middle Tertiary formations of California is exceptionally well developed in both marine and nonmarine facies, and includes a succession of invertebrate and vertebrate faunules that is one of the most complete in the world. In spite of this wealth of stratigraphic data, however, the boundaries of the Oligocene epoch (as established by various local geologists) have been particularly unstable. Indeed, many of the Oligocene formations have, at one time or another, been assigned either to the Miocene or Eocene epochs.

Since its introduction into California geological literature in 1906 (Arnold, R. 06a, pp. 15-16), the term Oligocene has been employed in a variety of ways. Schenck (35) and Kleinpell (38) have called attention to the lack of agreement among European geologists as to the precise scope of the Oligocene series at its type locality. This difference of opinion has been reflected in the variety of concepts among California stratigraphers.

CONCEPTS OF STRATIGRAPHIC CORRELATION

A study of the literature of the California Oligocene reveals two general methods employed in the classification of the middle Tertiary strata; i.e., an earlier, based on formations, and a later, based on paleontologic assemblages. The later has had the advantage, because of the intensive recent advanced studies of Foraminifera and other microfossils obtained from both surface exposures and the cores of hundreds of wells.

The earlier classification of the Oligocene (in use prior to 1935) was based largely upon a *chronologic-lithologic* conception of stratigraphic organization, which employed the following as significant criteria: (a) stratigraphic position of the formations between assumed Miocene and Eocene strata; (b) physical record of the formations, including position of unconformities, and changes in lithologic facies; and (c) faunal breaks, based largely on the study of littoral megafossiliferous facies.

One example of this type of stratigraphic procedure that may be cited is the case of the San Lorenzo formation, type Oligocene for the State. This formation was allocated to the Oligocene series on the basis of certain stratigraphic and paleontologic observations: (a) the San Lorenzo formation, in places, occurred unconformably below sandstones correlated with the ''Miocene'' Vaqueros formation; (b) limestones carrying an ''Eocene'' fauna were found some distance stratigraphically below the San Lorenzo shales; (c) the faunules of the San Lorenzo included the unique occurrence of certain deep-water molluscan species which had not been found elsewhere in either shallower-water Vaqueros (Miocene) or Tejon (Eocene) formations of the State; and (d) in general, the San Lorenzo shale fauna seemed to show an admixing of ''Eocene'' and ''Miocene'' elements.

Since 1935, however, a more stable classification has been developed, largely through the work of Schenck and Kleinpell, who have taken cognizance of the difficulty of using lithologic terminology in any chronologic classification. As their concept makes the distinction between stratigraphic and lithologic units, it has been called the *chronologic-biostratigraphic* system of stratal organization. In this method, the stratigraphic range of individual species and their association with different faunas are confirmed in as many sections of the same facies as possible. These distinctive assemblages, arranged in their correct position in the geologic column, delimit the zones and stages used in correlation. In very local areas or between separate wells in an oil field, fine-spun correlations are made by some micropaleontologists by matching the local ranges of individual species.

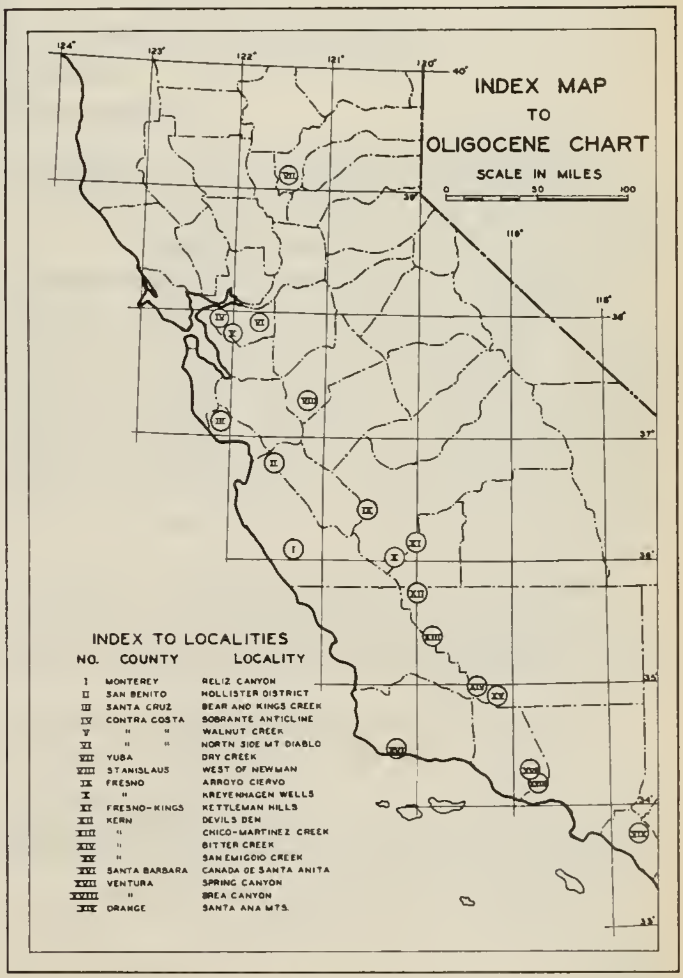

Fig. 84. Index map showing location of Oligocene sections shown on Plate III.

* Richfield Oil Corporation. Manuscript submitted for publication July 9, 1940.

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FIG. 83.

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Zone E, Ec
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4. *Margin*
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A study of the literature of the California Oligocene reveals two general methods employed in the classification of the middle Tertiary strata; i.e., an earlier, based on formations, and a later, based on paleontologic assemblages. The later has had the advantage, because of the intensive recent advanced studies of Foraminifera and other microfossils obtained from both surface exposures and the cores of hundreds of wells.

The earlier classification of the Oligocene (in use prior to 1935) was based largely upon a *chronologic-lithologic* conception of stratigraphic organization, which employed the following as significant criteria: (a) stratigraphic position of the formations between assumed Miocene and Eocene strata; (b) physical record of the formations, including position of unconformities, and changes in lithologic facies; and (c) faunal breaks, based largely on the study of littoral megafossiliferous facies.

One example of this type of stratigraphic procedure that may be cited is the case of the San Lorenzo formation, type Oligocene for the State. This formation was allocated to the Oligocene series on the basis of certain stratigraphic and paleontologic observations: (a) the San Lorenzo formation, in places, occurred unconformably below sandstones correlated with the "Miocene" Vaqueros formation; (b) limestones carrying an "Eocene" fauna were found some distance stratigraphically below the San Lorenzo shales; (c) the faunules of the San Lorenzo included the unique occurrence of certain deep-water molluscan species which had not been found elsewhere in either shallower-water Vaqueros (Miocene) or Tejon (Eocene) formations of the State; and (d) in general, the San Lorenzo shale fauna seemed to show an admixing of "Eocene" and "Miocene" elements.

Since 1935, however, a more stable classification has been developed, largely through the work of Schenck and Kleinpell, who have taken cognizance of the difficulty of using lithologic terminology in any chronologic classification. As their concept makes the distinction between stratigraphic and lithologic units, it has been called the *chronologic-biostratigraphic* system of stratal organization. In this method, the stratigraphic range of individual species and their association with different faunas are confirmed in as many sections of the same facies as possible. These distinctive assemblages, arranged in their correct position in the geologic column, delimit the zones and stages used in correlation. In very local areas or between separate wells in an oil field, fine-spun correlations are made by some micropaleontologists by matching the local ranges of individual species.

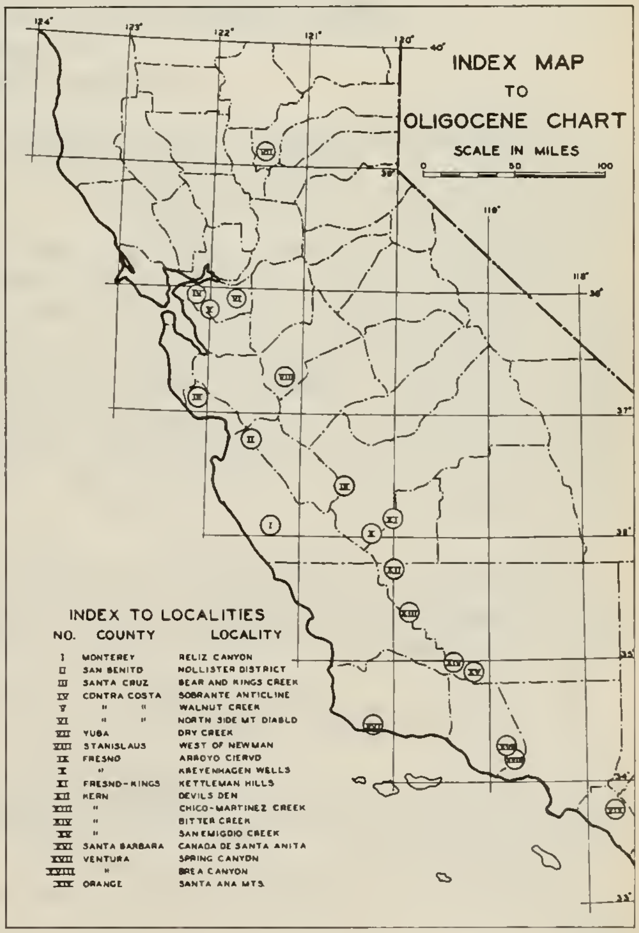


Fig. 84. Index map showing location of Oligocene sections shown on Plate III.

* Richfield Oil Corporation. Manuscript submitted for publication July 9, 1940.

This concept of stratigraphic classification permits a more stable division of the strata. Thus, even though the range of one species, or even of several species, is extended or restricted, the stratigraphic extent of the entire assemblage is affected only slightly. This is in direct contrast to the earlier lithologic-chronologic concept of stratal organization; as, for example, each time a lower occurrence of *Turritella inezana* was found, the base of the Vaqueros formation (which by the same definition is the base of the Miocene series) was lowered. Furthermore, the biostratigraphic-chronologic classification, through its system of dual nomenclature (approved in principle by the American Association of Petroleum Geologists; Ashley, G. H., et al. 39) has the advantage of allowing a stable, objective, lithologic or cartographic terminology.

EXPLANATION OF THE CHART

The accompanying chart is an attempt to focus attention on this ''ebb and flow'' of the term ''Oligocene'' as it has been used in classifying, chronologically, different formations in California. In short, the chart is a graphic attempt to show: (1) the rock sequence in representative sections throughout the State; and (2) the varying portions of these sections that have been assigned to the Oligocene system by different stratigraphers. Thus, the double lines on the chart embrace formations that have been classified as Oligocene—a usage of the term discussed above as the lithologic-chronologic concept. The strata included by the single lines with inclined hachures represent a concept of the Oligocene system that is based on a synchronization of European stages with local California stages recently established (Kleinpell, R. M. 38; Schenck, H. G. 36).

Bibliography: Ashley, G. H., et al. 39; Atwill, E. R. 35; Barbat and von Estorff 33; Branner, Newsom, and Arnold 09; Clark, B. L. 18; Clark and Anderson 38; Condit, D. D. 30; Cushman and LeRoy 38a; Effinger, W. L. 35; English, W. A. 26; Forrest, L. C. 37; Goudkoff, P. P. 34; Hoots, H. W. 30; Jenkins, O. P. 31; Kerr and Schenck 25; Kleinpell, R. M. 38; Schenck, H. G. 35a, 36a; Schenck and Kleinpell 36; Stock, C. 32; von Estorff, F. E. 30; Wagner and Schilling 23. Author also cites a paper read before the Pacific Section of the Society of Economic Paleontologists and Mineralogists April 5, 1940, "Oligocene correlations north of Coalinga," by R. R. Simonson.

CORRELATION CHART OF THE MIOCENE OF CALIFORNIA*

By ROBERT M. KLEINPELL**

Introduction by WILLIAM D. KLEINPELL***

The following stratigraphic chart, prepared by Robert M. Kleinpell, illustrates the time-stratigraphic relationships between the various subdivisions of the Miocene of central and southern California.

It depicts, in graphic form, eight stratigraphic columns, including the type sections of his six successive stages, or ''time-stratigraphic'' units, which, taken collectively, represent what he considers to be the entire sequence of rocks laid down during what is usually termed the Miocene in California. These six stages he has named, from oldest to youngest respectively, Zemorrian, Saucesian, Relizian, Luisian, Mohnian, and Delmontian. In addition, there is shown the type section of the Refugian stage, which is subjacent to the Zemorrian.

These stages are delimited largely on micropaleontological evidence, though lithologic and diastrophic evidence furnished important contributing criteria, to the end that these stages conform closely to natural geologic units.

On each of the stratigraphic columns on the chart the local formation names and member names are indicated, so that the positions they occupy with respect to the stages can be seen. The position of the various foraminiferal zones that make up the stages are also shown on the sections; while the correlation lines that unite the sections are horizons of chronologically significant faunal changes, and are thus considered to be time lines.

It has long been realized in tracing and correlating formations from place to place that the lithologic boundaries, or contacts, frequently tend to cut across the time boundaries, so that the same formation does not necessarily represent the same span of geologic time throughout its geographic extent.

Since any lithologic unit, such as a formation, is a natural geologic unit, it is ordinarily designated by the same formational or ''rock-stratigraphic'' name throughout its known extent, regardless of how its boundaries may vary from place to place in the geologic time-scale. This concept has led some authorities to advocate a ''dual stratigraphic nomenclature,'' involving, besides rock-stratigraphic terms, the use of a distinct set of terms for the names of time-stratigraphic units, known as stages.

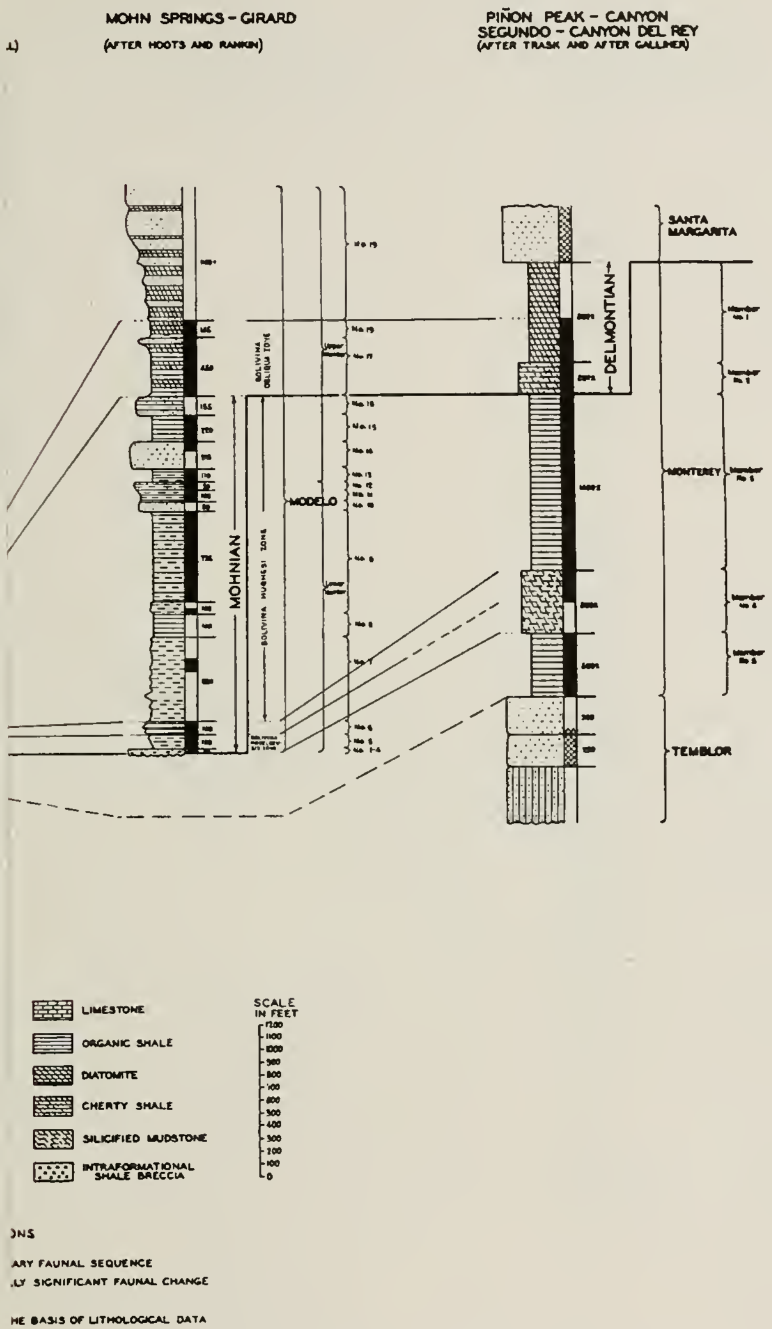
Such a dual nomenclature serves to emphasize the difference between formations, which may vary from place to place as to the time span they represent, and stages, which are represented by all the rocks formed within a certain time span, though they may vary greatly in lithology and other facies characters.

* In order to define graphically Kleinpell's stage names of the Miocene, now in general use in California, Figure 6 of "Miocene Stratigraphy of California" (1938) by R. M. Kleinpell is herein reprinted, through courtesy of its author and the American Association of Petroleum Geologists.

** Geologist, National Development Company, Manila, P. I.

*** Consulting Geologist, Bakersfield, California. Manuscript submitted for publication December 1, 1940.

PLATE IV



COLUMNAR SECTIONS
OF
MIDDLE TERTIARY STAGES AND ZONES
OF
CALIFORNIA
BY
R. M. KLEINPELL
1938

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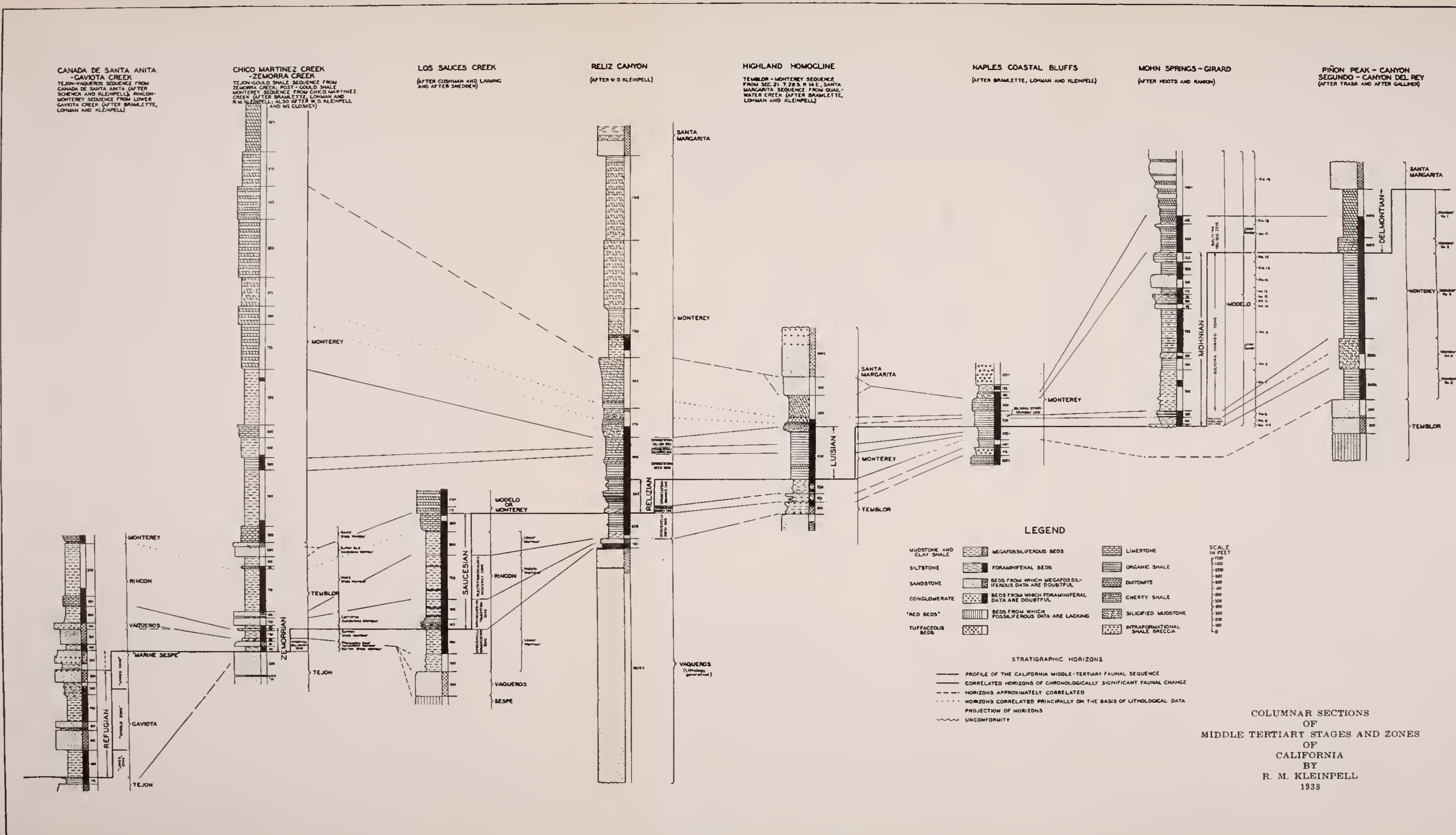

Accompanying Bulletin 118, Part Two

This chart is reproduced from figure 6 of Kleinpell, "Miocene Stratigraphy of California", American Association of Petroleum Geologists, 1938. *Courtesy of the American Association of Petroleum Geologists and R. M. Kleinpell.*

PLIOCENE CORRELATION CHART*

By U. S. Grant IV ** and Leo George Hertlein ***

The accompanying correlation chart represents an attempt to indicate the relative ages of some of the larger Pliocene stratigraphic units now commonly used by California geologists. It must be considered entirely tentative and subject to revision as more paleontologic and stratigraphic data become available. It is necessarily incomplete in that many named but less frequently used units are omitted. The vertical distances on the chart are supposed to represent units of time rather than thicknesses of sedimentary beds, though there is, of course, a rough correlation between the two. A chart of this simplified and standardized form does not lend itself readily to an accurate picturization of nature. It does not show how formations thin and thicken rapidly, interfinger with each other, and cross, obliquely, the time lines which can not be accurately determined. No accurate quantitative estimate of relative time durations is intended, but the horizontal correlations between formations are believed to represent approximate synchroneity.

The sharp lines drawn between formations and at the top and the bottom of the Pliocene are not often representative of sharp or definite breaks or limits. The boundaries of the Pliocene are generally indefinite and there is difference of opinion as to where they should be placed.

It will be noted that broken or dashed lines have been used to indicate the top and bottom of the Pliocene where formations are believed to extend across the epochal boundaries without apparent discontinuities in sedimentation. Some formations have been deliberately lumped to avoid complicating the chart with innumerable named units. For example, in the Santa Maria Basin the Schumann formation has been included in the Careaga formation which thus includes the old Schumann beds below and also the overlying marine sediments with *Dendraster ashleyi* and other fossils, formerly placed in the lower part of the non-marine Paso Robles formation. In this same basin, the Sisquoc formation, formerly considered by some field geologists to be entirely Miocene, is apparently Pliocene in part, since on the Sisquoc Ranch marine Pliocene fossils occur in a sand lens near its top. In a similar manner, the Paso Robles formation, even as restricted here, appears to extend from the Pliocene into the Pleistocene without any definite horizon at which to place the epochal boundary.

The base of the Tulare formation is considered Pliocene because of the presence in the base of the formation of *extinct genera* of non-marine Mollusca. The Lomita (and possibly part of the Timms Point), and the Santa Barbara formations are placed in the Pliocene, because of the presence in them of extinct Pliocene species such as *Pecten bellus, Pecten* (*Chlamys*) *opuntia, Terebratalia hemphilli,* etc.

The following names have been applied to lithologic units of the Pliocene of California, and are arranged by groups under geomorphic provinces. The names in parentheses have also been used for the formations listed. New names, which had not yet been formally described in literature when this report was written, have purposely been omitted. The stratigraphic position of each unit has been indicated where evidence as to its age seemed sufficient. Most of the names listed have been formally proposed as stratigraphic or petrologic units. A considerable number of names of beds and horizons have been used informally in geological and mining literature dealing with California; these terms, though they have served a convenient local use, were never intended to be employed generally, and therefore have been omitted from this list.[1]

KLAMATH MOUNTAINS PROVINCE

Name	*Age*
Crescent City beds	Upper or middle Pliocene
St. George formation	Upper or middle Pliocene

MODOC PLATEAU, CASCADE PROVINCE, AND NORTHERN COAST RANGES

Alturas formation	Upper Pliocene
Cache formation (Cache lake beds)	Upper Pliocene in part
Mark West andesite	
Petaluma formation	Upper Pliocene
St. Helena rhyolite	? Pliocene
Sonoma tuff (Sonoma group; Sonoma volcanics)	
Tolay volcanics	
Tuscan tuff (Tuscan formation)	
Wildcat formation	
Wilson Ranch beds	

COAST RANGES PROVINCE, SAN FRANCISCO REGION

Alamo formation	
Bald Peak basalt	
Berkeley group	
Contra Costa lake beds	
Green Valley formation[2]	
Grizzly Peak andesite	
Leona rhyolite	
Livermore gravel	
Merced formation	(Middle and upper Pliocene; not the uppermost part, which may be Pleistocene)
Moraga formation	
Northbrae rhyolite	
Orinda formation (Orindan formation)	Lower Pliocene
Pinole tuff	Middle Pliocene
Siesta formation (Siestan)	Middle Pliocene
Tassajara lake beds (of J.C. Cooper)	
Tassajara formation (of B.L. Clark)	

SOUTHERN COAST RANGES PROVINCE

Careaga formation	Upper Pliocene
Foxen formation	Middle and lower Pliocene
Harris Grade Pliocene	Lower Pliocene
King City formation	Lower Pliocene
Paicines formation	Upper Pliocene
Paso Robles formation	Upper Pliocene and Pleistocene
Poncho Rico formation	Pliocene (?) and Miocene
Purisima formation	Middle and lower Pliocene
Santa Clara lake beds	Upper Pliocene
Schumann formation	Middle Pliocene
Sisquoc formation (upper part)	Lower Pliocene

* Manuscript submitted for publication May 20, 1940.

** Professor, Department of Geology, University of California at Los Angeles.

*** Assistant Curator, Department of Paleontology, California Academy of Sciences, San Francisco, California.

[1] Some of these names can be found in the check list of California formation names by Gilbert Ellis Bailey (23).

[2] See Condit, C. 38, p. 248. B. L. Clark proposed the same name, apparently for the same formation, in 1940, in the program of the Geological Society of America, Cordilleran Section, Los Angeles, California, April 12, 13, 1940, p. 9. (Received at Library, California Academy of Sciences, April 8, 1940.)

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By U. S. Grant IV ** and Leo George Hertlein ***

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Petaluma formation	Upper Pliocene
St. Helena rhyolite	? Pliocene
Sonoma tuff (Sonoma group; Sonoma volcanics)	
Tolay volcanics	
Tuscan tuff (Tuscan formation)	
Wildcat formation	
Wilson Ranch beds	

COAST RANGES PROVINCE, SAN FRANCISCO REGION

Alamo formation	
Bald Peak basalt	
Berkeley group	
Contra Costa lake beds	
Green Valley formation [2]	
Grizzly Peak andesite	
Leona rhyolite	
Livermore gravel	
Merced formation	(Middle and upper Pliocene; not the uppermost part, which may be Pleistocene)
Moraga formation	
Northbrae rhyolite	
Orinda formation (Orindan formation)	Lower Pliocene
Pinole tuff	Middle Pliocene
Siesta formation (Siestan)	Middle Pliocene
Tassajara lake beds (of J.C. Cooper)	
Tassajara formation (of B.L. Clark)	

SOUTHERN COAST RANGES PROVINCE

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Paso Robles formation	Upper Pliocene and Pleistocene
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Sisquoc formation (upper part)	Lower Pliocene

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** Professor, Department of Geology, University of California at Los Angeles.

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GREAT VALLEY PROVINCE

(Includes some formations on west slope of the Sierra Nevada)

Name	*Age*
Asphalto lake bed	? Upper Pliocene
Chanac formation	Lower Pliocene
Coalinga beds	
Etchegoin formation	Middle and upper Pliocene
Jacalitos formation	Lower Pliocene
Kern River group	Pliocene and later
Kern River formation (Kern River series)	
Kettleman lake beds (older name for Tulare formation)	Upper Pliocene
Laguna formation	(?) Pliocene
McKittrick formation	Pliocene or Pleistocene
Mehrten formation	Miocene and (?) Pliocene
Nomlaki tuff member (of the Tehama and Tuscan formations)	
Rainbow beds	Miocene or Pliocene
San Joaquin formation	Upper Pliocene
Tehama formation	
Tulare formation (lower part only)	Upper Pliocene
Tuscan tuff (Tuscan formation)	

TRANSVERSE RANGES PROVINCE

Camulos formation	
Fernando group (Pliocene part)	
Gosnell shale (subsurface, part of Repetto)	Lower Pliocene
Hathaway formation	Upper Pliocene or lower Quaternary
Kalorama horizon (lower part)	
Las Posas formation	Upper Pliocene
Long Canyon member (Las Posas formation)	Upper Pliocene
Pico formation	Middle and upper Pliocene
Pipes fanglomerate	
Ridge Route formation	(?) Pliocene
Santa Ana sandstone	Upper Pliocene or lower Quaternary
Santa Barbara beds (Santa Barbara marls. *Pecten bellus* beds only.)	Upper Pliocene
Santa Maria formation	Pliocene and (?) Pleistocene
Santa Paula formation	Lower Pliocene
Saugus formation	Upper Pliocene and Pleistocene
Ventura formation (Ventura sands)	Upper Pliocene

LOS ANGELES BASIN PROVINCE

Name	*Age*
Jones sand	
La Habra conglomerate	Pliocene or lower (?) Pleistocene
Lomita formation	Upper Pliocene
Pico formation	Middle and upper Pliocene
Repetto formation	Lower Pliocene
Repetto siltstone	Lower Pliocene
San Pedro schist breccia and sandstone	(?) Pliocene
Timms Point formation	Upper Pliocene

PENINSULAR RANGES PROVINCE

Capistrano formation	(?) Pliocene or (?) upper Miocene
Eden beds	Lower Pliocene
Mt. Eden beds member	
Mt. Eden formation	
San Diego formation	Middle Pliocene
San Jacinto series	Pliocene and Pleistocene
San Mateo formation	
San Timoteo beds	Upper Pliocene
Sweitzer formation	(?) Upper Pliocene
Table Mountain formation	(?) Pliocene

MOJAVE AND COLORADO DESERTS AND BASIN RANGES PROVINCE

Avawatz formation	Lower Pliocene
Black Mountain basalt flow	Late Pliocene or Pleistocene
Carrizo formation	
Coso formation	
Coyote Mountain clays	
Imperial formation	
Indio formation (Palm Springs formation)	
Latrania sands	
Lion sandstone	
Mud Hill series	(?) In part Miocene to Pleistocene
Palm Springs formation	
Piutean series	
Red Rock Canyon beds	
Ricardo formation	Lower Pliocene
Yuha reefs	

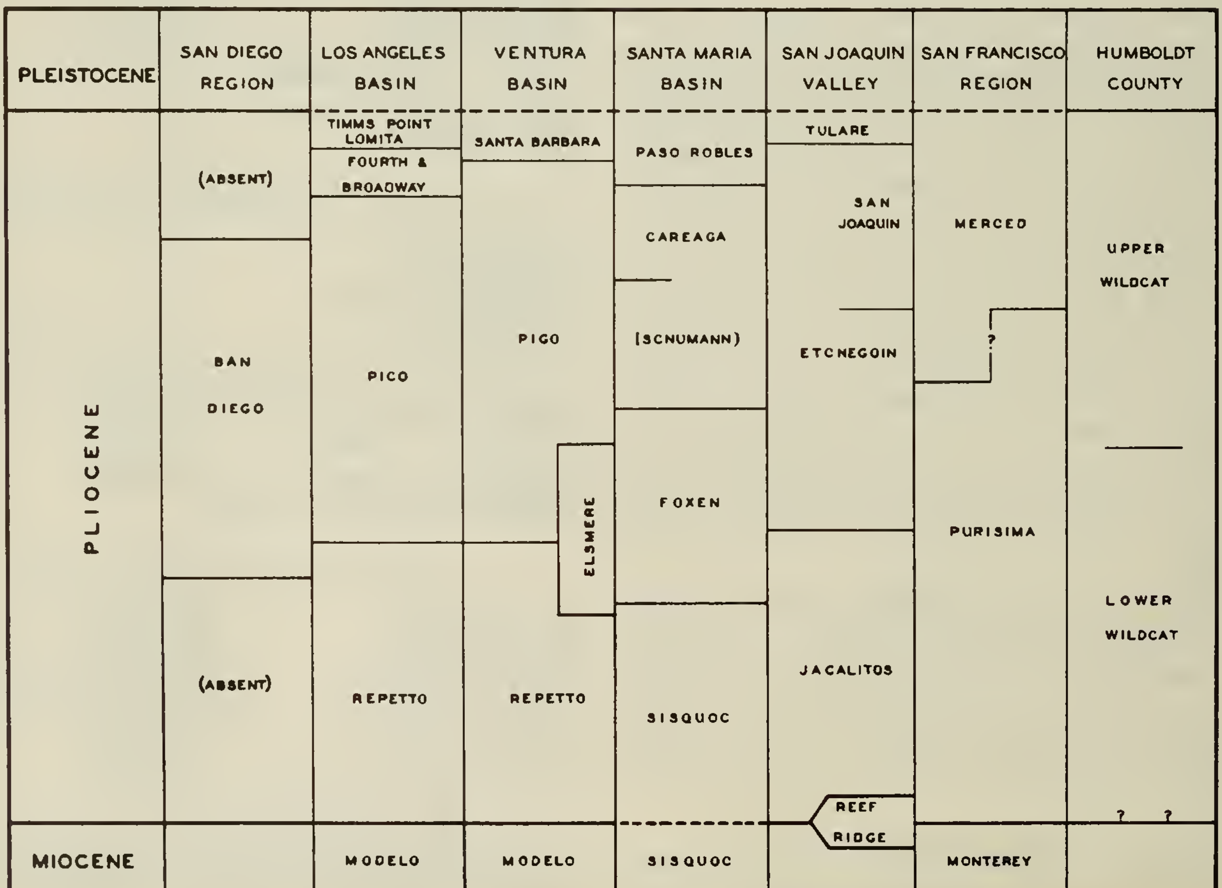

FIG. 85. Generalized correlation chart of the Pliocene.

THE PLEISTOCENE IN CALIFORNIA

By J. E. Eaton *

OUTLINE OF REPORT

INTRODUCTION

Although the Pleistocene series of California furnishes the maximum known marine record of the world for its epoch, it is relatively thin compared with most of the older series beneath it. The Pleistocene represents one of the greater revolutions of geologic time for which marine records are prevailingly sparse and fragmental on all continents.

Pleistocene sediments have many commercial uses. They comprise or immediately underlie most of the richer valley soils of the State. They have furnished the sand and gravel in many of the more available quarries. Many of the gold placer mines are in gravels of Pleistocene age. Various commercial salts in the desert region were accumulated during this geologic time.

The Pleistocene epoch of revolution is of paramount importance in California in the commercial occurrence of oil and gas. Almost without exception, the anticlines, faulted or tar-plugged homoclines, and other structures of producing oil fields of the State were formed chiefly as a result of Pleistocene diastrophism that folded, tilted, and fractured older generative and reservoir series. The great bulk of the commercial oils and gases migrated to, then accumulated and concentrated in their present traps as a result of this diastrophism. In places Pleistocene erosion has destroyed oil accumulations, while in others sediments of this age have hidden, and still hide, many potential oil fields. For these various reasons the writer considers that, as regards the finding of new oil deposits, possibly more can be learned in California from studying Pleistocene phenomena than those of any other single epoch.

BASIC PROBLEMS

The geologic record is most easily evaluated from rocks that can actually be examined. Intervals of more or less universal erosion on all continents, which involve phenomena quite as real as the rocks themselves but which are nowhere represented by visible objects, are difficult to evaluate, and provide many uncertainties leading to much difference of opinion.

This is well illustrated in California. The grandest single Cenozoic geologic phenomenon in the State is the Pleistocene revolution. During this time the older rocks were crushed, folded, thrust, and degraded thousands of feet, the remnants remaining after this process constituting the rugged mountain topography of today. Yet prior to work by Joseph Le Conte, there was little recognition of the magnitude of this feature or of the time at which it occurred. Even today some geologists attempt to correlate Pleistocene terraces only recently abandoned by the strand with adjacent highly deformed lower Pleistocene strata the eroded arches of which once extended thousands of feet higher, or assume that the Recent alluvial fan veneers of inland valleys grade conformably downward into underlying deformed lower Pleistocene strata, though almost the entire Pleistocene revolution, involving degradation over millions of years, intervened between the events. In an endeavor to illustrate the magnitude of this lost stratigraphic record occasioned by the Pleistocene revolution, in Fig. 86 the writer has drawn component events for the Pleistocene of the State roughly according to their indicated relative time relations.

Thus, the Pleistocene epoch represents a revolution dividing periods rather than a conventional stratigraphic division. If viewed 50,000,000 years hence, after its thin, meager sediments have been eroded from the continents, it would probably be referred to as a time of lost record between periods. Considering the geologic column as a whole, it seems best to consider both the Pleistocene epoch and the appendage called Recent as being an interval of revolution between the Tertiary and a period to come. Because of its nearness to us, its spectacular glacial phases, and the feature that it holds a record of primitive man, this interval has been a more fertile field for investigation and disagreement than has any other. There is at present no general agreement as to when it began, what it includes, or how it is to be divided. Before discussing what is Pleistocene in California it is therefore advisable to briefly review the history of the term, some prevailing ideas regarding what it represents, and data which may or may not ultimately modify the latter.

The Pleistocene was named by Lyell (Lyell, C. 39, appendix, pp. 616-621) in 1839. Lyell originally included deposits (other than Recent) containing marine invertebrate faunas of less than 30 percent extinction in the Pleistocene. In 1873 he (Lyell, C. 73, pp. 3-4) excluded certain older strata (his Newer Pliocene), and restricted the term to his Post-Pliocene. This restriction reduced the average extinction to 10 percent or less, the precise figure being indeterminate by reason of ecologic factors which are now known to cause the extinction in borderline horizons to vary from 3 or 4 percent at one locality to 12 percent or more in adjacent areas. As an average, strata having marine invertebrate faunas of 10 percent or less extinction are generally assigned to the Pleistocene.

In 1846 Forbes (Forbes, E. 46, pp. 402-403) inferred that the known Glacial epoch and the deposition of the Sicilian and Rhodian stratigraphic successions of Lyell were synchronic, and correlated these with one another. Lyell (Lyell, C. 73) seems to personally have had no evidence favoring such a synonymy, but he in effect acknowledged the possibility, and "to prevent confusion" advised geologists to use the term Pleistocene "as strictly synonymous with Post-Pliocene." The significance of the fact that Lyell retained the term Pleistocene in a purely stratigraphic sense, thus treating the inferred synonymy of the known Glacial and the Pleistocene as an interesting possibility yet to be proved, seems to have been generally overlooked by subsequent workers and commentators who have proceeded on the assumption that the two are synonymous.

That the known glacial stages of post-Pliocene age are included in the Pleistocene epoch follows from Lyell's definition of the epoch as being post-Pliocene and pre-Recent. On the other hand, definite evidence that any part of these known glacial stages or of the known interglacial stages is equivalent to typical marine Pleistocene strata of the Mediterranean region has not been produced, the supposed equivalency resting at present on inference.

* Consulting geologist, Los Angeles, California. Manuscript submitted for publication May 31, 1940.

Some factors suggesting the advisability of caution in such a correlation are as follows:

The known glacial stages of the Pleistocene form a descending series as regards magnitude. The earliest known glaciation was the most widespread, with subsequent glaciations decreasing progressively in intensity. Since the lower Pleistocene series of the Mediterranean region and also that at equivalent latitudes in North America reflects sustained temperate and warm-temperate climates, it is apparent that if the first known (maximum) glacial stage followed immediately upon these it must have been an exceedingly catastrophic event. The geologic record as a whole reveals that geologic phenomena tend to be cyclic; a phenomenon normally appears, rises to a maximum, and then declines to complete a cycle. The glacial series which occurred during the Pleistocene might therefore be expected to have occurred as such a cycle, rising rhythmically to a peak, and then declining over a more or less equal time. The present known glacial series exhibits an excellent example of half a cycle—the declining half. If the first known and maximum glaciation is either correlated with or placed immediately after the temperate lower Pleistocene we have an unnatural half-cycle and exclude the possibility of there having been a full, natural cycle.

The possibility, even probability, of a complete, natural cycle is to be kept in mind; that a preliminary cooling in late Pliocene and early Pleistocene times was followed by an ascending series of glacial stages the record of which has been almost or quite obliterated by the subsequent, known maximum ice sheet and ancient erosion. Such a normal cycle requires a lost interval above the temperate lower Pleistocene and below the first known and maximum ice sheet. Some inconclusive but suggestive data regarding the possibility that the required interval of lost record existed may be briefly reviewed.

In 1891 McGee (McGee, W. J. 91) recognized a major interval of erosion in the Mississippi Valley between Pliocene sediments below and the oldest known glacial stage above. He estimated (McGee, W. J. 93, p. 309) the duration of this interval at 5,000,000 to 10,000,000 years. Spencer (Spencer, J. W. 95, 03) recorded deep submarine valleys off American coasts which seemed to be related to this interval. Hilgard and Upham contributed related information and ideas. In 1899 Le Conte (Le Conte, J. 99) reviewed these data, added pertinent observations from the Sierra Nevada, and vigorously postulated a post-Pliocene and pre-Glacial lost interval of considerable duration, which, combined with the known declining glacial series, would provide a more complete cycle. Le Conte's hypothesis received attention for a few years but since his death has been almost forgotten, presumably because, due to the enormous degradation on all continents during the Pleistocene, definite correlation of the diastrophic and erosive phenomena with contemporaneous strata buried beneath the sea could not be shown. If and when a complete cycle for the Pleistocene epoch becomes established the credit for its discovery should go to Joseph Le Conte. In 1928 Eaton (Eaton, J. E. 28a) concluded from relations in California between the great interval of erosion, the subjacent marine sediments, and the known glacial series that the evidence in this State justified Le Conte's hypothesis, but here again inability to show precise relations between the known stratigraphic record of the coast and the known glacial record of the Sierra Nevada resulted in the evidence for a complete cycle within the Pleistocene being inadequate.

Whether data such as those mentioned ultimately prove to be valid or not, they show that the caution exercised by Lyell in his polite but firm insistence that Pleistocene is to be used as strictly synonymous with post-Pliocene was wise. They further illustrate the danger of concluding, as is so often done in California, that the earliest cool-temperate marine strata of the State represent the first known and maximum glaciation of the northern hemisphere. The present paper follows, as closely as possible, the conception of Lyell.

ASPECTS IN CALIFORNIA

Current geologic opinion in California regarding what stratigraphic horizon is to be taken as inaugurating the Pleistocene in the State is divided between three different views, as follows: (1) That the epoch began with the earliest cool-temperate marine invertebrate fauna in California, which occurs at the beginning of Santa Barbara (within upper Etchegoin) time; (2) That it began at the earliest horizon having no extinct fresh-water genera, which would seemingly be at some point within the Tulare; (3) That it began at an horizon, intermediate between these other two, where the percentage of extinction in the marine invertebrate fauna abruptly drops to an average of 10 percent or less coincident with the inception of an epeirogenic movement inaugurating the diastrophic revolution, which horizon is roughly the Santa Barbara-San Pedro contact in southern California, and the Etchegoin-Tulare contact in middle California.

The writer considers that the first-mentioned of these horizons is not the natural one, for the reasons that preparatory cooling in the upper Pliocene is to be expected, the first cool-temperate horizon is epeirogenically and physically an integral part of a thick, natural Pliocene unit, and the sharper, major change in fauna comes later. The second seems to have little to commend it, for it chooses the fragmental fresh-water record in preference to the basic marine record; if chosen, marine Pleistocene San Pedro of the south would apparently be represented by fresh-water Pliocene Tulare on the north. When it is considered that if an horizon having no extinct genus of terrestrial mammals were chosen as the criterion the Pliocene-Pleistocene contact could be moved upward to or even into the Recent, the inadvisability of taking other criteria in preference to the basic marine record becomes apparent.

The third interpretation is the one adopted in Fig. 86. The evidence for it is both faunal and epeirogenic, these two factors coinciding. Local ecologic conditions cause local differences, but, as an average, this horizon separates somewhat abruptly marine invertebrate faunas below it of 15 to 20 percent extinction from such faunas above having an extinction of 10 percent or less, the latter rapidly giving way upward to faunas whose extinction is almost zero. The epeirogeny which inaugurated and accompanied this faunal change is marked. Single sections are unreliable, for texture and related attributes are in large part functions of relative distances from a strand and of other qualifiers. From a regional view, however, it is remarkable how sharp and almost universal in the State was the coarsening at this horizon, which inaugurated the Pleistocene revolution in California and one of the major retreats of the sea during geologic time. In nearly all of the marine districts a Santa Barbara or allied fauna lies below, and a San Pedro or allied fauna above this contact.

Lower Pleistocene

Basal Pleistocene strata older than the typical San Pedro are seemingly present in parts of Los Angeles and Ventura basins. In view of the difficulty of regionally separating these, they are currently grouped with the coarse, temperate, overlying San Pedro. The coarse, highly deformed, and deeply degraded Signal Hill beds yielding a warm-temperate fauna are apparently younger than the San Pedro, but their precise relation to this substage is unknown. In Ventura Basin a coarse, steeply tilted, and profoundly degraded lower Pleistocene succession locally 4,350 feet thick in one homoclinal section is divided by an unconformity (Eaton, J. E. 28a, Fig. 5) into marine and brackish Hall Canyon above, and marine Barlow Ranch, San Pedro, and sub-San Pedro below. The whole rests upon 15,450 feet of marine Plio-

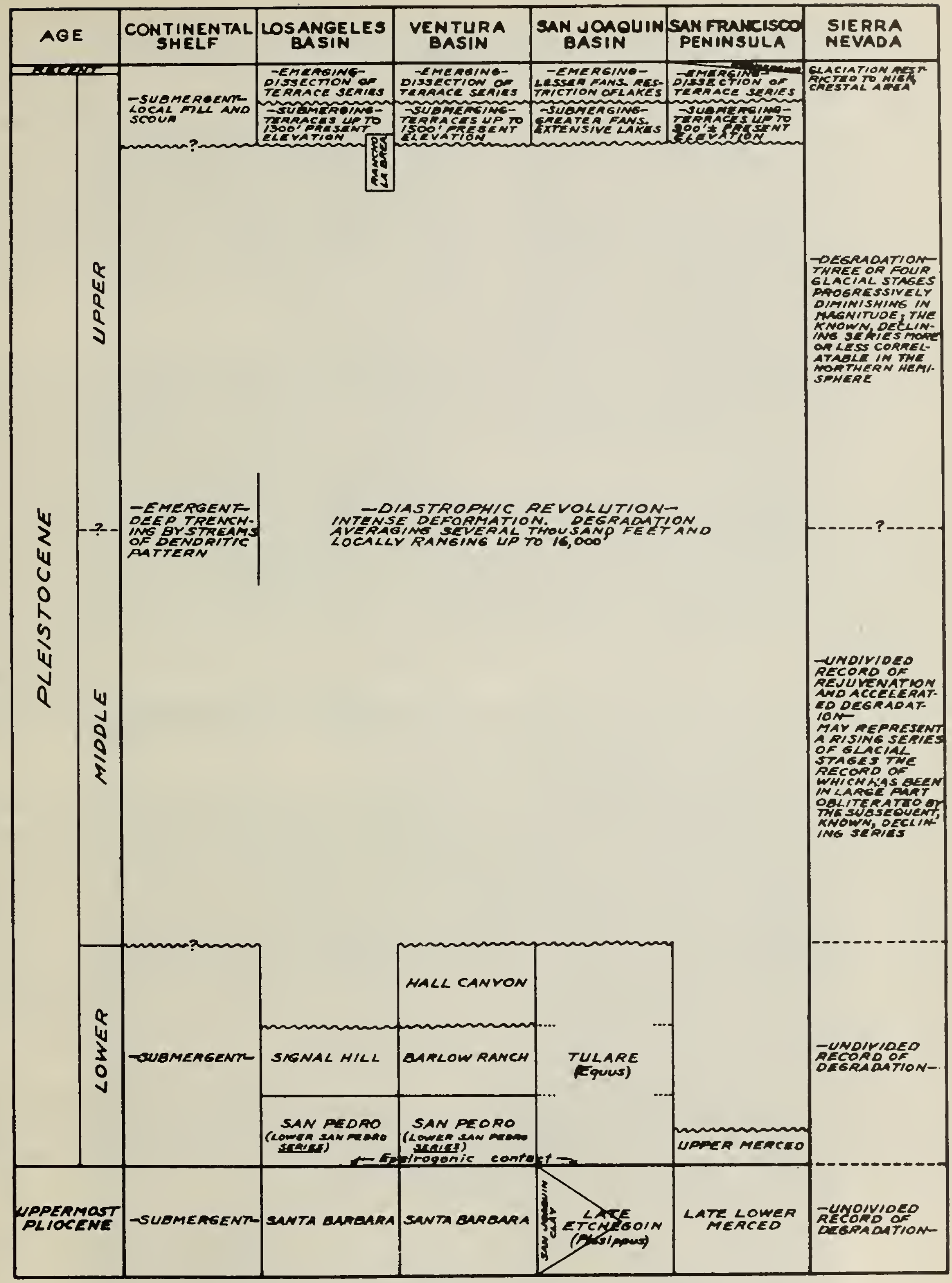

FIG. 86. Correlation chart of the Pleistocene of California.

cene, the extinction in whose uppermost portion of Santa Barbara age approximates 15 percent. The extinction in the basal Pleistocene here starts at around 10 percent and declines rapidly upward. According to a check-list published by Arnold (Arnold, R. 03, p. 55) the extinction in the Barlow Ranch fauna, which occurs a few hundred feet above the base, is but one or two percent. The typical Merced shows similar relations, the lower, thicker portion being silty Pliocene sand whose faunal extinction according to Martin (Martin, B. 16) averages 50 percent and an upper, thinner portion of lower Pleistocene sand in which Dall (Dall, W. H. 98, p. 337) states that few, if any, observed species are extinct. The upper Etchegoin, which locally contains a fine-grained lens known as the San Joaquin clay, yields an uppermost Pliocene fauna having Santa Barbara affinities. The overlying coarse Tulare, which occupies the stratigraphic position of the San Pedro, Barlow Ranch, and perhaps the Hall Canyon, is non-marine. All of the marine lower Pleistocene strata mentioned are prevailingly coarse and warm-temperate. Fine-grained facies and cool-temperate faunas, though locally present, are the exception.

Middle and Early Upper Pleistocene

At or near the inception of the middle Pleistocene the sea withdrew from California (and, judging from deep, dendritic trenching of the continental shelf, far from the State) in one of the greater recessions of geologic time. California was crushed as in an enormous vise; its strata were steeply tilted, folded, broken, and overthrust to produce the rugged scenery of today. The amount of erosion was almost incredible for a single epoch, amounting to a degradation of the State averaging several thousand feet and locally ranging up to 16,000 feet. The fact that the crests of at least two mountain ranges were degraded the maximum amount, and that the isolated Kettleman Hills within a broad, nearly bevelled plain were degraded at least 6,000 feet, reveals that the erosion was long and profound.

The Sierra Nevada block was tilted more strongly than before, causing its rejuvenated streams to deepen V-canyons several thousand feet in granite, as Le Conte has described. Three or four known glacial stages which have been correlated with the standard known glacial sequence rounded upper courses of these streams to U-canyons. Blackwelder (Blackwelder, E. 31) has shown that the oldest known glacial stage, the McGee, which he tentatively correlates with the Nebraskan, is ancient in terms of erosion. The position of this oldest of the known local glacial stages can not be precisely placed at present in relation to the coastal interval of erosion. However, the feature that the several thousand feet of coastal lower Pleistocene marine sediments which lie below the great interval of erosion are persistently temperate throughout causes the occurrence of any maximum glaciation immediately following them to appear extremely unlikely, and suggests that a lost interval approximately as long as the entire known glacial record may have elapsed between the deposition of these sediments and the maximum ice sheet. Whatever the actual relations between the record of the Sierra Nevada and that of the coastal region may be, in the latter we are dealing with titanic events in definite superposition for which the rest of the world, lacking so full a basic marine record, has no comparable known yardstick. As Lawson (Lawson, A. C. 93a, p. 128) has said: "The recency of the record, the vastness of the events, the precision with which they may be established, all contribute to make it the most fascinating as well as perhaps the most important chapter of our local geologic history."

Late Upper Pleistocene

In late upper Pleistocene time the sea returned, reoccupying the continental shelf and parts of coastal California, as is shown by nearly horizontal marine terraces extending up to about 1,500 feet, present elevation. Terraces of this latter height are known only from Ventura Basin, a hinge point, the maximum elevation of terraces decreasing north and south along the coast from this hinge. These late terraces rest upon the truncated edges of steeply dipping lower Pleistocene and older strata, the great interval of diastrophism and erosion intervening between. They yield a fauna that so closely resembles a fauna from similar facies of the deformed lower Pleistocene upon which they rest that ofttimes only their nearly horizontal attitude upon truncated edges of the older, steeply dipping strata allows the two to be differentiated. Late uplift of the State of 1,000 to 1,500 feet to its present elevation has caused streams to dissect these terraces, but in protected positions their almost uneroded surfaces testify to their late origin.

Along coasts of eastern North America and those of Europe the older of similar terraces are commonly assigned to positions far back in the Pleistocene, and are correlated with glaciations. Various geologists coming to California from these regions have endeavored to make each of the dozen or more late marine terraces of the State correspond with a glacial or interglacial stage. Yet the whole of the terrace series can represent only the last few percent of Pleistocene time, for the shallow ravines excavated in these terraces, leaving the surfaces between almost untouched, are negligible compared to the total degradation during Pleistocene time which degraded the State bodily an average of several thousand feet.

The Pleistocene record of California, which except for work on glacial phases in the high Sierras is almost unexamined, has possibilities of yielding data regarding the Pleistocene sequence as a whole whose record is elsewhere obscure.

FIG. 87A. Aerial view of outcropping Tertiary strata dipping east. Cretaceous rocks exposed in the distance, upper left corner. Location: Kreyenhagen Hills, west of Kettleman Hills. *Photograph (0-2336) by courtesy of the Fairchild Aerial Surveys, Inc.*

FIG. 87B. Aerial view northeastward across the Los Angeles Basin, showing Santa Fe Springs oil field in the foreground and the San Gabriel Mountains and part of the Transverse Ranges in the distance. *Photograph (0-3319) by courtesy of the Fairchild Aerial Surveys, Inc.*

Chapter VII

Occurrence of Oil

CONTENTS OF CHAPTER VII

STRATIGRAPHIC FORMATIONS OF THE PRODUCING ZONES OF THE LOS ANGELES BASIN OIL FIELDS

By Stanley G. Wissler*

OUTLINE OF REPORT

INTRODUCTION

For the past 15 years the author has been engaged in paleontologic studies of the foraminifers found in core samples from Los Angeles Basin oil wells. More than 200,000 core samples have been collected and examined. From these it has been possible to determine the foraminiferal succession from middle Miocene time well up into the Pleistocene. The stratigraphic column has been divided by means of index foraminifers, that is, by species which were found to have a limited vertical range, into a number of major subdivisions—five for the upper Miocene and seven for the Pliocene. Many smaller subdivisions have been made, based upon intermittent occurrences or marked changes in abundance of long-ranging species together with variations in the general faunal assemblages. The thicker of these have been designated foram zones or zonules and the thinner, subzones or subzonules. Still others have been termed foram marker horizons. Many of these subzones and marker horizons are 10 feet or less in thickness. Experience has demonstrated that the majority of these minor faunal horizons, as well as the major faunal zones and subdivisions, can be traced laterally over the greater part of the Los Angeles Basin. The Foraminifera, therefore, offer a feasible basis for reliable inter-field as well as intra-field oil well correlation.

With such a means of correlation readily available, the author has, for a number of years, been making a detailed stratigraphic study of the main oil producing horizons of the Los Angeles Basin. From some fields, thousands of core samples representing the majority of the producing wells have been studied. From others, samples of fewer wells were available. Yet for each field here considered it has been practicable to assemble a virtually continuous composite set of core samples for the entire producing interval. A number of these cored sections, augmented by drill cuttings, reach nearly to the surface. Others extend well up into the upper Pliocene. In a few local areas, especially in one or two of the eastern fields, individual stratigraphic intervals are sometimes nearly devoid of characteristic species. However, in general, it has been possible to determine the stratigraphic relationships of all of the producing zones with a considerable degree of accuracy. Unfortunately, it is impracticable, within the scope of this paper, to present the basis for all of the correlations or all of the stratigraphic data at hand. The more significant of these stratigraphic relations are summarized in this paper and presented graphically on the accompanying straight line correlation chart of the Los Angeles Basin oil fields (Plate V). More detailed lithologic variations within the upper Miocene and lower Pliocene are illustrated by several supplementary charts and tables.

ACKNOWLEDGMENTS

The writer wishes to thank E. B. Noble, Chief Geologist, and A. C. Rubel, Vice President, of the Union Oil Company of California for their permission to publish this paper and the accompanying charts. He is greatly indebted to all of his immediate colleagues in the Union Oil Company without whose assistance in the accumulation of data the preparation of this paper and these charts would have been impossible. Special mention should be made of Bradford C. Jones for his paleontologic work on the upper Miocene of the Basin; of A. T. Lee for his extensive studies of the Montebello and the East Coyote areas; of F. D. Crawford for his invaluable assistance in the preparation of the straight line correlation chart and paper; and of I. E. Silverman for drafting and aid in arrangement of the charts and sections. Dr. P. D. Trask has made helpful suggestions in regard to the arrangement and content of the paper.

GENERAL FEATURES OF THE LOS ANGELES BASIN OIL FIELDS

The term Los Angeles Basin is a local one commonly employed to designate a nearly level lowland area along the coast of southern California in the vicinity of the city of Los Angeles. This plain, which is approximately 22 miles wide and 46 miles long, possesses many of the topographic features of a basin. It is bounded on the north by the Santa Monica Mountains and by a line of hills extending southeastward to the Santa Ana Mountains; on the east by the foothills of the Santa Ana

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TABLE No. 1. GEOLOGIC FORMATIONS ENCOUNTERED IN LOS ANGELES BASIN OIL FIELDS

AGE	STAGE	FORAMINIFERAL DIVISION	FORMATION		LITHOLOGIC DESCRIPTION	THICKNESS	DISTRIBUTION
RECENT			ALLUVIUM		Buff sand, clay, and gravel	0 TO 100	Windblown sand in the El Segundo-Torrance area and brackish water deposits at Wilmington and Seal Beach
			LOCAL UNCONFORMITY				
UPPER PLEISTOCENE			TERRACE DEPOSITS. INCLUDE MARINE PALOS VERDES AND CONTINENTAL LA HABRA		Yellow brown and reddish clays, silts, sands, gravels, and conglomerates	0 TO 600	Generally present in west side fields as marine Palos Verdes and in east side fields as continental La Habra
			LOCAL UNCONFORMITY				
LOWER PLEISTOCENE		ELPHIDIUM CRISPUM	SAN PEDRO, TIMMS POINT AND LOMITA		Bluish gray sands, gravels, clays, and silts	0 TO 500	Generally present in west side fields Generally present on flanks of east side fields
			LOCAL UNCONFORMITY				
UPPER PLIOCENE		UVIGERINA AFF TENUISTRIATA CIBICIDES MCKANNAI GYROIDINA ALTIFORMIS	PICO	UPPER	Light olive gray to grayish olive and olive brown soft, massive claystone and siltstone fine to coarse gray sand	800 TO 1490	Present in all main fields
				LOCAL UNCONFORMITY			
UPPER PLIOCENE		UVIGERINA PEREGRINA	PICO	MIDDLE	Gray olive to dark olive brown soft, massive to well bedded claystone and siltstone, fine to coarse grey sand Thin streaks of soft, laminated platy shale occasionally present	0 TO 1350	West side Present in all fields East side Present at Santa Fe Springs and West Coyote
				LOCAL UNCONFORMITY			
UPPER PLIOCENE		BULIMINA SUBACUMINATA	PICO	LOWER	Fine to coarse, occasionally pebbly, gray sand olive brown to hair brown sandy siltstone and claystone	0 TO 540	West side Present in all fields except Torrance and Wilmington East side Present in all fields except Richfield
LOWER PLIOCENE		PLECTOFRONDICULARIA CALIFORNICA CIBICIDES MCKANNAI	REPETTO	UPPER	Fine to coarse, occasionally pebbly gray sand olive brown to hair brown sandy siltstone and claystone	200 TO 2040	Present in all main fields
LOWER PLIOCENE		KARRERIELLA MILLERI	REPETTO	MIDDLE	Fine to coarse, occasionally pebbly gray sand hair brown to dark hair brown sandy siltstone and claystone	500 TO 2540	Present in all main fields
				LOCAL UNCONFORMITY			
LOWER PLIOCENE		LIEBUSELLA PLIOCENICA	REPETTO	LOWER	Dark hair brown* to chaetura drab sandy siltstone and claystone fine to coarse, occasionally pebbly, gray sand	0 TO 1080	Present in all main fields except Richfield, Whittier, and Yorba Linda
			LOCAL UNCONFORMITY				
UPPER MIOCENE	DELMONTIAN	ROTALIA GARVEYENSIS	PUENTE	DIVISION A	Dark chaetura drab* and olive brown sandy micaceous siltstone and banded, platy shale fine to coarse gray sand with occasional conglomerates	430 TO 2690	Present in all main fields Present as Sycamore Canyon formation north of the Whittier fault zone
				LOCAL UNCONFORMITY			
UPPER MIOCENE	DELMONTIAN	BULIMINA SP (LG CRUSHED)	PUENTE	DIVISION B	Fine to medium compact gray sand dark chaetura drab shale with a few beds of platy and semiplaty shale	0 TO 1370	Present in all fields except Playa del Rey, Inglewood, and probably El Segundo
UPPER MIOCENE	DELMONTIAN	BULIMINA SP (LG CRUSHED) GYROIDINA ROTUNDIMARGO	PUENTE	DIVISION C	Bluish gray and dark brown platy laminated shale chaetura drab massive sandy claystone, and fine to medium sand	0 TO 1400	Present in all fields except Playa del Rey, Inglewood, and possibly Potrero
UPPER MIOCENE	MOHNIAN (UPPER)	BOLIVINA HUGHESI	PUENTE	DIVISION D	Bluish gray and dark brown hard banded platy shale semiplaty and massive dark chaetura drab shale and fine to medium silty sand The lower part is mainly dark chaetura drab to black, platy and semiplaty shale interbedded with fine to coarse sands Phosphatic layers and nodules are occasionally present On the east side lower D is middle Puente sandstone	0 TO 3020	Present or not reached in all fields Absent on crest of structure at El Segundo
				LOCAL UNCONFORMITY			
UPPER MIOCENE	MOHNIAN (LOWER)	BULIMINA UVIGERINAFORMIS BAGGINA CALIFORNICA	PUENTE	DIVISION E	West side fields Black and tan, oily, organic, phosphatic shale, sand and schist bearing conglomerate East side fields Hard, dense, massive to platy shale with occasional sand layers	18 TO 1300	West side Present or not reached in all fields East side Present at Richfield, elsewhere not reached
			LOCAL UNCONFORMITY				
MIDDLE MIOCENE	LUISIAN	VALVULINERIA CALIFORNICA	MONTEREY	DIVISION F	Dark grayish brown hard semiplaty silty shale and medium and coarse pebbly sandstone Volcanic tuff is present at Inglewood	0 TO 400+	West side Present at Wilmington and Inglewood, other fields? East side Absent at Richfield, other fields?
			LOCAL UNCONFORMITY				
MIDDLE MIOCENE	RELIZIAN		TOPANGA		Medium to coarse hard whitish and greenish sandstone and dense hard dark brown shale	0 TO 1700	West side Absent in the Playa del Rey-Wilmington fields, present at Huntington Beach, other fields? East side Present at Richfield other fields?
LOWER MIOCENE	SAUCESIAN		VAQUEROS (?)		Fine to coarse and conglomeratic greenish sand with streaks of green and red shale	0 150	West side Presumably absent East side Present at Richfield, other fields?
LOWER MIOCENE	ZEMORRIAN		SESPE		Red and green fine to coarse sand, claystone, and sandy claystone fine to coarse gray sand	0 TO 1210+	West side Absent East side Present at Richfield other fields?
OLIGOCENE	REFUGIAN						
			LOCAL UNCONFORMITY				
EOCENE			TEJON & MARTINEZ				West side Absent East side Probably present at Richfield Outcrops in the Santa Ana Mountains
CRETACEOUS			CHICO & TRABUCO				West side Absent East side Presumably absent Outcrops in the Santa Ana Mountains
			LOCAL UNCONFORMITY				
JURASSIC			FRANCISCAN		Greenish, grayish, or bluish serpentine, talc, or glaucophane schist	?	West side Basement rock of Playa del Rey-Wilmington fields, probably underlies at least some of the Inglewood-Newport fields East side Absent

* Hair brown and chaetura drab are terms adopted from Robert Ridgway ("Color Standards and Color Nomenclature") to designate certain shades of brown common to Pliocene and Miocene shales of the Los Angeles Basin

Mountains; and on the south and west by the San Joaquin Hills, the Pacific Ocean, and the Palos Verdes Hills. The region assumed its present form in late Quaternary time as evidenced by the steeply tilted marine lower Pleistocene strata in the surrounding hills. Previously it was a locus of deposition for many thousands of feet of upper Miocene and Pliocene sediments. These sediments consisting of sand and shale are the reservoir and source rock of one of the most prolific oil producing districts of the State.

The oil fields of the Los Angeles Basin are all within a radius of 30 miles of the city of Los Angeles. Structurally the more important fields are primarily anticlinal. Some of the less important marginal fields, such as Whittier, Brea-Olinda, and those of the Los Angeles city area are faulted monoclines. The anticlinal fields range from simple domes, such as Santa Fe Springs, to complicated faulted structures such as Dominguez, Rosecrans, Seal Beach, and Wilmington. In some fields the faulting is simple. In others differential horizontal movement has resulted in a complex series of normal and thrust faults.

As may be seen from the insert map on Plate V, the more important fields are arranged somewhat en echelon along four general lines of deformation. From west to east these structural trends are the Playa del Rey-Wilmington line with five fields; the Inglewood-Newport uplift with nine fields; the Santa Fe Springs-Richfield line, frequently called the Coyote Hills uplift, with six fields; and the Montebello-Brea-Olinda line with five fields. The two western trends, the Playa del Rey-Wilmington line and the Inglewood-Newport uplift, parallel the coast. North of Wilmington they are separated from one another by the El Segundo Plain, a synclinal area from 3 to 4 miles in width. A similar broad synclinal area, some 10 to 14 miles in width, known as the Downey Plain, occupies the nonproductive region between the Inglewood-Newport and the Coyote Hills uplifts. A third synclinal area 3 to 4 miles wide lies between the Coyote Hills uplift and the eastern marginal fields, Montebello, Whittier, and Brea-Olinda. Individual fields of each line are separated by nonproductive saddle-like areas. To the southeast the Playa del Rey-Wilmington line appears to converge with the Inglewood-Newport uplift in the Huntington Beach field. In like manner the two eastern structural trends converge to the southeast.

Topographically the Basin fields range from prominent elongated hills to inconspicuous tidal flats. None of the fields of the Playa del Rey-Wilmington line exhibit marked topographic expression. Wilmington and Playa del Rey were tidal flats and swamp lands until filled in by off-shore dredging operations. Torrance and El Segundo are characterized by low sand hills. Inglewood near the north end of the Inglewood-Newport line is located in the Baldwin Hills. These hills, which protrude about 300 feet above the level of the surrounding plain, are topographically one of the most noticeable features of the Basin. The Signal Hill area of the Long Beach field, with a surface elevation of 364 feet, is likewise very prominent. Dominguez is a fairly conspicuous feature, rising approximately 150 feet above the surrounding alluvial plain; on the other hand, the Athens-Rosecrans area to the north is relatively inconspicuous. Seal Beach and Huntington Beach are in part covered by tideland swamps and in part marked by low mesa-like areas standing from 50 to 150 feet above sea level. Santa Fe Springs, at the western end of the Coyote Hills uplift, has a surface relief of approximately 25 feet. West Coyote and East Coyote, on the other hand, are located along a prominent anticlinal ridge extending some 500 feet above the Downey Plain. East Coyote consists of two separate domes, the Hualde on the west and the Anaheim on the east. Of these the Hualde is the more pronounced as the Anaheim dome disappears beneath Quaternary alluvium toward the east. Richfield, like Santa Fe Springs, has little surface expression. The marginal fields, Montebello, Whittier, and Brea-Olinda, are located along the edge of the hills forming the northeastern boundary of the Basin.

STRATIGRAPHY

The rocks penetrated by wells of the Los Angeles Basin oil fields range in age from Recent alluvium to weathered and fractured Jurassic schist of the Franciscan formation. The Franciscan serves as the basement rock for the area west of the Inglewood-Newport uplift. It has been reached by numerous wells in fields of the Playa del Rey-Wilmington line and undoubtedly underlies some of the fields along the Inglewood-Newport uplift. The oldest Tertiary rocks encountered to date are at Richfield. Here a deep test penetrated some 1,200 feet of nonmarine Sespe red beds of Oligocene (?) age overlain by approximately 150 feet of Vaqueros sand of the lower Saucesian stage of the lower Miocene. Resting upon this Vaqueros is 975 feet of Topanga sand and shale representing the upper Saucesian stage of the lower Miocene and the Relizian stage of the middle Miocene. Some 1,700 feet of nearly unfossiliferous sands and shales believed to be Topanga have been reported from a deep well in the Huntington Beach field. Approximately 130 feet of middle Miocene sand and shale of the Luisian stage rests unconformably upon the Franciscan schist at Wilmington; and 400 feet of Luisian sediments have been penetrated in a deep test at Inglewood. Deep wells of the other producing fields have bottomed in the Puente formation of the upper Miocene. In the majority of the fields the Puente is conformably overlain by lower Pliocene sands and shales of the Repetto formation. Upper Pliocene sediments of the Pico formation usually rest conformably upon the Repetto. As a rule, Quaternary gravels, sands, and clays rest unconformably upon the Pico.

For the sake of convenience in discussing the subsurface section, the stratigraphic sequence of the Basin fields will be considered in detail from the surface down. The geologic formations are summarized in Table No. 1.

PLEISTOCENE

Wells drilled in the western fields of the Basin generally start in late Pleistocene marine terrace deposits of the Palos Verdes formation. While samples from this formation are available for only a few of the fields, data at hand indicate that the Palos Verdes consists of yellow-brown silts, sands, clays, and gravels, ranging in thickness up to 400 feet. No Foraminifera have been found in these sediments, but a few occurrences of megafossils have been noted in outcrops along the Inglewood-Newport uplift. Mollusca from exposures in the Long Beach field were described by Arnold (03, pp. 30-31) and correlated with his type upper San Pedro which was subsequently renamed the Palos Verdes formation (W.S.W. Kew *in* Tieje 26, p. 502) of upper Pleistocene age.

Other buff to reddish-brown sands, silts, and conglomerates, chiefly non-marine in origin, but apparently equivalent in age to the Palos Verdes deposits of the western fields, unconformably overlie lower Pleistocene and upper Pliocene sediments in the Repetto-La Merced Hills area at the north-central margin of the Basin. These upper Pleistocene sediments range in thickness from 0 to nearly 500 feet along the southern flank of the Montebello oil field and attain a maximum thickness of approximately 1,700 feet in the Repetto Hills east of Garfield Avenue. A similar unfossiliferous buff silt and reddish-brown gravel series is exposed over the major portion of the East and West Coyote oil fields where it ranges in thickness from 0 to 500 feet, and along the southern flank of the Puente Hills where it attains a maximum thickness of 1,350 feet near the Whittier field. This conglomerate series, known locally as the La Habra conglomerate, has been referred to the lower Pleistocene by Eckis (34, p. 49). Since it is now known that these La Habra sediments unconformably overlap onto fossiliferous strata of lower Pleistocene as well as upper Pliocene age, the La Habra series is considered in this paper as the correlative of the Palos Verdes formation of the western part of the Basin.

Fossiliferous bluish-gray sands, gravels, clays, and silts of the San Pedro formation of lower Pleistocene age unconformably underlie the upper Pleistocene sediments in most of the Basin fields. A lignitic deposit containing abundant carbonized fragments and bark of redwood and other plant debris is frequently encountered at the top of the San Pedro. The first Foraminifera generally appear in the clays and silts immediately below this lignitic deposit, and Mollusca become abundant in the underlying sand and gravel. The lignitic zone and underlying megafossil horizon occur 275 to 300 feet below the surface in the Wilmington area. They are underlain by approximately 400 feet of fossiliferous sand and gravel. San Pedro drill cuttings and core samples were available for study from the central fields of the Inglewood-Newport uplift. In the Rosecrans-Dominguez area abundant San Pedro megafossils occur just below the lignitic zone and 15 to 40 feet below the base of the Palos Verdes. Beneath this megafossil horizon is a 300-400 foot interval of fossiliferous gravel. The Long Beach section consists of approximately 75 feet of foraminiferal silt underlain by 280 feet of fossiliferous gravel. Approximately 200 feet of marine Pleistocene is exposed in a quarry near the northwest end of the Baldwin Hills. From 80 to 200 feet of these Pleistocene strata are encountered in wells of the Inglewood field.

In the Seal Beach area, approximately 500 feet of Pleistocene sands and clays have been cored in prospect holes. The foraminifers and megafossils occurring near the base of the Seal Beach Pleistocene are of Timms Point age. This Timms Point fauna has not been found in the Long Beach, Dominguez, or Rosecrans fields. It is assumed, therefore, that in these other fields the San Pedro rests unconformably upon the upper Pico.

PLIOCENE

Beneath the Pleistocene of the Los Angeles Basin is a 2,000-7,000 foot section of marine Pliocene rocks consisting of a monotonous series of alternating units of sands, sandy shales, clay shales, and siltstones ranging in thickness from a fraction of an inch to several hundred feet. The shales and siltstones grade imperceptibly in color from light grayish olive in the upper Pliocene to dark brown in the lower. Trask (Trask and Hammar 35, p. 122; Trask and Patnode 37b, p. 376) has found that this color gradation is accompanied by a gradual corresponding increase in the quantity of organic matter present. Foraminiferal remains are abundant throughout the shaly portions of the section, and, in some instances, megafossils are present, but nowhere in sufficient abundance to be of material assistance in making detailed correlations. It is difficult, therefore, to definitely subdivide these Pliocene sediments except on the basis of their microfaunal content.

The classification of the Los Angeles Basin Pliocene rocks has had a varied history. Outcrops along the northern boundary of the Basin were originally mapped as Fernando by Eldridge and Arnold (07, p. 22). Kew (24, pp. 69-70) raised the Fernando to group rank and included in it his newly defined Pico formation and Hershey's Saugus formation. After the publication of Kew's bulletin, geologists generally assigned the Los Angeles Basin Pliocene to the Pico formation. Shortly after the start of micropaleontological work in southern California, paleontologists recognized two major foraminiferal faunal assemblages within the subsurface section of the Pliocene. These were variously referred to as upper and lower Pliocene, upper and lower Fernando, or upper and lower Pico. As drilling proceeded and more subsurface data were made available, it became apparent that the upper Pliocene could be still further subdivided into three major faunal units. Since the lowest of these had some of the characteristics of a transition fauna, it was usually referred to as the upper-lower Pico transition zone, or simply the Pico transition zone. The two highest upper Pliocene faunal units were assigned to the upper Pico by some, and by others to the upper Pico and Saugus respectively. As more surface outcrop sections were sampled and studied, the situation was still further complicated since it became increasingly more aparent that the lower Pliocene foraminiferal fauna of the Basin was absent in the type Pico locality. Some paleontologists, therefore, discarded the name lower Pico for the lower Pliocene and referred to it merely as lower Pliocene; some dropped the name Pico transition zone and substituted lower Pico. The terminology became so involved that it was necessary for the Pacific Section of the Society of Economic Paleontologists and Mineralogists to appoint a committee on nomenclature to establish a uniform classification. In 1930 this committee proposed the name Repetto formation (Reed, R. D. 32, p. 31 footnote) for the lower Pliocene division, and restricted the term Pico to the upper Pliocene. Six major faunal divisions were recognized, four for the Pico and two for the Repetto. Characteristic species of Foraminifera were selected to designate these zones. This classification first appeared in print in 1932 (W. P. Woodring *in*

Gale 32, p. 4, Pl. 3). In 1933 (33, p. 248) and again in 1936 (36, p. 125) Reed published modified classifications in which different species of Foraminifera were selected to represent the same general divisions of the Pico as those recognized by the committee. Unfortunately Reed further confused the zonal classification of the Pico by using disparately one of the species selected by the committee to designate a different stratigraphic interval of the Pico. The present author's classification is essentially that originally advocated by the committee, the chief distinction being the use of three rather than two faunal divisions for the Repetto and the use of the terms upper, middle, and lower Pico, and upper, middle, and lower Repetto. A comparison of the classification used in this paper with that of the S. E. P. M. Committee is shown in Table No. 2.

TABLE No. 2

FORAMINIFERAL CLASSIFICATION OF THE LOS ANGELES BASIN PLIOCENE

S. E. P. M. COMMITTEE ON NOMENCLATURE—1930		STANLEY G. WISSLER 1940	
Formational Division	Foraminiferal Division	Foraminiferal Division	Formational Division
PICO	*Uvigerina* aff. *tenuistriata*	*Uvigerina* aff. *tenuistriata*	UPPER PICO
	Cibicides mckannai	*Cibicides mckannai-Gyroidina altiformis*	•
	Uvigerina peregrina	*Uvigerina peregrina*	MIDDLE PICO
	Bulimina subacuminata	*Bulimina subacuminata*	LOWER PICO
REPETTO	*Plectofrondicularia californica*	*Plectofrondicularia californica-Cibicides mckannai*	UPPER REPETTO
		Karreriella milleri	MIDDLE REPETTO
	Arenaceous	*Liebusella pliocenica*	LOWER REPETTO

UPPER PICO

The upper Pico is characterized by two major foraminiferal assemblages, the upper the *Uvigerina* aff. *tenuistriata* fauna and the lower the *Cibicides mckannai-Gyroidina altiformis* fauna, each of which is further subdivided into a number of zones and subzones. In wells the lithology consists of soft, rather massive, well sorted, micaceous siltstone and claystone interbedded with fine silty to medium grained, unconsolidated, gray sand and occasional beds of coarse, pebbly sand. Good parting planes within the siltstone are rare. The color varies from light olive gray to grayish olive with occasional streaks of olive brown. The light gray predominates in the upper part and the grayish olive and olive brown in the lower. Megafossils occur rarely throughout the formation, and a few ostracods are sometimes found. Approximately 150 different species of Foraminifera are present, some 45 of which occur abundantly.

Since the upper Pico has been incompletely cored in the Basin fields, it has been necessary in most cases to determine the top by means of ditch samples and electric logs. The upper Pico reaches a maximum thickness for the Basin fields of 1,600 feet at El Segundo. It is approximately 1,000 feet thick at Playa del Rey and 1,100 feet thick in the Torrance-Wilmington area. Along the Inglewood-Newport uplift it ranges from approximately 900 feet at Inglewood to 1,490 feet in the Northwest Extension of Long Beach and 1,440 feet at Seal Beach. Information in regard to the thickness of the upper Pico in the east side fields is incomplete. However, it is apparently about 400 feet thick at West Coyote and 600 feet thick in the East Coyote district. The approximate thickness of the upper Pico in the majority of the main Los Angeles Basin fields is listed in Table No. 3 and shown graphically in figures accompanying this report.

Fairly complete sections of the upper Pico have been cored in the Seal Beach, the Long Beach, the Inglewood, and the East Coyote fields; intermittent intervals in other fields and in many wildcat wells. At Inglewood the entire upper Pico is essentially silt. At Seal Beach the formation is predominantly fine-grained micaceous siltstone except for the lower 200 feet, approximately 40 percent of which is fine- to medium-grained sand. In contrast, the Long Beach section consists of a series of alternating units of sand and silt. In the East Coyote area the basal 200 feet is composed primarily of sand and gravel, and the upper portion of silt with a few sand units.

With the exception of the Repetto formation, the upper Pico has the greatest areal extent of the Los Angeles Basin Pliocene. It completely overlaps the middle Pico, resting upon progressively older lower Pico and upper Repetto sediments. In an unpublished report, Driver, Ferrando, and Holman[1] mapped and described in detail the lithology and micropaleontology of the Pliocene exposed in the vicinity of Fifth and Flower Streets and Fourth and Hill Streets in the city of Los Angeles. Here upper Pico strata of the *Cibicides mckannai-Gyroidina altiformis* division rest with an angular discordance of from 5 to 10 degrees directly upon upper Repetto sediments. Likewise, the upper Pico exposed in the vicinity of the Newport lagoon is unconformably superimposed upon the upper Repetto. Again in the Repetto Hills and in the Whittier-La Habra region the upper Pico rests directly upon the Repetto. The upper portion of the formation is exposed in the Baldwin Hills and the Coyote Hills. In the subsurface section the upper Pico overlaps the middle Pico in the Torrance-Wilmington area and in the Long Beach Harbor district of the Wilmington field rests directly upon the Repetto. The contact with the underlying strata is readily traceable by means of electric logs over this entire area. At the western end of East Coyote, wells pass directly from the upper Pico into lower Pico sediments. The contact comes at the base of a sand and gravel interval of variable thickness. It is probable that the upper-middle Pico contact is disconformable in some of the other Basin fields but insufficient data are available to definitely confirm this hypothesis.

[1] Driver, H. L., Ferrando, A., and Holman, W. H., "Pliocene of a part of the city of Los Angeles," presented before the Pacific Section of the S. E. P. M., May, 1931. Driver's unpublished map is incorporated in one covering a slightly larger area by Soper and Grant (32).

TABLE No. 3

APPROXIMATE THICKNESSES AND PERCENTAGES OF SAND OF THE PLIOCENE AND UPPER MIOCENE OF THE LOS ANGELES BASIN OIL FIELDS

FIELD	PICO						REPETTO							
	Total	Upper	Middle		Lower		Total		Upper		Middle		Lower	
	Thickness	Thickness	Thickness	Sand %	Thickness	Sand %	Thickness	Sand %	Thickness	Sand %	Thickness	Sand %	Thickness	Sand %
PLAYA DEL REY	2110	1000	840	37	270	36	2560	29	1290	40	1000	20	270	2
EL SEGUNDO	2960	1600	1080	46	280	65	2270	38	1110	45	940	34	220	11
TORRANCE	1500*	1100	400*	....	0	....	870	12	350	15	400	13	120	2
WILMINGTON	1190*	1100	90*	....	0	....	1020	45	320	51	580	44	120	38
INGLEWOOD	1940	900	630	15	410	43	3450	47	1570	52	1370	50	510	26
POTRERO	2625-2890	1100	1035-1300	47	490	71	4050	55	1810	63	1700	63	530	41
ROSECRANS	2620	1200	1060	50	360	76	3180	60	1300	60	1430	62	450	49
DOMINGUEZ	2230	1140	760	60	330	78	2800	62	1260	66	1190	58	350	50
LONG BEACH, Northwest Extension	2910	1490	1100	....	320	39	2710	64	1190	65	1170	61	350	59
LONG BEACH, South of Fault	2450	1160	1030	....	260	44	2860	63	1240	63	1230	62	390	67
LONG BEACH, North of Fault	2030	1000	800	41	230	57	2230	66	1120	66	850	67	260	58
SEAL BEACH	2730	1440	1030	....	260	49	2250	55	1150	49	770	60	330	63
HUNTINGTON BEACH, Old Field	1990	1270	440	22	280	37	1420	44	710	46	600	47	110	17
MONTEBELLO, West	720	....	....	....	....	....	4530	24	1450	6	2350	31	730	38
MONTEBELLO, Main Field	....	....	....	....	....	....	5060	41	1450	7	2530	56	1080	50
SANTA FE SPRINGS	1170	....	....	....	400	37	4880	58	2040	49	2100	64	740	67
WEST COYOTE	1890*	400*	950	....	540	21	4280	43	2000	35	1450	48	830	52
EAST COYOTE, Hualde Dome	1090*	600*	0	....	490	15	2970	27	1550	11	1120	47	280	28
EAST COYOTE, Anaheim Dome	....	....	0	....	500	29	3090	22	1840	13	960	43	290	15
RICHFIELD	....	....	....	....	....	....	700*	15	200*	....	500*	....	....	....

* Part of section missing due to unconformity, maximum known thickness indicated.

MIDDLE PICO

The middle Pico division as used in this paper comprises the *Uvigerina peregrina* faunal assemblage [2] composed of a number of zones and subzones. In general the section is predominantly shale. In wells the sediments consist of fairly soft, massive to well bedded, well sorted, fine, sandy, micaceous claystone and siltstone interbedded with fine and medium to coarse grained gray sand and occasionally with coarse pebbly sand. Thin streaks of soft, laminated, platy shale, composed of thin alternating bands of dark olive brown, organic claystone and light olive gray, inorganic silt, separated by very fine sandy parting planes, are fairly common. Foraminifers are very abundant in the darker bands. In appearance this laminated shale is similar to that which occurs in the Miocene, but is softer and less dense than the hard, brittle Miocene type. The shales grade irregularly in color from grayish olive and olive brown in the upper part to olive brown and dark olive brown in the lower. Mollusca occur rather commonly throughout the middle Pico, one of the most common forms being *Hyalopecten randolphi tillamookensis* (Arnold). In general foraminifers are very abundant. The average foraminiferal content per unit volume of original material was determined for the shaly intervals in several of the fields. It was found that in the west side fields tests of Foraminifera compose approximately 1.2 percent of the shales. Individual 60 cc. samples in which the foraminiferal content is as high as 10 percent and the number of individual specimens present is as great as 150,000 are not uncommon. Foraminiferal remains are less abundant in the east side areas as exemplified by West Coyote where on an average they compose only 0.17 percent per unit volume of the shales.

Middle Pico sections of maximum thickness occur in the synclinal areas separating the structural trends. The thickness in the Basin fields ranges from 0 to a maximum of 1,300 feet at Potrero. The approximate thickness and ratio of sand to shale for the various fields is indicated in Table No. 3. At Playa del Rey and El Segundo the more sandy parts of the section occur near the top, middle, and base, the basal interval being somewhat less sandy than the other two. Because of unconformities at the top and base, the Torrance and Wilmington middle Pico sections are incomplete. In the Inglewood field at the north end of the Inglewood-Newport uplift, the middle Pico is essentially shale with sands occurring in the lower 200 feet. Similarly at Potrero the lower third is predominantly sand with a few minor sand units scattered throughout the remainder of the section. In the Rosecrans-Dominguez area, on the other hand, the middle Pico is an alternating series of sand and shale units. Lithologically the Long Beach and Seal Beach sections are similar to

[2] In taking the top of the middle Pico at this point, the author differs from Reed who takes the top of the *Bolivina robusta* zone, which comes near the middle of the *Uvigerina peregrina* division, as the top of the middle Pico (Reed, R. D. 33, p. 248; Reed and Hollister 36, p. 125).

TABLE No. 3—Continued

APPROXIMATE THICKNESSES AND PERCENTAGES OF SAND OF THE PLIOCENE AND UPPER MIOCENE OF THE LOS ANGELES BASIN OIL FIELDS

FIELD	PUENTE									
	Division A		Division B		Division C		Division D		Division E	
	Thickness	Sand %	Thickness	Sand %	Thickness	Sand %	Thickness	Sand %	Thickness	Sand %
PLAYA DEL REY	450*	6	0		0		100*	0	60*-430*	0-68
EL SEGUNDO	850	35			680	31	0-340*	0-31	16*-266*	0-60
TORRANCE	480	23	300	17	330*	5	460*	24	46*-113*	0-31
WILMINGTON	730	42	590	43	910	26	1660	44	60*	33
INGLEWOOD	770*	14	0		0		0		120*	16
POTRERO	840+	35								
ROSECRANS	1090	51	730+	43						
DOMINGUEZ	1140	50	840	61	1100	49	1275+			
LONG BEACH, Northwest Extension	1000+	62								
LONG BEACH, South of Fault	1310	65	1200	73	1210	40				
LONG BEACH, North of Fault										
SEAL BEACH	860	65	1370	72	1400	46				
HUNTINGTON BEACH, Old Field	430	32	550	51	550					
MONTEBELLO, West	2690	48								
MONTEBELLO, Main Field										
SANTA FE SPRINGS	1700	44	1200	36	1300+					
WEST COYOTE										
EAST COYOTE, Hualde Dome										
EAST COYOTE, Anaheim Dome	450*-800		450							
RICHFIELD	620	46	320-1000	94-45	530	24	3020	80	1300	

* Part of section missing due to unconformity, maximum known thickness indicated.

Potrero. The Huntington Beach section is predominantly shale in the upper part with considerable sand in the lower 100 feet. At Santa Fe Springs the upper portion is predominantly shale with a few thin sand units; the lower 100 feet is essentially sand. At West Coyote the section seems to be almost entirely shale.

Apparently the middle Pico is absent in the Montebello field. There is no middle Pico at East Coyote and probably none at Richfield. Information from wildcat wells indicates that it is likewise absent in the Whittier and Brea-Olinda districts. Strata of the *Bolivina robusta* zone of the middle Pico outcrop at the fork in Potrero Canyon northwest of Santa Monica. As far as is known, there are no other outcrops of middle Pico in the Los Angeles Basin region. Evidence from wells in which the middle Pico is present indicates that the contact between it and the underlying lower Pico is conformable except in the Torrance-Wilmington area where the middle Pico has overlapped the lower Pico and rests with angular discordance upon the Repetto.

As may be seen from the straight line correlation chart, Plate V, oil is produced from the basal middle Pico sand in the Inglewood, Potrero, and Long Beach fields. This basal middle Pico sand is, therefore, stratigraphically the highest commercial oil horizon of the Basin.

LOWER PICO

The lower Pico strata are characterized by the *Bulimina subacuminata* faunal assemblage. The sediments invariably contain a higher percentage of sand than those of the overlying middle Pico. They consist of fine to coarse gray sand, occasionally pebbly, interbedded with rather massive, sandy, micaceous shale and siltstone. The color of the shale ranges from dark olive brown to hair brown [3] in the western fields and from grayish olive to olive brown in the eastern fields. Megafossils are very rare. The quantity of foraminiferal tests per unit volume of the shales in the western fields, 0.5 percent, is approximately one-half that of the middle Pico. In the eastern fields the quantity of foraminifers is about the same as in the middle Pico, 0.15 percent. In both regions the number of different species present is approximately half that of the middle Pico.

The lower Pico has a greater areal extent than the middle Pico. Except for some of the marginal areas, it is present over the entire Basin. Due to local deformation the lower Pico and a portion of the Repetto were removed from the crest of the Torrance and Wilmington structures before the middle Pico was deposited. The thickness in the other western fields ranges from 230 feet at Long Beach to 490 feet at Potrero. Lower Pico has been cored in the Montebello, Santa Fe Springs, West Coyote, and East Coyote fields. The thickness along the Coyote Hills uplift varies from 400 feet at Santa Fe Springs to 540 feet at West Coyote. Information on the other eastern fields is incomplete. Indications are that the lower Pico is missing in the Richfield, Brea-Olinda, and Whittier areas. The thick-

[3] A term adapted from Ridgway to designate a particular shade of brown common to Pico and Repetto shales. Ridgway, Robert 12, Pl. XLVI.

ness and approximate ratio of sand to shale for the individual fields is given in Table No. 3. In fields where the lower Pico is present, the contact between it and the underlying Repetto is always conformable. Oil is produced from the lower Pico sands in the Inglewood and Long Beach fields.

REPETTO FORMATION

The Repetto formation, characterized by the *Plectofrondicularia californica* fauna, has been divided into three major foraminiferal units: the *Plectofrondicularia californica-Cibicides mckannai* division, the *Karreriella milleri* division, and the *Liebusella pliocenica* division. As a matter of convenience these three main faunal units have been designated upper, middle, and lower Repetto. To further facilitate subsurface correlation, 18 foram zones and 67 subzones have been established. Foram zones 1 through 5 comprise the upper Repetto; 6 through 14, the middle; and 15 through 18, the lower Repetto. In this paper the Repetto stratigraphy will be discussed from the standpoint of the formation as a whole and from the standpoint of the three major units, upper, middle and lower Repetto, since lack of space prevents detailed consideration of each individual foram zone and subzone.

The Repetto sediments consist of a series of alternating units of fine to coarse, loose to compact, occasionally pebbly, poorly cemented sand and sandy micaceous shales, siltstones, and claystones. Hard calcareous sandstone lenses ranging in thickness from a few inches to several feet are frequently encountered. Coarse pebbly sands occur in a number of horizons in the upper and middle Repetto in fields of the Inglewood-Newport uplift. Pebbly sands likewise occur at a few horizons in the upper Repetto and in the upper part of the middle Repetto at Santa Fe Springs. Similarly at West Coyote pebbly sands are found in the upper and lower parts of the middle Repetto. At East Coyote pebble conglomerates are usually encountered in the upper and lower part of the middle Repetto. Fairly thick coarse conglomerates are present in the lower part of the middle and the upper part of the lower Repetto at Montebello. In general the Repetto shales become finer textured, denser, darker colored, and more organic from top to bottom of the section. In the west side fields they grade from dark olive brown to chaetura drab.[4] In the east side fields the shales are coarser textured, less organic, and the colors are lighter, ranging from grayish olive to hair brown. Claystones and fine siltstones predominate at Playa del Rey, Torrance, and Huntington Beach; sandy shales and siltstones in the other west side fields. Shaly intervals of the east side fields are sandier and more micaceous than those of the west side. They often tend to contain small irregularly shaped fine grained sand inclusions. Several thin layers of volcanic ash and bentonite occur in the lower part of the upper Repetto. A few of these have a fairly wide lateral extent. Two one-foot beds of ash and bentonite, separated by approximately 325 feet of sands and shales, were cored in numerous wells in the Playa del Rey field. The lower of these has been cored in several wells in the Dominguez, Montebello, and East Coyote fields.

[4] A term adapted from Ridgway to designate a particular shade of dark brown common to lower Repetto and upper Miocene shales. Ridgway, Robert 12, Pl. XLVI.

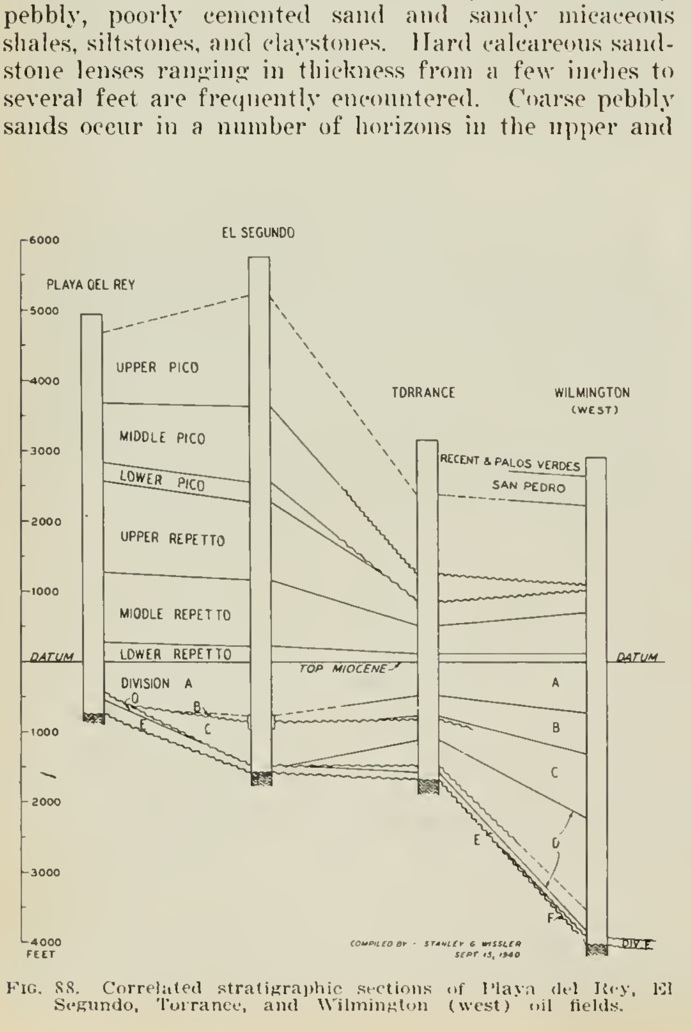

FIG. 88. Correlated stratigraphic sections of Playa del Rey, El Segundo, Torrance, and Wilmington (west) oil fields.

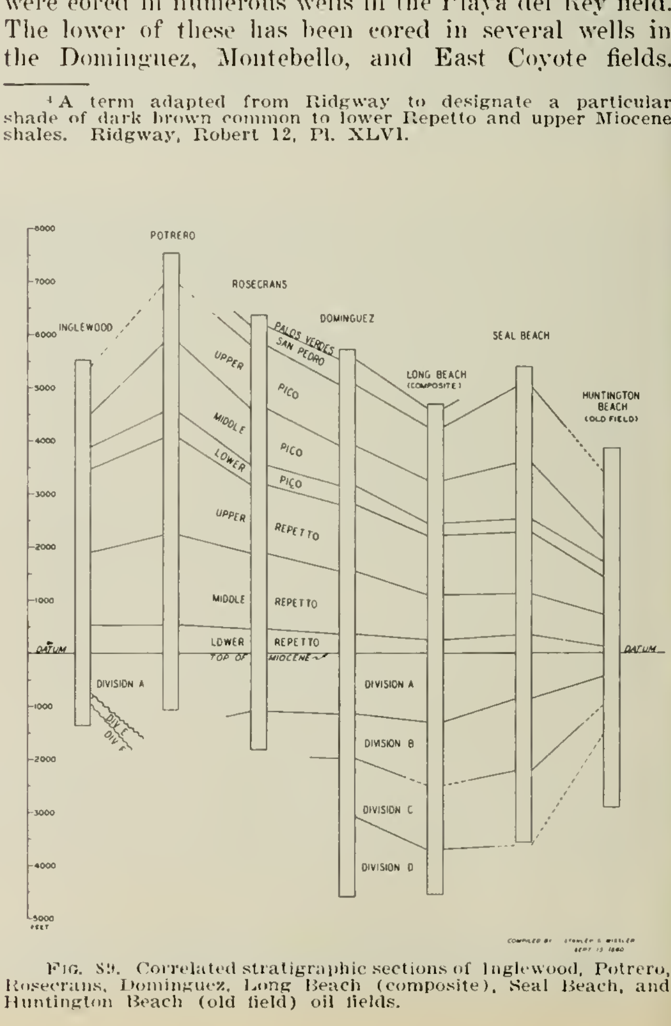

FIG. 89. Correlated stratigraphic sections of Inglewood, Potrero, Rosecrans, Dominguez, Long Beach (composite), Seal Beach, and Huntington Beach (old field) oil fields.

This same bentonite is present in the Repetto outcrop section at Malaga Cove.

Mollusca are irregularly distributed throughout the formation. Woodring (38, p. 11) has found that the typical species are *Lima hamlini* Dall, *Limopsis phrear* Woodring, and *Fusitriton oregonense* (Redfield). Radiolaria are fairly common in certain horizons in the lower part of the lower Repetto in the Torrance and Huntington Beach fields. Foraminifers are abundant but constitute a smaller percentage of the sediments than in the Pico formation. The approximate foraminiferal content per unit volume of the shales for the west side fields is 0.32 percent for the upper Repetto; 0.22 percent for the middle; and 0.08 percent for the lower. It is considerably less for the east side fields: 0.18 percent for the upper, 0.04 for the middle, and 0.03 for the lower Repetto. In some fields carbonized wood is fairly abundant in one or two horizons in the middle Repetto. In one of the west side fields there is a 10-foot interval in the lower part of Foram Zone No. 6 in which carbonized plant remains make up approximately 10 percent by volume of the sediments. Throughout the Basin finely divided particles of carbonized wood are particularly characteristic of the lower Repetto. The percentage by volume of carbonized wood in the lower Repetto shales averages approximately 0.7 percent for the west side fields and 0.23 percent for the east.

Apparently the Repetto formation attains its maximum thickness somewhere in the area between Santa Fe Springs and Montebello. Montebello with 5,060 feet has the thickest section while Santa Fe Springs is second with 4,880 feet. The formation thins towards the southwest with the thinnest section at Torrance (figure 90). In a north-south direction the formation thickens and becomes more sandy towards the central portions of the Basin; thins and becomes less sandy towards the margins. The central fields of the Inglewood-Newport uplift, Rosecrans, Dominguez, and Long Beach, have the highest Repetto sand percentage of the Basin fields (Table No. 3). As would be expected, the field with the thinnest Repetto section, Torrance, is the least sandy. Wilmington, however, with the next thinnest Repetto section has the highest sand ratio, 45 percent, of the Playa del Rey-Wilmington line. This apparent anomaly is explained by the fact that the field occupies the same relative central position along the long axis of the Basin as Long Beach and Santa Fe Springs. Santa Fe Springs, at the northwestern end of the Coyote Hills uplift, has the highest sand percentage, 58 percent, of the eastern fields. Figure 91 illustrates graphically the variation in lithology across the Basin from Santa Fe Springs to Wilmington.

The upper and middle Repetto are about equal in thickness, and in general make up from 80 to 90 percent of the formation. In the west side fields both are comparatively sandier than the lower Repetto. Along the Playa del Rey-Wilmington line the upper and middle are quite sandy while the lower is essentially shale in the Playa del Rey, El Segundo, and Torrance fields. At Wilmington the sand percentage for the lower Repetto is relatively high but is less than that of the upper and middle Repetto. The entire Repetto is predominantly sand in the fields of the Inglewood-Newport uplift, with the lower Repetto less sandy than the middle and upper. On the other hand the upper Repetto in the east side fields is relatively less sandy than the middle and lower. The upper Repetto sediments at Santa Fe Springs and West Coyote contain a high percentage of sand, but are less sandy than those of the middle and lower Repetto. At East Coyote the middle Repetto is poorly sorted and contains an appreciable amount of sand and conglomerate while the lower Repetto is from 15 to 28 percent sand. At Montebello both the middle and the lower Repetto are poorly sorted. Numerous conglomerates occur in the lower half of the middle and the upper half of the lower Repetto. The upper half of the middle Repetto is essentially shale at West Montebello but is sandy in the main field. The lower half of the lower Repetto is shale in both West Montebello and the main field.

The Repetto formation has the greatest areal extent of the Los Angeles Basin Pliocene. It is present in all of the producing fields with the exception of the Los Angeles City field and the Puente field and outcrops at various localities in the hills surrounding the Basin. Upper Repetto clay shale is exposed in a small down-faulted block of Pliocene sediments in the Potrero Canyon area at the northwest corner of the Basin. Lower Pliocene strata exposed on a southward-dipping monocline in the vicinity of Fifth and Flower Streets in the city of Los Angeles have been mapped and described by Driver, Ferrando, and Holman.[5] This section is particularly noteworthy because of the marked angular unconformity which separates the middle and lower Repetto. The unconformity cuts out a portion of the lower Repetto and the greater portion of the middle Repetto. In addition, there are several local disconformities within the upper Repetto. The contact between the lower Repetto and the underlying upper Miocene appears to be conformable in the Los Angeles City district.[6] The Repetto formation is present in its entirety in the type area in the Repetto Hills. The best and most complete exposures are along the west side of Atlantic Boulevard and along Fremont Avenue. Here in the type locality the formation consists of approximately 3,100 feet of massive, olive-brown, micaceous siltstone with several very thin conglomeratic sandstone lenses in the upper 700 feet.[7] The Repetto likewise outcrops in several areas in the Puente Hills. Approximately 500 feet of upper Repetto and 100 feet of middle Repetto siltstone are incompletely exposed along the west side of Newport Bay. This Newport section is disconformably overlain by upper Pico and rests unconformably upon the upper Miocene. The Repetto outcrops in a number of localities along the northern slope of the Palos Verdes Hills. The best exposure is in a syncline on the sea cliff at Malaga

[5] Driver, H. L., Ferrando, A., and Holman, W. H., *op. cit.*

[6] Because of the rather abrupt change in lithology, Soper and Grant (32, p. 1053) were of the opinion that there might be a slight erosional unconformity at this contact. On the other hand Driver (personal communication) found a normal faunal sequence across the contact and failed to find any indication of discordance in dip or strike.

[7] The Repetto formation was first defined in print by Reed (32, p. 31 footnote). He incorrectly placed the top of the formation at the top of three beds of coarse felspathic sandstone occurring approximately 2,500 feet above the Pliocene-Miocene contact. He stated that the overlying 600 feet of lithologically similar siltstone belongs to the lower Pico formation on the assumption that it carries a mixed fauna. Repetto forms occur throughout this interval. This 600-foot interval was correctly assigned to the Repetto formation by Edwards (34, p. 795), giving the Repetto formation an approximate thickness of 3,100 feet in the type locality.

Cove, where Repetto rests upon Malaga mudstone of the upper Miocene and is unconformably overlain by the Palos Verdes sand. This section consists of approximately 110 feet of massive, foraminiferal siltstone, the lower 37 feet of which is middle Repetto and the upper 73 feet, upper Repetto. The upper 25 feet of this section is inaccessible; the lower 85 feet has been sampled continuously. There is no apparent discordance in dip between the Repetto and the Malaga mudstone, but there is a marked hiatus at the contact since all of the lower Repetto and the basal part of the middle Repetto are missing. The missing interval is represented by 150 feet of claystone in the nearby Torrance field and by 500 feet of sand and shale in the Dominguez field. Furthermore, there is evidence to indicate that the Malaga mudstone of this area correlates with Division C of the upper Miocene as used in this paper. If this is true, there is approximately 800 feet of Miocene strata in the Torrance field which is younger than this Malaga mudstone. Within the Malaga Cove Repetto section, at a point approximately 15 feet above the base, there is a second hiatus which cuts out the greater part of the middle Repetto. This hiatus is represented by approximately 250 feet of strata at Torrance and 750 feet at Dominguez.

The Repetto-Miocene contact is conformable in all of the west side fields; it is also conformable at Santa Fe Springs and West Montebello. At East Montebello the Repetto has overlapped part of the upper Miocene. Approximately 200 feet of lower Repetto and 500 feet of upper Miocene strata are missing at this unconformity on the crest of the structure. All of the lower Repetto and part of the upper Miocene are cut out by an unconformity in the eastern part of the East Coyote field. Much of the middle Repetto and all of the lower Repetto are missing at Richfield. The Pliocene-Miocene contact is probably likewise unconformable at Brea-Olinda. Incomplete data make it impossible to definitely determine the nature of the contact in the other east side fields.

The Repetto formation has been the major source of oil of the Los Angeles Basin area. Every individual sand interval within the formation has been productive in the Long Beach field; various sand intervals are productive in the other fields. However, no single sand interval is productive in every field as may be seen from the straight line correlation chart, Plate V.

MIOCENE

Miocene rocks have been penetrated in varying degrees by deep wells in all of the Basin fields. The author recognizes six major foraminiferal faunal divisions for the upper and middle Miocene, as follows: Division A, characterized by the *Rotalia garveyensis* faunal assemblage; Division B, by the Division A assemblage plus *Bulimina* sp. (large, crushed); Division C, by the *Bulimina* sp. (large, crushed)-*Gyroidina rotundimargo* assemblage; Division D, by the *Bolivina hughesi* assemblage; Division E, by the *Bulimina uvigerinaformis* and *Baggina californica* assemblages; and Division F, by the *Valvulineria californica* assemblage. Divisions A, B, C, D, and E comprise the upper Miocene; Divisions A, B, and C,[8] the Delmontian stage; Division D, the upper Mohnian and Division E, the lower Mohnian stage. Division F represents the Luisian stage of the middle Miocene. In wells the upper Miocene is generally referred to the Puente formation. In the type area the Puente formation contains an upper shale member, a middle sand member, and a lower shale member. Faunal divisions A, B, C, and the upper part of D are included in strata mapped by English (26, geologic map, Pl. I) as upper Puente in the eastern part of the Puente Hills. Division E is represented in the Puente Hills by the lower Puente shale. The middle sandstone comprises the lower part of Division D. These lithologic units are recognizable as such in only a few of the eastern fields. Elsewhere subsurface correlations must be based entirely upon microfaunal evidence.

The upper Miocene shales of the Los Angeles Basin area may in general be distinguished from those of the Pliocene by the very poor state of preservation of their foraminiferal assemblages. Both arenaceous and calcareous foraminifers are in many cases much more abundant than they are in the lower Pliocene, but, due in part to the fragile nature of the tests of many forms and in part to the compaction and compression to which the Miocene strata have been subjected since deposition, they are so badly crushed that only a small portion of the fauna can be extracted by washing. Hence, it has been necessary to examine the crushed foraminifers within the unwashed core samples. Under such conditions specific, and even generic, identifications are often difficult. However, it has been feasible to recognize some 60 subzones or marker horizons within the upper Puente shale interval, that is, within divisions A, B, C, and the upper half of D. Many of these marker horizons have been carried laterally over the major portion of the Basin. Complete sections of the lower part of Division D and Division E have been cored in so few wells that it has not yet been practical to attempt to subdivide them.

Thin-shelled foraminifers are present in such abundance along the bedding planes in some intervals of the upper Miocene that they frequently give an iridescent, pearly luster to the surface of the shale. The foraminifers are quite abundant in the shales throughout the A division; they are relatively rare in the B division shales, tending to occur in narrow, localized horizons; they are abundant in the shales of the C division, particularly in the lower part, and in the upper half of Division D; less abundant and more poorly preserved in lower D. Recognizable foraminifers are quite rare in the majority of the core samples from the E division although unidentifiable spots, originally foraminiferal tests, are frequently numerous. Foraminifera are likewise rare in the F division. The only megafossil commonly found in the upper Miocene core samples is a small, thin-shelled "mud pecten," *Hyalopecten pedroanus* (Trask). This pecten is fairly abundant in the thin platy, argillaceous shales of the lower half of the C division. Fish remains, consisting of bones and scales, are fairly common, and

[8] It is possible that some paleontologists might place faunal Division C at the top of the Mohnian stage rather than in the lower part of the Delmontian. In the type Mohnian outcrop section Kleinpell (38, p. 127) placed the contact between the Mohnian and the overlying Delmontian within an unfossiliferous interval.

more or less complete specimens are occasionally found in the platy shales. Microscopic claws and fragments of decapods are frequently present.

UPPER MIOCENE

Division A

Lithologically Division A varies from fairly soft, banded, platy shale to hard, massive, dark chaetura drab and olive brown, sandy, micaceous siltstone interbedded with rather poorly sorted, fine to coarse sand and occasional conglomerates. The platy shale consists of alternating bands of various shades and combinations of light and dark brown organic claystone and light grayish, fine, sandy, nonorganic silt with thin partings of fine, micaceous sand and occasional bands of nearly black biotitic shale. The alternating bands vary in thickness from several inches to paper thin laminations. In cores the thin laminated type of shale is often called "poker chip" shale because of its tendency to split into thin disks. Along the Playa del Rey-Wilmington line the shales are predominantly claystone and very fine, micaceous siltstone. Thick and thin platy and semiplaty shales are irregularly distributed throughout the section. The top of the "poker chip" shale tends to come approximately 30 to 40 feet below the Miocene contact. Thin layers of impure diatomite are associated with the "poker chip" shale at this horizon in the Torrance-Wilmington area, and some diatomaceous shale likewise is present in the Lawndale-El Segundo district. The entire A division is shale in the Playa del Rey field. The upper third of the section is predominantly shale in the other fields of the Playa del Rey-Wilmington line, with the lower two thirds approximately half sand. The upper one third to one half of the section along the Inglewood-Newport line is shalier than the lower portion. The shaly intervals consist primarily of massive, fine to coarse textured, micaceous siltstone. Thick banded semiplaty shale is rarely present, and the thin platy "poker chip" type of shale is almost entirely absent. The sands in general are medium to coarse in texture, frequently somewhat angular, poorly sorted, and exhibit a marked tendency toward cross bedding. There are a few lenses of coarse pebbly sand in the lower portion of the A division at Seal Beach. As in the case of the Playa del Rey-Wilmington line, the most northerly field, Inglewood, has the smallest percentage of sand. The entire Division A is relatively sandy in the central fields of the line, Rosecrans, Dominguez, Long Beach, and Seal Beach. as may be seen from the sand percentages listed in Table No. 3. In contrast, the lithology in the Huntington Beach field is similar to that of Torrance and Wilmington. In the eastern areas all or portions of Division A have been cored by wells at Montebello, Santa Fe Springs, East Coyote, Brea-Olinda, and Richfield. In these fields, the section consists of alternating units of fairly hard, massive, chaetura drab and dark chaetura drab, sandy, micaceous shales and siltstones interbedded with fine to medium grained sand. Platy and semiplaty shales occur in a few horizons. At Montebello the sands tend to become coarse and conglomeratic in places and the shales are lighter colored in the upper part of the section than in the other fields but become progressively darker with depth.

Like the Repetto, Division A attains its maximum thickness in the Santa Fe Springs-Montebello area; it ranges from 1,700 feet at Santa Fe Springs to 2,690 feet, at West Montebello. It is slightly over 600 feet thick at Richfield and from 450 to 800 feet on the Anaheim Dome of East Coyote. The Miocene has not been reached in the main part of the West Coyote field although apparently a few hundred feet of uppermost Division A strata have been penetrated by an edge well; unfortunately, no samples were available for examination. Along the Inglewood-Newport uplift Division A thickens gradually from 770 feet at Inglewood to a maximum of approximately 1,310 feet at Long Beach and then thins to approximately 430 feet in the Old Field area of Huntington Beach. Along the Playa del Rey-Wilmington line the thickness varies from approximately 450 feet at Playa del Rey to 850 feet at El Segundo. The basal portion of the section is missing in the Playa del Rey and Inglewood fields, and the upper 500 feet is absent in the East Montebello area. It is possible that the lower 50 to 100 feet is missing in the Lawndale-El Segundo region.

From the standpoint of oil production, the A division is the most important faunal unit of the upper Miocene. It is the main producing interval of the Lawndale, Torrance, and Wilmington fields of the Playa del Rey-Wilmington line. A few semicommercial wells produce from this interval at Inglewood and Potrero. It contains all or portions of the major Miocene producing zones discovered to date at Rosecrans, Dominguez, Long Beach, Seal Beach, and the Old Field area of Huntington Beach; all of the Miocene production at Montebello and all of the important Miocene production at Santa Fe Springs. A small portion of the Miocene production of East Coyote and the upper Chapman zone production of Richfield are likewise from this interval.

Division B

Division B consists of alternating units of fine to medium grained, rather well sorted, compact sand and massive sandy, fairly hard, dark chaetura drab shale with a few occasional beds of platy to semiplaty organic shale. Strata of the B division are missing in the Playa del Rey, El Segundo, and Inglewood fields. It has not been penetrated at Potrero, Montebello, or West Coyote. The section is predominantly shale at Torrance. In the Wilmington and the Rosecrans fields, it is approximately 57 percent shale. It is predominantly sand at Dominguez, Long Beach, and Seal Beach. At Huntington Beach there are approximately equal amounts of sand and shale with the shale tending to be concentrated in the middle and lower portions of the interval. On the east side of the Basin at Santa Fe Springs, Division B is predominantly shale with sand units in the middle and lower parts. The East Coyote section is principally shale. In the western part of Richfield the B division is almost entirely sand; in the eastern portion of the field the upper half is shale and the lower half is sand. The thickest and sandiest sections are in the Long Beach and Seal Beach fields. Santa Fe Springs is almost as thick as Seal Beach but is considerable less sandy. The thinnest section is at Torrance.

The B division is the second most important Miocene producing interval of the Basin. It is productive throughout at Long Beach. It contains the lower Terminal zone of the Wilmington field; the basal part of the upper zone at Torrance; the middle and lower Eighth zone of Dominguez; the lower part of the upper McGrath and the upper part of the lower McGrath zone at Seal Beach; the lower two-thirds of the lower Ashton zone at Huntington Beach. On the east side of the Basin, it embraces the major portion of the lower Chapman zone of Richfield and a few intermittent sand intervals at Santa Fe Springs from which a semicommercial well has obtained a small amount of oil.

Division C

In most of the fields the C division is predominantly shale interbedded with fine to medium silty sand. The shale varies from the hard, brittle, thin platy, laminated type, composed of alternating layers of unfossiliferous bluish gray silt and dark brown, organic, foraminiferal claystone to the massive, sandy, micaceous, chaetura drab variety. The C division is absent at Playa del Rey where strata of the A division rest unconformably upon the lower part of Division D. In the El Segundo-Lawndale area the C division is approximately two-thirds shale. Fairly massive shales predominate in the upper half of the El Segundo section; platy shale is common in the lower half; and thin beds of sand, ranging up to 20 feet in thickness, are irregularly distributed throughout. At Torrance the interval is essentially hard, brittle, very fossiliferous, platy shale with a few thin beds of sand. Likewise, at Wilmington the section is predominantly shale. Here the shales are mainly the massive, sandy type in the upper two-thirds of the interval but are chiefly platy in the lower one-third. Division C strata are cut out by overlap in the Inglewood field. Nothing is known in regard to the section which may be present at Potrero and Rosecrans. The Dominguez section consists of alternating bodies of fine to medium grained silty sand and shale with sands predominating near the top, middle, and bottom. The shales are primarily fine textured, massive, silty claystones with some arenaceous siltstones through the upper two-thirds of the interval. The lower 300 feet is mainly sand with a few scattered beds of platy shale 100 feet from the base. Intermittent cores taken through the interval at Long Beach indicate that the section is similar in lithology to Dominguez. The Seal Beach section has been cored in one or two wells. It is slightly less sandy than Dominguez. The shales are mainly of the massive, argillaceous type. The interval has been intermittently cored in the Old Field area of Huntington Beach, where it seems to be predominantly shale. It has been penetrated by numerous wells in the Seventeenth Street-Barley field, and Tideland areas, but few samples were available for examination. The data at hand suggest that the C division is almost entirely shale at the northern end of the Tideland-Barley field area; while to the south the underlying middle Puente sand of the D division rises progressively higher stratigraphically until it occupies the lower half of Division C at the crest of the structure. Various geologists have suggested that this sand-shale contact represents an unconformity. A detailed study of available cores and electric logs has convinced the author that this contact marks a gradational change from a sand to a shale facies. On the east side of the Basin, cored sections of the C division were available from one well at Santa Fe Springs, one well at East Coyote, and numerous wells at Richfield. At Santa Fe Springs the section is apparently predominantly fine silty sand. Shales are chiefly massive, silty and sandy claystones with small amounts of the platy type. The Division C sediments of the Anaheim Dome of East Coyote are in general similar to Richfield. At Richfield the upper half of the C division contains an appreciable percentage of fine and coarse sand interbedded with platy and some sandy micaceous shale. The lower half is the typical, hard, brittle, thin and thick platy shale separated by thin layers and partings of fine sand.

Along the Playa del Rey-Wilmington line the C division attains a maximum thickness of slightly over 900 feet in the Wilmington field. There is an unconformity within the section at Torrance which has cut out approximately one-half the division. The same unconformity may have cut off the top of the section at El Segundo. Along the Inglewood-Newport uplift the thickness varies from approximately 550 feet in the Old Field area of Huntington Beach to 1,400 feet at Seal Beach. In the east side fields it ranges from approximately 530 feet at Richfield to more than 1,300 feet at Santa Fe Springs.

All except the basal 50-75 feet of the C division lies within the lowest oil-producing zone of the Seal Beach field. The lower portion is productive at Huntington Beach, at Wilmington, and at Long Beach. The upper half is productive at Richfield.

Division D

The D division is best known in the Wilmington and Richfield fields. In the upper part it consists of hard, brittle, banded, bluish-gray and brown, thin platy, foraminiferal and diatomaceous shale; and semiplaty and massive, dark chaetura drab, argillaceous shale interbedded with fine to medium-grained silty sand. A few hard calcareous shales are present. The lower part of the section is primarily dark chaetura drab to black, platy and semiplaty, organic, bituminous shale interbedded with fine to coarse sands. Irregularly distributed through this black shale are occasional thin, buff-colored, lenticular, phosphatic layers and nodules up to an inch in diameter. Foraminifera are relatively rare as compared with the upper part of the section. At Playa del Rey Division D is represented by only the basal 100 feet of this black shale. The entire D division is absent in wells on the crest of the El Segundo structure. The upper 300 feet, predominantly bluish-gray and brown platy shale, is present in wells in the southeasterly portion of the field. Both the upper and the lower units, separated by approximately 100-125 feet of medium-grained sand, are found at Torrance. There is a hiatus approximately 85 feet below the base of this sand which is representative of approximately 750 feet of section in the Wilmington field and in nearby wildcat wells. A 1,660-foot Division D section, apparently complete, is present at Wilmington. It is fairly sandy throughout. Division D appears to be missing in the Inglewood field. The upper 900 feet has been penetrated at Dominguez and Long Beach; it consists of alternating units of fine- to medium-textured, poorly sorted sand and massive dark chaetura drab, argillaceous shale. In the Old Field area of Huntington Beach the upper portion of the section consists of platy shale followed by the middle Puente sandstone member. In the Tidelands area the contact between the shale and the underlying sand, which appears to be gradational, rises in section toward the south until the entire division is represented by sand near the crest of the Tidelands structure.

On the east side of the Basin the section may be divided into two parts. Upper D consists of hard, brittle, banded, bluish-gray and brown, thin and thick platy, foraminiferal shale and fine- to medium-grained sand. Lower D is represented by the middle Puente sandstone, composed of coarse- and medium-textured sand with a few thin beds of sandy shale becoming more noticeable toward the base. Upper D is approximately 700 feet thick at Richfield; shale predominates in the uppermost 100 and the basal 200 feet, and medium-grained sand in the middle 400 feet. The middle Puente sandstone is about 2,325 feet thick, giving a total thickness of 3,025 feet for Division D at Richfield. At East Coyote available samples indicate that upper D consists of several alternating units of shale and sand. Upper D is approximately 65 percent sand on the Hualde Dome. One well on the Anaheim Dome has penetrated approximately 2,500 feet of middle Puente sandstone.

The D division is the third most important upper Miocene interval of the Basin from the standpoint of oil production. It contains the Del Amo zone of Torrance, the major part of the Ford zone of Wilmington and the De Soto zone of Long Beach, the main part of the producing zone of the Tidelands area of Huntington Beach, the deep production at the west end of East Coyote, and the Kraemer zone of Richfield.

Division E

Underlying Division D in the fields of the Playa del Rey-Wilmington line is a highly organic, oily, black and tan, phosphatic shale unit known locally as the nodular shale. This nodular shale has been penetrated by numerous wells at Playa del Rey, El Segundo, and Torrance; by several wells at Wilmington; and by one well at Inglewood. The phosphatic material occurs in the form of thin, discontinuous, tan and gray, lenticular layers and nodules up to one inch in diameter. These layers and nodules tend to be somewhat elongated, paralleling the bedding. Analyses show that they are largely calcium phosphate (Hoots, Blount, and Jones 35a, p. 189). Trask (Trask and Hammar 35, p. 123) has found that the organic content of this shale runs as high as 13 percent in the Playa del Rey field. Interbedded with the nodular shale are occasional thin streaks of buff to olive-green bentonite. These bentonites are particularly noticeable in the Playa del Rey, El Segundo, and Torrance fields. The black, oily, bituminous matrix in which the phosphate occurs is identical in appearance with the basal black shale member of the overlying D division. The lithologic contact between this basal black shale of Division D and the underlying nodular shale appears to be gradational in the Playa del Rey and Torrance fields, as there is a gradual increase in the amount of phosphatic material present. On the other hand, there is an unconformity at the top of the nodular shale at El Segundo. At Wilmington it is conformably overlain by sand.

Foraminifers are present throughout much of the nodular shale interval, but the majority are so poorly preserved that specific determination is impossible. Lower Mohnian foraminifers of the *Baggina californica* zone are present in a lithologically similar phosphatic shale outcropping at the base of the Modelo in the Santa Monica Mountains, west of Stone Canyon reservoir. Definite lower Mohnian species of the *Bulimina uvigerinaformis* zone have been found in the lower part of the nodular shale in various wells at Playa del Rey and El Segundo. Similar lower Mohnian foraminifers of the *Bulimina uvigerinaformis* zone occur throughout the cored phosphatic shale interval at Inglewood and from a point near the top of the nodular unit to the base at Wilmington. Only a few identifiable species have been found in the nodular shale at Torrance.

Since these lower Mohnian foraminifers are restricted to the nodular shale, the top of the E division has been placed somewhat arbitrarily at the top of this lithologic unit. It is possible that the contact between the upper and lower Mohnian actually comes within the phosphatic shale unit at Playa del Rey since the lower Mohnian species found so far appear to be limited to the lower part of the shale. It is equally possible, however, that they may be present throughout the shale as at Wilmington but in such a poor state of preservation as to be unrecognizable.

The nodular shale in the Playa del Rey, El Segundo, and Torrance fields is conformably underlain by a basal marine conglomerate or ''graywacke'' containing sand and abundant detrital fragments of schist up to several feet in diameter. This schist-conglomerate carries a molluscan fauna of upper Miocene age which has been correlated (Corey, W. H. 36, p. 152) with that found in the basal Modelo conglomerate or ''graywacke'' (Hoots, H. W. 31, p. 105) of the Santa Monica Mountains. Since the basal conglomerate of the Santa Monica Mountains constitutes the basal unit of the type Mohnian section (Kleinpell, R. M. 38, p. 127) the schist-bearing conglomerate of these oil fields is included in faunal Division E.

At Playa del Rey, El Segundo, and Torrance the schist-bearing conglomerate rests unconformably upon the underlying Franciscan schist. At places along the crest of these old schist highs, the basal conglomerate is missing, and the overlying nodular shale rests directly upon the Franciscan. The nodular shale ranges in thickness from 60 to 140 feet at Playa del Rey; from 16 to 106 feet at El Segundo; and from 46 to 78 feet at Torrance. It is approximately 60 feet thick at Wilmington and is about 100 feet thick at Inglewood. The conglomerate ranges from 0 to 290 feet at Playa del Rey; from 0 to 160 feet at El Segundo; and from 0 to 35 feet at Torrance. This basal schist-conglomerate is the lower oil-producing horizon at Playa del Rey and the only productive interval at El Segundo; it is barren at Torrance.

Huntington Beach is the only other west side field in which the E division has been penetrated. Instead of the nodular shale and schist-bearing conglomerate, the section is represented by the lower Puente shale member. It consists of hard, dense, massive, chaetura drab, argillaceous shale; banded, thick platy, chaetura drab and gray shale; and platy and semiplaty, dense, black, micaceous shale. Occasional thin streaks and spots of phosphatic material are associated with the banded and platy shale. Fish scales are common, carbonized plant remains are locally abundant, and foraminifers are relatively rare. One well penetrated approximately 1,350 feet of this shale before entering the underlying Topanga formation.

On the eastern side of the Basin, the lower Puente shale has been completely penetrated at Richfield where it consists of 1,300 feet of hard, dense, dark chateura drab, platy shale with a few sand units in the upper part. Occasional thin layers and spots of phosphatic material occur in the lower part. Foraminifers are rare. A highly altered greenish-gray igneous intrusive was encountered near the base of the shale. Somewhat similar diabase intrusions may be seen in outcrop in the lower Puente shale in the vicinity of the old Puente oil field. All of the wells of the latter field were drilled in the lower Puente shale. No samples were available for study, but one of these wells is reported to have bottomed in the lower Puente after having been drilled to a depth of 5,827 feet. The oil production apparently comes from fractured shale. Wells are small but have proved extremely long lived. A few barrels of oil have been produced from sands in the lower Puente shale member by several wells near the town of Puente, Los Angeles County, California, and by a well on the northeastern flank of the Puente Hills approximately 6 miles south of the town of Chino, San Bernardino County.

CORRELATION OF THE UPPER MIOCENE SUBSURFACE SECTION WITH OUTCROP SECTIONS

Upper Miocene rocks are exposed in all of the ranges of hills bounding the Los Angeles Basin. Outcrop sections in some of these areas have been sampled and studied in detail. The relation of the more important surface exposures to the subsurface section is considered below.

The Palos Verdes Hills on the western margin of the Basin, just southwest of the Torrance and Wilmington oil fields, are composed principally of Miocene shale. Woodring and Bramlette (Woodring, Bramlette, and Kleinpell 36), who have mapped the area, recognized five major lithologic units; a basal silty shale; a porcellaneous and cherty shale; a phosphatic, bituminous shale; a diatomite; and an upper radiolarian mudstone; with a total thickness of 2,500 feet. They designated the three lower units the Altamira shale member of the Monterey formation; the next higher, the Valmonte diatomite member; and the upper, the Malaga mudstone member. The upper, phosphatic shale unit of the Altamira is lithologically similar to the phosphatic nodular shale of the west side oil fields. Furthermore, it is characterized by the same lower Mohnian foraminiferal assemblage. In the type area this phosphatic shale unit has an average thickness of 150 feet (Woodring, Bramlette, and Kleinpell 36, p. 139), which is approximately the same as that of the nodular shale of the Playa del Rey field. In the Point Fermin area, the phosphatic shale is interbedded with coarse-grained sand carrying slabs and brecciated fragments of glaucophane schist. The Point Fermin schist-bearing sand occupies the same general stratigraphic position as the basal schist-bearing conglomerate of Division E of Torrance, El Segundo, and Playa del Rey, and is undoubtedly of the same approximate age.

The Valmonte diatomite of the Palos Verdes Hills has an estimated thickness of 750 feet (Woodring, Bramlette, and Kleinpell 36, p. 143). Associated with the diatomite in the eastern part of the hills are upper Mohnian foraminiferal assemblages of the *Bolivina hughesi* zone (Woodring, Bramlette, and Kleinpell 36, p. 145). Kleinpell's Peck Park assemblage from U. S. G. S. Locality No. 20 (Woodring, Bramlette, and Kleinpell 36, p. 144) near the middle of the Valmonte is equivalent to a marker horizon which comes from 200 to 400 feet below the top of Division D in the west side fields. Thin laminae of fairly pure diatomite are frequently present in the platy shale of Division D in the Torrance, Wilmington, and El Segundo fields. Much of the shale of the upper half of Division D is more or less diatomaceous in the Torrance area, but nowhere in the Basin fields are thick beds of pure diatomite encountered similar to those that are mined commercially along the northeastern slope of the Palos Verdes Hills.

The Malaga mudstone member is about 300 to 600 feet thick in the Palos Verdes Hills (Woodring, Bramlette, and Kleinpell 36, p. 147). It consists of massive, fine-grained, dark brown siltstone and radiolarian mudstone with a few laminated diatomite beds. Both radiolaria and diatoms are fairly abundant, but abundant foraminifers have been found at only one locality. The faunal assemblage from this locality (U. S. G. S. Locality No. 24, Woodring, Bramlette, and Kleinpell 36, p. 148) is of lower Delmontian age and is similar to that of Division C of the subsurface section. Although lithologically identical facies are not present in the well section, the Locality 24 assemblage, together with the conformable relationship between the Malaga mudstone and the subjacent Valmonte diatomite, would seem to fully substantiate the correlation of the Malaga member with Division C.

In the Santa Monica Mountains at the northwest margin of the Basin, some 5,000 feet of upper Miocene rocks of the Modelo formation unconformably overlie older Miocene and pre-Miocene strata (Hoots, H. W. 31, p. 102). The Modelo consists of two lithologic members. The lower, with a maximum thickness of 2,750 feet, is composed of alternating units of hard, platy, opaline, and soft, earthy shale interbedded with coarse gray and brown sandstone. Phosphatic shale occurs at the base of this lower member near Stone Canyon reservoir and at other scattered localities. In much of the area there is a fossiliferous basal conglomeratic "graywacke." The upper member is primarily soft, white, punky, diatomaceous shale. Although the most complete exposures are along the northern flank of the mountains, portions of the lower Modelo outcrop in a narrow band north and west of the Beverly Hills oil field. The greater part of the formation is exposed along Topanga Canyon Boulevard north of Mohn Springs. This section, which was first described by Hoots (31, p. 103) and was later chosen by Kleinpell (38, p. 127) as the type section for the Mohnian stage of the upper Miocene, has been sampled and studied in detail. Hoots recognized 19 lithologic units, of which 1 through 12 formed his lower Modelo member, and 13 through 19 his upper.

Kleinpell chose Hoots' units 1 through 16 as the type for the Mohnian stage. The Foraminifera of Hoots' units 1 through 5 are representative of the lower half of Division E of the subsurface section, and those of units 6 through 8, the upper half. The foraminiferal assemblage of unit 9 is equivalent to that of the lower half of Division D of the well section. Units 10 through 17 are relatively unfossiliferous. Kleinpell arbitrarily placed the contact between the Mohnian and Delmontian at the top of unit 16. On this basis units 10 through 16 are correlative with the upper part of Division D. From a lithologic standpoint it is possible that unit 17 might likewise be included in Division D. Unit 18 carries definite lower Delmontian foraminifers similar to those found in the lower part of Division C in the well section. Unit 19 is not exposed along Topanga Canyon Boulevard and was not sampled. On the basis of stratigraphic position it must be representative of portions or all of Divisions B and A of the well section.

To the east of the Santa Monica Mountains in the city of Los Angeles, just south of the old Los Angeles City oil field, and in the Repetto Hills farther to the east, uppermost Miocene of Division A conformably [9] underlies the lower Repetto. In mapping the Los Angeles City area, Arnold (Eldridge and Arnold 07, map, p. 144) included the upper 2,500 feet of this Los Angeles City Miocene in the Fernando formation.

Eldridge (Eldridge and Arnold 07, Pl. X, p. 102) and later English (English 26, p. 40 and map, Pl. I) introduced a similar error in mapping the Miocene-Pliocene contact in the Whittier Hills area near the northwestern end of the Puente Hills. They placed the contact at the top of a brown sandstone outcropping approximately a quarter of a mile north of the Turnbull Canyon road just northeast of the town of Whittier. In a paper presented before the 1936 annual fall meeting of the Pacific Section of the American Association of Petroleum Geologists, M. L. Krueger (36) pointed out that each of the previous workers had included a maximum of 3,800 feet of upper Miocene shales, sands, and conglomerates in the lower part of the Fernando formation of supposed Pliocene age. For these upper Miocene sediments Krueger proposed the name Sycamore Canyon formation. The Sycamore Canyon formation is a mappable unit which may be distinguished in the field by the occurrence of numerous cobble conglomerates. In outcrop this lithologic facies is confined to the area north of the Whittier fault.

In the type area the Sycamore Canyon unconformably overlies middle Puente sandstone which in turn rests upon lower Puente shale carrying lower Mohnian foraminifers of Division E of the subsurface section. A sample from one horizon 1,035 feet below the top of the Sycamore Canyon formation contains an excellent upper Mohnian foraminiferal assemblage equivalent to the upper part of Division D of the well section. Foraminifers were probably originally fairly abundant in the higher strata, but, unfortunately, due to surface weathering, only a few poorly preserved impressions, limonitic casts, and unidentifiable spots remain. Therefore, it is impossible to determine where the top of Division D comes within the type Sycamore Canyon section and whether Divisions A, B, and C are represented. Undoubtedly Division D extends upward 100 feet above the abundant foraminiferal horizon to the base of the prominent conglomerate exposed on the north side of Sycamore Canyon. It is possible that this conglomerate may mark a hiatus within the type Sycamore Canyon section as there is insufficient interval between the base of this conglomerate and the Repetto for the remainder of Division D and all of Divisions C, B and A. On the other hand the nature of the contact between the Sycamore Canyon and the overlying Repetto is not definitely known. That it is probably unconformable is suggested by a lack of definite lower Repetto foraminifers in the superjacent strata, and further, by the fact that there is a definite hiatus at the Miocene-Pliocene contact in the East Montebello field.

In the area north of La Habra, the Sycamore Canyon formation unconformably overlies the upper Puente shale which in turn rests upon middle Puente sandstone. Here identifiable foraminifers are relatively scarce in shale exposures of both the Sycamore Canyon and upper Puente formations. However, a well preserved foraminiferal assemblage of upper Mohnian age, equivalent to Division D of the subsurface section, was found in crumpled upper Puente shale at one locality along the Hacienda Canyon road. Intermittent core samples throughout the lower two-thirds of the Sycamore Canyon formation and almost the entire upper Puente were available from a well in this same area. Foraminaferal assemblages of Division C and the upper part of D were present in the Sycamore Canyon core samples from this well. Slightly older Division D foraminifers were found in the core samples from the upper Puente shale.

In the eastern portion of the Puente Hills English (26, pp. 37-38 and map, Pl. I) included in the upper Puente sediments containing several shale, sand, and conglomerate members; these shales carry upper Miocene foraminiferal assemblages representative of faunal divisions A, B, C, and D of the subsurface section. Krueger considers the strata containing Divisions A, B, C, and the upper part of D in this area the equivalent of his Sycamore Canyon formation.

From the foregoing it appears that faunal Divisions A, B, and C, as well as the upper part of D, of the subsurface section are the correlative of Krueger's Sycamore Canyon formation. Since Divisions A, B, and C are not recognizable in the type area of the Sycamore Canyon formation and sufficient surface samples containing identifiable foraminifers are not available to definitely determine where in Division D the Sycamore-upper Puente contact should be placed, the entire upper Miocene of the subsurface section has been referred in this paper to the Puente formation.

Sections of the lower Puente shale have been sampled in several areas in the Puente and San Jose Hills. This shale contains well-developed foraminiferal assemblages of the *Bulimina uvigerinaformis* and the *Baggina californica* zones of the lower Mohnian. Therefore, as previously noted, the lower Puente shale member is stratigraphically equivalent to Division E of the well section. On the basis of stratigraphic position, the middle Puente sandstone is considered to be equivalent to the lower part of Division D of the well section.

[9] *See* footnote 6.

MIDDLE MIOCENE

Division F

Middle Miocene strata of Foram Division F, carrying Luisian foraminifers of the *Valvulineria californica* zone, have been cored in the Wilmington and Inglewood fields. One Wilmington well located near the crest of the structure in the southwestern part of the field penetrated approximately 130 feet of these middle Miocene sediments before entering the underlying Franciscan schist. The section consists of about 35 feet of dark grayish-brown, hard, semiplaty, silty, micaceous, foraminiferal shale underlain by nearly 95 feet of coarse pebbly sandstone containing schist fragments. That the contact between the foraminiferal shale of Division F and the overlying phosphatic shale of Division E is unconformable is suggested by the rather distinct lithologic change and abrupt faunal break. The *Baggina californica* fauna which normally immediately overlies the middle Miocene is missing as is the uppermost middle Miocene fauna.

The micaceous, foraminiferal shale of Division F is not present in the northwestern part of the Wilmington field, nor has it been encountered in the Long Beach Harbor district. In these areas wells pass from the phosphatic shale of Division E directly into an unfossiliferous, schist-bearing basal sandstone.

An Inglewood well located on the southwest flank of the structure drilled 400 feet into middle Miocene strata of Division F. Here the phosphatic shale of Division E rests upon 67 feet of highly altered, tuffaceous, volcanic rock containing numerous phenocrysts of calcite and bentonitic material in a bluish-gray groundmass of bentonitic clay, plagioclase feldspar of the oligoclase-andesine group (An20 - An40), and secondary pyrite with very minor amounts of chlorite. The basal 27 feet of this volcanic tuff is interbedded with shale and oil sand. Beneath the tuff is a 333-foot interval 52 percent of which is hard, medium- and coarse-grained sandstone and 48 percent dense, brownish-black, micaceous shale. Luisian foraminifers of the *Valvulineria californica* zone were found in the shale. Because of the interbedded nature of the contact between the volcanics and the subjacent shales, the top of Division F in the Inglewood well is taken at the top of the tuff. Since basal lower Mohnian and uppermost Luisian foraminifers are missing, the contact bebetween the tuff and the superjacent phosphatic shale of Division E is believed to be unconformable.

This Inglewood well came in for an initial production of approximately 360 barrels per day with the casing cemented near the base of the nodular shale. Although at present the well is only a small producer, it is important since it is the first in the Los Angeles Basin area to obtain oil in commercial quantities from the middle Miocene.

Some geologists correlate the Division F sediments of the Inglewood field with the Topanga formation which unconformably underlies the Modelo of the Santa Monica Mountains. As originally defined (Kew, W. S. W. 23) the Topanga included the strata between the Vaqueros and the Modelo formations. There are three main lithologic units (Hoots, H. W. 31, pp. 94-96); a lower, coarse conglomerate member, a middle unit of conglomeratic sandstone, basalt, and gray shale, and an upper unit of thin bedded shale and sandstone. An upper Relizian faunule of lower middle Miocene age has been found in a shale (Hoots, H. W. 31, p. 99) interbedded with the basalt of the middle unit. As far as is known, no foraminifers have been found in the upper member of the Topanga. While it is possible that this upper member may be in part Luisian in age, it is questionable, in view of the prominent angular unconformity between the Topanga and the overlying Modelo, whether a correlation with the Inglewood middle Miocene is warranted. On the other hand, this Inglewood section may be directly correlated with Luisian strata of the middle Altamira shale member of the Monterey formation of the Palos Verdes Hills. Hence, in this paper the Inglewood strata of Division F are referred to the Monterey formation.

There are several tuff beds associated with the middle Altamira shale member of the Palos Verdes Hills (Woodring, Bramlette, and Kleinpell 36, pp. 133-135). One of these, the Miraleste tuff, which may be traced along most of the northern flank of the hills, is from a few inches to 6 feet thick. Two others in the western part of the hills, one a 60-foot bentonitic tuff at La Venta Inn in the Malaga Cove district, and the other a 40-foot tuff near Lunada Bay, closely approach in thickness the tuff of the Inglewood well. It is probable that some one of these middle Altamira tuffs is equivalent to that of Inglewood since all occur in the same general time-stratigraphic unit.

OLDER MIOCENE AND OLIGOCENE(?)

A 1,700-foot interval of coarse- to medium-textured, hard, whitish, calcareous, granitic sandstone interbedded with unfossiliferous, dense, dark chaetura drab, micaceous, argillaceous, shale was cored beneath the lower Puente in the Huntington Beach field. R. B. Hutcheson [10] has correlated this interval with the Topanga formation.

Approximately 975 feet of definite Topanga sediments unconformably underlies the lower Puente at Richfield. The section consists of hard, coarse- to medium-grained, gray and greenish-gray sandstone interbedded with a few sandy shale units. A basal 90-foot shale interval carries a Saucesian foraminiferal fauna equivalent to that of the lower part of the Media shale member of the Temblor formation of the west side of the San Joaquin Valley and identical to that found at the top of the Freeman silt of the east side of the San Joaquin Valley. It is probable, therefore, that the overlying sandy portion of the Topanga represents the Olcese sand interval of the valley. Hence, the Topanga is in part Saucesian and in part lower Relizian in age. Conformably underlying this basal Topanga shale of Richfield is 150 feet of coarse-textured, greenish-colored, lower Miocene sandstone of the Vaqueros formation. Approximately 600 feet of similar middle and lower Miocene sediments of the Topanga and Vaqueros formations (English, W. A. 26, p. 25) are exposed beneath the overlapping lower Puente shale along the northwestern flank of the Santa Ana Mountains just south of Richfield. Approximately 1,200 feet of non-marine Sespe red beds of Oligocene (?) age have been penetrated below the Vaqueros at Richfield.

[10] Personal communication.

Similar Sespe red beds (English, W. A. 26, p. 23) conformably underlie the Vaqueros in the Santa Ana Mountains area.

No oil has been produced to date from any of these older Miocene or Oligocene formations.

CORRELATION CHART OF LOS ANGELES BASIN OIL FIELDS

This paper is accompanied by a straight line correlation chart (Plate V) showing the productive zones of the major Los Angeles Basin oil fields. Some of the older and less important fields, those of the Los Angeles City area, Beverly Hills, the Whittier fields, Brea-Olinda, Puente, Kraemer, and Newport Beach, have been omitted for lack of sufficient data. The columns for the various fields are arranged from left to right in accordance with their geographic positions from north to south in their respective lines of folding. The producing zones indicated on the chart represent those intervals which to the writer's knowledge yield or have yielded oil. The approximate average percentage of sand and shale for each producing zone is likewise shown. In figuring these percentages, conglomerates have been treated as sands, and no distinction has been made between sands of high and low permeability. Formations and foraminiferal zones are indicated at the extreme right and left of the chart. There is no vertical scale for the individual fields. Instead, the top and the bottom of each producing zone and of the overlying capping or shut-off shale have been placed in their correct stratigraphic positions with respect to the faunal subdivisions in which they occur. In some of the fields it was not possible to locate all of the horizon markers within the upper Miocene. Producing intervals in these fields were located on the chart within their respective faunal divisions in accordance with their relative position between the two nearest recognizable markers.

STRATIGRAPHIC VARIATION CHARTS

While the straight line correlation chart indicates the approximate average percentage of sand and shale for each producing interval, and Table No. 3 gives the general sand percentage for each major faunal division, lithological changes within the different faunal divisions are best illustrated by the accompanying stratigraphic variation charts (figures 90-94). The original plan for these charts was to present for each field a large-scale columnar section showing every individual foraminiferal subzone and minor lithologic unit. As it was impossible to reduce these larger detailed columnar sections sufficiently for inclusion in the paper, it was necessary to group the sand and shale intervals of each field into what appeared to be natural lithologic units for that field without regard to the faunal sequence. The sand-shale percentage of each of these natural lithologic units, with correlation lines joining the respective foraminiferal zones, is shown diagrammatically on the charts. Repetto foraminiferal subzones and Miocene foraminiferal horizons markers have of necessity been omitted.

PLAYA DEL REY-WILMINGTON FIELDS

The fields of the Playa del Rey-Wilmington line follow two general structural trends arranged somewhat en echelon. The fields are similar in that all are underlain by Franciscan schist. The most northerly field, Playa del Rey, has two producing zones. The upper originally extended from near the top of Repetto Foram Zone 4, Subzone 3 to the top of Repetto Foram Zone 8, Subzone 5. None of the corresponding sands within this interval have been productive in the El Segundo, Lawndale, or Torrance fields, notwithstanding the fact that Repetto sands within this part of the section are almost universally productive in other fields of the Basin. The lower production at Playa del Rey is from the basal conglomerate of Division E and from the weathered and fractured surface of the underlying Franciscan schist. All of the oil produced by the El Segundo field comes from this basal conglomerate and fractured schist. The few producing wells of the Lawndale area obtain their oil from the upper part of Division A. Wells of the Redondo Extension of the Torrance field produce from minor sand streaks which range stratigraphically from a horizon near the top of Repetto Foram Zone 17 almost to the base of Miocene Division A. The upper production of the main Torrance field, the second most important field of the group, comes from sands extending from near the top of Miocene Foram Zone 3, Division A, to a short distance below the top of Division B. The cementing point for the water string of the older upper zone wells has varied stratigraphically from a point near the base of Repetto Foram Zone 12 to below the top of the Miocene. Our data indicate that a few thin lenticular streaks of oil sand with an aggregate thickness of less than 10 feet are frequently encountered within this interval. Since it is doubtful that these minor sand streaks have had any appreciable influence upon the production, they have not been included in the upper producing interval shown on the straight line correlation chart. The lower zone, the Del Amo, which is located within the upper part of Division D, is productive in the Lomita-Harbor City area. A few wells have attempted to obtain production from sand intervals between the upper and lower zones. Several of these have been short-lived small producers.

The Wilmington field, the most important producer of the line, is separated from Torrance by a structural saddle. Although the field is located along the same structural trend as Torrance, in lithology and stratigraphic range of the producing intervals it more nearly resembles fields of the Inglewood-Newport uplift. The anticlinal structure is complicated by a series of transverse normal faults which have resulted in the formation of five major structural blocks within the present producing limits of the field. In accordance with the terminology in general use in the field, there are four main producing zones. However, from a production standpoint there are actually seven, as all of the Wilmington operators recognize an upper and lower Tar zone, an upper and a lower Ranger zone, and an upper and a lower Terminal zone, plus a deeper zone, the Ford. The six upper zones, which are separated from one another only by intervening impervious shale bodies, range stratigraphically from the upper part of Repetto Foram Zone 7 to slightly below the top of Miocene Division C. The deepest zone, the Ford, extends from the lower part of Division C through the upper third of Division D. To date all of the Ford zone wells have been located on the two westerly blocks. The thickness of the Repetto sands varies considerably between adjoining fault blocks. While it has been suggested that this variation, particularly noticeable on the down-thrown blocks, indicated progressive faulting and folding during the deposition of the Repetto (Winterburn, R. 40, p. 6), it is more likely due primarily to differential horizontal displacement along the faults as there is a rapid regional thickening down dip toward the northeast.

The general lithology of the Playa del Rey-Wilmington fields has been considered under the discussion on stratigraphy. The lithologic variation between the four principal fields is illustrated graphically on figure 92. A study of this chart fails to reveal any apparent reason for the diverse stratigraphic distribution of the oil-producing intervals of these fields.

Playa del Rey-Wilmington Unconformities

There are a number of unconformities indicated upon the stratigraphic variation chart for the Playa del Rey-Wilmington fields. The oldest of these, which comes at the top of the Franciscan schist, is unquestionably erosional as the schist surface must have been above sea level for a long period of time prior to middle Miocene. During the middle Miocene the sea gradually encroached from the southwest over the area now occupied by the Palos Verdes Hills until, by early upper Luisian time, it had transgressed over what are now the Wilmington and Inglewood oil fields. Apparently this transgression was followed by a short period of local emergence and erosion, resulting in the unconformity between Divisions E and F. This hiatus continued through early lower Mohnian time, since earliest lower Mohnian sediments as well as uppermost Luisian are missing in the Wilmington and Inglewood fields.

Following this emergence the sea advanced considerably beyond the present boundaries of the Basin, and a long period of deposition began. The thin veneer of weathered clastics covering much of the old schist surface in the Playa del Rey-Torrance region was reworked

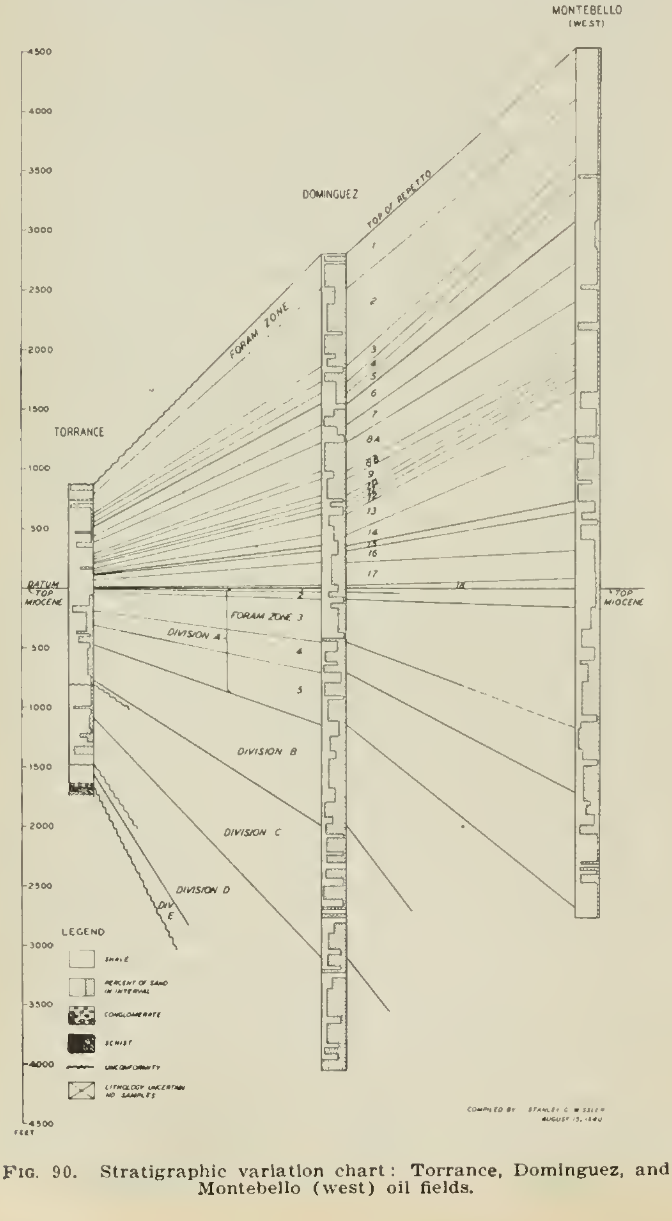

Fig. 90. Stratigraphic variation chart: Torrance, Dominguez, and Montebello (west) oil fields.

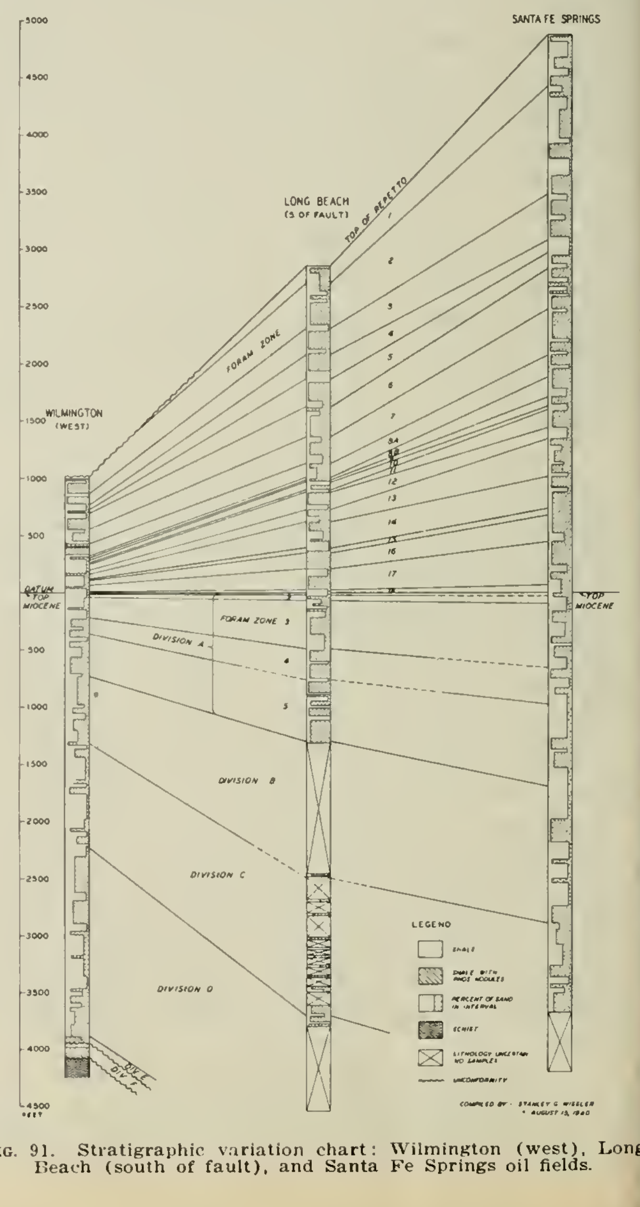

Fig. 91. Stratigraphic variation chart: Wilmington (west), Long Beach (south of fault), and Santa Fe Springs oil fields.

to become the basal conglomerate of Division E. Black mud and phosphatic material gradually accumulated above the conglomerate to form the overlying nodular shale. In early upper Mohnian time, following the deposition of the basal sediments of Division D, the Playa del Rey, El Segundo, and Torrance structures started to develop. This orogeny lifted the present axial area of the Torrance field, the greater part of the El Segundo structure, and much of the Playa del Rey region above the general level of the sea floor. Deposition ceased over these uplifted areas, and some local submarine erosion apparently took place, particularly on the El Segundo structure. This produced the unconformity within the lower part of Division D at Torrance, at the top of Division E at El Segundo, and at the top of lower D at Playa del Rey. Meanwhile, deposition appears to have been continuous in the Wilmington area and upon the flanks of the Torrance and El Segundo structures, where the hiatus is represented by some 700-900 feet of sediments. The crest of the Torrance anticline was gradually overlapped during the deposition of the upper strata of Division D. Some 300 feet of upper D was deposited over the southeastern flank of the El Segundo structure while the crest was completely overlapped by the basal sediments of Division C. The hiatus continued in the Playa del Rey area until late Miocene time when deformation temporarily ceased, and the uplift was overlapped by upper Miocene sediments of Division A. A later period of deformation resulted, in the Torrance and El Segundo fields, in an unconformity within the upper part of Division C. During this hiatus some 500 feet of additional sediments accumulated along the flanks of these structures. Apparently deposition was continuous over the main part of the Wilmington area throughout this later hiatus and until middle Repetto time. Following the deposition of Repetto Foram Zone 8B, the highest part of the Wilmington structure was lifted above the general sea floor, resulting in a minor unconformity which is particularly noticeable in the Long Beach Harbor area. As the apex of the structure is approached, progressively younger Repetto Foram Zone 8A sediments rest upon Foram Zone 8B strata until, near the present southern boundary of the field, Repetto Foram Zone 7 shales rest directly upon Zone 8B. This lower Pliocene orogeny did not materially affect the Torrance structure although its presence in the Malaga Cove area to the southwest is indicated by the absence of all of the strata between the lower part of Repetto Foram Zone 6 and Repetto Foram Zone 12. A still later deformation during early middle Pico time resulted in the removal of all of the lower Pico and the uppermost Repetto strata from the crest of the Torrance-Wilmington anticline. The area was then overlapped by middle Pico sediments which are separated by an additional rather widespread unconformity from the superjacent upper Pico. Finally there are several unconformities within the Pleistocene of the Palos Verdes Hills, some of which probably extend over the Torrance-Wilmington area.

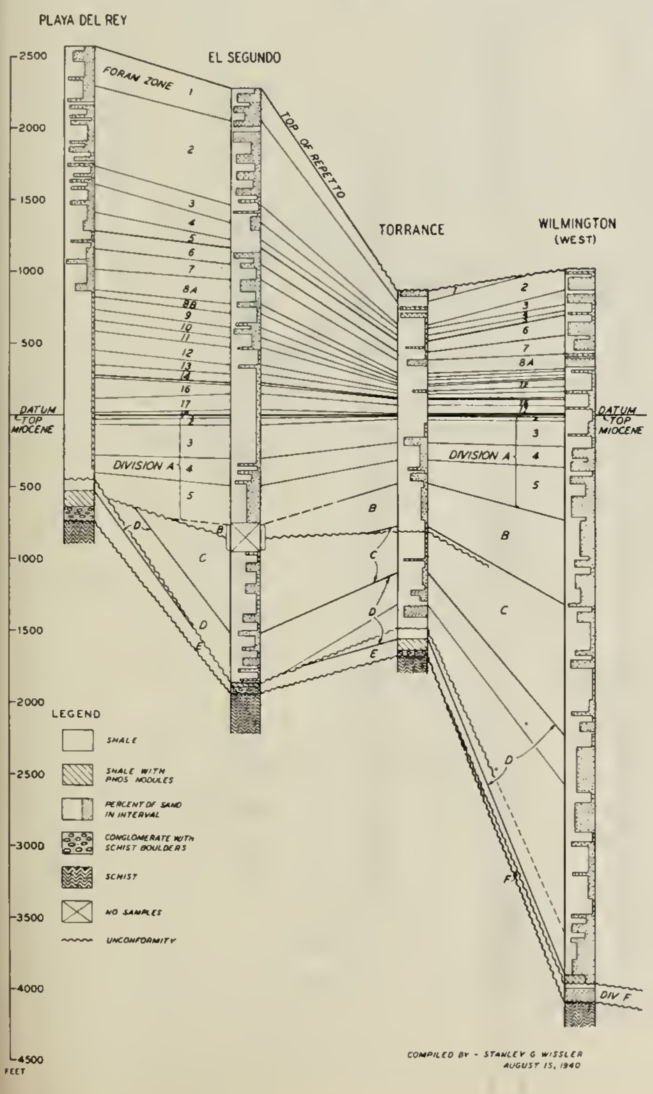

Fig. 92. Stratigraphic variation chart: Playa del Rey, El Segundo, Torrance, and Wilmington (west) oil fields.

INGLEWOOD-NEWPORT FIELDS

The fields of the Inglewood-Newport uplift consist of a series of faulted domes en echelon arrangement along the deep-seated Inglewood-Newport fault zone; a fault zone which may well represent the line of demarcation between the metamorphic basement rock on the west and the granitic basement rock on the east. With the exception of two minor fields, Beverly Hills and Newport, the producing intervals are indicated on the straight line correlation chart. The reservoir sands range stratigraphically from the lower part of the middle Pico into the upper part of the middle Miocene. In a number of the central fields of the uplift, sands overlying the oil zones carry "dry" gas. No attempt has been made to indicate these "dry" gas sands on the correlation chart. While there is considerable variation between individual fields in the stratigraphic range of the producing intervals, the difference is less marked than in the fields of the Playa del Rey-Wilmington trend. The distinction between the different oil zones is in most cases more or less arbitrary since, with the exception of Potrero and Athens, a well drilled near the top of any one of the main structures in the early days of development would have encountered a vertically continuous series of oil-bearing sands, interrupted only by intervening shales, from the top of the first producing sand to the basal part of the B division of the upper Miocene. Such a well drilled in the Long Beach field would have penetrated a 6,300-foot interval of oil-bearing strata, 65 percent of which is reservoir sand; an interval ranging from the lower part of the middle Pico through the upper third of Miocene Division C, with a still deeper zone, the De Soto, extending through the upper third of Division D. It is not surprising, therefore, that the Long Beach field had produced to January 1, 1940, a total of 636,066,820 barrels of oil; approximately 25 percent of the total oil production of the Los Angeles Basin and 11 percent of the total production of the State. In addition to Long Beach, two other fields, Inglewood and Potrero, produce from middle and lower Pico as well as high upper Repetto sands. The first productive sands of the Huntington Beach field are encountered at the top of Repetto Foram Zone 2. Sands above Subzone 8 of Repetto Foram Zone 2 are not productive in other fields of the line. The saturation of the higher upper Repetto and Pico sands may be explained by upward migration along fault planes which intersect the lower reservoir sands of the aforementioned fields. On the other hand, saturated sands are not encountered in the Seal Beach field until Foram Zone 7 in the middle Repetto is

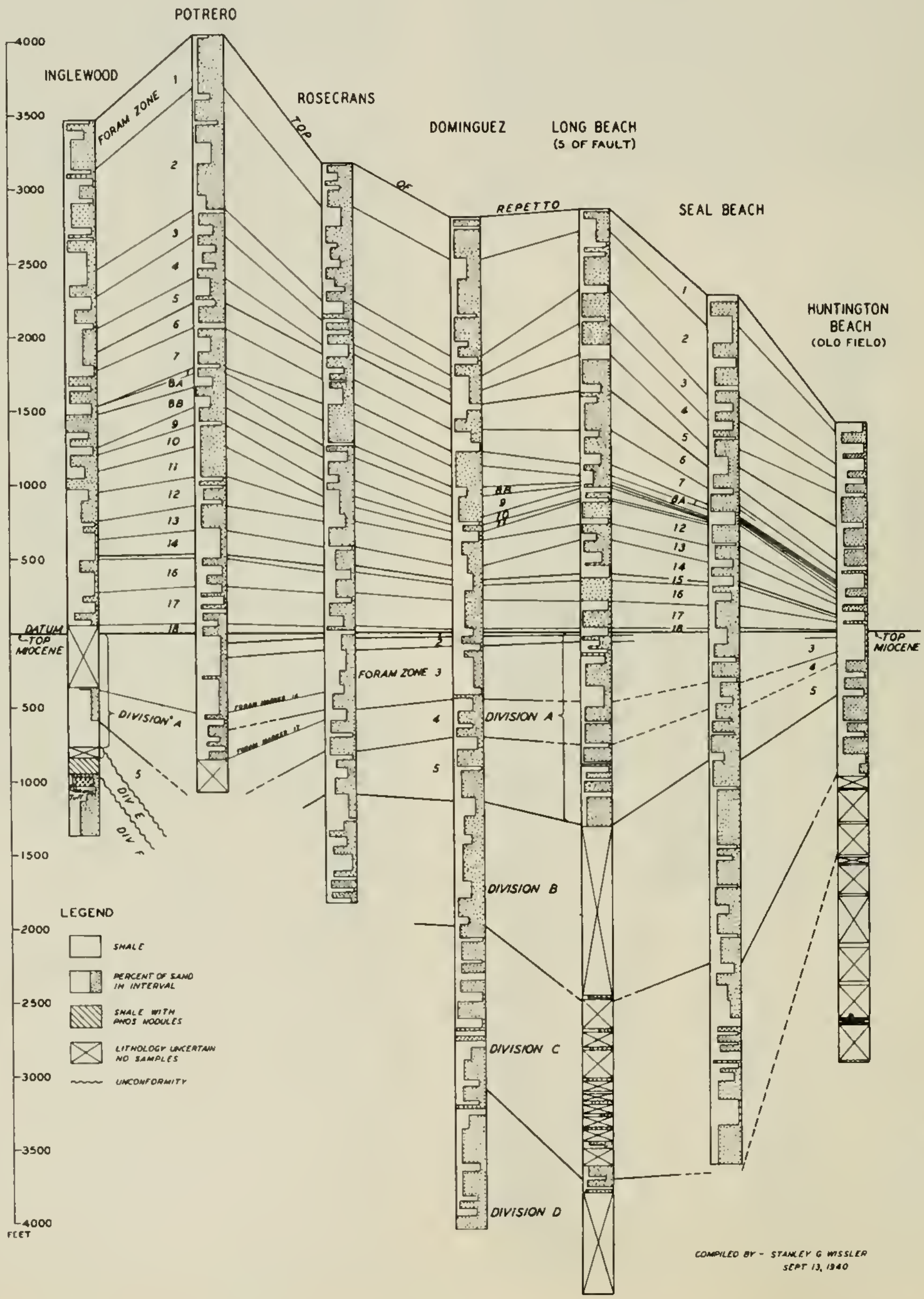

FIG. 93. Stratigraphic variation chart: Inglewood, Potrero, Rosecrans, Dominguez, Long Beach (south of fault), Seal Beach, and Huntington Beach (old field) oil fields.

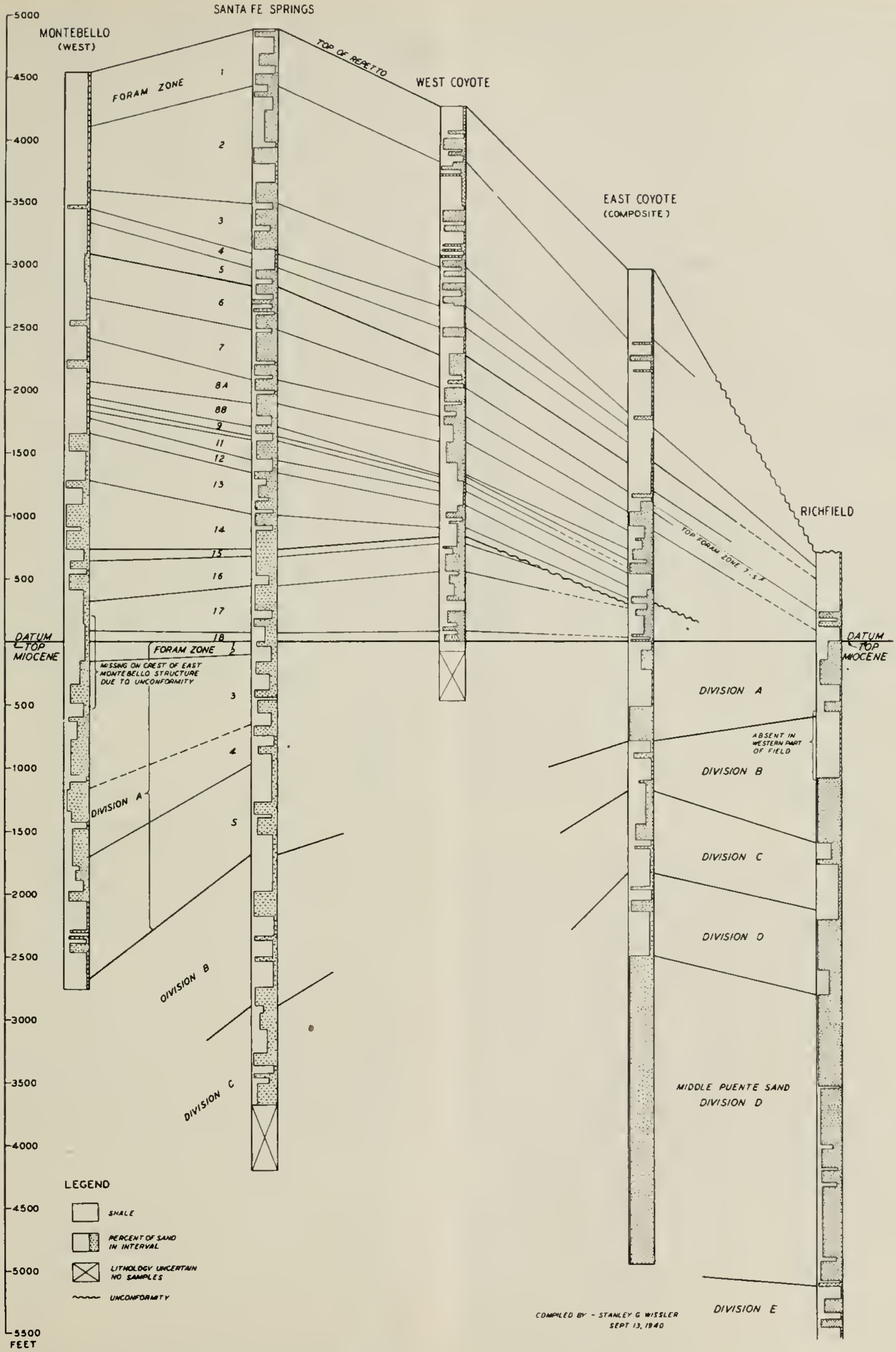

FIG. 94. Stratigraphic variation chart: Montebello (west), Santa Fe Springs, West Coyote, East Coyote (composite), and Richfield oil fields.

reached, although faulting in this field likewise extends to the surface. The failure of the Seal Beach fault to serve as a channel of migration to stratigraphically higher sands indicates a lack of permeability.

Separate columns are shown on the straight line correlation chart for four of the producing areas of the Huntington Beach field: the Old Field area, where oil was first discovered, the Main Street area, the Tidelands area, and the Five Points area. Columns were omitted for the Seventeenth Street (Townsite)-Barley Field area, and the Surf area. There were originally four producing intervals in the Seventeenth Street area. The first, the Tar zone, is equivalent to the Bolsa zone of the Old Field area. The second, the Jones sand, which is approximately 150 feet thick, comes just below the Pliocene-Miocene contact. A third, less productive interval, sometimes called the Middle or Upper zone, lies between the Jones and the Lower zone. It is approximately equivalent to the lower Ashton zone of the Old Field area. The Lower zone, the principal producer, is the same as the producing sand of the Tidelands area. The base of the capping shale overlying this Lower zone grades stratigraphically from a point above the middle of Miocene Division D to just below the top of the lower D division. It has been suggested by some that this sand-shale contact represents an unconformity. The samples available to the author indicate on the other hand that the contact is gradational, and it is so indicated on the column for the Tidelands area. Should more complete data prove the latter conclusion erroneous, the Lower zone sand would all come within the lower half of the D division and be the exact correlation of the middle Puente sandstone of the Richfield district. A few wells in the Surf area in the extreme southeastern part of the Huntington Beach field produce from the Surf zone, a zone apparently equivalent to the producing sand of the Tidelands pools.

The only core samples available from the Beverly Hills field, at the north end of the Inglewood-Newport uplift, represent very steeply dipping Division A upper Miocene strata from below the productive interval. According to information published by Hoots (31, pp. 132-133, Pl. 4), the productive beds are of Repetto age. The Newport field, at the south end of the uplift, was abandoned after producing less than 150,000 barrels of oil. There were two productive areas, the Mesa area and the Beach area. Production in the Mesa area was obtained from a few thin sand lenses in the north-dipping, upturned beds of the upper Miocene which are truncated by upper Pico (?) and lower Pleistocene sediments. The few productive wells in the Beach area likewise obtained their oil from the upper Miocene.

The lithologic variation within the upper Miocene and Repetto strata of the Inglewood-Newport fields is illustrated graphically on figure 93. The upper Miocene thickens from Huntington Beach to Long Beach and then thins gradually toward Inglewood where the greater part of the section is cut out by an unconformity. The Repetto thickens as a whole from Huntington Beach to Potrero and then thins slightly to Inglewood. The sand content increases from Huntington Beach to Long Beach and decreases gradually to Inglewood.

Certain intervals thicken and thin anomalously with respect to the regional behavior. There is a slight thinning in Repetto Foram Zones 1 and 2 from Seal Beach to Long Beach. Zone 2 thickens abruptly from Long Beach to Dominguez. Zones 3, 4, and 5 thin from Long Beach to Dominguez, thicken from Rosecrans to Potrero, and thin to Inglewood. Zones 6 and 7 thin slightly from Long Beach to Dominquez and Rosecrans and thicken to Potrero and Inglewood. The sands of Repetto Foram Zones 8 and 9 thicken gradually from Huntington Beach to Long Beach; thicken rapidly from Long Beach to Dominguez and gradually from Dominguez to Rosecrans; and then thin toward Potrero and Inglewood. Zone 12 thickens from Huntington Beach to Seal Beach, thins to Dominguez, and then thickens to Potrero and Inglewood. Repetto Foram Zone 14, which is particularly thick in Long Beach, thins by losing sand to Dominguez, whereas the overlying Zone 13 thickens by gaining sand. Some intervals which are predominantly shale in one field become so interbedded with sand in others as to be lithologically entirely unrecognizable; at the same time sandy intervals may became shale bodies, much to the chagrin of one who attempts to correlate solely by means of electric logs. The author recalls an instance in which an individual made what seemed from a comparison of the electric logs to be a perfectly logical correlation of two producing wells within one of the Basin fields only to find, when the paleontologist was consulted, that the correlation was in error some 1,500 feet. Similarly, the Brown shale of Long Beach frequently has been correlated with the Third Callender shale of Dominguez, a correlation which on lithology alone seems reasonable, but becomes absurd once the foraminiferal faunas are taken into account.

In the majority of the Inglewood-Newport fields stratigraphic thicknesses seem to vary considerably between different fault blocks. The Repetto of the Main Street area of Huntington Beach is thicker and more sandy than that of the Old Field area across the fault to the northeast. The Repetto section south of the fault in the Long Beach field is appreciably thicker than that north of the fault. Sections on opposite fault blocks in the Dominguez and Rosecrans fields likewise vary in thickness. In the Potrero field the basal middle Pico sand is 265 feet thicker on the west side of the main fault than on the east. These rather abrupt changes in thickness on opposite sides of the faults are frequently accompanied by appreciable differences in abundance and state of preservation of the microfauna. In such instances the lithology and thickness as well as the abundance and state of preservation of the foraminiferal assemblage on one side of a fault may closely match that of a relatively distant location on the opposite side. Therefore the author is of the opinion that, while some of these differences in thickness may be due to progressive movement contemporaneous with deposition, many of them are due to differential horizontal movement which has brought sections of different thicknesses and microfaunal character into juxtaposition.

Inglewood-Newport Unconformities

There are unconformities in the Inglewood field between Divisions E and F and between Divisions A and E. These same unconformities, and possibly one within the upper part of the C division, may be present in other fields of the line. There is more section present in Repetto Foram Zone 14 in some Seal Beach wells than others. This discrepancy may be due to a local depositional unconformity or to faulting. The somewhat anomalous thickening and thinning within the middle part of the Repetto in the fields of this line is probably related to the orogeny which produced the unconformity between Foram Zones 7 and 8B in the Long Beach Harbor area of the Wilmington field, and the hiatus within the middle Repetto of the Malaga Cove outcrop section. An unconformity separates the middle and the upper Pico in some of the central fields of the line. There is apparently an unconformity between the upper Pico and the Pleistocene in the Long Beach, Dominguez, and Rosecrans fields. Likewise, the contact between the San Pedro and the overlying Palos Verdes is generally assumed to be unconformable.

SANTA FE SPRINGS-RICHFIELD FIELDS

The Santa Fe Springs-Richfield fields follow two general en echelon lines of folding. Santa Fe Springs, at the western end of the line, has been the second most prolific producer of the Basin. Structurally it is a simple dome, apparently the only unfaulted dome of the Basin. The nine oil-producing zones range stratigraphically from the lower part of Repetto Foram Zone 2, Subzone 8, to just below the middle of upper Miocene Division A. Deeper non-commercial production has been obtained by one well from sands within the B division of the upper Miocene. The absence of faulting in this field confirms the implication made in discussing the occurrence of oil in fields of the Inglewood-Newport line, namely, that oil normally occurs as high stratigraphically as Subzone 8 of Repetto Foram Zone 2 and that all of the oil found in the Los Angeles Basin in younger strata may be explained by upward migration along faults from deeper reservoir sands.

West Coyote, the next field of the line, has four main producing zones with an upper, semicommercial sand in Repetto Foram Zone 2, Subzone 4, originally productive near the apex of the structure. Commercial production ranges stratigraphically from the top of Subzone 10 of Zone 2 about the middle of Zone 17, Subzone 2, with an intermediate, non-productive interval from the top of Repetto Foram Zone 8, Subzone 2, to the base of Zone 12. For the past year one well has produced from a deeper zone, the McNally, a 300-foot interval the top of which would seem to be located about 150 feet below the Pliocene-Miocene contact. Insufficient data were available to definitely place this interval within the upper Miocene section; hence, it has not been indicated on the straight line correlation chart.

The East Coyote field has four separate productive areas and six main producing horizons. Three of the different areas, the Hualde Dome, the Anaheim Dome, and the Yorba Linda district, sometimes called the Yorba Linda field, are shown on the straight line correlation chart. All six of the main producing zones are productive on the Hualde Dome at the western end of the field. They are the Hualde zone, the upper Anaheim zone, the lower Anaheim zone, the Second zone, the Third zone, and the Stern zone. The Hualde zone, which is productive only near the apex of the structure, is located in Repetto Foram Zone 2, Subzone 1. The upper Anaheim ranges from Repetto Foram Zone 4, Subzone 4 to the base of Subzone 2 of Zone 7. Of this interval, the upper portion is principally shale with numerous small, lenticular inclusions and thin streaks of fine sand. The main sand is in the lower part of Foram Zone 6 and the upper part of Foram Zone 7. The lower Anaheim extends from the top of Subzone 5 of Repetto Foram Zone 7 into the lower part of Zone 8, Subzone 3. The Second zone lies between the lower Anaheim and the Third zone. The base of the Second zone sand, which comes at the top of the Third zone shale, is not a fixed stratigraphic point since it varies from the top of Subzone 2 of Repetto Foram Zone 10 into Foram Zone 13, Subzone 4. The Third zone sand series extends from the lower part of Repetto Foram Zone 13, Subzone 4b to the Pliocene-Miocene contact. The Stern zone, originally discovered by an edge well some 10 years ago, is in process of development at the present time. It is located in the upper part of the D division, with the top of the producing sand approximately equivalent to the top of the Kraemer sand of Richfield.

On the Anaheim Dome commercial production is obtained from the upper and lower Anaheim zones. These two producing intervals are stratigraphically equivalent to the upper and lower Anaheim sands of the Hualde Dome except for the fact that the top of the main sand comes near the top of Repetto Foram Zone 6 rather than near the base. The Mathis and Wright sands, two thin sand bodies in the lower part of Division A, are productive near the eastern end of the dome. Near the crest of the structure a few semicommercial wells produced from a sand interval which ranges from the upper part of Repetto Foram Zone 10 into Zone 13, Subzone 4. A few other wells have obtained minor amounts of oil from intermittent sands ranging from the middle of Repetto Foram Zone 17 into the lower half of Division A of the upper Miocene. In the Carlton area at the extreme eastern end of the East Coyote field proper, a number of small wells produce from an interval averaging approximately 38 percent sand which is equivalent to the lower Anaheim. In the Yorba Linda district, which is probably a continuation of the East Coyote structure, there are two 75-foot sand bodies separated by a shale; some wells obtain oil from the lower sand and others from the upper. The entire interval, which averages approximately 68 percent sand, is stratigraphically equivalent to the lower Anaheim.

The Richfield field has two producing zones, the Chapman and the Kraemer, both of which are upper Miocene in age. The Chapman zone extends from the middle of Miocene Division A to the middle of Division C. In the eastern part of the field the Chapman zone is separated into an upper and a lower interval by an intervening shale body. Apparently due to unconformity this shale is absent in the western part of the field, and the two sands merge to form a single unit. The lower zone, the Kraemer, lies within the upper part of the D division and is separated from the underlying middle Puente sandstone member of the lower D division by 100 feet of shale.

There is a small producing area not included on the chart, known as the Kraemer field, which is located approximately 3 miles east of Richfield. The majority of the wells produce from an interval which is stratigraphically equivalent to the Chapman zone of the main field. However, one deeper well near the crest of the structure obtains production from the Kraemer sand equivalent.

Stratigraphic variation of the lower Pliocene and the upper Miocene strata between fields of the Santa Fe Springs-Richfield line is illustrated by the stratigraphic variation chart, figure 94. Since sufficient data were not available for the preparation of such a chart for all of the eastern marginal fields, a column for West Montebello was appended to the Santa Fe Springs-Richfield chart. The section shown for the East Coyote field is composite, the Repetto part of the column being taken from the Hualde Dome, the area in which development is at present most active, and the Miocene from the Anaheim Dome, since steep dips and faulting have been encountered by the deep Hualde Dome wells drilled to date.

The Quaternary, which is from 1,100 to 1,200 feet thick at Santa Fe Springs, thins rapidly to West Coyote and then thickens somewhat toward East Coyote. The upper Pliocene thickens from Santa Fe Springs to West Coyote and thins to East Coyote and Richfield. The lower Pliocene and upper Miocene thin regionally from Santa Fe Springs to Richfield. While a few individual faunal zones are slightly anomalous in this respect, as a whole both the upper and middle Repetto conform to this regional thinning and become more shaly toward the southeast. In contrast the lower Repetto thickens from Santa Fe Springs to West Coyote and then thins toward East Coyote where in the western part of the field the upper third of the lower and the basal part of the middle Repetto are cut out by an unconformity. All of the lower Repetto and the upper part of Division A of the upper Miocene are missing at this unconformity in the eastern part of East Coyote and in the Richfield field. Furthermore, only the lower portion of the upper Repetto and the upper part of the middle Repetto are present at Richfield. The upper Repetto, which is 49 percent sand at Santa Fe Springs, is predominantly shale at East Coyote and Richfield. In this respect East Coyote and Richfield resemble the eastern marginal fields, Montebello, Whittier, and Brea-Olinda, a resemblance readily explained by their geographic position near the eastern boundary of the Basin.

In general the sand and shale units of the east side fields tend to be much more lenticular than those of the west side fields. This lenticularity which is noticeable at only a few horizons at Santa Fe Springs, is considerable in the other fields. In one area on the northern flank of the Santa Fe Springs field, the Foix sand, which comes in the lower part of Repetto Foram Zone 2, is entirely replaced by shale. The 40-50 foot shale body which comes at the base of the upper Repetto at Santa Fe Springs is much nearer the base of the Meyer shale on the crest of the structure than on the flanks due to compensating thickening and thinning of the immediately overlying and underlying sands. Apparently there is considerable lenticularity within the Repetto at West Coyote. The upper Repetto, which is quite sandy in the western part of the field, becomes shaly to the east. The first sand in the upper 99 zone, which is approximately 150 feet thick in a wildcat well a mile west of West Coyote, is 35 feet thick near the center of the field and is entirely replaced by shale in the eastern part of the field. Lateral lithologic variation due to lenticularity of the sands is particularly striking in the Repetto of the East Coyote area. The contact between the base of the Second zone sand and the Third zone shale in the Hualde Dome ranges stratigraphically from a point in Repetto Foram Zone 13, Subzone 4 to the top of Zone 10, Subzone 2. Likewise there is very appreciable well to well variation in the percentage of sand present in the upper and lower Anaheim zones. Individual sand units thicken and thin rapidly and frequently completely disappear locally. The uppermost Miocene sands are also quite lenticular. The 300-foot sand which is present in the lower part of the A division in some Anaheim Dome wells is almost entirely shale in others.

Santa Fe Springs-Richfield Unconformities

In the western part of the Richfield field the lower Chapman shale, which comes in the upper half of Division B of the upper Miocene, is cut out by an unconformity so that the upper Chapman sand rests directly upon the basal part of the lower Chapman sand. The entire lower Repetto and the upper part of the upper Miocene are missing at the unconformable contact between the Pliocene and the Miocene in the eastern part of East Coyote and in the Richfield field. The upper part of the lower Repetto is cut out by this same unconformity in the Hualde Dome area. Furthermore, the interval between the top of Division A and the top of Division D is abnormally short on the Hualde Dome, suggesting the presence of an additional hiatus within the upper Miocene strata. There is probably an unconformity within the upper part of the middle Repetto or the lower half of the upper Repetto in the Carlton area and in the Yorba Linda field. The contact between the Pico and the Repetto appears to be unconformable at Richfield and in the Yorba Linda area. The upper Pico rests directly upon the lower Pico in East Coyote whereas they are separated by 950 feet of middle Pico sediments at West Coyote. It is probable that the contact between the Pico and the overlying Pleistocene is unconformable in all of the fields of this line.

MONTEBELLO-BREA-OLINDA FIELDS

Montebello is the only one of the eastern marginal fields represented on the straight line correlation chart. There are three separate producing areas, the original Main Field area in the center with the more recently discovered West Montebello on the west and East Montebello on the east. The latter comprise two buried west-trending en echelon structures in basal Pliocene and upper Miocene strata separated by a structural saddle over which is superimposed the elongated Main Field dome formed of later Pliocene and Pleistocene sediments.[11] The West Montebello structure is a simple slightly asymmetrical dome while East Montebello is bisected by a northwest-trending overthrust fault with production limited to the downthrown western block. As a further complication the eastern and western ends

[11] For structural map and cross-section, *see* Atwill, E. R. 40, pp. 1122-1124.

of the Main Field dome overlap portions of the two older structures.

There are three producing zones in the Main Field area, the First, the Second, and the Third, ranging stratigraphically from the basal part of Repetto Foram Zone 5 into Repetto Foram Zone 13, Subzone 4. The upper and lower portions of the First zone are predominantly shale with the main sand, which is approximately 200 feet thick, extending from a point just below the top of Repetto Foram Zone 6, Subzone 3 to the top of Zone 7. The Second zone, which is less important than the First, is composed of a number of small sand bodies scattered through a shale interval. The Third zone is quite conglomeratic. No commercial production has been obtained from the lower Repetto or from the upper Miocene in the Main Field area.

There are nine productive zones at West Montebello, known as the First, the Second, the Third, the Fourth, the Fifth, the Sixth, the Masser, the Seventh, and the Eighth. Wells which obtain production from the first three zones are located in the northern part of the West Montebello area and are actually edge wells of the Main Field structure as far as these shallow zones are concerned. The top of the First zone is the same as in the Main Field, but, due to lenticularity of the sands, the base of the First zone and the top of the Second are slightly higher stratigraphically than the corresponding interval on the crest of the Main Field structure. Similarly the Third zone sand in the West Montebello field is located in the upper part of Foram Zone 14 rather than in Zone 13 as in the Main Field. The so-called Fourth zone, which comes at the top of Foram Zone 16, has been productive in only one or two wells; it is, therefore, shown as semicommercial on the chart. The Fifth zone ranges from the lower part of Repetto Foram Zone 17, Subzone 2 to the top of Miocene Foram Zone 3 of Division A. The Sixth and Masser zones occur in Miocene Foram Zone 3 of Division A, the Seventh in the lower part of Miocene Zone 4 and the Eighth in the upper half of Foram Zone 5 of Division A.

The East Montebello area, which is the least important of the three, has seven producing zones. The First and Second are a continuation of the Main Field structure. The next deeper, the Ciocca, is located in the lower part of Repetto Foram Zone 17, Subzone 1. There is an unconformity between the Pliocene and Miocene in this area so that on the apex of the structure the Ciocca sand rests directly upon the Nutt shale. The Nutt zone is located in the middle of Miocene Foram Zone 3. The Farmer, Cruz, and Baldwin zones extend from near the middle of Miocene Foram Zone 4 to about the middle of Zone 5 of Division A.

Data were not available for the preparation of a separate stratigraphic variation chart for the eastern marginal fields. An average lithologic column for the West Montebello field is shown on figure 90. The same column is likewise appended to the stratigraphic variation chart for the Santa Fe Springs-Richfield fields, figure 94. As many of the lower Pliocene and upper Miocene sands of the Montebello area are extremely lenticular, there is considerable well to well variation in the thickness of individual sand bodies. There is a general increase from west to east in the percentage of sand present in the lower Pliocene sediments. The main sand of the First zone, which is approximately 200 feet thick in the central part of the Main Field area, is represented by only 10 feet of sand at West Montebello, while the entire First zone interval is predominantly sand at East Montebello. Likewise, the Second zone interval becomes increasingly sandy to the east. The lower Repetto thickens approximately 40 percent from West Montebello to the central part of the Main Field and then thins towards East Montebello where the basal part of the section is missing. The middle Repetto thickens slightly from west to east while the upper retains approximately the same thickness. There is a slight increase in the percentage of sand present in some of the upper Miocene producing intervals of East Montebello as compared with West Montebello, but the general thickness of the upper Miocene section is approximately the same.

Insufficient data were available to warrant including the other east side fields on the straight line correlation chart. Our information indicates that of the three producing zones of the Whittier field the First zone ranges from the lower part of Repetto Foram Zone 7 into the upper part of Foram Zone 8; that the Second zone extends from a point in Repetto Foram Zone 9, Subzone 2 to the middle of Foram Zone 10; and that the top of the Third zone comes in the lower part of Repetto Foram Zone 13, Subzone 4. There are several productive sand intervals within the Repetto and upper Miocene of the Brea-Olinda field. The top of the first producing sand is approximately equivalent to the top of the Meyer sand of Santa Fe Springs. The deepest producing interval of economic importance is about equivalent to the lower Chapman sand interval of Richfield. The oil production of the Puente field comes from fractured lower Puente shale of the E division.

SUMMARY

1. Since middle Miocene time the Los Angeles Basin has been a locus of deposition for many thousands of feet of sediments consisting of alternating lithologically similar units of sand and shale varying in thickness from a few inches to several hundred feet.

2. Foraminifera are abundant throughout the Los Angeles Basin sediments. The foraminiferal succession is readily divisible into twelve major units, seven for the Pliocene and five for the upper Miocene, and further into a great number of small zones and subzones.

3. Rocks penetrated range from Pleistocene terrace deposits to Jurassic schist of the Franciscan formation.

4. The more important oil fields of the Los Angeles Basin follow four general structural trends.

5. Oil is produced from sands ranging in age from the upper Pliocene to middle Miocene, and in two fields from the weathered and fractured surface of the Franciscan schist.

6. Although productive sands are encountered in three fields in the basal part of the middle Pico, in two fields in the lower Pico, and in five fields in the upper half of the upper Repetto, the majority of the oil comes from the lower half of the upper Repetto, from the middle and the lower Repetto, and from the upper Miocene. In addition, one well is now producing from sands of middle Miocene age.

7. In many of the more important fields there was originally a vertically continuous series of reservoir

sands interrupted only by intervening shales from the top of the first producing sand to the middle of the upper Miocene.

8. Oil in the Los Angeles Basin fields normally occurs as high stratigraphically as the middle of the upper Repetto formation. All oil found in younger strata may be explained by upward migration along fault planes from deeper reservoir sands.

9. Sections of upper Pliocene rocks of maximum thickness are encountered in the synclinal areas between the structural trends. Of the Basin fields maximum sections of nearly equal thickness are present at El Segundo, Long Beach, Potrero, and Seal Beach.

10. The lower Pliocene and upper Miocene attain their maximum thickness in the Montebello-Santa Fe Springs area. Both thin in a southwesterly direction across the Basin toward Torrance and Wilmington. Along the structural trends they thicken toward the center of the Basin and thin toward the edges.

11. The central fields of the Inglewood-Newport uplift have the highest sand percentage of the Basin fields. Long Beach, the field with the highest sand percentage, has been the most prolific producer of the Basin.

12. No single sand or shale body extends as such over the entire Basin. In general the lateral variation from sand to shale is so extreme that interfield correlations based on lithology alone or on a comparison of electric logs are impracticable and extremely precarious. Therefore, Foraminifera offer the only feasible means of reliable interfield correlation.

13. The presence of a number of unconformities within the upper Miocene and the Pliocene section indicates a succession of periodic orogenic movements along the major structural trends since early upper Miocene time.

14. The rather abrupt changes in thickness often encountered on opposite sides of faults in the Basin fields are more frequently due to differential horizontal movement which has brought sections of different thicknesses into juxtaposition than to progressive movement contemporaneous with deposition.

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PLATE V

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SERIES	RICHFIELD		SUB-ZONE	FORAM ZONE	FAUNAL DIVISION	FORMATION	SERIES
					Cushman		

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** Paleonto.
mitted for pub
permission of E. I
President, of the U

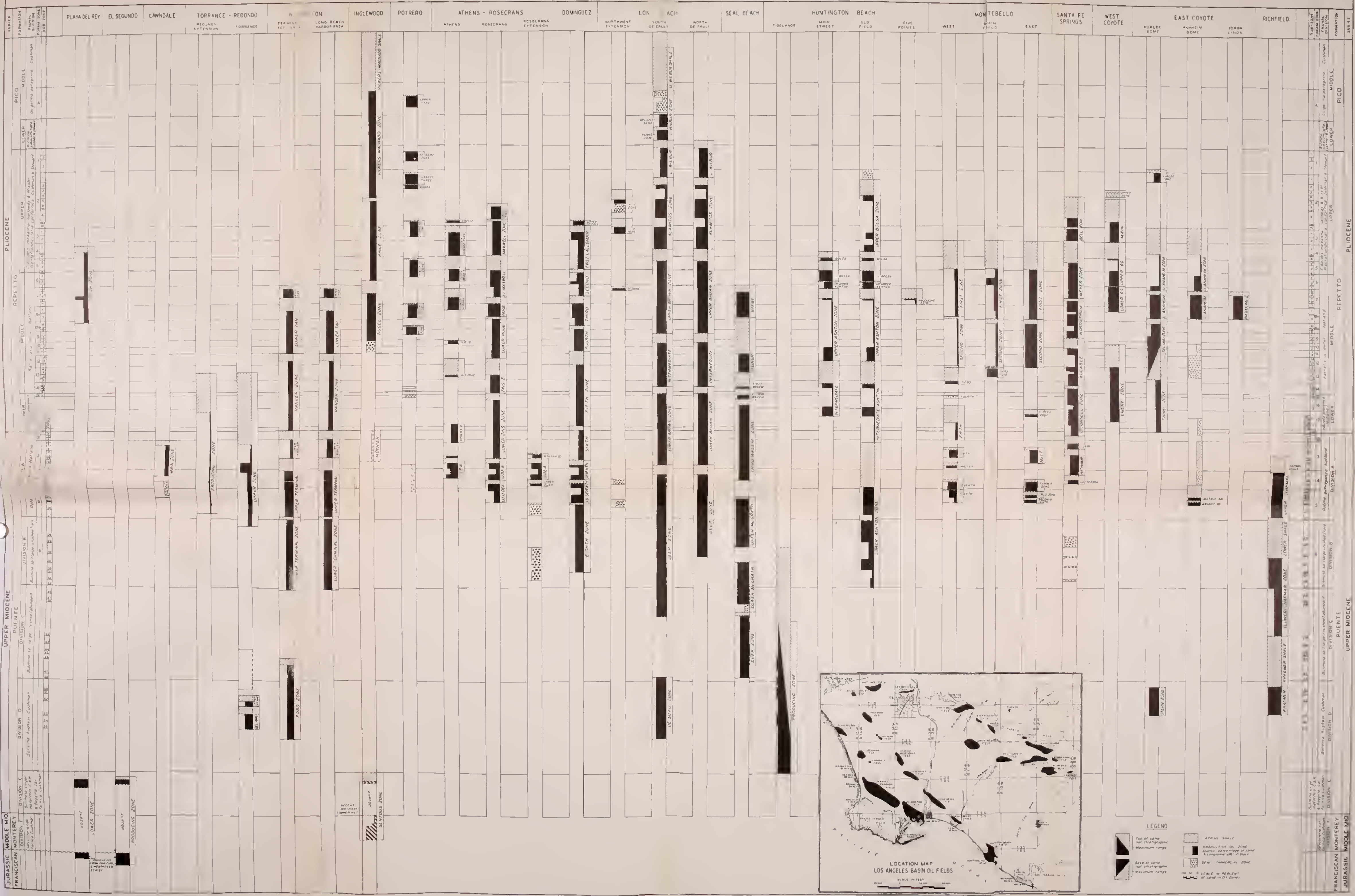
DIVISION OF MINES
WALTER W. BRADLEY, STATE MINERALOGIST
OLAF P. JENKINS, CHIEF GEOLOGIST

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
DIRECTOR

PLATE V

STRAIGHT LINE CORRELATION CHART OF LOS ANGELES BASIN OIL FIELDS

STANLEY G. WISSLER ... 1940



Accompanying Bulletin 118 Part Two

CORRELATION OF THE OIL FIELDS OF THE SANTA MARIA DISTRICT

By Stanley G. Wissler* and Frank E. Dreyer**

OUTLINE OF REPORT

INTRODUCTION

The Santa Maria district, one of the oldest producing regions of California, is located in the northwestern part of Santa Barbara County in the vicinity of the town of Santa Maria. There are ten producing fields or areas: Santa Maria Valley, Orcutt (formerly called the Santa Maria field), Lompoc (also known as Purisima), East Cat Canyon, West Cat Canyon, Los Flores, Doheny Bell, Gato Ridge, and Arroyo Grande. Since all but three of these were discovered long before the days of systematic sampling and coring and before the advent of the electric log, our knowledge of their stratigraphy and structure is somewhat incomplete. However, it has been possible to assemble sufficient samples to determine the stratigraphic position of most of the producing zones. The location of the fields and their general stratigraphic section, as well as the position of the producing intervals, are shown on the accompanying straight line correlation chart and insert map.

During the last four years a large number of wells have been drilled in the Santa Maria Valley field. The foraminiferal sequence and the stratigraphic section have been determined by detailed studies of some 16,000 samples collected from the majority of these wells. Much of the data obtained from this investigation were included by C. R. Canfield (39) in his paper "Subsurface Stratigraphy of the Santa Maria Valley Oil Field and Adjacent Parts of the Santa Maria Valley, California." Most geologists working in the area have adopted Canfield's subsurface section as a general type for the district. It is so used in this discussion.

SANTA MARIA VALLEY FIELD

Since the stratigraphic section of the Santa Maria Valley field is discussed in detail in Canfield's article on the field in Part Three of this bulletin, only a brief summary of the subsurface section is necessary here. From the surface down the rocks consist of:

- Recent and Pleistocene, alluvium and stream gravels
- Lower Pleistocene (?) and Pliocene, Paso Robles formation
- Pliocene, Careaga formation
- Pliocene, Foxen formation
- Lower Pliocene and upper Miocene, Sisquoc formation
- Upper Miocene, Santa Margarita (?) formation
- Lower upper Miocene and middle Miocene, Monterey group
- Cretaceous and Jurassic basement complex

RECENT AND PLEISTOCENE, ALLUVIUM AND STREAM GRAVELS

These include the "Yellow Gravels" of the Santa Maria Valley proper as well as some older bench gravels and terrace deposits. The latter are frequently referred to as the "Orcutt" formation. The total thickness of both the younger and older gravels varies from 400 to 1,600 feet. Unconformably underlying the "Yellow Gravels" is the Paso Robles formation.

LOWER PLEISTOCENE (?) AND PLIOCENE, PASO ROBLES FORMATION

The Paso Robles, frequently referred to as the "Blue Gravels," is differentiated from the overlying beds in well sections by the change in color and by the abundance of Monterey chert pebbles. This formation varies from 200 to 500 feet in thickness. The Paso Robles rests unconformably upon the Careaga formation.

PLIOCENE, CAREAGA FORMATION

The Careaga formation (Canfield's Foxen gravel and Foxen fine sand member) consists of an upper member of from 20 to 70 feet of unfossiliferous bluish-gray gravels and a lower member of from 110 to 500 feet of fine-grained fossiliferous sand. In places a few beds of impure concretionary limestone are encountered at the top of the formation. In the type area the Careaga is separated from the underlying Foxen by a slight angular unconformity. The exact character of the contact within the Santa Maria Valley field is unknown, but it appears to be conformable, at least in the deeper parts of the area.

PLIOCENE, FOXEN FORMATION

The Foxen consists of an upper massive light olive-gray siltstone from 300 to 1,820 feet thick and a lower silty tar sand from 140 to 310 feet thick. Foraminifera are fairly abundant in the upper one-half to two-thirds of the formation. The middle 110 to 550 feet of siltstone constitutes the *Uvigerina foxeni* zone. The lower 140 to 800 feet of the formation is nearly unfossiliferous except in the extreme eastern part of the field where it contains arenaceous Foraminifera. The formation is not productive in the Valley field nor in the other oil fields of the district. The contact between the basal Foxen and the underlying Sisquoc is unconformable in

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** Paleontologist, Union Oil Company of California. Manuscript submitted for publication January 13, 1941. Published with the permission of E. B. Noble, Chief Geologist, and A. C. Rubel, Vice President, of the Union Oil Company of California.

CORRELATION OF THE OIL FIELDS OF THE SANTA MARIA DISTRICT

By Stanley G. Wissler* and Frank E. Dreyer**

OUTLINE OF REPORT

INTRODUCTION

The Santa Maria district, one of the oldest producing regions of California, is located in the northwestern part of Santa Barbara County in the vicinity of the town of Santa Maria. There are ten producing fields or areas: Santa Maria Valley, Orcutt (formerly called the Santa Maria field), Lompoc (also known as Purisima), East Cat Canyon, West Cat Canyon, Los Flores, Doheny Bell, Gato Ridge, and Arroyo Grande. Since all but three of these were discovered long before the days of systematic sampling and coring and before the advent of the electric log, our knowledge of their stratigraphy and structure is somewhat incomplete. However, it has been possible to assemble sufficient samples to determine the stratigraphic position of most of the producing zones. The location of the fields and their general stratigraphic section, as well as the position of the producing intervals, are shown on the accompanying straight line correlation chart and insert map.

During the last four years a large number of wells have been drilled in the Santa Maria Valley field. The foraminiferal sequence and the stratigraphic section have been determined by detailed studies of some 16,000 samples collected from the majority of these wells. Much of the data obtained from this investigation were included by C. R. Canfield (39) in his paper "Subsurface Stratigraphy of the Santa Maria Valley Oil Field and Adjacent Parts of the Santa Maria Valley, California." Most geologists working in the area have adopted Canfield's subsurface section as a general type for the district. It is so used in this discussion.

SANTA MARIA VALLEY FIELD

Since the stratigraphic section of the Santa Maria Valley field is discussed in detail in Canfield's article on the field in Part Three of this bulletin, only a brief summary of the subsurface section is necessary here. From the surface down the rocks consist of:

- Recent and Pleistocene, alluvium and stream gravels
- Lower Pleistocene (?) and Pliocene, Paso Robles formation
- Pliocene, Careaga formation
- Pliocene, Foxen formation
- Lower Pliocene and upper Miocene, Sisquoc formation
- Upper Miocene, Santa Margarita (?) formation
- Lower upper Miocene and middle Miocene, Monterey group
- Cretaceous and Jurassic basement complex

RECENT AND PLEISTOCENE, ALLUVIUM AND STREAM GRAVELS

These include the "Yellow Gravels" of the Santa Maria Valley proper as well as some older bench gravels and terrace deposits. The latter are frequently referred to as the "Orcutt" formation. The total thickness of both the younger and older gravels varies from 400 to 1,600 feet. Unconformably underlying the "Yellow Gravels" is the Paso Robles formation.

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those areas in the Valley field in which it has been cored.[1]

LOWER PLIOCENE AND UPPER MIOCENE, SISQUOC FORMATION

The Sisquoc consists of somewhat indurated light-gray and greenish-gray siltstone and claystone, locally somewhat diatomaceous and sandy. The thickness in the Santa Maria Valley field varies from 115 feet to 1,100 feet. Elsewhere in the Valley it attains a maximum thickness of nearly 6,000 feet. The paleontologic evidence indicates that the Sisquoc formation is in part lower Pliocene and in part upper Miocene in age. While the basal part of the Sisquoc is frequently saturated with tar, it is not commercially productive in the Santa Maria Valley field. It is, however, economically important in other fields of the district. The Sisquoc rests with a marked angular discordance upon the underlying older Miocene strata.

UPPER MIOCENE, SANTA MARGARITA (?) FORMATION

Wells drilled in the southern part of the Valley field encounter from 10 to 400 feet of semiplaty, mouse-gray and brown, silty shale with occasional interbedded streaks of fine silty sand, followed by a thin basal conglomeratic sand. No identifiable Foraminifera have been found in this shale series. While it is possible that it merely represents a higher unfossiliferous zone of the underlying Monterey formation, this unit is generally assigned as a matter of convenience to the Santa Margarita (?) formation on the basis of its stratigraphic position. The Santa Margarita (?) is productive in the southern part of the Valley field where it conformably overlies the Monterey and forms the upper part of the first oil zone. It is not present over the structurally higher area of the field.

LOWER UPPER MIOCENE AND MIDDLE MIOCENE, MONTEREY GROUP

The lower upper Miocene and the middle Miocene in the Santa Maria district are represented by seven major foraminiferal zones: (1) the "Arenaceous" zone, and (2) the *Bolivina hughesi* zone, of upper Mohnian age: (3) the *Bulimina uvigerinaformis*, and (4) the *Baggina californica* zone, of lower Mohnian age; (5) the *Siphogenerina collomi-Siphogenerina nuciformis* zone, and (6) the *Siphogenerina reedi* zone, of Luisian age; and (7) the *Valvulineria ornata-Uvigerinella obesa* zone of Relizian age. While the seven foraminiferal zones are generally grouped together as the Monterey formation, several of them are distinct mappable lithologic units, each of which might be considered as a separate formation. The six higher are here considered as comprising the Monterey formation proper. For the seventh the name Point Sal formation has been proposed (Canfield, C. R. 39, p. 67).

In the subsurface section of the Valley field all seven faunal zones are characterized by fairly definite lithologic facies: Foram Zone 1, by oil-saturated, fractured, hard, brown, platy shale; Foram Zone 2, by hard, fractured, brown, platy, siliceous shale, cherty shale, and chert; Foram Zone 3, by moderately hard, light- and dark-brown, banded, platy, foraminiferal shale, with numerous thin streaks of bentonite; Foram Zone 4, by platy, banded, brown, foraminiferal shale and buff-colored phosphatic shale; Foram Zone 5, by hard, platy, dark-brown shale with thin laminations of buff-colored phosphatic shale and occasional thin phosphatic layers; Foram Zone 6, by oil-saturated, soft, fine, silty sand to hard, coarse, calcareous sand; and Foram Zone 7, by soft, steel-gray and brown, silty, pyritiferous, clay shale interrupted at frequent intervals by hard calcareous sandstone. As a matter of convenience Canfield assigned lithologic names to these faunal units of the Valley field. Unfortunately, these names, some of which are primarily applicable only to the faunal units of the Santa Maria Valley oil field, have been adopted for general use by the majority of the operators in the area and applied to other fields of the district. This has resulted in some local confusion that could easily be avoided by a return to the original numerical foraminiferal zonal designation of the respective units. For instance, the term "Cherty Zone" originally used by Canfield to designate Foram Zone 2, the *Bolivina hughesi* zone, of the Valley field has been applied to cherty intervals of different age in several of the other fields of the district under the misapprehension that the presence of chert always indicates the presence of Foram Zone 2. Actually Zone 2 is cherty only in the Gato Ridge and the Santa Maria Valley fields.

Because of the unconformable nature of the contact with the superjacent and subjacent formations and the presence of local disconformities between the various faunal units, Monterey sections of varying age and thickness are encountered in different parts of the Valley field. Foram Zone 7, the Point Sal formation, is present only in the southeastern part of the field. It attains a maximum thickness of about 3,650 feet. The entire Monterey group has a maximum aggregate thickness of approximately 5,200 feet.

No intermediate water has yet been found in the Monterey formation of the Santa Maria Valley field. The complete section is productive in various parts of the field but not in its entirety in any one area. In general there are two main producing intervals (fig. 95). The upper extends from the fractured Santa Margarita (?) shale through the cherts of Foram Zone 2, and the lower, from the top of Foram Zone 5 through Zone 6. The exact stratigraphic position of the producing horizons of the upper zone is dependent upon the amount of fracturing present and is therefore variable from place to place. In the Cole area in the south-

[1] Cores taken in a number of early wells across the Foxen-Sisquoc contact show a 1-foot, fossiliferous, oil-saturated, Sisquoc-shale-pebble conglomerate zone at the base of the Foxen tar sand. Because of this apparent unconformity and the distinct change in lithology, the top of the underlying siltstone was taken as the top of the Sisquoc formation. This contact is readily discernible in well cuttings and is quite prominent on the electric log. From a study of the cores from one of the Los Flores wells in conjunction with recent surface mapping in the district for the U. S. Geological Survey, M. N. Bramlette has come to the conclusion that the top of the Sisquoc formation as used in surface mapping comes approximately 1,000 feet higher in the subsurface section than the point originally chosen. Bramlette has based his conclusion primarily on the occurrence in the cores of the Los Flores well of a Sisquoc *Nuculana* and a 10-foot zone of *Bolivina obliqua* Barbat and Johnson. On this basis all of the Foxen tar sand and the greater part of the arenaceus zone or unfossiliferous interval which underlies the *Uvigerina foxeni* zone should be included in the Sisquoc. Both the *Bolivina obliqua* and the *Nuculana* are so rare that they are scarcely ever found in well cuttings. Furthermore, *Bolivina obliqua* has been found by the authors and other paleontologists in surface exposures in unquestioned Foxen sediments both in and immediately below the *Uvigerina foxeni* zone. It is impracticable, therefore, to attempt to locate Bramlette's contact in the subsurface section.

western part of the field production is obtained from fractured, hard, siliceous shale and chert in Foram Zones 3 and 4. In addition, in the southeastern part of the field, production is obtained from upper sands of the Point Sal formation.

The Monterey group rests unconformably upon a basement complex of calcite-veined sandstone, slickensided shale, and serpentinized lavas in part Jurassic and in part Cretaceous in age.

ORCUTT OIL FIELD

The Orcutt field, which is located at the western end of the Solomon Hills, has been more deeply eroded than the Santa Maria Valley. With the exception of a few isolated outliers, all of the younger Pliocene and Pleistocene beds, which outcrop far out on the flanks, have been removed from the top of the structure. The greater portion of the productive area is overlapped by a thin mantle of the upper Careaga gravels, which attains a maximum thickness on Mount Solomon of 500 feet. The lower Careaga fine sand member and the underlying Foxen siltstone are missing over the greater part of the field, and the upper Careaga gravel rests unconformably upon the Sisquoc, which here is a diatomaceous siltstone and claystone, very often tar saturated. Wells start either in the Careaga or directly in the Sisquoc formation which varies in thickness from 1,600 feet to 2,000 feet. Samples from several wells drilled near the western end of the field suggest that the Santa Margarita (?) formation may overlie the Monterey along the flanks of the Orcutt structure, but insufficient cores are available to definitely demonstrate this possibility. Certainly over the main part of the structure the Sisquoc rests unconformably directly upon Foram Zone 1 of the underlying Monterey. The same stratigraphic section is present as in the Valley field. Lithologically the section is essentially the same except for the fact that the cherty interval occurs in Foram Zones 3 and 5 instead of in Foram Zone 2. The Monterey formation proper is underlain by the gray and brown clay shale of the Point Sal formation which in turn rests unconformably upon the underlying non-marine, green, blue, and reddish sands and interbedded conglomerates of the Lospe formation.[2] The Lospe is generally considered to be the equivalent of the continental Sespe formation of the Santa Barbara coast which is Eocene, Oligocene, and lower Miocene in age. The thicknesses of the formations and the location of the producing intervals are indicated on figure 95.

The production of the Orcutt field comes from three separate oil zones. The First zone occurs in fractured shale in the basal part of the Sisquoc and the upper part of the Monterey. This zone has never been of particular importance commercially. The Second zone is encountered in fractured cherts extending from the lower part of Foram Zone 3 into the upper part of Foram Zone 5. For many years the bulk of production from this field came from this zone, but it is now virtually depleted. The Third zone production comes from lenticular sand bodies in Foram Zone 6 of the Monterey and from the upper 150 feet of the Point Sal formation. At present this is the chief producing interval of the field.

CASMALIA OIL FIELD

Surface rocks in the Casmalia field consist of punky, diatomaceous shale and porcellaneous shale of the Sisquoc formation. Wells generally start in the lower or porcellaneous shale member. The underlying subsurface section is essentially the same as that of Orcutt. Too few well samples are available to furnish reliable estimates of the thickness of the different formations. Wells which penetrated the Monterey section encountered the top of the Lospe much higher than would be expected. The question as to whether the Monterey is thinner in the Casmalia field than at Orcutt or whether the deeper wells were located in a fault zone can not be answered until additional wells have been drilled. The producing zones of the Casmalia field are equivalent to the First and Second oil zones of Orcutt. Sands equivalent to those of the Third zone of Orcutt, while present, are too silty and impermeable to produce.

WEST CAT CANYON, DOHENY BELL, AND LOS FLORES OIL FIELDS

The West Cat Canyon, Doheny Bell, and Los Flores fields are all located along the same structural trend and may, when finally drilled up, prove to be a virtually continuous area. There are very few samples from the old wells of the Doheny Bell and West Cat Canyon areas, but the recently drilled Los Flores wells indicate that the subsurface section is much like that of the Santa Maria Valley, with the chief difference one of thickness. The surface alluvium and "Yellow Gravels" and the underlying Paso Robles are approximately half as thick as in the Valley field. The Careaga and Foxen undifferentiated are together about 1,900 feet thick. The underlying Sisquoc is much thicker (2,800 feet) than in the Santa Maria Valley (1,100 feet) and is much siltier. There is approximately 1,200 feet of Monterey in the Los Flores area; no Santa Margarita (?) has been recognized to date.

The production of West Cat Canyon and Doheny Bell is from sand lenses in the middle and lower Sisquoc which are absent in the Los Flores area. There is a possibility that some Doheny Bell wells have upper Monterey production. The Los Flores wells produce from Monterey cherts of Foram Zone 3.

EAST CAT CANYON OIL FIELD

Little is known about the stratigraphy of the East Cat Canyon field. Wells produce from sand lenses in the middle and lower Sisquoc. One deep well pene-

[2] The term Lospe formation is an unpublished name which has for a number of years been applied locally to the 2,600-foot section of unfossiliferous, continental beds underlying the Point Sal formation. The type area is on the southwest slope of Mount Lospe, near the western end of the Casmalia Hills, approximately 2 miles south of Point Sal Landing and half a mile north of Lions Head Beach (Guadalupe quadrangle). The best exposures are in Chute Creek which has eroded a narrow channel down the southern slope of Mount Lospe. The lower 650 feet of the Lospe formation consists of well-bedded, maroon and greenish-gray sandstone and conglomerate separated by an unconformity from the underlying Franciscan. The middle 1,000 feet is composed of greenish-gray sandstone and sandy shale, with two prominent 50-foot white and greenish tuff beds in the upper 230 feet. Above the upper tuff is approximately 950 feet of gypsiferous, gray and greenish-gray clay shale. Unconformable above the gypsiferous shale of the Lospe is the Point Sal formation which likewise has its type locality in Chute Creek. On the basis of its red color and continental origin the Lospe is generally correlated with the Sespe formation of upper Eocene, Oligocene, and lower Miocene age.

trated the Monterey but failed to obtain production. Scattered samples indicate that a complete Monterey section is present.

GATO RIDGE OIL FIELD

While there is a thin veneer of Careaga sand over part of the Gato Ridge oil field, the majority of the wells start in the Sisquoc formation. The Sisquoc, which has a normal thickness of approximately 1,800 feet, consists of fairly soft, very fossiliferous claystone and siltstone with streaks of tar sand. Some wells on the western flank have encountered a thin section of unfossiliferous, very hard, banded, gray and brown, calcareous and siliceous shale which may represent the Santa Margarita (?) formation. Most wells bottom in the upper part of Foram Zone 3 at the Monterey. Information from a deep test indicates that a thick (4,000 feet) but normal Monterey sequence is present. The entire Monterey section down to the top of Foram Zone 6 is cherty.

The main production is from fractured Monterey cherts in the lower part of Foram Zone 2 and the upper part of Foram Zone 3. In addition, the basal part of the Sisquoc is productive in the northwestern part of the field.

LOMPOC (PURISIMA) OIL FIELD

The lithology of the Lompoc oil field is quite different from that of the Santa Maria Valley field. Some 200 to 600 feet of Careaga sand unconformably overlies the Sisquoc which is essentially diatomaceous shale and diatomite. The Sisquoc diatomaceous shale grades imperceptibly downward into hard, brittle, platy, siliceous shale with interbedded bands and lenses of chert. Although very few foraminifers were found in the available samples, it is probable that the section represents both the Santa Margarita (?) formation and Foram Zones 1 through 5 of the Monterey formation of the Santa Maria Valley. The production is obtained from fractured and shattered intervals in the lower Sisquoc and upper Monterey.

ARROYO GRANDE (EDNA) OIL FIELD

For many years heavy oil has been obtained from a number of small wells in the Arroyo Grande field located approximately 3 miles north of Pismo Beach. The production is from oil sands, sealed up dip by asphalt, in the Pismo formation of lower Pliocene-upper Miocene age. So little is known of the subsurface conditions of the field that it has not been included on the chart.

STRAIGHT LINE CORRELATION CHART OF SANTA MARIA DISTRICT OIL FIELDS

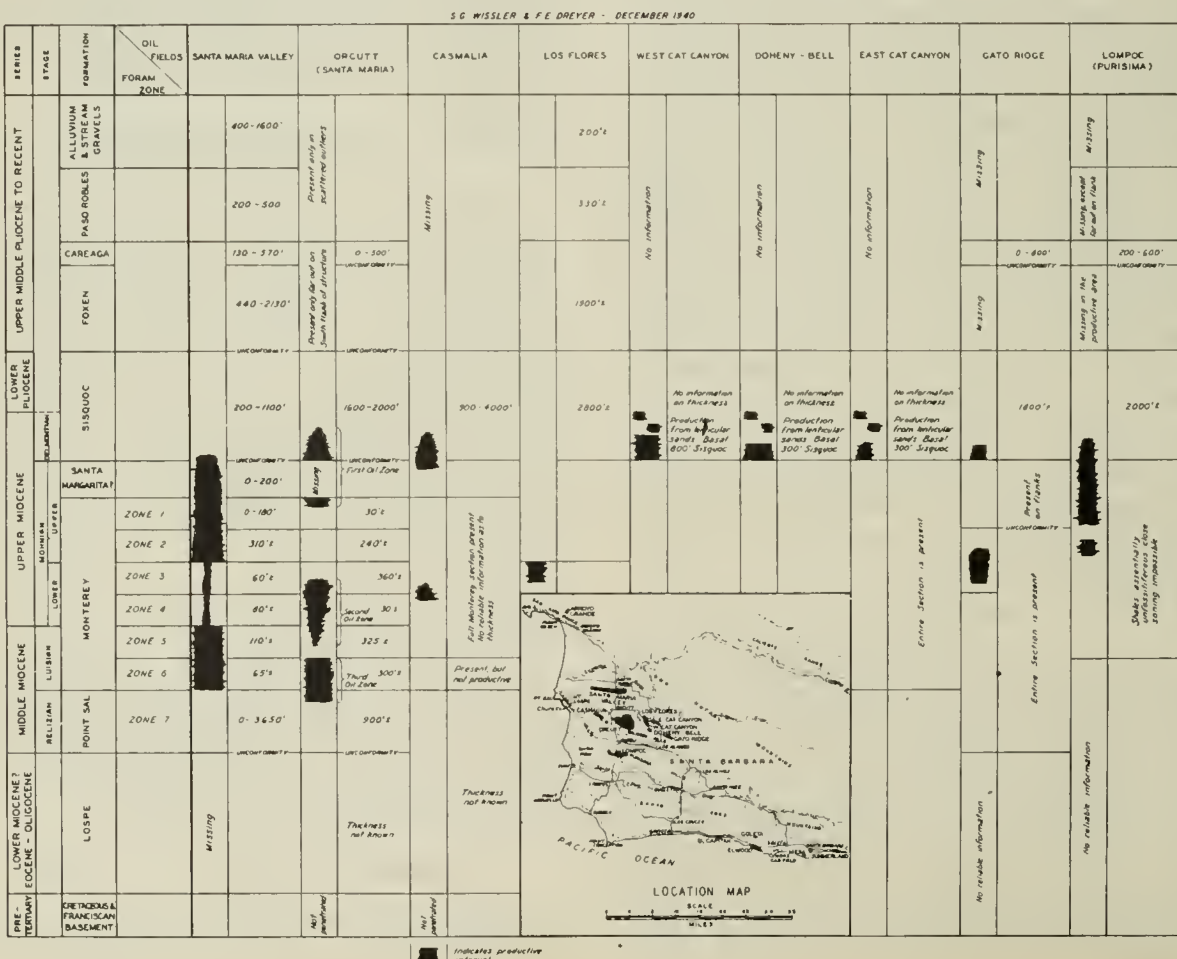

FIG. 95.

CORRELATION OF OIL FIELD FORMATIONS ON EAST SIDE SAN JOAQUIN VALLEY

By Glenn C. Ferguson *

OUTLINE OF REPORT

INTRODUCTION

This paper is an explanation of the accompanying straight-line correlation chart of formations and producing zones in oil fields on the east side of the San Joaquin Valley. Fields considered in this study include Wasco, Rio Bravo, Greeley, Fruitvale, Kern Front, Premier, McVan, Mountain View Extension, Mountain View, Edison, Kern River, Mount Poso, North Poso, Dominion, Knob Hill, Coffee Canyon, and Round Mountain. The correlations here indicated are based on the results of several years of detailed study by the writer, of foraminifera from wells drilled in this area. In some parts of the stratigraphic column, because of varying sedimentary facies, correlations between fields have not been clear. An interpretation of these conditions has been offered, but the author recognizes that other interpretations may be equally good.

The chart is drawn without reference to scale, and specific correlations between fields are based on time horizons. By projecting foraminiferal markers on a straight line from one field to another and by identifying the lithologic units, it is possible to show graphically lateral variation in stratigraphy. Inasmuch as faunal zones do not carry through continental beds, the limits of these members have been indicated by jagged lines. The thickness and relative position of the oil sands have been indicated separately from those of major lithologic divisions. The Miocene time stratigraphic units, as recently defined by Kleinpell (Kleinpell, R. M. 38), are indicated for the Miocene epoch, thus showing the time relationship of the variously named lithologic units.

A straight-line chart of this type presents many mechanical problems in construction, especially when formation thicknesses vary considerably. In several instances a given formation varied from zero to several hundred feet in thickness within the limits of a field. For this reason, maximum and minimum figures for thickness have been indicated as nearly as possible. When a formation or a part of one is absent, a cross has been drawn through the missing portion. Lenticular sands have been graphically represented by a wedge extending into the shale member to which they belong. No attempt has been made to plot lithology, because this information can be obtained from separate reports on the individual fields. Furthermore, within the Miocene the lithologic units or geologic members are well defined and a clue to their character can be found in their local names; for example: "Round Mountain *silt*"—"lower Fruitvale *shale*"—"Olcese *sand*." These terms have been applied in the past to major lithologic divisions or formational members on the extreme east side of the valley. They have here been expanded, even though the lithology may be somewhat changed, to include equivalent beds in the central valley fields. Variations of beds laterally has presented a unique problem in correlating time horizons, and for this reason a discussion of stratigraphic conditions will serve to clarify the results indicated on the chart.

Beds older than the Vedder sand, the oldest important producing horizon in this particular area, will be mentioned only in passing, for they have not been included on the correlation chart. Definition of terms will be considered for each individual member from the Vedder to the Recent. In general, the stratigraphy of this area is one in which beds grade laterally valleyward from coarse clastics to fine marine sediments.

STRATIGRAPHY

The Older Rocks

The oldest rocks in this region are granites and metamorphics which form the basement complex. They are doubtless pre-Tertiary in age, but an exact age assignment except by petrographic means is impossible. North and east of Bakersfield the Walker formation rests directly upon these rocks. This formation is of continental origin, consisting principally of green, gritty clays and sands and carrying a relatively high percentage of decomposed ash. Valleyward, marine Eocene sediments rest on the basement, and it is highly probable that the Walker, at least in part, is a land-laid facies of these sediments. The marine Eocene consists largely of shales, but considerable sand has been cored in some of the deeper wildcat wells drilled in the middle part of the valley. The Eocene shales can readily be correlated with the Kreyenhagen of the Coalinga district. The sands are somewhat older and are probably related to either the Domengine or Capay. Above the Eocene, brown, organic shales have been cored which have been assigned to the Oligocene, and these, for the most part, have been correlated with the Tumey shale outcropping in the area north of Coalinga. Approximately 1,000 feet of brown shale rests on the Tumey in the central valley fields. These shales, according to Kleinpell's classification, belong to the Zemorrian stage. They can readily be correlated with the upper part of the type San Lorenzo, which has been referred in the past to the Oligocene. Kleinpell, in correlating the

* Union Oil Company of California. Manuscript submitted for publication June 14, 1940.

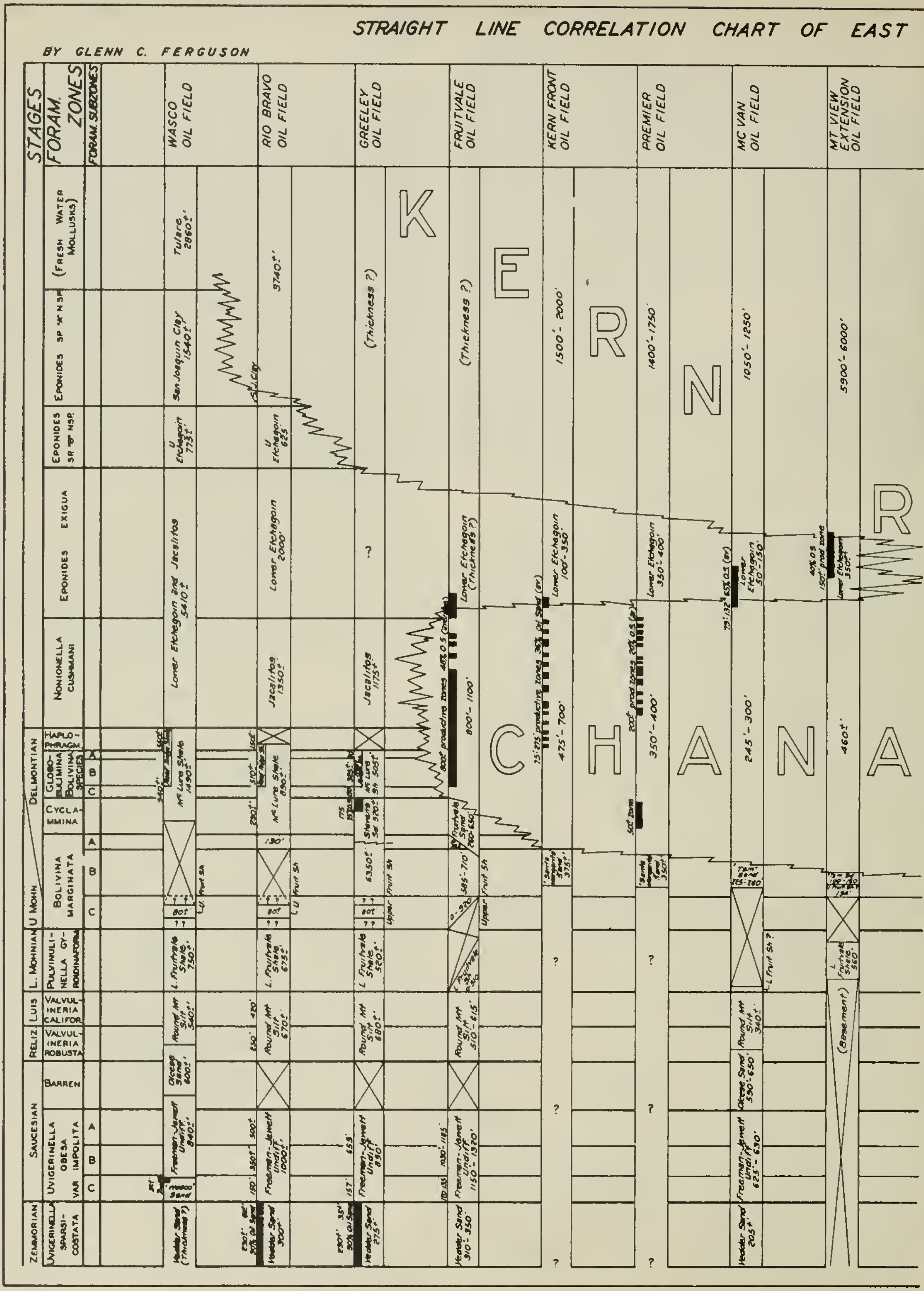
STRAIGHT LINE CORRELATION CHART OF EAST
BY GLENN C. FERGUSON
STAGES
FORAM. ZONES
FORAM. SUBZONES
WASCO OIL FIELD
RIO BRAVO OIL FIELD
GREELEY OIL FIELD
FRUITVALE OIL FIELD
KERN FRONT OIL FIELD
PREMIER OIL FIELD
MC VAN OIL FIELD
MT VIEW EXTENSION OIL FIELD
KERN
CHANA
DELMONTIAN
U MOHN
L. MOHNIAN
LUIS
RELIZ
SAUCESIAN
ZEMORRIAN
(FRESH WATER MOLLUSKS)
EPONIDES
EXIGUA
NONIONELLA CUSHMANI
BOLIVINA MARGINATA
BARREN
UVIGERINELLA OBESA VAR IMPOLITA
UVIGERINELLA SPARSICOSTATA

FIG. 96A.

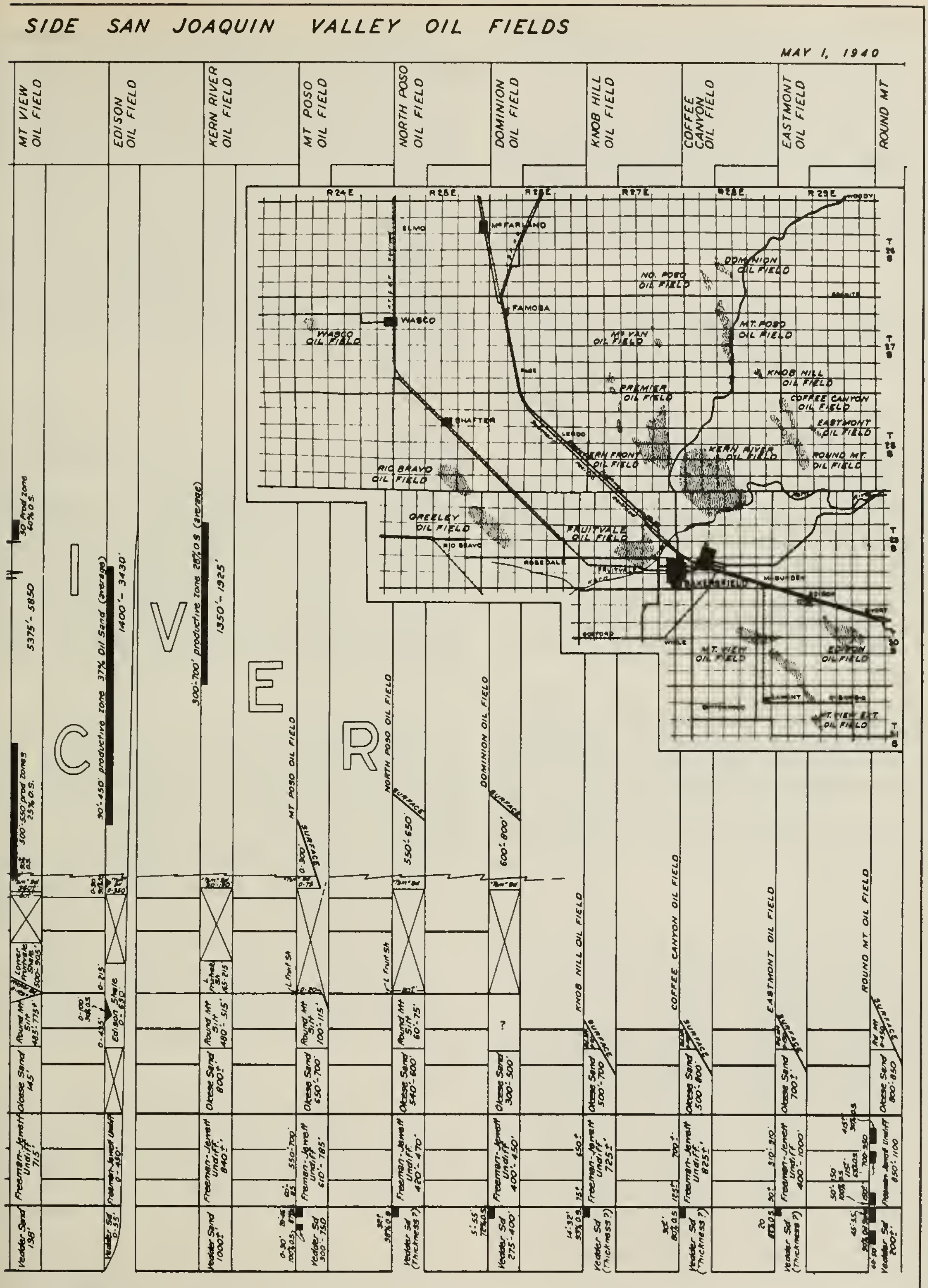
SIDE SAN JOAQUIN VALLEY OIL FIELDS
MAY 1, 1940
MT VIEW OIL FIELD
EDISON OIL FIELD
KERN RIVER OIL FIELD
MT POSO OIL FIELD
NORTH POSO OIL FIELD
DOMINION OIL FIELD
KNOB HILL OIL FIELD
COFFEE CANYON OIL FIELD
EASTMONT OIL FIELD
ROUND MT
R 24 E
R 25 E
R 26 E
R 27 E
R 28 E
R 29 E
McFARLAND
FAMOSA
WASCO
WASCO OIL FIELD
SHAFTER
NO. POSO OIL FIELD
DOMINION OIL FIELD
MT. POSO OIL FIELD
MT VAN OIL FIELD
PREMIER OIL FIELD
KNOB HILL OIL FIELD
COFFEE CANYON OIL FIELD
EASTMONT OIL FIELD
KERN RIVER OIL FIELD
ROUND MT. OIL FIELD
KERN FRONT OIL FIELD
RIO BRAVO OIL FIELD
GREELEY OIL FIELD
FRUITVALE OIL FIELD
ROSEDALE
BAKERSFIELD
MT. VIEW OIL FIELD
EDISON OIL FIELD
MT. VIEW EXT OIL FIELD
C I V E R
5375'-5850
1400'-3430'
1350'-1925'
90'-450' productive zone 37% Oil Sand (average)
300'-700' productive zone 28% O.S. (average)
500'-550' prod zones 25% O.S.
MT POSO OIL FIELD
NORTH POSO OIL FIELD
DOMINION OIL FIELD
KNOB HILL OIL FIELD
COFFEE CANYON OIL FIELD
EASTMONT OIL FIELD
ROUND MT OIL FIELD
SURFACE
550'-650'
600'-800'
Round Mt Silt
Olcese Sand
Freeman-Jewett Undiff.
Vedder Sand

FIG. 96B.

depositional stages with similar divisions in Europe, has shown that both the Zemorrian and Saucesian would there be allotted to the Oligocene. In order to follow the nomenclature of the San Joaquin Valley these divisions are here included in the Miocene.

At least a part of the above-mentioned beds is found in the basal portion of the type Temblor on the west side of the San Joaquin Valley, and no doubt would be classified as Vaqueros (lower Miocene) by some paleontologists. These same beds grade laterally into a sandy facies on the extreme east side of the valley, and they might easily be classified as the lower portion of the Vedder sand.

Vedder Sand

The Vedder sand is the oldest oil-bearing sediment of any importance on the east side of the San Joaquin Valley, and beds from this point upward in the stratigraphic column will be considered in some detail. This sand was first found to be productive in the Mount Poso field on the Vedder lease by the Shell Oil Company, and the producing zone was arbitrarily named the Vedder sand. This sand has been discovered and found to be productive in many other east-side fields. In the Poso-Round Mountain area two productive zones are found within the Vedder sand. These zones are separated by a siltstone varying from 20 to 40 feet in thickness. The lower zone is commonly referred to the lower Vedder sand. The entire thickness of sands here included in the Vedder varies from a few feet to several hundred feet. The Vedder is assigned to the lower Miocene and it is included in Kleinpell's Zemorrian stage of deposition.

Freeman-Jewett

On the extreme east side of the valley a silt member rests immediately upon the Vedder sand. This silt grades upward into an ashy phase. The lower portion has been locally termed the Jewett silt. The upper ashy phase has been similarly termed the Freeman silt. This division is extremely gradational and varies considerably from one well to another. A distinct faunal break can not be found in this part of the section and, for this reason, these two units are here grouped together as the Freeman-Jewett.

The Freeman-Jewett silt is lower Miocene in age and belongs to the Saucesian stage of deposition. It is, in general, equivalent to a portion of the type Temblor of Carneros Creek, beginning at a point approximately 100 feet above the top of the Carneros sand and extending down to within 100 or 200 feet of the so-called *Phacoides* Reef. This silt can readily be recognized on the basis of foraminifera in the central valley fields, but the upper ashy phase is no longer recognizable on the basis of lithology. In the Rio Bravo field this upper portion is interbedded with sand. This sand is fine-grained and tight, and to date no production has been obtained from it. Compared to the west side of the valley, this interbedded zone is related to the Carneros sand within the type Temblor. However, because of its position with respect to overlying beds in the Rio Bravo field, it has been commonly assigned to the Olcese sand. Although doubtful, the uppermost part of this sand may be the equivalent of the lowermost part of the Olcese in its type area, but the major portion is definitely stratigraphically lower.

Olcese Sand

Overlying the Freeman-Jewett series northeast of Bakersfield is a thick, fine- to coarse-grained sand. The upper portion of this sand is abundantly fossiliferous and is undoubtedly marine in origin. The extreme lower portion carries a few silt stringers, and the presence of foraminifera indicates that it is also of marine origin. The middle portion, on the other hand, possesses some nonmarine characteristics and it may actually be a land-laid deposit. This sand, including all three divisions, has locally been termed Olcese sand. The upper portion is undoubtedly the stratigraphic equivalent of the lower Gould shale on the west side of the valley. Very likely the Olcese also includes beds which are the age equivalent of the button bed sand and most of the Media shale of the type Temblor. The lower part was deposited during late Saucesian and the upper part during early Relizian.

Round Mountain Silt

Above the Olcese sand is a shale or silt member varying in thickness from a few feet to several hundred feet. This member has locally been termed the Round Mountain silt.

The Round Mountain silt includes the equivalent of the upper part of the Gould shale, and probably all of the Devilwater silt on the west side of the valley. This member thickens toward the valley and, in the central valley wells, it represents all of the Relizian and Luisian time stages of deposition. In the Round Mountain area east of Bakersfield, it is somewhat more limited, representing only late Relizian and early Luisian. The reason for this variation in extent of time limits from one area to another will be discussed below.

Lower Fruitvale Shale

Above the Round Mountain silt there is a body of shale which carries a distinctive foraminiferal assemblage. This shale, in general, thins toward the edge of the valley and thickens in the opposite direction. It has locally been termed lower Fruitvale shale.

The lower Fruitvale shale belongs to the lower Mohnian stage of deposition and it is the time equivalent of at least a part of the so-called McDonald shale of the west side of the valley. It occupies a position correlative to the middle or upper Monterey of the coastal district.

A lenticular sand of limited areal extent, but sometimes attaining considerable thickness, wedges in at the contact between the lower Fruitvale shale and the Round Mountain silt. This sand is locally known as the Wicker sand.

Wicker Sand

The Wicker sand is principally confined to the region north and northwest of the Edison field. The exact relation of this sand to the Round Mountain silt is only a matter of speculation. It seems to be present at the expense of the Round Mountain silt, and yet shale stringers within the sand carry a lower Fruitvale shale fauna.

In some areas the lower Fruitvale shale and the Round Mountain silt are indistinguishable, lithologically. This is true particularly in the Edison oil field. Thus, the term Edison shale came into use.

Edison Shale

The Edison shale is a lithologic unit consisting of a dark gray to brown, platy shale, but it can readily be subdivided by means of foraminifera. There can be little question but that the Edison shale includes the equivalents of both the Round Mountain silt and a considerable portion of the lower Fruitvale shale. The lower Fruitvale shale appears to be truncated and overlapped towards the east by the upper Fruitvale shale.

Upper Fruitvale Shale

The upper Fruitvale "shale" consists mainly of siltstone interbedded to some extend with sand, and perhaps is best developed in the Fruitvale field. It belongs, in part, to the upper Mohnian stage of deposition, and is the equivalent of the so-called Antelope shale on the west side of the San Joaquin Valley. The upper Fruitvale shale appears to grade into Santa Margarita sands both laterally towards the east and stratigraphically upward.

Santa Margarita Sand

The Santa Margarita sand rests progressively on older and older beds towards the east. The evidence is insufficient to be certain whether this sand rests unconformably on older beds, or whether it becomes progressively older up-dip, representing a facies equivalent of shales down dip. Certainly it is separated by an unconformity when it rests on lower Fruitvale, and ultimately on the Round Mountain silt in outcrop. This transgressive sand is variously referred to as the "Fruitvale" or "Santa Margarita" sand. It is, in a general way, related to or connected with the Stevens sand in the central valley fields.

Stevens Sand

The Stevens sand is that sand first discovered and found productive in the Ten Sections oil field. It is upper Miocene in age, and very likely should properly be included in the Delmontian stage of deposition. This sand is highly variable in thickness and lateral extent. Overlying the Stevens sand in the central valley fields is a siliceous shale which is a minimum of 500 to 1,000 feet thick. This shale has been referred to the west-side term "McLure" shale.

McLure Shale

The McLure shale, as defined by Gerard Henny (30, p. 404), was divided into three parts. The upper division consists of dark brown clay and silty shale approximately 90 feet thick. The middle portion is composed of "hard, siliceous brown shale with micro-organisms," about 320 feet thick. The lower portion, which is about 390 feet thick, consists of "brown, siliceous shale, softer and less resistant to erosion than shale #2." This lower portion often grades to sand laterally, and it is this division which is the stratigraphic equivalent of the producing Stevens zone in the Greeley field. In Rio Bravo this division is represented by a shale similar in character to the outcropping beds. The hard siliceous middle portion is the stratigraphic equivalent of the cherty zone in well sections above the Stevens sand. This is based on a detailed study of surface sections in the Reef Ridge area. The upper 90 feet thickens northward along Reef Ridge apparently as the result of additional beds coming in unconformably below the Pliocene. This upper division, including the added beds, is Barbat and Johnson's (34a) Reef Ridge shale.

The McLure shale belongs to the Delmontian stage of deposition, and is uppermost Miocene in age. Kleinpell took the base of the Reef Ridge shale as his earliest Delmontian in the San Joaquin Valley, but in other areas he included in the Delmontian, beds which are obviously older than any part of the McLure shale as represented in the type section. Note should be made regarding a faunule occurring in isolated spots along Reef Ridge immediately below the base of the McLure, but which is separated from it by an unconformity. Kleinpell correctly placed this faunule in his Mohnian. His failure, however, to recognize the unconformity separating this faunule from the McLure caused him mistakenly to include both within the same stage. To conform with his divisions in other areas he should have included the McLure in the Delmontian stage as he did the Reef Ridge.

Reef Ridge

The term "Reef Ridge" as here used is synonymous with the upper division of the McLure. Too often, in well sections, beds which are obviously Pliocene in age have been erroneously included in the Reef Ridge (Miocene). This recurring error on the part of some paleontologists and geologists has resulted in considerable confusion in placing correctly the top of the Miocene in well sections.

The time equivalent of the McLure shale including the Reef Ridge appears to be found on the extreme east side of the San Joaquin Valley in the land-laid Chanac formation.

Chanac Formation

The Chanac formation, as recognized in well sections drilled in the Bakersfield area, is composed of those land-laid beds resting on the Santa Margarita sand and underlying the marine Pliocene. As suggested above, the Chanac grades valleyward into the McLure-Reef Ridge shale.

Above the McLure-Reef Ridge shales, a group of claystones and siltstones, here referred to the Jacalitos, is found in the central valley oil fields.

Jacalitos

The Jacalitos is best developed in the central valley fields. The lower portion of this member has often been referred to the Reef Ridge. It contains a good Pliocene microfauna, and there should be little doubt as to its age. The Jacalitos either is progressively overlapped toward the extreme east edge of the valley, or it grades into the upper part of the continental Chanac. The evidence is not clear as to which is the case.

Above the Jacalitos is a series of sands and silts which are here referred to the restricted Etchegoin.

Etchegoin

The Etchegoin is that portion of the Pliocene below the top of the *Mulinia densata* zone and above the originally defined Jacalitos formation. This follows the present classification of the San Joaquin Valley Pliocene by the United States Geological Survey (Woodring, W. P. 34). The division between the Jacalitos and Etchegoin is more or less arbitrary, but the base of the Etchegoin is here taken on the first occurrence in well sections of *Nonionella cushmani* Stewart and Stewart. The upper part of the Etchegoin grades laterally into the continental Kern River series of the Bakersfield area. The lower portion extends farther eastward to form the marine finger between the Kern River and the Chanac formation. Beds immediately above the Etchegoin in fields along the Greeley-Rio Bravo uplift are composed largely of claystones and siltstones. These constitute the lower portion of the San Joaquin clay.

San Joaquin Clay

The upper part of the San Joaquin clay is represented by continental deposits. Although the interval has not been cored, there is a reasonable chance that the continental beds extend downward, and actually include a part of the upper Etchegoin in the Greeley field. The San Joaquin clays, as represented in both the Wasco and Rio Bravo fields, grade upward as well as laterally eastward and southeastward into Kern River deposits.

Kern River Formation

The Kern River formation is a land-laid series of Pliocene and Pleistocene age, and represents a facies or the time equivalent of marine and brackish water beds deposited farther out in the valley.

With the exception of recent deposits which are composed largely of reworked earlier continental beds, the Kern River formation is the youngest formation in this area. Certainly strata constituting this formation are the youngest oil-producing beds in this area.

PRODUCTIVE BEDS

As indicated on the chart, oil is produced from several different zones within the various fields on the east side of the valley. The most productive zone at present undoubtedly is the Vedder sand. Other zones have produced considerable quantities of oil in the past, but none at present approaches the Vedder production figures.

Some oil is produced in the Edison field from beds which have been questionably assigned to the Walker formation. The amount of production obtained is relatively small and is hardly worth mentioning. Considerable oil has been produced from sands within the Freeman-Jewett silt interval, particularly in the Round Mountain field. The lowest sand in this part of the section has been termed the Elbe zone. To be more specific, this zone occurs immediately above the Vedder sand, and practically all the wells in the southern part of the Round Mountain field are producing from it. Limited production has been obtained from lenticular sands within the Edison shale in the Edison oil field, but elsewhere on the east side of the valley this part of the section is unproductive.

The next production of any importance comes from the Santa Margarita sand. Except for limited amounts in the Edison field, production from this sand is pretty well confined to the Mountain View field. With respect to total production to date, the oil zones within the Chanac and Kern River formations have produced perhaps as much oil as any other zone found in fields considered on the accompanying chart. A limited amount of production has been obtained from the Etchegoin finger which wedges between the Chanac and Kern River formations in the Bakersfield area.

Correlations of oil zones as well as formational members have been based on occurrences of foraminiferal horizons and to a lesser extent on sequence and superposition.

CORRELATIONS

The lower Miocene can be closely subdivided on the basis of foraminiferal horizons and zones and, therefore, correlations become a relatively simple problem. These foraminiferal subdivisions allow a close comparison of the stratigraphic position at which the Vedder sand first appears in various fields. That part of the producing horizon in the Rio Bravo field which is often referred to as the Rio Bravo sand has been traced from well to well eastward through the Fruitvale area and thence to the Poso Creek field and it has been proven practically beyond question to be the exact stratigraphic equivalent of the upper Vedder sand. That part of the producing horizon which has simply been referred to as the Vedder sand has been traced in a similar manner, to the lower Vedder of the Mt. Poso field.

Unless an unconformity exists at the top of the Vedder, the productive sand in the Wasco field appears in the section about 100 feet stratigraphically higher than it does at Rio Bravo. The evidence is not strong for an unconformity, but it may exist. If not, the sand simply grades higher in the section in a northerly direction. In either case there seems little question but that the sands are actually connected between fields; that is, the productive sand in the Wasco field is not an entirely isolated sand.

The Olcese sand, the next prominent sand above the Vedder, appears to be limited to an area north, northeast, and northwest of Bakersfield. The western zero isopach trends in a northwesterly direction, thus limiting its distribution. A large portion of this sand unquestionably grades laterally towards the southwest into shales, but there seems to be little doubt that an unconformity either exists at some point not far below the base of the Round Mountain silt or at some lower point still within the stratigraphic limits of the Olcese. This is evidenced by the fact that wells in the Rio Bravo and Greeley fields apparently pass directly from the Round Mountain silt into the Freeman-Jewett, while in the Round Mountain area there is perhaps as much as 700 feet to 1,000 feet of Olcese sand between these two silt members. However, the base of the Round Mountain silt in the Round Mountain area probably does not come at the same stratigraphic position as the base found in the Rio Bravo area. Similarly there appears to be a good possibility that the top of the Freeman-Jewett in the Rio Bravo field is stratigraphically higher than the top in the Round Mountain district. This, of course, suggests lateral gradation. However, when foraminiferal subzones are compared, and when stratigraphic intervals are considered, there certainly is a strong suggestion that an unconformity actually exists, cutting out a large portion of the Olcese sand in a general southwesterly direction. Isopachs drawn on this sand body rather suggest a shore line facies of possible shale equivalents valleyward. The Round Mountain silt is a fairly constant member and with certain limitations, it is a valuable time unit. The lower Fruitvale shale is also a fairly constant member except it becomes much thinner towards the east, as previously stated, and becomes much more silty. There is very strong evidence that an unconformity exists at the top of this shale as is indicated by the fact that numerous subzones recognized in the southwestern portion of the valley are absent in the Bakersfield region. The lower subzones remain more or less constant with respect to the underlying Round Mountain silt. The upper Fruitvale shale is very well developed in the westerly portion of the Fruitvale field and can readily be recognized in the fields along the Rio Bravo-Greeley uplift, as well as in many of the fields eastward from Fruitvale. The lower beds of this member appear to be progressively overlapped toward the east allowing for rapid thinning in this direction. The upper portion of this member grades laterally into Santa Margarita sand, and this in turn grades laterally up dip into coarse, continental clastics, the Chanac formation. While the evidence is not conclusive, this interpretation is the most satisfactory. Other interpretations can be made but the sedimentary cycle is typical of a transgressive-regressive stage of deposition and it is so here interpreted. There can be little doubt that the Chanac (or Kern River series) actually does rest unconformably in outcrop on middle and lower Miocene, but this is beyond the point of transgression of the Santa Margarita (upper Fruitvale) sea. From the Fruitvale area west through a series of wildcats the Chanac appears to grade laterally in a westward direction into a coarse marine sand, and thence into McLure shale. The lower part of the Chanac may possibly grade westward into the upper part of the Stevens sand but most of the Stevens sand is related to the Fruitvale sand of the Fruitvale field. The upper portion of the Chanac, as represented by its maximum thickness, may actually be the time equivalent of the lower Jacalitos. If such is the case, the Chanac formation bridges the time gap between the Miocene and Pliocene epochs. On the other hand, the Jacalitos may simply be progressively overlapped by younger Jacalitos beds and finally by the Etchegoin.

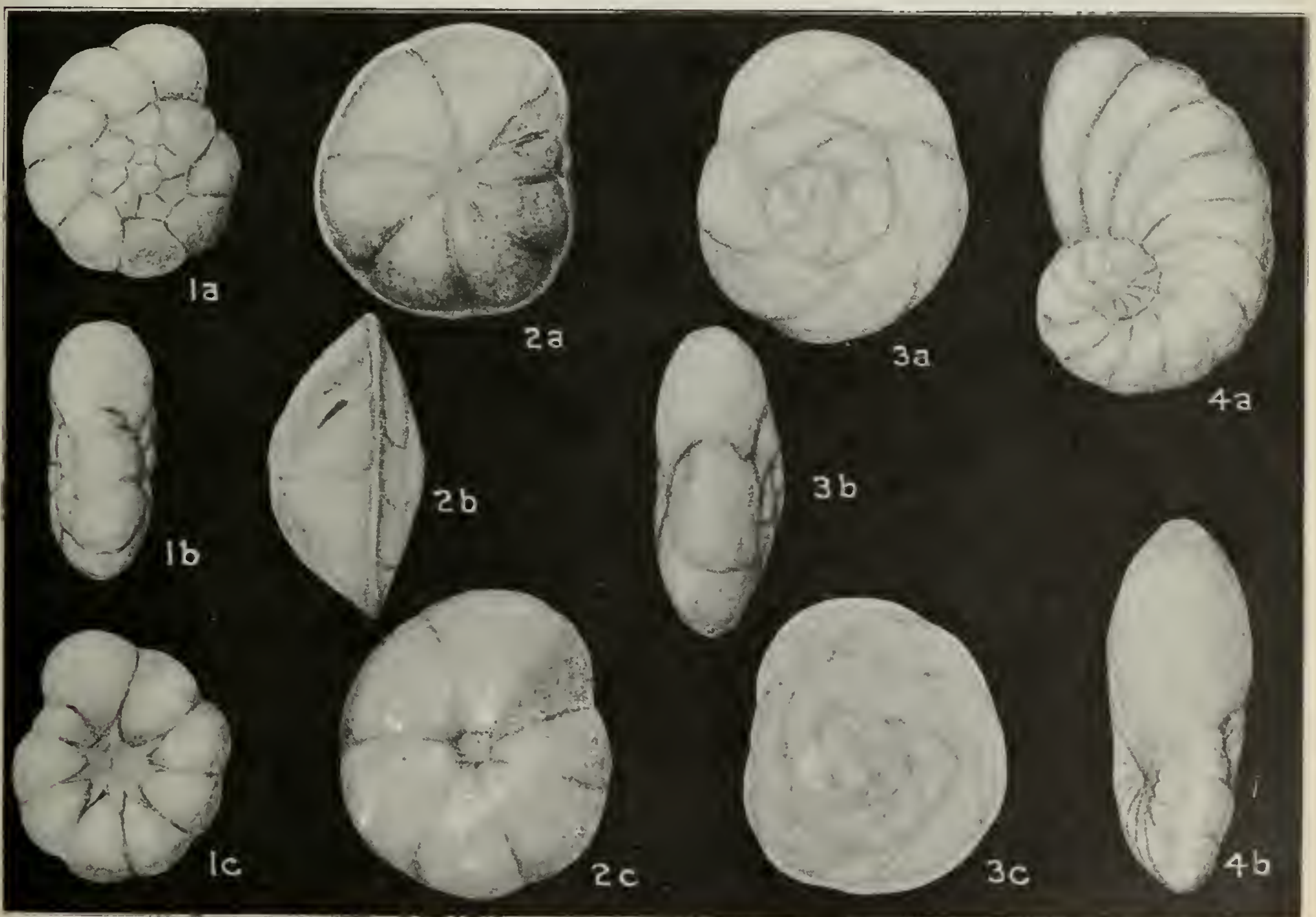

Fig. 97. (1 to 4). Tertiary Foraminifera from oil field formations, east side San Joaquin Valley. *Drawn by R. W. Bauer.*

1a, 1b, 1c. *Eponides* sp. A, n. sp., x60.
2a, 2b, 2c. *Eponides* sp. B, n. sp., x85.
3a, 3b, 3c. *Eponides exigua* (H. B. Brady), x130.
4a, 4b. *Nonionella cushmani* R. E. and K. C. Stewart, x130.

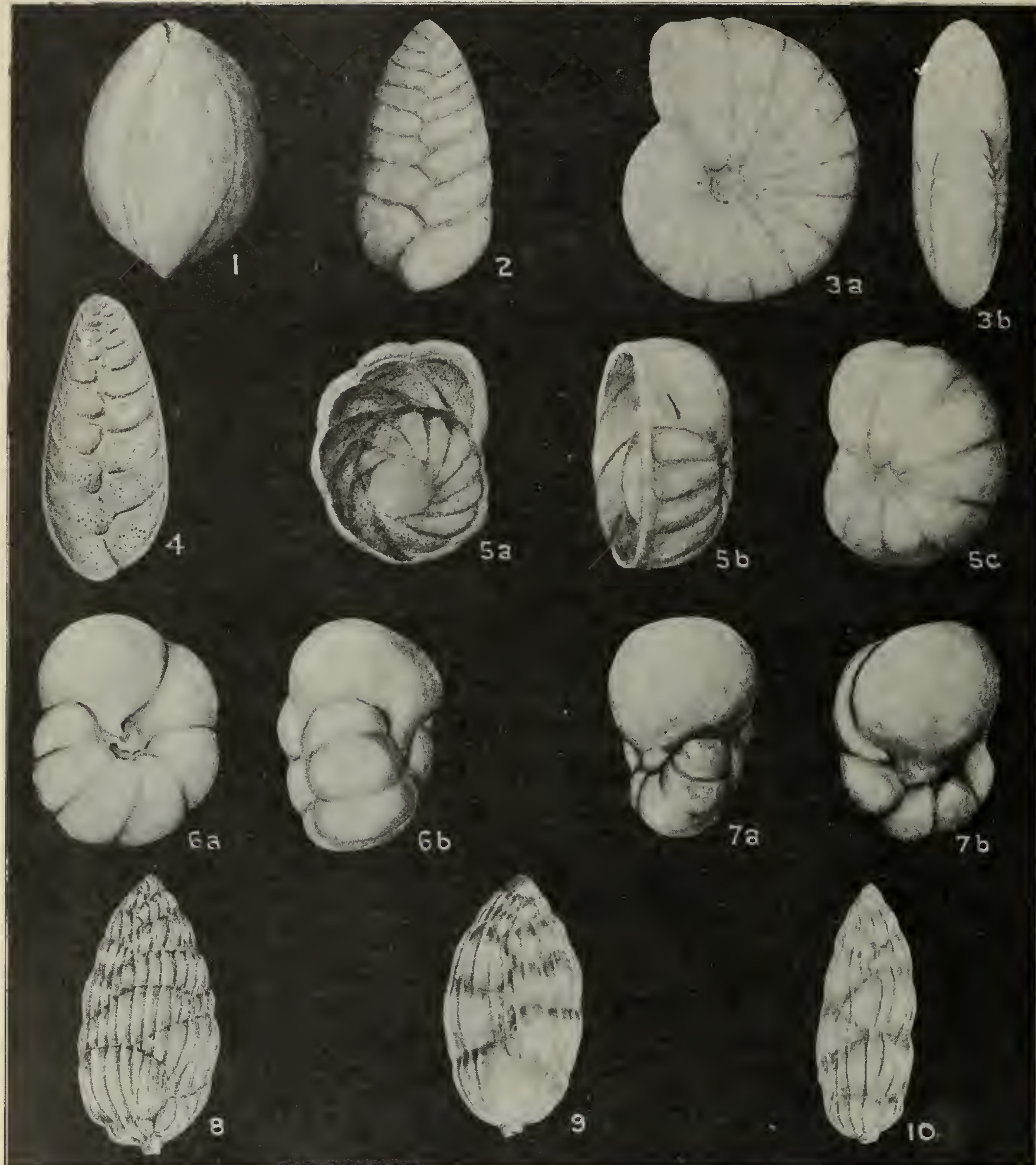

FIG. 98. (1 to 10). Tertiary Foraminifera from oil field formations, east side San Joaquin Valley. *Drawn by R. W. Bauer.*

1. *Globobulimina pacifica* Cushman, x60.
2. *Bolivina* sp. (of Barbat and Johnson), x135.
3a, 3b. *Cyclammina* sp., x45.
4. *Bolivina marginata* Cushman, x60.
5a, 5b, 5c. *Pulvinulinella gyroidinaformis* Cushman and Goudkoff, x145.
6a, 6b. *Valvulineria californica* Cushman, x45.
7a, 7b. *Valvulineria robusta* (R. M. Kleinpell), x45.
8. *Uvigerinella obesa* var. *impolita* Cushman and Laiming, x65.
9. *Uvigerinella sparsicostata* Cushman and Laiming, x65.
10. *Siphogenerina smithi* R. M. Kleinpell, x40.

CORRELATION OF OIL FIELD FORMATIONS ON WEST SIDE OF SAN JOAQUIN VALLEY

By Paul P. Goudkoff *

OUTLINE OF REPORT

INTRODUCTION

This paper is to give an explanation of, and to furnish some additional comments to, the accompanying straight-line correlation charts of formations developed in the oil fields on the west side of the San Joaquin Valley. These fields are: Coalinga Nose and Coalinga Northeast Extension; East Coalinga; Kettleman North Dome; Devils Den Old Area and Alferitz area; Lost Hills; North Belridge; Buttonwillow and Semitropic; South Belridge; McKittrick-Temblor area; McKittrick Franco-Western area; McKittrick West End; Canal, Ten Sections and Coles Levee; Tupman, Elk Hills; Buena Vista Hills; Midway-Sunset Republic area, Williams area, and Maricopa Flat; Wheeler Ridge.

The first column on the left in each chart shows the age of formations. The youngest beds are divided merely into Pleistocene, and upper and lower Pliocene. For the Miocene strata there are indicated the time-stratigraphic units as defined by R. M. Kleinpell (38). The Eocene sediments (except the youngest) are segregated into "molluscan stages" proposed by B. L. Clark and H. E. Vokes (36, p. 853). For the uppermost Eocene, instead of the Gaviota stage of Clark and Vokes, the Refugian stage is used, as defined by H. G. Schenck and R. M. Kleinpell (36).

In the second column in the charts are given the faunal characteristics of formations and zones. For the Pleistocene, Pliocene and most of the Miocene zones, organic remains are used which are identical to those indicated by Glenn C. Ferguson in his chart showing the correlation of San Joaquin Valley east side oil fields (published in this volume). The only difference, as compared with Ferguson's chart, is in the introduction of one more upper Miocene zone (characterized by *Bolivina obliqua*). This zone, included by Ferguson in the upper division of the McLure shale, can be easily recognized, in the writer's opinion, as a distinct lithologic and microfaunal unit in a number of west side fields.

In selecting characteristic fossils for the lowermost Miocene and for the Eocene zones the writer has followed suggestions made by Kleinpell (38, pp. 137-151; fig. 14 in pocket) and Boris Laiming.[1] Also Laiming's symbols designating the zones (A-1, A-2, etc.) are used for the Eocene zones of the Tejon-Transition, Domengine and Capay stages, in the third column of the charts.

In the columns showing the stratigraphic sequence in the fields, the following symbols are used: *cross*—indicating absence of certain zones or formations; *letter G*—gas sand; *square with black lower right corner*—horizon with minor oil production; *solid black*—principal oil-producing sands (figures on the right give the approximate thicknesses of these sands); *black circles*—horizons with non-commercial oil or gas showings.

STRATIGRAPHY

With the exception of the Oil City field not discussed in this paper and producing from the early Upper Cretaceous beds (Panoche formation), all the fields on the west side of the San Joaquin Valley derive their oil and gas from the Tertiary and post-Pliocene strata.

Gatchell Sand

The oldest of the Tertiary oil horizons is the Gatchell sand discovered in 1938 by the Petroleum Securities Gatchell well No. 2 in the Coalinga Nose field (also known as the East Coalinga Extension field). In this field the sand attains a thickness of about 645 feet and is entirely confined to the part of the Arroyo Hondo member of the Lodo formation defined by Laiming[2] as zone B-3. Farther to the north, in the so-called Amerada area, the sand has a thickness of over 800 feet and extends into somewhat older beds of the Arroyo Hondo, embracing the upper part of Laiming's zone B-4.

Within the Coalinga Nose field, the Gatchell sand is rapidly pinching out toward the west. A foraminiferal study of the wells in which no sand was found (in Sec. 12, T. 20 S., R. 15 E., M. D., and Sec. 1, T. 19 S, R. 15 E., M. D.) clearly indicates that the disappearance of the Gatchell sand is not due to any hiatus in the disposition of the Arroyo Hondo beds, but merely to a gradation of the sand into argillaceous beds. In wells where only a small thickness of the sand was encountered (for instance in the NE¼ Sec. 12, T. 20 S., R. 15 E., M.D.) the heavy mineral characteristics of the sand, as well as the foraminiferal content of the beds directly above and below the sands, show very definitely that this thin sand represents a lower portion of the Gatchell. Thus the grading of the Gatchell sand into clayey beds starts within its upper part. Similar conditions are noted by

* Geologist, Los Angeles, California. Manuscript submitted for publication August 15, 1940. Information regarding the stratigraphy of the McKittrick oil field as well as that of the Devils Den Old Area has been furnished to the writer by Glenn C. Ferguson. The data concerning stratigraphic position and thickness of the oil sands in the old East Coalinga field and Kettleman North Dome have been obtained from Martin Van Couvering and A. Van Couvering. Downs McCloskey and Glenn B. Gariepy have made a number of helpful suggestions. James M. Hamil and Boris Laiming criticized an early draft of the manuscript. To all of them the writer is very grateful.

[1] "Some foraminiferal correlations in the Eocene of San Joaquin Valley, California," paper presented before the Sixth Pacific Science Congress on August 1, 1939, at Berkeley, California. *See also* "Eocene foraminiferal correlations in California," in this volume.

[2] *Op. cit.*

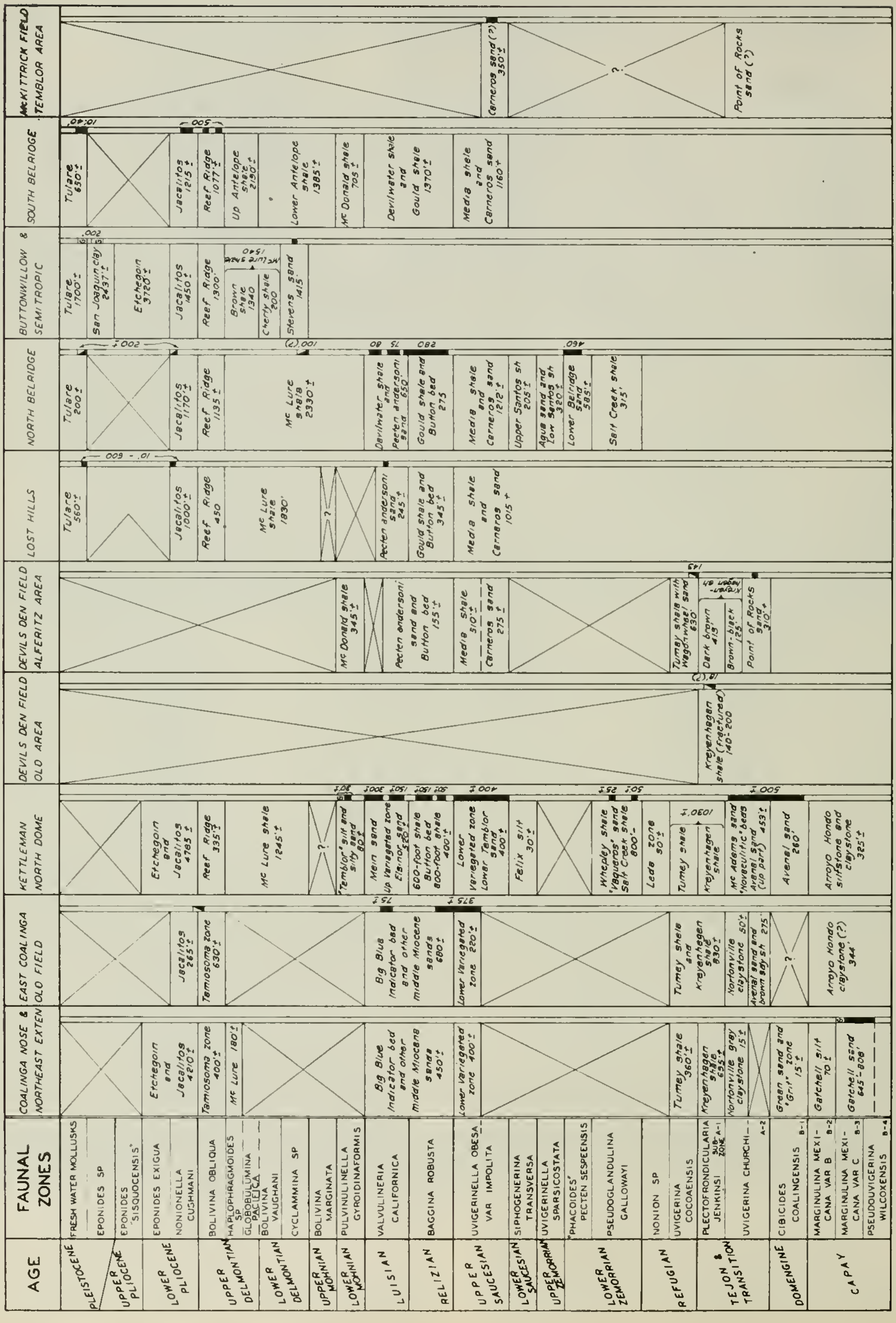

FIG. 99A. Straight line correlation chart of the west side San Joaquin Valley oil fields.

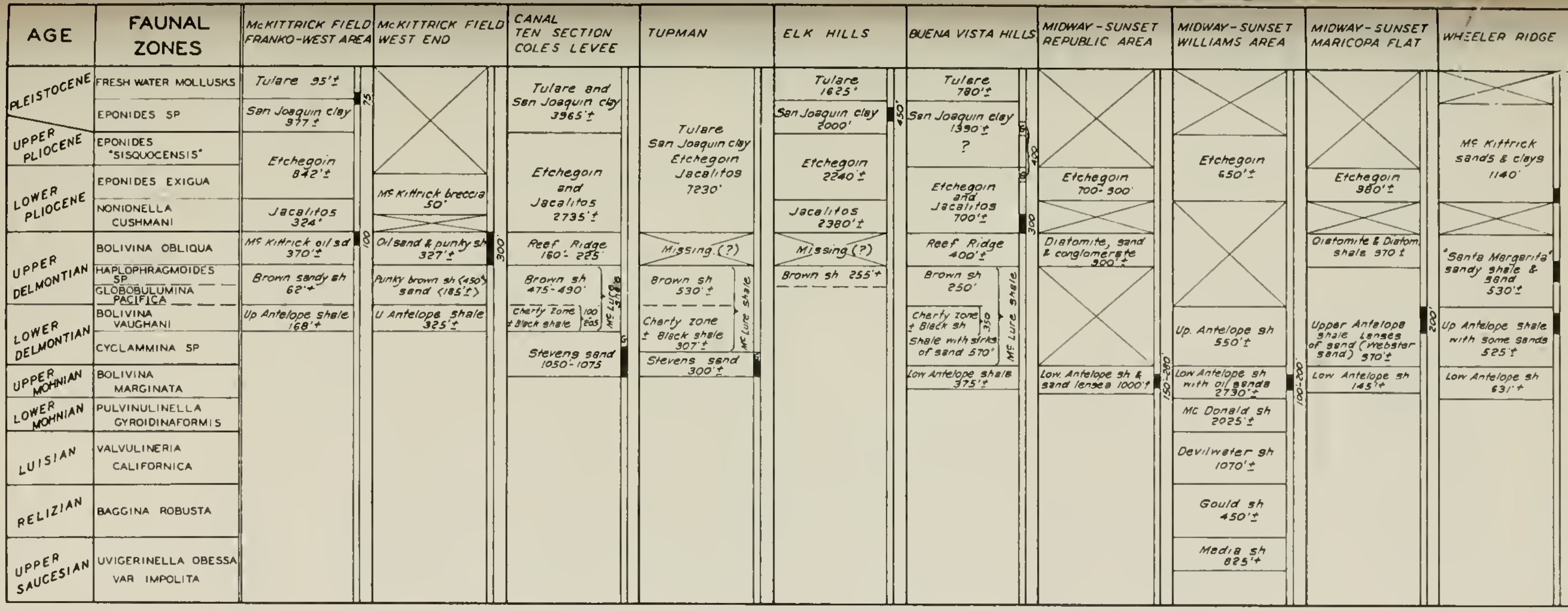

Fig. 99B. Straight line correlation chart of the west side San Joaquin Valley oil fields.

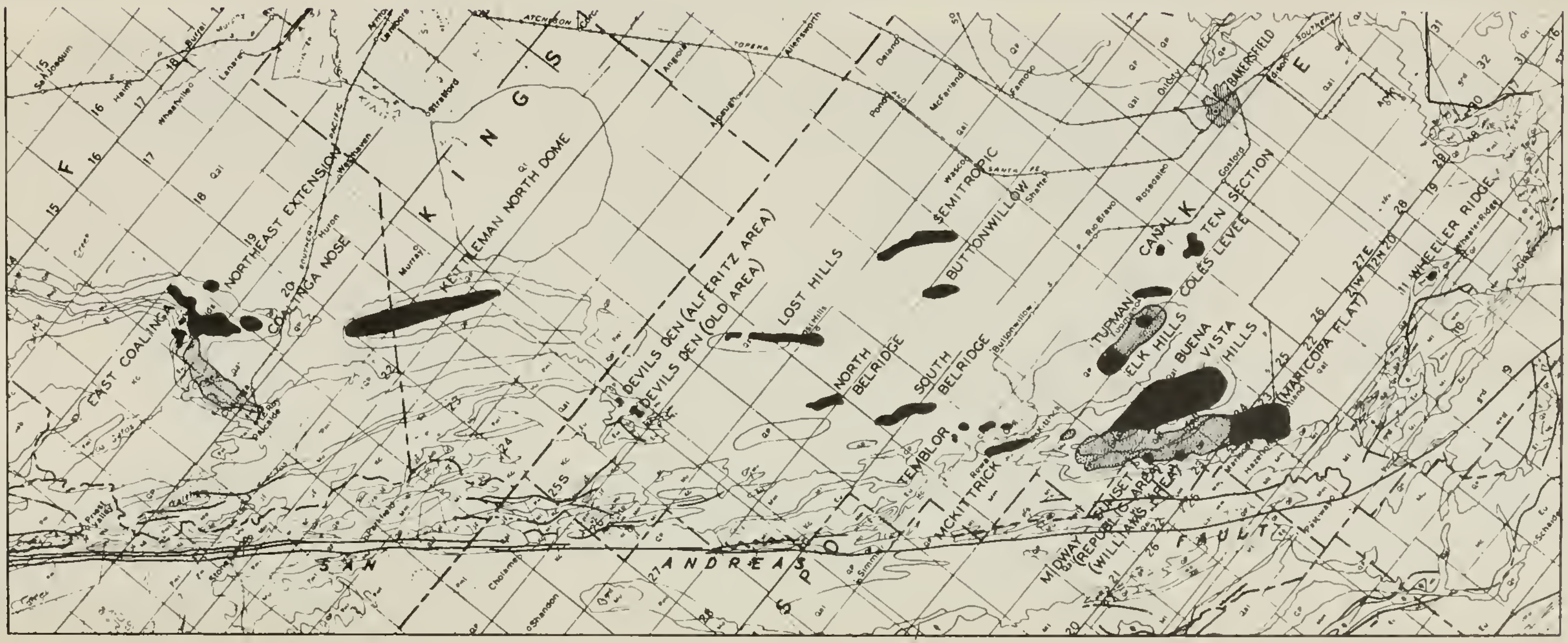

Fig. 100. Index map to figure 99, showing location of east side San Joaquin Valley oil fields. *Drawn on outline Geologic Map of California, by Olaf P. Jenkins.*

comparing the wells in the Coalinga Nose field with those drilled in the so-called Bandini area (Sec. 18, T. 19 S., R. 15 E., M. D.).

No sand equivalent to the Gatchell has been recognized in the Kettleman North Dome, as there the whole thickness of the Arroyo Hondo (including the top of zone B-3) is represented by siltstone and claystone. Also, only silty and clayey beds compose the Arroyo Hondo formation in the old East Coalinga field. This latter assumption is based only, however, upon the study of logs from wells drilled between 1912 and 1917, from which no cores or ditch samples are now available.

Avenal Sand

The Arroyo Hondo member of the Lodo formation in the whole area of the Coalinga district is separated from the overlying Domengine strata by a distinct break in deposition. This break finds its expression in the variable thickness of the Domengine beds, in the variable micro-organic content of the Arroyo Hondo horizon directly below its contact with the Domengine, and in the frequent abundance of glauconite at this contact. In the East Coalinga Extension field, the Domengine is represented by the "Grit" zone with a minor amount of interbedded silt or silty claystone. In the Kettleman North Dome, Domengine age should be assigned to the lower 260 feet of what is called there the Avenal sand. In the old East Coalinga field, as far as one can judge from a study of well logs, the Domengine appears to be missing. Farther to the north and northeast of the Coalinga Northeast Extension field (in T. 17 S., R. 15 E., and T. 18 S., R. 17 E., M.D.), the Domengine is again represented by sand attaining a thickness from 150 to 211 feet.

Upper Eocene Producing Sands

Recent foraminiferal studies by Crume (40) have shown that at least a part of the Avenal sand is younger than the Domengine and belongs to the same foraminiferal zone (A-2 of Laiming) as the basal 400 to 500 feet of the Kreyenhagen and the clay shale member developed north of Mount Diablo and referred to by Reed and Hollister (36) as Nortonville. In the Kettleman North Dome, zone A-2 is represented by about 450 feet of strata penetrated by the K.N.D.A. 4-18 J well, below the Kreyenhagen shale. The sediments in this zone are composed of sands (including the McAdams sand) with inter-bedded "novaculitic" beds, and brownish-black, in part lignitic, shale. In the old East Coalinga field, 325 feet of the beds underlying the Kreyenhagen and logged as gray silt, sand and brown sandy shales, may be referred to zone A-2. In the Coalinga Nose and Coalinga Northeast Extension, only a small thickness of gray claystone, conformably underlying the Kreyenhagen and separated from the underlying Domengine by a layer of "green" glauconitic sand, belongs to zone A-2. Equivalent to this zone are also the brown-black shale forming the basal 125 feet of the Kreyenhagen, and the Point of Rocks sand in the Alferitz area of the Devils Den field. According to information obtained by the writer from Glenn Ferguson, the Point of Rocks sand unconformably underlies the Carneros sand in the Temblor area of the McKittrick field.

Kreyenhagen Shale

This formation, as shown on the accompanying charts, forms the middle member of the Kreyenhagen group and the upper part of Clark and Vokes' Tejon and Transition stages. It is reported as furnishing a small production of oil (from the fractured zone of the shale) in the Old Area of the Devils Den field (Howard, P.J. 39, p. 15; Huguenin, E. 23, p. 9). Lacking core samples or any other information regarding the micro-organic content of the fractured zone in this field, it is impossible to ascertain whether the producing horizon actually falls in the Kreyenhagen proper or in the overlying Tumey shale, which is often referred by field geologists to the Kreyenhagen also.

Sediments of the Refugian Stage

These sediments are represented in the West Side fields by the Leda zone, Tumey shale and Wagonwheel sand (also known as the *Thyasira* sandstone) which is interbedded with the Tumey shale apparently in the form of lenses. This sand is yielding a small amount of oil in the Alferitz area of the Devils Den field.

Whepley Shale, Vaqueros Sandstone and Salt Creek Shale

The Whepley shale is a layer cored by some of the Kettleman North Dome wells between the so-called Felix silt and Vaqueros sandstone. The Felix silt overlaps the Whepley shale and, due to this overlap, the shale is gradually decreasing in thickness towards the northwest, and is entirely missing in the northwest half of the Dome, where the Felix silt rests directly upon Vaqueros. In some wells near the southeastern end of the North Dome, there is a body of shale (about 40 feet thick) within the Vaqueros which contains certain arenaceous foraminifera. This body of shale is separated from still another shale body which carries foraminifera similar to those of the Whepley shale and which grades into the Leda zone. The foraminiferal content of all the three shales just mentioned is typical of the lower Zemorrian stage of Kleinpell and suggests the following correlations:

1. The Whepley shale proper is equivalent to that exposed directly below the *Phacoides* Reef (Vaqueros) and above the Eocene Cavernous sand in Salt Creek and in Chico Martinez Creek, and also to the intermediate shale cored by North Belridge wells between the Bloemer and the Belridge sands.

2. The shale with arenaceous foraminifera is correlative with that cored by the Union Oil Gibson well (in North Belridge) above 586 feet below the top of the lower Belridge sand.

3. The second and third shales of the Kettleman North Dome are equivalent to the top, middle portion, and base of the body of shale (without any interbedded sands) cored by the Amerada Petroleum Beer No. 1 and Beer No. 3 wells below a portion of the lower Belridge sand and above the beds of Refugian stage. The name Salt Creek shale has been applied to this body of shale by some geologists.

Lower Belridge Sand

This sand (comprising the Bloemer and the Belridge sands of North Belridge) is in part correlative with the Vaqueros sand of the Kettleman North Dome. The upper part of this sand, however, is missing in the North Dome wells. This upper part is correlative to the *Phacoides* Reef exposed in Salt Creek and in Chico Martinez Creek. As one may see from the above, the lower Belridge sand (as well as the Vaqueros of the

North Dome) is interbedded with the Whepley and the Salt Creek shales and forms with these shales one stratigraphic unit.

Lower Santos Shale and Agua Sand

The lower Santos shale and the Agua sand embrace the upper Zemorrian beds, as defined by Kleinpell. They were cored by the North Belridge wells and are well developed on the surface along Media Agua Creek and in the hills southwest of the MacDonald anticline. But they are missing in the Kettleman North Dome, in the Old East Coalinga field, and in Coalinga Nose and Coalinga Northeast Extension. The Agua sand is assumed to be correlative with the so-called Pyramid Hill sand of the east side of the San Joaquin Valley.

Upper Santos Shale

This belongs to the lower part of the Saucesian stage and is equivalent to a part of the Jewett silt of the east side fields. In the Kettleman North Dome, the lower Santos shale is believed to be represented by the Felix silt. In the Old East Coalinga, Coalinga Nose, and Coalinga Northeast Extension fields, the upper Santos shale, as well as the whole sequence of the Zemorrian beds is missing.

Carneros Sand and Media Shale

These formations should be considered as the upper part of type Temblor. They belong to the upper Saucesian stage. In the part of the west side of the San Joaquin Valley southeast from the Lost Hills field, these formations are either easily distinguishable as a body of sand overlain by a nearly solid shale, or represent a series of interbedded beds, with sands prevailing in the lower, and shales prevailing in the upper part. In the Kettleman North Dome, the Media shale has its equivalent in the lower Variegated beds, while the Carneros sand should be correlated with the so-called lower Temblor sand. The Variegated beds are characterized by an andesitic assemblage of heavy minerals (augite and hornblende). On the basis of these minerals, the lower Variegated zone of the Kettleman North Dome can be correlated with that part of the subsurface section of the Old East Coalinga, Coalinga Nose, and Coalinga Northeast Extension fields between the middle Miocene sands and the Tumey shale. Almost the entire thickness of the lower Variegated beds and of the lower Temblor sand is productive in the Kettleman North Dome. In the Old East Coalinga field the lower Variegated includes one of the productive zones of this field. The Carneros sand (believed to overlie unconformably the Point of Rocks sand) furnishes some production in the Temblor area of the McKittrick field.

Middle Miocene Formations

The middle Miocene sediments embrace the Relizian and Luisian stages. They are represented by beds which vary lithologically in different areas. These sediments consist almost entirely of sand in the Coalinga Northeast Extension, Coalinga Nose, and in the Old East Coalinga fields. They are composed of sands with minor amounts of shale in the Kettleman Hills, Devils Den, Lost Hills and North Belridge fields, but become more shaly in South Belridge and southeast of that field. Because of the sandy character of the middle Miocene sediments in the northwesterly fields the correlation of these sediments is rather difficult, and quite often it does not permit a division of the strata into Relizian and Luisian stages. Such is the case in the Coalinga Northeast Extension, Coalinga Nose, and in the Old East Coalinga fields, in which the middle Miocene can be recognized merely as a part of the section between the first occurrence of uvarovite (a mineral typical of the Big Blue) and the first occurrence of augite and hornblende which mark the lower Variegated zone. As one may see from the accompanying charts, the Relizian and Luisian sediments include a number of productive sands in the Old East Coalinga, Kettleman North Dome, and North Belridge oil fields. On the east side of the Valley, the middle Miocene strata are represented by the uppermost portion of the Olcese sand and by the Round Mountain silt.

Lower Mohnian Beds

The lower Mohnian beds are well characterized microfaunally, and are found in a large area along the west side of the San Joaquin Valley. Beginning at the north they outcrop in the Reef Ridge area in the basal part of the McLure shale. The lower Mohnian beds were cored and designated as the McDonald shale in some wells in the Alferitz area of Devils Den, in a deep well in the South Belridge field, in a number of wildcat wells between South Belridge and Midway-Sunset, and in some of the Wheeler Ridge wells. In the writer's opinion an equivalent of the McDonald shale, in Kettleman Hills, is a series of silty sands and silts with a minor amount of silty shale, forming about 80 ft. or more of the sequence directly below the McLure shale and above the first sand (Main sand) which carries *Pecten andersoni*. Such a correlation is based on the presence of a certain species of *Haplophragmoides*, identical to that associated with *Pulvinulinella gyroidinaformis* and confined to the lower Fruitvale shale of the east side of the San Joaquin Valley. The upper part of the so-called "Temblor" in the Kettleman North Dome is the only example in the west side fields where the lower Mohnian beds are productive.

Upper Mohnian Strata

The beds of the upper Mohnian stage are well represented by a part of the Antelope shales in subsurface sections in South Belridge, Buena Vista Hills, Midway Sunset district and Wheeler Ridge; by the lower part of the Stevens sand with interbedded shale in the Canal, Ten Sections, and Tupman fields; and by a part of the McLure shale in North Belridge. In the Lost Hills, and, probably, in the Kettleman North Dome, the upper Mohnian stage is either missing, or forms the lower part of the McLure shale as developed in these fields. In the Coalinga Nose and Coalinga Northeast Extension the upper Mohnian beds are definitely lacking. Productive horizons confined to the sediments of this stage are: the lower part of the Stevens sand; sands in the Republic, Williams and Maricopa Flat areas of the Midway-Sunset district, and some of the sands in the Wheeler Ridge field.

Lower Delmontian Sediments

In the Central Valley fields, these sediments are represented, in the writer's opinion, by that part of the McLure shale beginning with the so-called cherty zone (which contains *Bolivina vaughani*) and embracing part of the Stevens sand down to the first occurrence of *Bolivina marginata*. As is commonly known, the Stevens sand disappears approaching the South Belridge and Rio Bravo fields on the north, and the Buena Vista Hills on the west. The disappearance of the sand is apparently due to a gradational change of the sand into shale. A study of core material from the Tupman wells indicates that the first part to grade into shale is the upper portion of the sand. Toward the east, the Stevens sand, as well as the overlying portion of the McLure shale, appears to grade gently into the Fruitvale sandy series. In the Midway-Sunset, Wheeler Ridge and South Belridge fields, the lower Delmontian stage is represented by the upper part of the Antelope shale. In North Belridge, Lost Hills and Kettleman Hills, the lower Delmontian stage should be assigned to a larger part of the McLure shale. In the most northwesterly fields (Coalinga Nose and Coalinga Northeast Extension) the lower Delmontian sediments are entirely cut out by an overlap of upper Delmontian upon the middle Miocene strata.

Upper Delmontian Sediments

For the prototype of these sediments along the west side of the San Joaquin Valley, the writer has chosen the lower part of the so-called "Caving Blue shale" as described in his paper on the subsurface stratigraphy of Kettleman Hills (Goudkoff, P.P. 34). The beds of this stage are best represented in the subsurface section of the Kettleman North Dome and of the South Belridge fields. Their equivalents in the Central Valley fields are, in the writer's belief, the uppermost part of the McLure shale (down to the top of the cherty zone) and the overlying siltstone or silty shale which carries *Nonion belridgensis*, *Nonionella cushmani* and *Virgulina californiensis*, but lacks *Elphidium* faunas (indicating the Pliocene age). In the Midway-Sunset district, the upper Delmontian stage is represented by a series of sands and pebbly beds, with a minor amount of diatomite and diatomaceous shale. In the Coalinga Nose and Coalinga Northeast Extension fields, upper Delmontian age is assigned to a small thickness of brown shale carrying certain species of *Haplophragmoides* and to the overlying sands known as the *Tamiasoma* zone. It may be noted, however, that the molluscan fauna furnished by cores from some of the Coalinga Nose wells failed to give any information beyond the fact that this fauna was either of uppermost Miocene or of lower Pliocene age.

Post-Miocene Sediments

The Pliocene and post-Pliocene formations shown on the accompanying charts are divided in accordance with descriptions of these formations by Ferguson.[3] The only difference between Ferguson's and the writer's divisions is that the lowermost part of the Jacalitos formation (in which the *Elphidium* faunas are lacking) is referred by the writer to the Reef Ridge.

[3] *See* "Correlation of oil-field formations on east side San Joaquin Valley," in this volume. *See also* Gester and Galloway (33), and Barbat and Galloway (34).

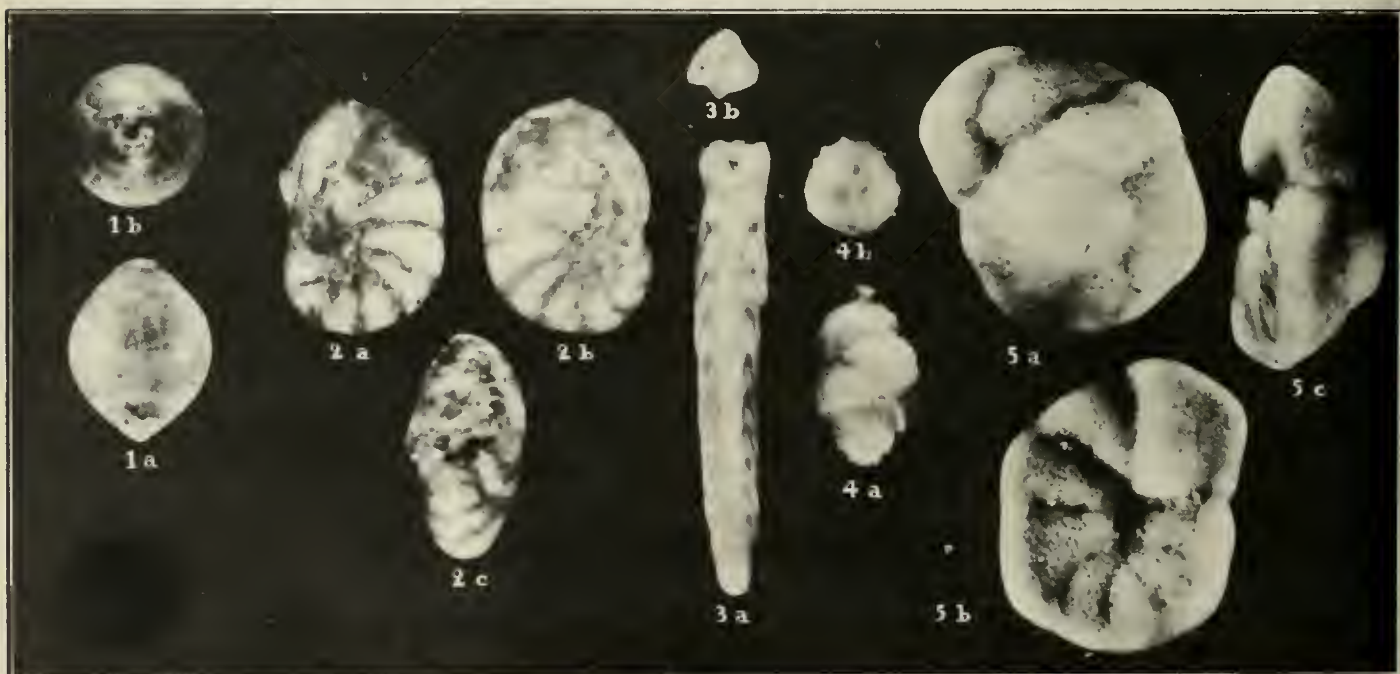

FIG. 101. (1 to 5). Tertiary Foraminifera from oil field formations, west side San Joaquin Valley. *Photographed by Manley L. Natland. Plate prepared by Genevieve E. Estes.*

1. *Pseudoglandulina* sp., x45; a, front; b, apertural view. Lower Miocene, Zemorrian stage, depth 3097 ft. in Amerada Petroleum Corp. well Beer No. 1, Kern Co.

2. *Nonion* sp., x90; a, ventral; b, dorsal; c apertural view. Leda zone, Refugian stage, depth 8703-8713 ft. in Kettleman North Dome Assoc. well No. 38-34-J, Kettleman Hills oil field.

3. *Plectofrondicularia jenkinsi* Church, x40; a, side; b, apertural view. Zone A-1, Eocene. Markley fm. type section; Cal. Acad. Sci. Loc. No. 1832, Contra Costa Co.

4. *Uvigerina churchi* Cushman and Siegfus, x30; a, side; b, apertural view. Zone A-2, Eocene. Loc. No. 219, 230 ft. above base of Kreyenhagen fm., Cantua Creek section, Coalinga quad.

5. *Cibicides coalingensis* (Cushman and Hanna) x40; a, dorsal; b, ventral; c, peripheral view. Zone B-1, Eocene. Oil City section, Coalinga. Loc. No. 2, 10 ft. below top of Domengine fm.

ORIGIN, MIGRATION, AND ACCUMULATION OF OIL IN CALIFORNIA

By Harold W. Hoots *

OUTLINE OF REPORT

INTRODUCTION

Much has been learned about the history of the earth and the origin of its surface features since, from 1775 to 1817, the dynamic teacher Abraham Werner inspired his students at Freiberg with enthusiastic interest in earth history, but dogmatically taught them to believe in erroneous theories as to the origin of volcanoes, minerals, and igneous and sedimentary rocks. Werner's teachings had little fact to support them and fortunately were opposed at about the same time by the scientific investigations of James Hutton who established, through the writings of Robert Playfair, much of our present-day conception of the origin of stream valleys, rocks, volcanoes, and sedimentational irregularities such as unconformities. These and other features of the earth's crust, according to Hutton, were due to processes which can be seen in operation today along the seashore and in the interior of our lands. Study of these earth processes of volcanic activity, erosion, deposition, life, and structural deformation thus became the foundation of the modern science of geology.

Some earth processes, such as the formation and accumulation of oil and gas, can not, however, be subjected to observation. They either are completed or are proceeding too slowly or in places too inaccessible to be detected by present methods of study. We can not, therefore, profess to know with the same certainty as much about the origin of oil and gas as we know about the origin of a stream or glacial valley, a sandstone containing marine fossils, or a layer of scoriaceous basalt. We can only develop a theory based on careful observations of the occurrence of oil and gas, their chemical and physical characteristics, and the types of rock with which they are commonly associated.

* Chief Geologist, Richfield Oil Corporation, Los Angeles, California. Manuscript submitted for publication March 22, 1940.
The writer is indebted to the Richfield Oil Corporation for permission to publish this paper and to several colleagues who through discussion have helped clarify some of the problems herein considered. He acknowledges particularly the constructive criticism of Ralph Reed, Roger Revelle, Howard Pyle, Parker Trask, Rollin Eckis, and Mason Hill, each of whom read part or all of the manuscript.

The writer approaches the task of discussing the origin, migration, and accumulation of oil and gas with apprehension principally because generally accepted theories, although reasonable and supported by a wealth of evidence, can not be supported by direct observation and are not without some contradictory evidence. He is encouraged, however, by the success with which the science of geology is following these theories in the search for additional supplies of oil and gas. Petroleum geology's basic tenets are founded on sound scientific reasoning and 80 years of practical experience, and may be accepted as essentially correct.

Uncertainty and difference of opinion develop in attempts to determine with precision the original biological identity of the source material, the means by which, and the time interval during which this material was transformed into oil and gas and moved to areas of commercial accumulation. The relation of source beds to reservoir rocks and the distance through which oil and gas migrate are likewise matters of controversial opinion because of our inability to reconstruct and understand conditions of the past from the available fragmentary record. The desire of geologists to settle these important problems has led them to advance ideas and theories in some instances without sufficient data or adequate analysis of pertinent information available. There is a tendency to propose a single universally applicable explanation for processes which may have had considerable variety. The present writer is guilty of all of these faults. He has found that existing data and his inability to gather, catalog, and interpret additional pertinent facts permit only broad generalizations as to the origin of oil, the identity and distribution of source material, and the time, causes, and manner of migration and accumulation. Present studies in oceanography, marine biology and sedimentation, core analysis, and subsurface engineering, should better equip geologists to collect critical data on individual fields and areas and to avoid some of the present more objectionable assumptions.

THE ORIGIN OF OIL AND GAS

EARLY THEORIES

The origin of petroleum was a favorite subject for speculation many years before the birth of petroleum geology and before the existence of large quantities of oil and gas was known. Little essential evidence was available to guide the earlier speculations that were proposed to account for the then known occasional occurrence of oil in seepages. No subsurface information was available and the origin and relations of surface rocks, fossils, and land features were likewise subjects of speculative controversy.

The modern era of theories to account for the origin of petroleum began in 1866[1] with the proposal of Berthelot that oil might have its origin in deep-seated chemical reactions between water, carbon dioxide, and the free alkaline metals which might be present in the interior

[1] F. W. Clarke (24, pp. 744-755) presents an excellent summary of early literature on the origin of petroleum.

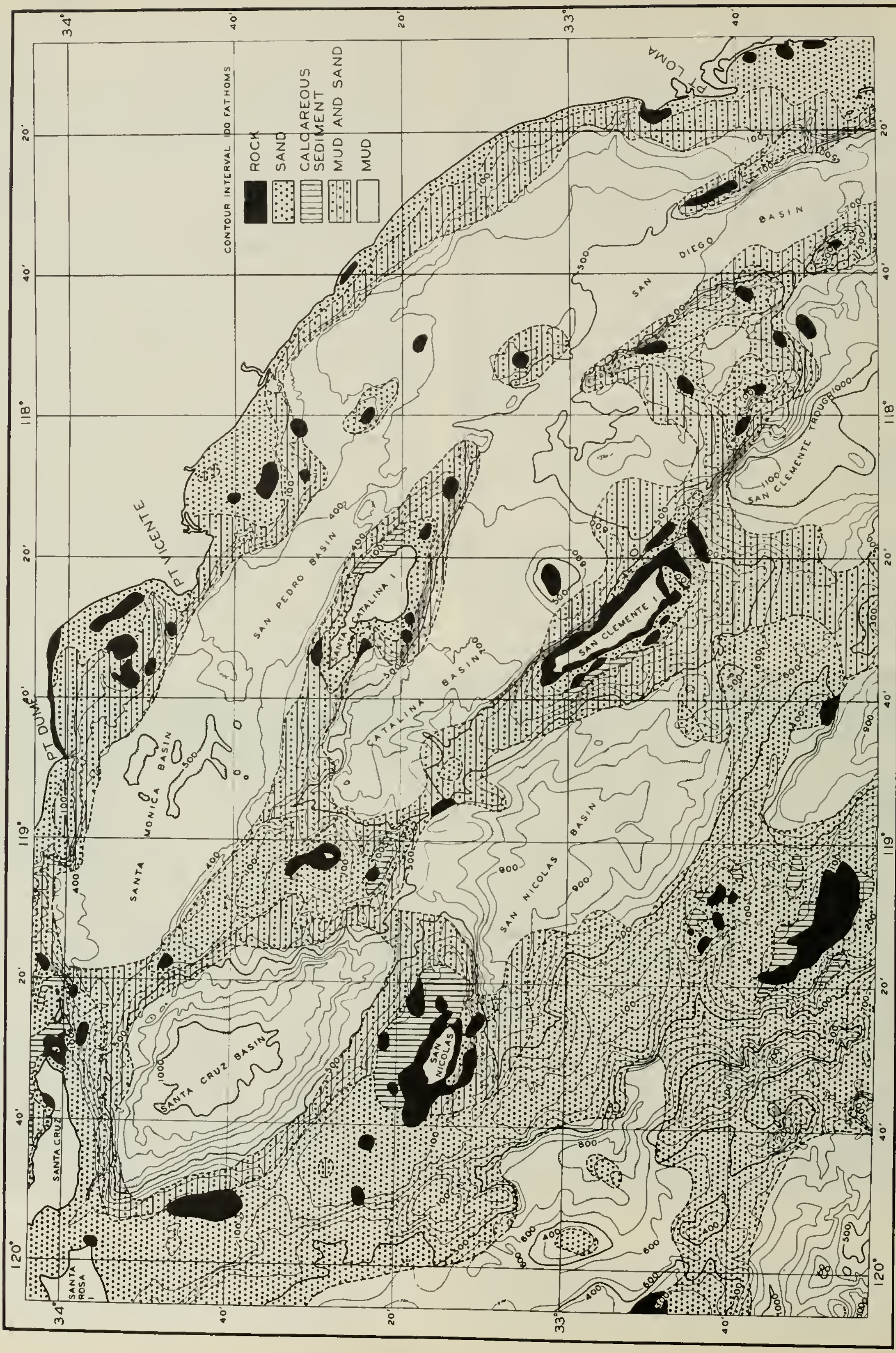

FIG. 102. Topographic map of sea floor off southern California, showing distribution of sediments and rock bottom.

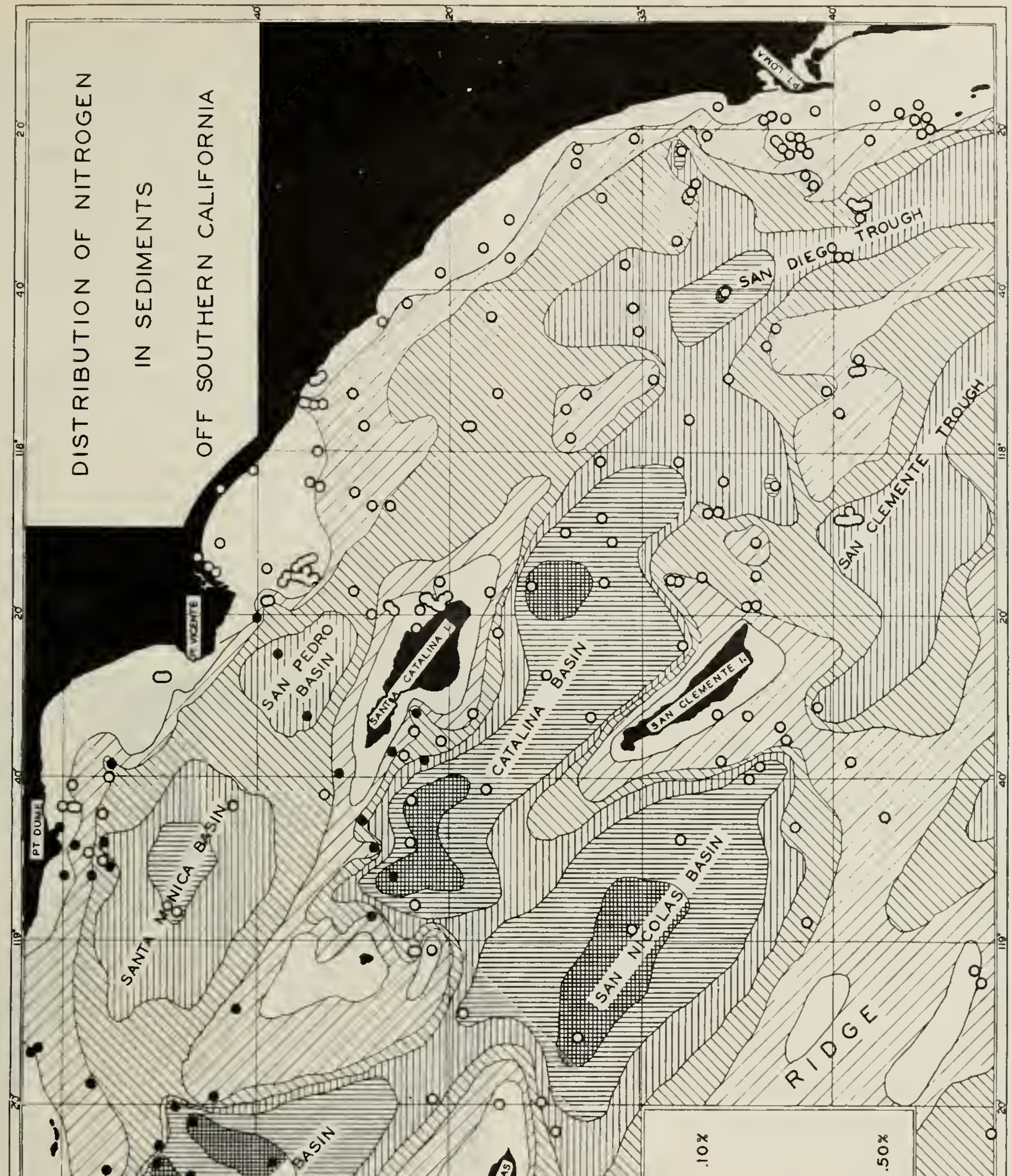

FIG. 103. Map showing distribution of nitrogen in Recent sediments off southern California.

of the earth. This was the beginning of the inorganic theory which for many years received considerable support from chemists who, with several variations in the inorganic ingredients used, were able to obtain in the laboratory mixtures of hydrocarbons chemically resembling petroleum.

Small quantities of hydrocarbons found in meteorites and in volcanic emanations led to two additional ideas: (1) oil is of meteoric origin; it was suggested that hydrocarbons essential to the formation of petroleum were present in sufficient amounts in the material from which the earth was originally formed; and (2) oil is of volcanic origin because volcanic gases contain hydrocarbons. Similar occurrences of small globules of oil in vesicular lava, occasional seeps in granitic rocks, and a few commercial quantities of oil in schist and serpentine near their contact with sedimentary rocks, have more recently suggested to some investigators a similar igneous or inorganic origin for petroleum. The inorganic theories have received support from many laboratory experiments and apparently can be accepted as chemically sound, but their adequacy in meeting the issues involved has been properly challenged by F. W. Clarke (24, p. 747), our foremost authority of geochemistry.

"The [inorganic] theory is plausible, but is it capable of proof? Furthermore, does it account for any accumulations of petroleum such as yield the commercial oils of to-day? These essential questions are too often overlooked, and yet they are the main points at issue. We may admit that hydrocarbons are formed within volcanoes, but the quantities definitely traceable to such a source are altogether insignificant. Bitumens occur in small amounts in many igneous rocks, but never in large volume. They are, moreover, absent, at least in significant proportions, from the Archean, and first appear abundantly in Paleozoic time. From the Silurian upward they are plentiful, and commonly remote from great indications of volcanic activity. . . . These considerations serve to show the need of great caution in dealing with this class of problems and to warn us against hasty generalizations. Speculations based upon individual occurrences of petroleum are of very little value. The entire field, in all of its complexity, must be taken into account."

Shortly after the inorganic theory was proposed other chemists were distilling hydrocarbons and oil from various types of organic matter. As early as 1865 Warren and Storer (Clarke, F. W. 24, p. 43) prepared a lime soap from fish oil, which, on destructive distillation in the absence of free air, yielded a mixture of hydrocarbons similar to kerosene and which had all of the ingredients of a true artificial petroleum. C. Engler's famous investigations in 1888, and those of W. C. Day in 1899, demonstrated that synthetic petroleum could be made by direct distillation of fish oil, wood and fish, and wood alone.

The origin of oil is a chemical problem whose solution depends on the application of sound chemistry to facts of association and distribution supplied by geology. It seems apparent that oil may be, and probably has been, formed in nature in several different ways; but it is of vital interest to know the origin of only that oil which occurs naturally in commercial quantities. Fully 99% of all known oil throughout the world occurs within or in close proximity to sedimentary rocks which either contain adequate organic remains or were deposited under conditions favorable to abundant plant and animal life. The weight of chemical and geological evidence combined has led to the general acceptance of the organic theory for the origin of all known commercial accumulations of oil and gas.

ORGANIC ORIGIN

Organic remains of plants and animals are composed to a large extent of carbon and hydrogen, the two essential elements of petroleum and natural gas. These remains collect in the muds of the sea-bottom and, under favorable conditions of accumulation where oxygen is limited, either are transformed by anaerobic bacteria into oil or oily compounds before or soon after burial, or are preserved from decay, buried by mud, and, through a period of long geologic time, are converted into oil by the chemical or thermodynamical processes which accompany deep burial and deformation by folding. A combination of all of these agencies may be essential to the generation of petroleum.

Conditions of Accumulation on the Sea-Bottom

Submarine sounding and sampling operations conducted to determine depths, character of sediments, and conditions of deposition on the sea floor (fig. 102) have gathered a wealth of data showing the organic content of sea-bottom sediments to be small in the open sea far from shore and in those widespread parts of the continental shelf where the sea-bottom has little relief and currents or waves have an opportunity to freshen by circulation the bottom water. Recent echo soundings of the continental shelf off the coast of southern California by the U. S. Coast and Geodetic Survey, and the detailed submarine topographic maps prepared therefrom by

FIG. 104. Relief model of the Philippine region. *Photograph reproduced by courtesy of U. S. Coast and Geodetic Survey. Used by Parker D. Trask (37a, p. 391).*

Shepard and Emery (Shepard, F. P. 37) have shown the submarine topography of this region to be characterized by a system of closed basins separated by ridges or other highs. The bottom water of these basins below the depths of their connecting sills or saddles has little or no circulation and in it is accumulating only very fine sediment containing hydrogen sulfide and a relatively high percentage of organic matter. Extensive dredging and coring operations have shown that only under such nearly stagnant sea-bottom conditions, where the supply of free oxygen and the destructive activities of scavengers and anaerobic bacteria are limited or lacking, do recent sediments commonly contain large quantities of organic matter. Under more open sea-bottom conditions, where free oxygen is supplied in abundance, much of the organic matter is destroyed before or during burial by rapid bacterial decomposition, or is consumed by scavengers which in turn die and are destroyed by bacteria.

The relief model of the Philippine Islands and adjoining sea-bottom reproduced in figure 104 illustrates another region in which the sea-bottom is characterized by many closed basins favorable to the accumulation and preservation of organic matter. The Norwegian fiords, the Black Sea, and the Gulf of California have sediments rich in organic matter (Strom, K. M. 39, pp. 356-362; Trask, P. D. 39a, pp. 447-449). The Norwegian fiords and the Black Sea are known to be deep basins with shallow outlets and to contain stagnant water. Recent but incomplete investigations by the Scripps Institution of Oceanography indicate the presence of several enclosed basins in the Gulf of California.[2]

The following excellent summary of the factors affecting the organic content of the sediments is by Revelle and Shepard (Revelle, R. 39, pp. 264-266).

"The organic matter content of any sediment is dependent on the relative rates of deposition of organic and inorganic materials, and on the amount of decomposition of the organic constituents after deposition. The rates of deposition in turn are a function of the relative supply of organic and inorganic debris and the relative effects of transporting agencies on the two types of material. Since the carbonaceous and nitrogeneous remains of organisms have a density close to that of water, they are moved by currents so weak that they can transport only very fine-grained inorganic particles; hence organic matter is deposited principally with silts and clays. * * *

"Several reasons may be cited for the extremely high organic content of the sediments in depressions. Let us suppose that dead plankton and humus settle to the bottom at a rather uniform rate over the entire region. If this is true much of the organic debris falling on topographic highs will be swept by waves and currents into more protected areas, especially into the completely protected basins, where currents below sill depth must be negligible. Once the organic matter comes to rest at the bottom of a basin it can only be removed by decomposition resulting chiefly from the action of organisms, particularly bacteria. The rate of bacterial decomposition may be greatly retarded in the absence of an adequate supply of oxygen. The available hydrographic evidence suggests that the dissolved oxygen supply in the bottom waters of the basins is very small owing to the slow renewal of the water below sill depth. Beneath the surface of the sediments, furthermore, there is known to be a considerable oxygen deficit and highly reducing conditions and the greater part of the bacterial activity has been shown to be confined to the thin, watery surface layer of the sediments. Owing to the relatively rapid deposition of fine-grained, impervious, inorganic debris, on the floors of the basins and probably also to the absence of larger organisms which might churn the sediments over, only a moderate amount of decomposition can take place at the surface before the materials are buried."

Organic Material

All animals of the sea exist on food composed of plants and smaller animals. Thus the smallest plants are the original organic source of most of the organic matter found in marine sediments. These minute organisms are eaten by small animals, such as copepods, and these in turn are eaten by larger animals. Some of the minute organisms are attacked but only partially destroyed by bacteria in the upper water layers. Dead plants and animals, remains of those only partially destroyed, and excretions of undigested organic substances, sink to the sea-bottom and, in stagnant basins where the supply of free oxygen, decomposing bacteria, and scavengers is limited, are preserved through burial by mud and fine silt for later conversion into petroleum.

Trask (Trask, P. D. 39a, p. 446) has found that the muds in the deep enclosed basins off southern California contain as much as 8% organic matter, whereas the sands on intervening ridges contain only about 1%. It would appear from this relation, and the generally observed fact that shales are more organic than sandstones, that muds which later are converted into shales, and organic material which goes to form oil, must require similar conditions for their deposition and preservation. Fine clay or mud particles are deposited and left undisturbed only in quiet water, and it is in enclosed basins of poor circulation that there exist both quiet water and conditions favorable to the preservation of organic matter. The fine-grained sediments and associated organic matter may later become deeply buried and, through the influence of pressure, temperature, and cementation acting through millions of years, be transformed into gray, black, or brown shales, the color depending upon the quantity and nature of the organic matter retained in the shale. Shale may be light gray or black due to small or large amounts of organic matter[3]; it may be brown, due, among other reasons, to transformation of its organic matter to substances more nearly approaching petroleum.

Organic matter in the black and brown marine shales of the California Tertiary, when examined in thin sections with the microscope, is seen to consist commonly in greater part of dark amber to yellow translucent substances without organic structure or biological identity. Some appear to be bituminous and to be, or to have been, in a fluid or semi-fluid state and to have filled every available space between the small mineral grains which make up the body of shale.[4] It seems likely that this brown structureless organic substance has been derived by bio-chemical and thermo-chemical decomposition from abundant less resistant types of organic matter and is now in a physical and chemical state closely approaching petroleum. Some California Tertiary black shale yields considerable heavy black oil when subjected to the action of a suitable solvent such as carbon tetrachloride, and the remaining organic matter yields still larger quantities of oil by distillation when this solvent-treated shale is heated.

Most organic shales also contain occasional organic bodies that may be readily identified. These are commonly foraminifera, coprolites, spore exines and fragments of algae (Hoots, H. W. 35a, pp. 191-194). The siliceous tests of diatoms, radiolaria, and other microscopic forms may also be present.

It would appear that the organic matter of muds consists of two broad types: one which, during geologic

[2] Roger Revelle, oral communication.

[3] According to W. H. Twenhofel (39, pp. 1180-1181), muds may be black because of the presence of organic matter, the monosulfide of iron, or the black oxides of manganese, but the blackness of any extensive deposit of shale is due to the presence of organic matter.

[4] See description of organic matter in Miocene oil shale by W. H. Bradley, *reproduced* by H. W. Hoots (35a, pp. 190-194).

time, undergoes changes of a chemical and physical nature, readily loses its biological identity and becomes a fluid or semi-fluid yellow or brown substance; and the other, which is resistant to change through long periods of rock formation and becomes fossilized in shales in recognizable biologic form. The former appears to be bituminous and is probably the progenitor of petroleum. The difficulty and uncertainty attached to the task of determining the identity of the unstable type of organic matter which goes to form petroleum, seems obvious for its original form has been lost in the process of oil generation. Trask (Trask, P. D. 37, pp. 156-157), in his study of organic matter in recent and ancient sediments, has devoted attention to this problem but has concluded that it can best be considered after more information is available on the chemical nature of the organic constituents of sediments. He has found that cellulose, fats, and simple proteins are ordinarily present in sediments in amounts too small to be the principal source of petroleum and concludes that the oil must come from undigestible residues that probably consist mainly of complex compounds and are deficient in oxygen.

Generation of Petroleum

Organic matter may be accepted as the source material for petroleum; but after it is deposited with muds[5] in protected areas of the sea floor, how and when is it converted into petroleum? Does the change occur entirely as a result of decomposition by aerobic and anaerobic bacteria on the sea-bottom before burial or by anaerobic bacteria after burial, or must the organic matter be buried by an appreciable thickness of sediments and the change to oil depend on the resulting increased temperature and pressure and a time period of a few thousand or a few million years? These and other variations of the organic theory are almost as old as petroleum geology. Opinion is divided but there is considerable evidence to indicate that bacteria, by inducing chemical change, play an important role in converting the deposited organic matter into methane and other substances of a semi-bituminous nature which, after burial and by the influence of moderate temperature and pressure, may be converted to oil.

It is common knowledge that organic shale when subjected to high temperature will yield oil by distillation and cracking. Laboratory experiments indicate, however, that pressure alone can not convert fossil organic matter in shale to oil. Some geologists have contended that the moderate temperatures and high pressures accompanying deep burial and in play through long periods of geologic time are alone sufficient to convert organic matter to petroleum. Such may be the case, but it is doubtful if appreciable amounts of organic matter have been subjected to these influences without first having experienced critically important biochemical changes on the sea floor soon after burial.

Several early investigators (Morrey, C. B., *cited in* Brownocker, J. A. 03, p. 313; Daly, M. R. 16) and some recent authors (Stuart, M. 26, pp. 1-100; Brooks, B. T. 34) lean toward the belief that bacterial decomposition of organic matter is the only agency necessary for the generation of petroleum. Should petroleum originate in this manner it would seem that oil would be found in recent muds of the sea-bottom. Trask and Wu (Trask, P. D. 30, pp. 1451-1452, 1460-1461), however, could detect no trace of liquid hydrocarbons in their richest organic marine sediments collected from favorable sites throughout the world. They conclude that petroleum present in sediments at the time of their accumulation can not be a major factor in the formation of commercial oil pools.

Wallace Pratt (34, pp. 235-245) has proposed an intriguing theory for the generation of petroleum entirely as a result of compaction and accompanying thermo-chemical processes and hydrogenation. He believes the process of oil formation includes two stages (pp. 242-244):

> (1) An early stage is analogous to commercial "cracking" operations[6] as a result of which part of the organic matter in the sea-bottom muds and oozes of ordinary sedimentary processes is converted by cracking into gaseous and heavy liquid hydrocarbons. This stage may well be contemporaneous with, or follow immediately, the period of greatest volume reduction in the new sediments during and as a result of initial compacting by the weight of overlying beds. The relatively high temperature which is characteristic of young sedimentary rocks, the result, perhaps, of friction caused by the movements of compaction, may be a controlling factor at this stage. As compaction proceeds, the gas and part of the oil cracked from the source material move out of the muds and into the pore spaces of adjacent sands along with other fluids.
>
> [7] Once methane and heavy oil are brought together in these natural reservoirs (which are) subject to growing pressures as the overlying beds gradually consolidate and transmit more fully the stresses previously absorbed in part through yielding and flowage, the stage is set for (the) hydrogenation (of stage 2).
>
> (2) A second, long-continued stage is analogous to the "hydrogenation" processes[8] in commercial refinery operations during which the heavy, unsaturated oils, characteristic of our geologically young oil fields and presumably generated in stage 1, are enriched in hydrogen. Cracking continues during this stage and there results a slow transformation through various intermediate stages into the light gravity, fully saturated oils that characterize our geologically old oil-field rocks. The hydrogen required by the processes of stage 2 may be free hydrogen from the earth's deeper interior, or, more likely, it may be obtained from the methane generated in stage 1 along with the original heavy oils.

That oil is generated from organic matter in sediments, principally marine muds or mudstones, after moderate or deep burial is broadly accepted. The organic matter may be of many different types and whether the process results entirely from biochemical changes before, during, and after burial, from chemical changes induced by the moderate temperatures and pressures accompanying the burial and compaction of sediments, or from a combination of the two, is debatable, and has slight prospect of immediate solution. Chemical, dynamic, and biologic conditions in sediments for the few thousand or few million years after burial can not be observed or reproduced with certainty in the laboratory. Bacteria capable of changing organic matter to methane and substances of semi-bituminous nature, as well as moderate heat, pressure, and geologic time, with their attendant chemical changes, are all present, and apparently are capable of playing important roles in the process of petroleum generation. In the absence of proof that any one of these agencies alone can carry the process to completion, it is reasonable to assume that each of them contributes to a series of chemical and physical changes, the products of which are petroleum and gas. Before and after burial, bacteria alter the original organic matter to substances which are later

[5] Organic matter deposited in marls may have been the source of oil formed in some limestone reservoirs of Mid-Continent and Mexican fields.

[6] Cracking is a process by which the molecules of a mixture of hydrocarbons can be split up and rearranged through the application of heat.

[7] This paragraph by Pratt is taken from his page 242 and is inserted here in an attempt to consolidate his more detailed explanation.

[8] Hydrogenation is a modern refining process by which unsaturated hydrocarbons such as butylene are converted, by the addition of hydrogen, to the corresponding saturated hydrocarbons, such as butane, which are common in petroleum.

converted through a series of chemical changes induced by compaction, heat, pressure, and the presence of catalysts, to petroleum and associated gas. The original products, according to Pratt (Pratt, W. E. 34, pp. 242-243), would be methane and an unsaturated heavy oil formed by cracking and forced from the shale into adjoining porous reservoirs during compaction. Hydrogenation or methylation would gradually saturate the molecules of the heavy oil with hydrogen derived from methane or other sources, and this process together with continued cracking would produce progressively lighter oil. Some methane would always remain and the ultimate product would be a mixture of gaseous and liquid hydrocarbons.

More precise knowledge of the process or processes responsible for the generation of petroleum would be of practical value as an aid in determining for each petroliferous district the time, geologically, when the process was complete and oil was available for migration to, and accumulation in, structural and stratigraphic traps. With such information, exploration for new fields would be more precise in that structural or stratigraphic traps developed too late in the geologic history of a specific district or region could be avoided.

GENERATION AND MIGRATION TO SAND

Determination of the time of petroleum generation and movement from its source bed to a porous reservoir is one of the important practical problems of petroleum geology. In California the surface evidence of many geologic structures, both anticlines and faults, has obviously resulted from late Pleistocene deformation. Were these structural features developed before or after petroleum generation and migration? Some are barren of oil or gas, while others have provided many of California's finest oil fields. The latter group, with the possible exception of the Kettleman Hills anticline[9] and some structurally complex or incompletely drilled producing structures on which data are few, consistently show thinning of the upper several thousand feet of beds across the axes of the folds and thus provide acceptable evidence that these structures, although folded in late Pleistocene time, had their beginning not later than the early Pliocene and continued to develop during Pliocene sedimentation. They were present in subdued form to trap existing oil or gas during or shortly after the deposition of the present oil-bearing formations. Stratigraphic traps, such as the Miocene-Pliocene erosional and transgressive unconformities of the Midway-Sunset district and the Santa Maria Valley, the buttressing Scalez (upper Pliocene) sand of the Buena Vista Hills field, the Pliocene continental sands lensing out up-dip in the Kern River area, the possible middle Miocene overlap of the Vedder sand of the Poso Creek-Round Mountain district, and the rapid depositional pinch-out of the East Coalinga Eocene sand, all provided at least regional traps for existing oil as soon as the immediately overlying impervious bed was deposited. There is, therefore, no precise information as yet which may be used to date the accumulation and, working backwards, the generation, of oil accumulated in California fields. Generation, migration from source beds to reservoir sands, and accumulation in most, and possibly all, known structural or stratigraphic traps may have occurred at any time subsequent to the burial of the source bed and the producing reservoir. The entire process may have consumed a comparatively short or a long geologic time interval and may not yet be completed.

Whatever may be the process, tremendous quantities of oil have been generated and have become concentrated in known fields. A dozen or more California fields before becoming partly depleted by production had quantities of oil which, if brought to the surface, would be sufficient to cover approximately 1,000 acres of each field with 100 feet of oil and, in addition, tremendous quantities of gas. These large quantities, together with the wide distribution, geographically and stratigraphically, of known producing fields force the conclusion that the process is not accidental and dependent upon a peculiar and unusual distribution of organic material or condition of sedimentation, burial, or structural deformation. Conditions for petroleum generation apparently were favorable over extensive regions where organic marine Miocene and Pliocene muds accumulated, and the same is probably true for Oligocene and Eocene. Through the usual course of events these organic muds and associated sands were subjected to geologic processes which generated petroleum in large quantities and forced it to move from the organic mud or shale in which it formed to porous and permeable sands, and to continue to migrate through the sands until trapped by an anticline, a fault, or an unconformity, or lost through seepage at the surface. What were these processes? Their common occurrence evidenced by wide distribution geographically and through several geologic epochs suggests that they must be associated with the normal history of sediments, i.e., deposition, burial, and structural deformation.

M. J. Munn (09a, p. 520) was one of the first to suggest that the compaction of sediments, resulting from burial and deformation, is the critical process responsible for the generation and migration of oil and gas, and that it would cause these fluids to migrate upward from deep to progressively shallower beds.

Most newly deposited marine muds, according to Athy (Athy, L. F. 34, pp. 814-815), have porosities ranging between 70% and 90%, and the upper 100 ft. of freshly deposited mud probably has an average porosity of about 50%.[10] All of this pore space in such marine muds must be filled with sea water. Subsequent burial, compaction by the weight of overlying sediments, and cementation transform these muds to clay or shale and by so doing materially reduce their porosity and drive out much of the enclosed connate water. Athy found that in Kay County, Oklahoma, shale from shallow core holes has an average porosity of 20% but at depths of 4,500 ft. the average porosity is only 4%. Hedberg (Hedberg, H. D. 26, pp. 1050-1059), working on shale samples from Kansas and correlating his and previously published

[9] Questionable identification of subsurface stratigraphic markers in this field throws doubt on suggested evidence of thinning across the anticlinal axis.

[10] These values for porosity and water content may be too high for average figures. Studies of Dr. Roger Revelle reveal that Recent marine sea-bottom muds vary in water content according to texture, character, and depth within a core. Samples of well-sorted diatomaceous mud from the Gulf of California have median grain sizes varying between two and four microns and contain from 68 to 90% water. Samples of more argillaceous type muds from southern California of the same texture contain from 45 to 65% water. Revelle believes it likely that only part of the water in the finer grained sediments is interstitial and that much of it is absorbed on the surfaces of the colloidal flakes of clay or opal. He considers this whole problem to be complex and generalizations at this time hazardous.

results, shows higher porosity values of 30% for 1,000 ft. of overburden, 15% for 4,000 ft., and 8% for 8,000 ft. His further conclusion that porosity of shale decreases with geologic age is supported by the studies of Rubey (Rubey, W. W. 31, pp. 34-38) on outcrop samples of Cretaceous shale from Wyoming. Rubey shows also that the porosity of shale decreases with increase in dip and is, therefore, effected by some types of folding. Athy (Athy, L. F. 34, p. 816; 30a, pp. 31-35) found a close correlation between the porosity and bulk density of shales and, after determining the density of 2,200 shale samples and assuming that decrease in porosity and increase in density of shale with depth of burial are the results of compaction, found it possible to compute the relation between compaction and depth of burial. His compaction-depth of burial curve begins with a compaction of 0 for near-surface muds having a porosity of 48% and shows that compaction of 20 to 25% has occurred by the time clay has been buried 1,000 ft.; 35% at 2,000 ft.; 40% at 3,000 ft.; 45% at 5,000 ft.; and 47% at about 7,000 ft. His data indicate that 50% of the fluid present in a surface mud has been squeezed out at a depth of burial of 1,000 ft., 70% at 2,000 ft., 85% at 4,000 ft., and more than 90% at 6,000 ft. He concludes that during increasing burial enormous quantities of fluid move almost continuously from the compacting muds to permeable non-compressible beds, such as sands, which furnish relief of pressure through outlets to the surface. Athy found that St. Peter glass sand deposited under water settled 11% during a period of continual jarring, but when placed under a pressure of 4,000 lb. per sq. in., compacted only 2% more. He concluded that settlement in sand is due chiefly to rearrangement of grains, and occurs soon after deposition and before cementation.

Burial and its accompanying expulsion of fluids from compressible sediments is an experience necessary to the formation of fine-grained sedimentary rocks. No shales have avoided it. In addition to the effect from burial, lateral compression may cause additional compaction. The resulting movement of large quantities of water offers the most positive opportunity for oil to move along and across the bedding of fine-grained source beds into adjoining permeable beds. Because of this fact most theorists agree that petroleum generation and its migration to the reservoir takes place during compaction. Unless this be accepted one must postulate that large quantities of oil are generated in and migrate through shales after compaction, when porosity and permeability have become greatly reduced.

There is little information available on the porosity of shales associated with oil-producing sands in California. Limited data [11] indicate that cores of middle Pliocene clay-shale from a burial depth of about 4,000 ft. have porosities of 20% to 25%. Miocene and older shales of California are generally more highly indurated and appear to be more dense and less porous. It would not be surprising to find the porosity of many of them to run as low as 10%. Compaction is probably not complete for these comparatively young Tertiary rocks but available evidence indicates that it has already reduced the porosity and the quantity of contained fluids in Pliocene clay-shale by at least 50% and in older rocks by possibly 70% to 80%. Presumably these expelled fluids consisted of fossil sea water and, in some cases, oil and gas.

Pliocene shales associated with producing oil sands in California, although found by Trask (Trask, P. D. 36, p. 249) to contain 1.0 to 3.5% organic matter, and to be considered as likely source beds, now contain little or no free oil [12] whether they be obtained from a burial depth of 4,000 ft. or 10,000 ft. If it be assumed that these shales are source beds, it must be admitted that their present non-bituminous nature is evidence that the process of oil generation and migration from the shale is now essentially complete. It might then be assumed that a burial of 4,000 ft. and a time interval equivalent to the age of middle Pliocene strata are the maximum necessary for the generation and migration of oil from some source beds. Since these Pliocene shales contain practically no free oil, their 20% to 25% of pore space must be filled with connate water. Oil and gas formed in them must have been among the first fluids to move from the compacting muds into adjoining porous sands. The original sea-bottom ooze contained 45% to 90% water and the quantity of oil formed and expelled during compaction must have been small in comparison to the large volume of associated water. According to Athy (Athy, L. F. 30a, p. 33), if the upper 10 ft. of a 50-ft. shale bed contains oil and is overlain by a porous sand bed which serves as an outlet for fluids squeezed from the shale, calculation shows that by the time the bed has been buried 1,000 ft., more than 40 times as much fluid has passed through each foot of the upper 10 ft. of shale as still remains in it. Ample energy for this bulk movement of fluid would be supplied by compaction of the shale but the effectiveness of this pressure in accomplishing complete transfer of all oil from the compacting shale probably would be materially increased by the force of selective capillary movement described by McCoy (McCoy, A. W. 26, p. 1028) and other investigators. This force, according to the experiments of McCoy, is adequate to cause oil in an oil-soaked shale and water in an adjoining saturated sand to displace each other under atmospheric pressure and without regard to the force of gravity. Capillarity would not be effective, however, until compaction had expelled considerable fluid and compressed the ooze to the physical state of a solid or semi-solid with connecting capillary openings.

It is not surprising that most of our probable source beds of shale are now barren, or practically barren, of free oil when consideration is given to the quantity of connate water which has been forced through them and the probable effectiveness of selective capillarity. McCoy (26, pp. 1028-1032) presents a detailed explanation of his ideas of the mechanics of the interchange of oil in shale and water in sand and, in a later article (34, p. 259), summarizes them as principles of the replacement theory. He says:

"The replacement theory of the migration of oil can be briefly stated as follows: Connate or mixed water of the reservoir stratum enters the petroleum source rock after liquid oil has been generated and forces the oil back into the reservoir bed, the oil in the source bed being replaced by an equal volume of water. This process of replacement is possible because: (1) the adhesive tension between water and the wall of the source rock is much

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[11] Personal communication from Howard C. Pyle and John E. Sherborne of the Union Oil Company of California.

[12] Trask (36, p. 253) has found lower Pliocene shales in the Santa Fe Springs field to contain an average of 1.5% of bitumen soluble in carbon tetrachloride. Most of this soluble bitumen represents substances other than petroleum.

greater than that between oil and that substance, and (2) the displacement pressure of water caused by the adhesion of the water for the source rock wall in capillary openings is greater than the surface tension at the oil-water interface or the cohesive tension of the oil and thus causes small globules of oil to be separated from the oil column and to be forced back inside the water tube of the capillary. Eventually, these oil particles pass back through the capillaries to the reservoir or the source of the incoming water."

Most theoretical evidence bearing on the time of oil generation and migration, particularly the ease with which migration from clay-muds can be explained through compaction, favors generation and migration into sands at an early stage before the process of compaction and cementation has developed a serious barrier to large scale migration.

LATERAL MIGRATION

All sediments in California offering possibilities as source beds for petroleum have been buried to depths of from 2,000 to 20,000 ft. or more throughout extensive depositional basins, and there is little evidence to indicate an appreciable difference in the organic or source character of these sediments throughout the greater part of these large basins. An abundance of plant and animal life in the upper waters of these basins, deficiency of oxygen in deeper waters and in bottom sediments, and fairly rapid burial by argillaceous mud, are conditions favorable to the accumulation and preservation of organic matter that presumably were widespread throughout much of the Tertiary. The extensive nature of these conditions and those of burial and compaction leads to the conclusion that the generation of oil and gas was a regional, rather than a local, process and that these hydrocarbons must have been widely distributed geographically in the marine muds and, after compaction, in associated sands throughout these extensive basins. How did these hydrocarbons become concentrated to form the many distinct oil fields scattered throughout these basins and how was all trace of them removed from the sands of intervening areas? These problems are among the most important of petroleum geology and have led to the expression of many divergent views.

Geologists have learned much about the habits of occurrence of oil and methods of finding it but their success might be vastly improved if the manner of migration and accumulation could be accurately determined. A drop or a barrel of oil, however, gives no recognizable clue to its past experiences. Its origin, the distance through which it has traveled, and the natural forces responsible for its migration and accumulation into pools, are questions the answers to which must depend principally on deductive reasoning. Such reasoning must be based on present knowledge of the distribution of source material, distribution and variations of the character of oil, and our understanding of the forces effective in sediments during geologic time.

HISTORY OF THEORIES

That oil is indigenous to the strata in which it is found was suggested by T. Sterry Hunt [13] in his "Geology of Canada" as early as 1861. The opposing view that oil migrates into arched strata from a disseminated source was expressed by Henry D. Rogers [13] in 1863.

[13] For reference to these early papers see Howell, J. V. 34, pp. 3-6.

Interest in the importance of migration to oil accumulation was encouraged by Malcolm J. Munn (09a) who, in 1909, advanced his hydraulic theory as a companion to the anticlinal theory to account for oil and gas accumulation. He contended that moving water, under both hydraulic and capillary pressure, is an active agent in causing the migration and accumulation of oil and gas and that the hydrostatic and capillary pressures of enclosing water are the forces effective in confining oil and gas to structurally high areas.

R. Van A. Mills (20), in 1920, presented the results of a series of laboratory experiments and concluded that, under ordinary field conditions, the up-dip migration of oil and gas due to the propulsive force of their buoyancy in water and the migration caused by hydraulic currents are among the primary factors influencing accumulation.

John L. Rich has been the most recent and consistent champion of migration. In his first paper in 1921 (21), and in more recent ones (23, 31), he has contended that lateral migration has been extensive in many instances where conditions have been favorable for large scale circulation of water and that huge accumulations of oil in structurally favorable spots, with intervening barren areas, constitute a strong argument for long distance migration.

Frank R. Clark (34) has recently advocated that all oil has formed from local source material within or contiguous to the limits of oil fields, and that accumulations of oil occur only where the location of ample source material coincides with favorable structure. As evidence he cites a number of individual Mid-Continent fields, characterized principally by local sand lenses, where little or no lateral migration seems possible, and the occurrence of occasional favorable structures that are barren of oil and gas.

LATERAL MIGRATION VERSUS LOCAL ORIGIN

Opposing opinions deal principally with the lateral distance through which oil and gas have migrated. Some investigators [14] insist that considerable lateral migration through sands is essential and that migration of several miles or several hundred miles is not unreasonable and, in some cases, can hardly be questioned. Others (Clark, F. R. 34; *see also* McCoy, A. W. 34) contend that lateral migration could not have occurred without leaving behind at least films of oil on grains of sand throughout the reservoir, that long distance migration is impossible in the many instances of local sand lenses productive in eastern Kansas, Oklahoma, and Texas, and that in all cases, therefore, it is more reasonable to conclude that little or no lateral migration has occurred, that source material is localized, and that accumulation of oil occurs only where the location of an adequate supply of source material coincides with a favorable structural or stratigraphic trap.

California oil and gas fields as a group can not be explained by assuming the occurrence of an adequate supply of source material only in those local areas favorable to accumulation. All possible source beds are too uniform in apparent source character from anticline to syncline throughout the oil producing districts of the State. Even though it be argued that opinion as to such

[14] Notably J. L. Rich (34).

uniformity, based on comparison of hand specimens, thin sections, and analyses for organic material, is not an acceptable guide to the original distribution of actual source material, the wide distribution of oil and gas fields, and their occurrence wherever favorable structural and stratigraphic traps are known must be explained. There are 25 anticlinal oil or gas fields in the southern San Joaquin Valley south of Coalinga and 20 in the Los Angeles Basin, yet not one definitely closed anticline involving recognized source and reservoir rocks has been found barren in these districts.[15] With only localized occurrences of adequate source material and no migration, surely some of these anticlines, either along the borders or in the central parts of these basins, would be unproductive. Furthermore, there are several fields along the east side of the San Joaquin Valley and in Ventura and Santa Barbara counties where accumulation of oil and gas occurs in continental beds that are barren, or almost barren, of organic matter other than lignitized plant fragments. These continental beds are believed to grade basinward through distances of several miles into marine strata.

Unless it be argued that oil can originate in inorganic-appearing continental beds and that, in spite of the circumstances mentioned above, no oil was generated in areas outside the limits of present producing fields, it must be admitted that oil has migrated laterally several miles in at least some instances. Vertical migration might account for accumulation in the continental beds in all but one instance where the oil sand rests on granite, but even in these instances lateral migration seems to be an essential earlier step.

The occurrence of a structural or stratigraphic trap involving beds known to produce oil in neighboring areas appears to be the one essential for an oil or gas field in the productive districts of California. Favorable relations between source beds, permeable reservoir rocks, and an impervious cap-rock, of course, must be present but these same factors are also essential to lateral migration, and accumulation of oil and gas.

The oil of some pools may have been derived entirely from source material within and contiguous to these pools. This seems particularly probable in the case of restricted sand lenses of the Mid-Continent and Gulf Coast mentioned by Frank R. Clark (34, pp. 323-328) and possibly also in the case of fault accumulations where there may have been no outlet permitting circulation of fluids in the reservoir. The presence of nearby source material and the force of selective capillarity of water and oil during compaction may be responsible for such pools. These occurrences, however, are commonly recognized as special cases which can not be accepted as examples of the hundreds of large fields that obviously have formed under conditions of extensive reservoir circulation.

F. H. Lahee (34b, pp. 247-248) has conveniently summarized several lines of evidence considered by Clark to justify the conclusion that migration has not been important and that all oil pools have formed in place from local organic accumulations. Five of Clark's principal arguments for local origin are presented below in small type, and each is followed by a presentation of opposing evidence, principally from California fields.

(1) The presence of dry (oil-free) structures, apparently having all requisite conditions of closure and reservoir rock, in districts where other similar structures yield oil.

With the possible exception of the Lost Hills field, as previously stated, no closed structures, barren of both oil and gas, are known in the major oil-producing districts of California.[16] Other explanations, apparently reasonable, have been offered for at least some of the barren structures in the Mid-Continent. The relation of the time of oil migration to the time of the first folding must be a critical factor.

(2) The difficulty of explaining migration of oil from a widely distributed source to a local trap (particularly a lensing sand) where there seems to be no evidence of an outlet or an area of lower pressure toward which fluids could move.

The probability that local source material contributes the oil in restricted sand lenses is mentioned above. Large-scale accumulation in extensive sands truncated by an unconformity or in overlying sands buttressing against the unconformity may be similar to those in restricted sand lenses in that the oil originated in contiguous beds of shale, moved into the water-saturated sand by means of capillary interchange and, without much lateral migration, became concentrated up-dip by reason of buoyancy and without the aid of moving water. One must doubt, however, the adequacy of this process to account for the large accumulations of oil in traps of this sort. Up-dip migration of at least several miles is essential but seems probable only under those conditions wherein the force of moving water is effective. Such conditions may have existed in all such traps as a result of (1) an up-dip outlet for fluids at points outside the area of accumulation, or (2) leakage of water by selective capillarity through sub-capillary pores along the unconformity or in the overlying shale caprock. The extensive Eocene Gatchell sand of the East Coalinga nose either lenses out or is terminated by an unconformity within the structurally closed area of accumulation, but it crops out at the surface several miles to the northwest. The producing sands associated with the Miocene-Pliocene unconformity of the Midway-Sunset district probably had an outlet through leakage, and many of them through outcrops outside the areas of accumulation.

Each separate accumulation of oil, particularly those against faults, in synclines, or by reason of unconformities, requires individual consideration. Some accumulations against faults and in synclines appear to be older than these structural features and to have formed when the structure was broadly anticlinal. Pleistocene deformation in several California areas apparently has seriously altered the structure which, at an earlier date, induced migration and accumulation.

(3) The paucity of evidence of residual oil absorbed on the grains of sands through which this oil must have moved into the reservoir, if it migrated at all.

It is generally conceded that all marine sands, and probably all others which now serve as oil reservoirs,

[15] The Lost Hills structure, apparently faulted, has not produced commercially from the regionally productive Temblor-Vedder zone but it contains saturated oil sand in this zone that may well have been the original reservoir for the large quantity of oil produced from higher sands.

[16] Two or three deep anticlines, mapped with closure by the seismograph, have proved to be barren, due possibly to unfavorable structural features not detected. Many producing anticlines, it is true, have sands above the oil zones that are barren or contain only gas, but these higher sands commonly are associated with light gray silty and sandy shales that appear to be low in organic matter and probably are deficient in source material for oil.

were saturated with water before oil was forced into them by compaction and capillary interchange. Since water has a greater affinity or adhesion tension for grains of silica than has oil (Garrison, A. D. 35; Benner, F. C. 38), it is unlikely that oil entering a water-saturated sand would come in contact with, and become absorbed on the surfaces of, the sand grains. It is to be expected, therefore, that sands originally saturated with water and later serving as carrier beds for the migration of oil and water will be free of oil.

(4) The engineering data of oil fields, often revealing only very slow water encroachment, and sometimes practically none, where easy movement would be expected if the oil had migrated from afar into its reservoir.

Edgewaters of an oil field are under considerable pressure but must overcome friction in order to move through capillary openings of a sand reservoir. Time is an essential factor. A producing oil well depletes the reservoir pressure in the area immediately around the well, and, if in a field under volumetric control, its production declines because reservoir fluids can not move toward the well fast enough to preserve the reservoir pressure. A lag in the movement of reservoir fluids at points distant from the well is obvious. Fluid is moving but, presumably because of the effectiveness of friction, not fast enough to effect immediate water encroachment at the edge of the field. The lag may cover a period of many years, but this is small compared to the length of the geologic epoch available for migration and accumulation. In the case of sand lenses full of oil before being drilled, no water encroachment can be expected.

(5) The frequently observed absence of a very close correlation between depth and measured fluid pressures in reservoirs containing oil and gas.

There are few, if any, cases in California where the static bottom-hole pressure in a blanket type sand on an unfaulted structure is not closely correlative with the depth.

The preceding discussion serves to emphasize some of the more important reasons for believing that the oil fields of California have been formed as a result of appreciable lateral migration. Migration probably extended to all areas of oil generation and was effective in an up-dip direction from all synclinal areas existing during the period of oil generation and compaction. Distance of migration in California was limited by the extent of the homoclines that formed the flanks of basins and probably did not exceed a few tens of miles.

THEORY OF ACCUMULATION

INTRODUCTION

Oil from springs was found to be of commercial value as a source of illuminating oil as early as 1855. The fact that oil was locally concentrated into "pools" from which commercial quantities could be extracted was first established in 1859 by Colonel Drake's famous discovery well. Speculation concerning geological conditions controlling its accumulation began immediately and led, within two short years, to the development of the anticlinal theory. The principles of this theory have stood the test of 80 years of geological prospecting and no longer can be challenged. Increased knowledge of the various geological features which serve as traps for the accumulation of oil, however, has seen the term "anticlinal theory" gradually replaced by the more inclusive term "structural theory" which, without important restatement of principles, satisfactorily accounts for all present known commercial accumulations.

The structural theory of accumulation, accounting for the local concentration and segregation of oil and gas in the structurally higher parts of water-bearing sands, does not include lateral migration as a necessary factor. Accumulation is an observed fact, whereas lateral migration, if it occurred, is an event of the past, cannot be observed, and must remain a matter for deduction based on our interpretation of the available fragmentary record. It is not surprising, therefore, to find general agreement among geologists as to the observable geological conditions which affect accumulation, but considerable disagreement in the emphasis to be placed on various parts of the fragmentary record pertaining to the genesis and movement of oil.

STRUCTURAL THEORY OF ACCUMULATION [17]

In 1842 Sir William Logan, director of the Geological Survey of Canada, observed that oil seepages near the mouth of the St. Lawrence River were located on anticlines. The publication of this observation in 1844 [18] preceded by 15 years Colonel Drake's discovery in Pennsylvania of the first commercial accumulation of oil. In 1860, nine months after Drake's success, Professor Henry D. Rogers of the University of Glasgow made probably the earliest statement of the fact that the newly discovered oil fields of Pennsylvania were located on anticlines.

The first clear statement of the structural or anticlinal theory of oil accumulation was made in 1861 by T. Sterry Hunt, of the Geological Survey of Canada. Hunt, Professor E. B. Andrews of Marietta, Ohio, Henry D. Rogers, and William Logan made additional contributions in support of the theory and, in 1865, Hunt summarized the conditions necessary for oil accumulation as follows: (1) A source bed (Hunt insisted on limestone); (2) Proper attitude of the strata (anticlines); (3) Suitable fissures to act as reservoirs; (4) Impermeability of surrounding and overlying strata, to prevent escape of the accumulated oil.

It seems remarkable that the conditions now considered necessary for the accumulation of oil were recognized so soon and that the wealth of data made available since has made no important change in these early concepts. That sandstones, without fracturing, were sufficiently porous to serve as oil reservoirs was suggested by Alexander Winchell in 1860 and appears to have been accepted by Hunt in a restatement of his views in 1868. In 1865 Winchell stated that both oil and gas formed in the same source beds and migrated upward into the crest of the anticline under the same factors.

The structural or anticlinal theory was bitterly opposed by J. Peter Lesley, director of the Second Geo-

[17] The reader is referred to the excellent historical paper on this subject by J. V. Howell (34) which has served as the source for the summary presented here.

[18] For references to these early statements see J. V. Howell (34).

logical Survey of Pennsylvania, from as early as 1865 until his death in 1889. Lesley's emphasis of the importance of porous sandstones as reservoirs, however, contributed to the abandonment of the older idea that crevices were essential to accumulation.

J. V. Howell (34, pp. 10, 13) states that as early as 1875, sixteen years after the drilling of the Drake well, the structural theory had been accepted and referred to in published reports by Logan, Hitchcock, H. D. Rogers, E. W. Evans, E. B. Andrews, Alexander Winchell, and Henry Hind, in North America, and by H. Hoefer and probably others in Europe. The following facts regarding petroleum seem to have become rather generally known and accepted by geologists of that time.

1. Petroleum is of organic origin, and to be sought for only in sedimentary rocks.
2. In the regions then being prospected, the fields, almost without exception, were located on anticlines.
3. The rocks generally were saturated by water, and through these beds the oil and gas, by reason of their lighter specific gravity, tended to rise to the higher portions of the reservoir.
4. An impervious bed overlying the reservoir rock was essential.
5. Sandstones constituted the most common reservoirs. By this time most geologists believed that fissures were not necessary for accumulation, though many still believed that they were necessary to permit the oil and gas to enter the reservoir from the source beds.
6. Gas usually occurred with oil and was effective in causing it to flow. Solution of gas in petroleum was recognized, but its full significance was not appreciated.

Lesley continued his prejudice and opposition to the anticlinal theory and, inasmuch as he was director of the largest official geological organization and the only one operating in the oil-producing areas, his dominating influence led to a decline in the popularity of this theory between 1875 and 1885. As early as 1865 he flatly stated that the supposed anticlines in the Pennsylvania oil districts did not exist, and in 1880 he reiterated his opposition as follows:

"The supposed connection of petroleum with anticlinal and synclinal axes, faults, crevices, cleavage planes, etc., is now a deservedly forgotten superstition. Geologists well acquainted with the oil regions never had the slightest faith in it, and it maintained its standing in the popular fancy only by being fostered by self assuming experts, who were not experienced geologists."

Of the numerous geologists working under Lesley, only I. C. White seems to have kept an open mind on the problem of oil accumulation and, after leaving the Survey for commercial work in 1883, to have become a staunch advocate of the anticlinal theory. After two years of commercial work searching principally for gas to be used in industrial plants, White published a paper which led to his being credited with developing the anticlinal theory, an honor he has many times denied. Although not the originator of the theory, his field studies and his practical application of its principles to the discovery of new oil and gas fields resulted in a renewal of its popularity and laid the foundation for the science of petroleum geology as it is known today.

I. C. White's efforts and results were supported at about this same time by the work of Edward Orton who, as State Geologist of Ohio, made a study of the occurrence of oil and gas in fields of northwestern Ohio. Orton found that oil and gas accumulation here was related to a broad flat anticline (Cincinnati arch), but that some of the pools occurred not on the crest of the fold but in areas of "arrested dip" or terraces on the flanks. Orton later laid much stress on terrace accumulation and, in his work on the fields of Ohio and Indiana, emphasized the importance of the Trenton limestone as the source of oil and gas and pointed out that its porosity and value as a reservoir were due to the extent of dolomitization. He also introduced the use of contours as an improved means of portraying the structure of oil and gas fields.

Little advance was made in the study of oil accumulation for the 10 years following the studies of White and Orton. About 1900, however, the United States Geological Survey began a systematic examination of the oil fields of the Appalachian states, particularly Pennsylvania and Ohio, and later extended these studies to all oil-producing districts of the United States. Numerous publications by the Survey and the technical papers published elsewhere by members of this organization continued for many years to be the principal source of new facts regarding the occurrence of petroleum.

Extensive exploration for oil from 1910 to 1915 in provinces of diverse geologic character led to the discovery of new fields in which conditions of accumulations were new and varied. Of these the most important were accumulations around salt domes, along faults, and in sand lenses. Although it was immediately apparent that the fundamental principles of the structural theory could be applied to these new types of geologic traps, attention was directed to the need for general recognition and classification of all such features known to be favorable to oil accumulation. In 1916 F. G. Clapp (17) presented his first classification of oil and gas fields according to structure, giving proper recognition to the different types of structure, in addition to anticlines, that were responsible for accumulation.

J. V. Howell (34, p. 20) points out that until about 1917 the majority of petroleum geologists were engaged in the search for anticlines but that since that time there has been an increasing tendency to interpret structure and associated oil possibilities in the light of fundamental principles of accumulation and of expanding knowledge of regional geology. It was at about that time that interest first developed in the role played by paleogeography in influencing the distribution of reservoir sands.

Present understanding of oil and gas accumulation had its beginning in the anticlinal theory and became comprehensive in the successful application of the principles of this theory to types of geologic traps other than anticlines. Although the anticline is now recognized as only one of the types of trap favorable to accumulation, structure clearly has played an important role in the concentration and segregation of oil and gas in all fields whether they produce from anticlines, the flanks of salt domes, fault accumulations, or the so-called stratigraphic traps or up-dip pinch-outs of reservoir sands. The anticline is the easiest type to find and, possibly for that reason, appears to be the most common.

Producing stratigraphic traps of major size, such as the truncated and buttressing sands of the Midway-Sunset district, have been recognized since about 1912, but their tremendous possibilities became more generally apparent with the discovery of the East Texas field in 1930. Traps of this type are commonly concealed and difficult to find for they result from a combination of favorable stratigraphic relations and structure which commonly can not be detected by present methods of surface exploration.

ACCUMULATION IN CALIFORNIA

The most remarkable feature of the California oil industry is the small size of its productive territory when consideration is given to the quantity of oil that has been produced, the size of known reserves, and the remaining opportunities for new discoveries. Inspection of a map of the State reveals that oil production and known accumulation in appreciable quantity is confined to four isolated districts in the southern part of the State (see fig. 105). These four districts have a combined area of 5,750 sq. mi., only 3.63% of the area of California. They have produced 5,394,783,000 bbl. of oil[19] and, in addition, have an estimated proved reserve of 3,800,000,000 bbl. No area of equal size in the world can approach this record. A few pertinent statistics on these districts are presented below:

KNOWN FIELDS

Oil-Producing District	*Area (Sq. Mi.)*	*Past Production (M. Bbl.)*	*Estimated Proved Reserves (M. Bbl.)*	*Estimated Ultimate Production (M. Bbl.)*	*Proved Acres*	*Average Estimated Ultimate Per Acre (Bbl.)*
San Joaquin Valley	3,935	2,297,378	2,200,000	4,497,378	137,300	32,630
Los Angeles Basin	700	2,576,137	1,100,000	3,676,137	30,200	122,100
Ventura-Santa Barbara	860	368,688	300,000	668,688	3,800	167,185
Santa Maria	255	152,580	200,000	352,580	14,400	24,000
Totals	5,750	5,394,783	3,800,000	9,194,783	185,700	49,276

The accumulation of an estimated nine billion barrels of oil within such a limited area requires remarkably favorable conditions for the genesis, retention, and concentration of petroleum. Extensive and thick deposits of rich source beds and an unusual abundance of structural and stratigraphic traps to collect and retain the oil are the obvious factors directly responsible, but it is of interest to summarize briefly, and in simple terms, the geologic events assumed to have been effective in the development of these factors.

Major parts of southern California, from the Cretaceous to at least the close of the Tertiary, were covered by comparatively shallow seas which received from nearby eroding land masses thousands of feet of detrital sediments consisting principally of mud, silt, and sand. Organic life was abundant in these seas and the conditions on the sea-bottom were favorable for the preservation and rapid burial of organic remains. With continued sinking of the sea-bottom and the burial of its organic sediments by new detritus from the land, biochemical and thermo-chemical agencies generated oil and gas or their ancestral hydrocarbons throughout the water-soaked organic muds. Further compaction of these buried muds by the weight of thousands of feet of overlying sediments improved conditions for generation and refinement of oil, drove the oil and gas and much of the water into adjoining beds of permeable sand, and continued to force these fluids laterally through the continuous blanket sands toward bordering areas of lower pressure. During this lateral and in general up-dip migration, the oil and gas, being lighter than water, gradually moved to the top of the permeable sand

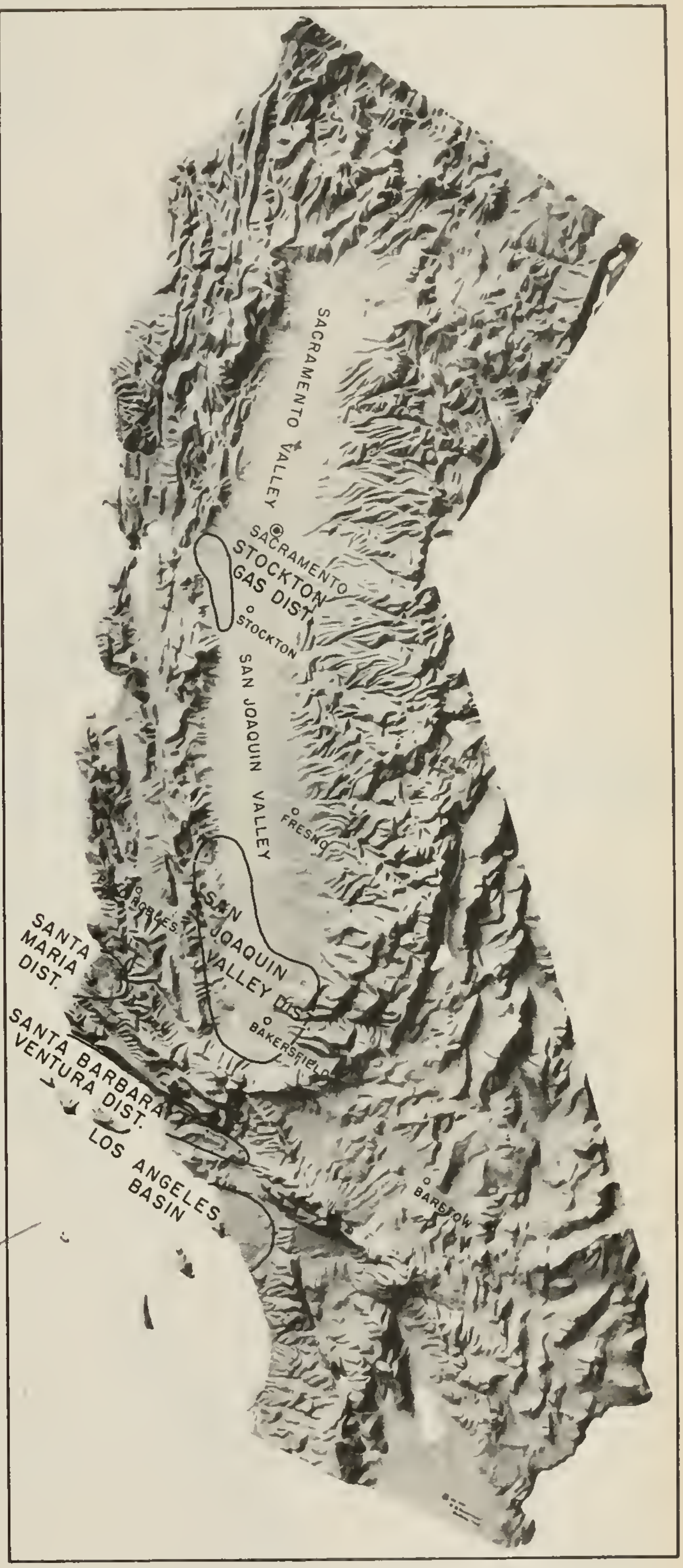


FIG. 105. Relief model of California showing oil-producing districts. *Photo of relief map (copyright) by courtesy of H. A. Sedelmeyer, Berkeley, California.*

[19] January 1, 1940.

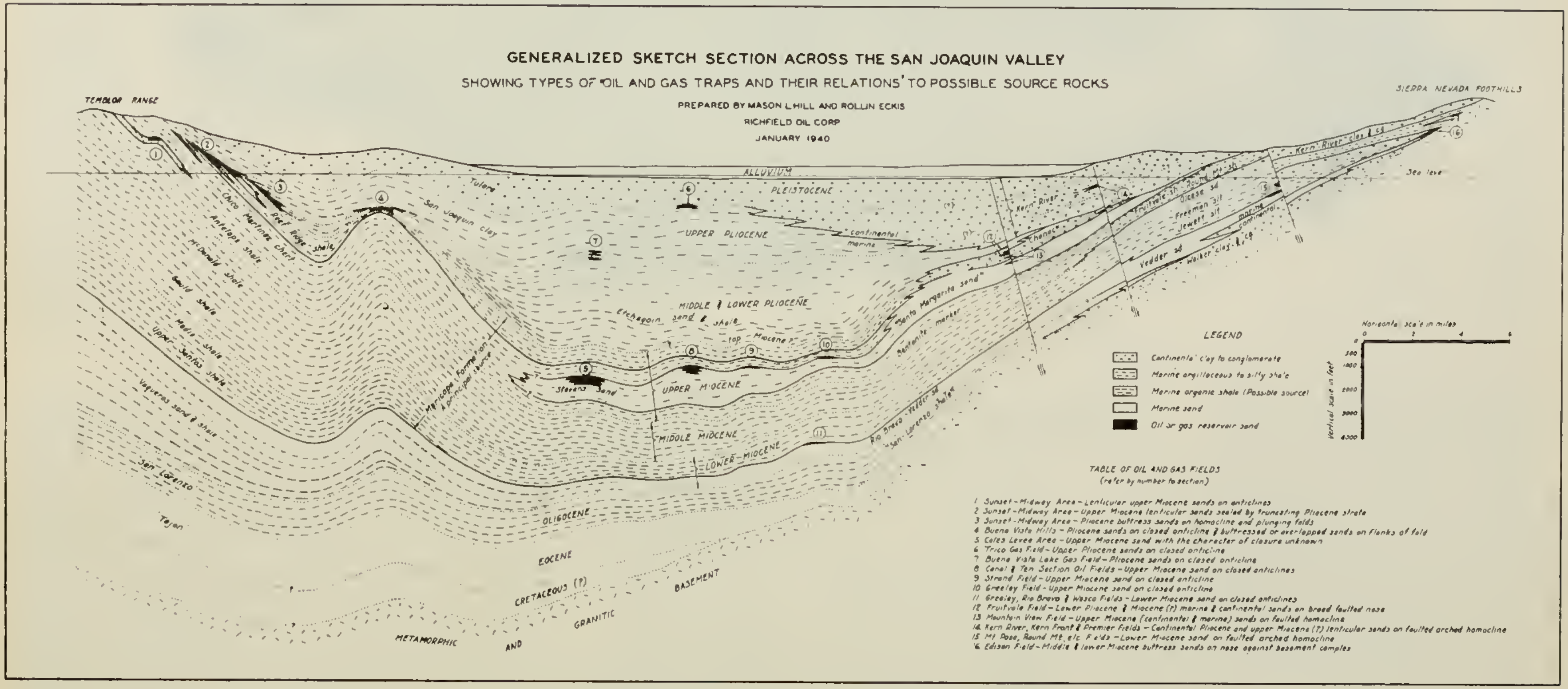


FIG. 106. Geologic section across southern San Joaquin Valley.

and became trapped in the first closed anticline which lay in the path of these moving fluids.

Thinning of oil-bearing strata across the axes of numerous anticlines in California indicates that these structures were growing during the Pliocene and probably during the Miocene. Adequate data for older beds, particularly those of Eocene age, are lacking. These anticlines have continued to grow throughout at least the latter part of the Tertiary and thus may have involved all formations through which oil and gas, during this period, could have been migrating.

The existence of anticlines throughout critical late Tertiary time, during which Miocene and Pliocene oil and gas were forming, moving, and accumulating, is only one of the favorable conditions which have led to the concentration and retention of vast quantities of oil. The growth of these structures along the bottom of the Tertiary seas apparently was an expression of dynamic forces which, in addition, elevated the depressed adjoining land areas and caused these seas to shift position, to retreat from areas of elevation and folding, and to transgress depressed areas of earlier elevation and erosion. Several unconformities, many sand lenses, and broad lateral changes in lithology were developed which thereafter could serve as stratigraphic traps for oil. Features of this type that have effectively trapped large quantities of oil include the truncated and buttressing sands of the Midway-Sunset district, the buttressing Sealez sand of Buena Vista Hills, the truncated Monterey shale of the Santa Maria Valley, and the Eocene Gatchell sand lens-out of the East Coalinga anticline. The effectiveness of these stratigraphic traps was due to a favorable relation between them and local structure, and possibly also to pressure outlets which permitted connate water, oil, and gas to flow into them from structurally lower high-pressure areas.

Oil accumulated in this manner, probably before the end of Pliocene time, in closed anticlines and broad structurally favorable areas around the borders of basins where stratigraphic traps prevented the escape of oil to the surface. Elevation and structural deformation by folding and faulting became widespread and more acute throughout California during the Pleistocene and as a result the sea was drained from all pre-exisitng basins, and folds and faults within areas of oil accumulation were accentuated and new ones were formed. The oil adjusted its position and became confined to the higher parts of these structural traps, principally by reason of its buoyancy but possibly also as a result of continued compaction and circulation of fluids.

TYPES OF RESERVOIRS

Sand or sandstone of varying hardness, texture, and permeability is the reservoir for 98% of the oil in California. This type of reservoir yields practically all of the oil from fields of the San Joaquin Valley, the Santa Barbara-Ventura district, and the Los Angeles Basin, and a large share from some fields of the Santa Maria district.

Thick, highly permeable sands like those of the Los Angeles Basin Pliocene, the Miocene of Elwood and the San Joaquin Valley, and the Eocene of East Coalinga are responsible for high rates of production and unusually large recoveries per acre. Most of these more prolific sands are of the blanket type covering extensive areas, but some are lenses having only limited distribution.

Other types of rock serving as reservoirs, and the areas in which they produce, are listed below in the approximate order of their importance.

Fractured chert and/or shale (Miocene)	— Santa Maria district: Orcutt, Santa Maria Valley, West Cat Canyon, Gato Ridge, Lompoc, and Casmalia. North Belridge and Elwood.
Schist-fragment conglomerate (Miocene)	— Playa del Rey and El Segundo fields in the Los Angeles Basin.
Fractured Schist (Jurassic?)	— El Segundo field where it receives oil from contiguous schist-fragment conglomerate.
Siltstone and sandy shale (Pliocene)	— Yields gas in Buttonwillow field of San Joaquin Valley; this type may yield minor amounts of oil in several fields.

Marine sands are the reservoir for probably 95% of the oil in the State. Fields in which commercial oil production is obtained from non-marine sands occur along the east and west sides of the San Joaquin Valley and in the Santa Barbara-Ventura district. The more important ones are enumerated below.

Field	Age of Sand	Oil Accumulation
East Side San Joaquin Valley		
Kern River Kern Front Premier Fruitvale Mountain View	Pliocene and upper Miocene	In lenticular sands and in sands abutting against faults.
West Side San Joaquin Valley		
South Belridge Elk Hills Buena Vista Hills flanks Midway-Sunset	Lower Pleistocene and upper Pliocene	In lenticular and buttress sands, principally on flanks and noses of anticlines.
Santa Barbara-Ventura District		
Capitan Elwood South Mountain Bardsdale Shiells Canyon Torrey Canyon	All Sespe, principally Oligocene	In anticlines. Sands probably lenticular.

These occurrences of sizable accumulations of oil in non-marine beds present problems of origin and migration for California geologists. Since it is generally agreed that such quantities of oil can originate only in marine strata, these occurrences offer acceptable evidence of either lateral or vertical migration. The producing continental Pliocene and upper Miocene beds along the east side of the San Joaquin Valley grade laterally down dip into marine strata believed by many to have been the source of this oil. The continental Sespe formation of the Santa Barbara-Ventura district grades westward, and probably also southward, into marine strata which offer a reasonable source of oil. The Sespe oil, however, may have been derived from any one of three possible sources: (1) from marine Sespe by lateral migration, (2) from marine Pliocene or Miocene beds by migration laterally and vertically through and along faults, or (3) from underlying marine Eocene strata by vertical migration.

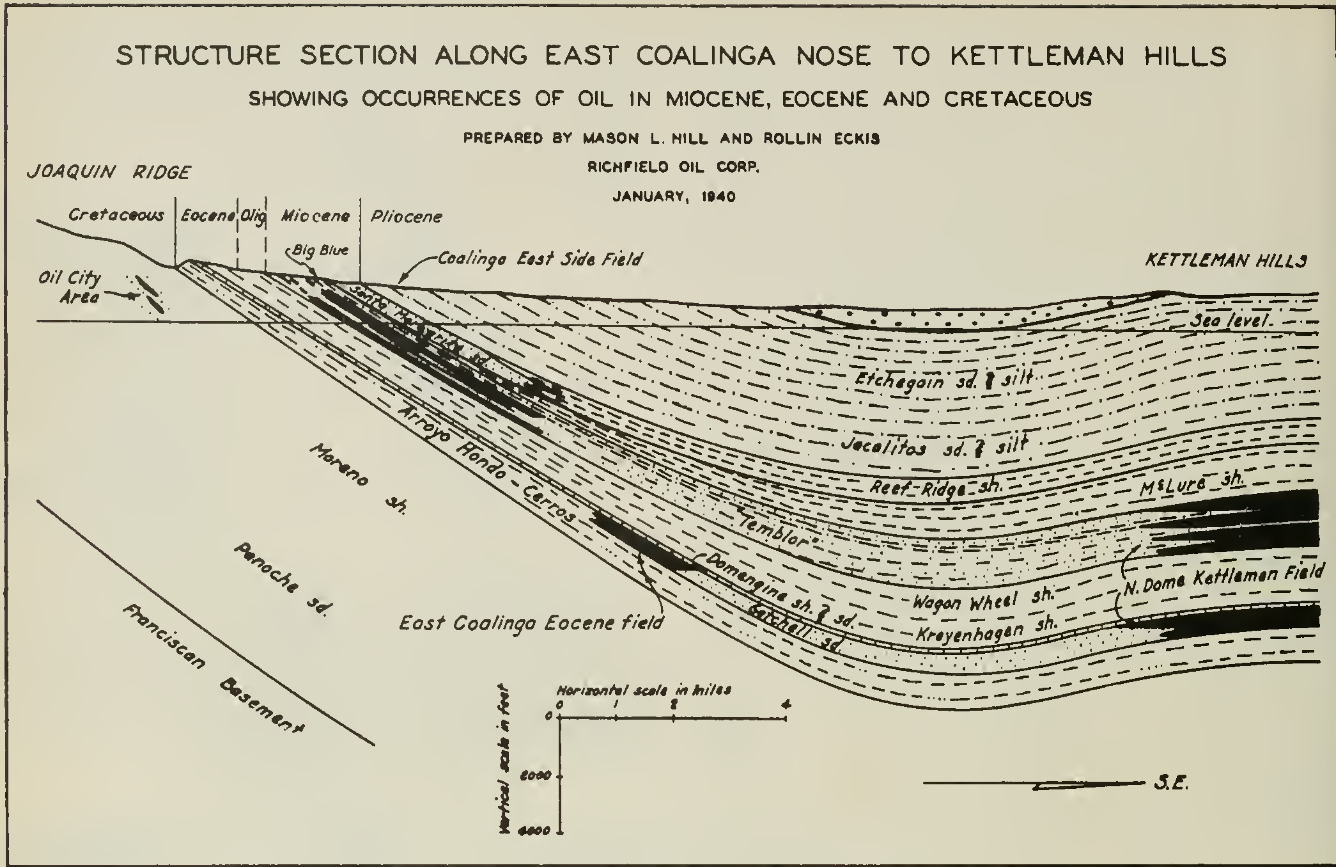


FIG. 107. Geologic section along East Coalinga anticline and Kettleman North Dome.

TYPES OF TRAPS

The term "trap" is used for that geologic feature which has served to attract and retain a commercial quantity of oil or gas. It must involve an adequate reservoir rock having an overlying impermeable stratum competent to prevent escape of these hydrocarbons. Practically all important traps, whether they be anticlines, homoclines, sand lenses, or faults, either are entirely structural or are associated with structure essential to the concentration of oil and gas. The closed anticline is the most common purely structural type. The fault trap and the prolific sand lens, or so-called stratigraphic trap, require association with tilted and favorably arched strata which have served to encourage up-dip migration and local concentration of oil or gas. Accumulation in all of them apparently has been in accordance with the principles of the structural theory.

Fig. 106, a generalized section across the San Joaquin Valley, serves to illustrate the character and stratigraphic distribution of most of the important types of oil and gas traps in California. Others are shown in Fig. 107, a longitudinal section extending down the Coalinga anticline and into Kettleman Hills. Since such two-dimensional diagrams fail to illustrate the important third dimensional character of these traps, a tabulated classification with examples from California is presented below. Many traps are the result of a combination of favorable conditions, either entirely structural or partly structural and partly stratigraphic, and for that reason these types are listed more than once in this classification.

Classification of Types of Traps with California Examples

I. *Structural Traps*
- A. *Folds*
  - 1. *Anticline*
    - a. Closed anticline—Kettleman, Santa Fe Springs, Elwood.
    - b. Faulted anticline—Inglewood, Long Beach, Huntington Beach.
    - c. Plunging nose—
      - (1) With reservoir sand abutting up-dig against fault —Fruitvale.
      - (2) With reservoir sand open up-dig to surface—"Temblor" sand of Coalinga nose.
- B. *Faults*
  - 1. Those causing distinct accumulations in arched or homoclinal strata—Kern Front, Mountain View, Fruitvale, Whittier.
  - 2. Those affecting distribution of oil within an anticline—Inglewood, Huntington Beach, Long Beach, and Ventura Avenue.

II. *Stratigraphic-Structural Traps*
- A. *Sand Lenses*
  - 1. Buttress and other sand lenses of a converging series, occurring on flanks or nose of anticline or in plunging syncline—Pliocene of Midway-Sunset and flanks of Buena Vista Hills and Elk Hills.
  - 2. Other sand lenses resulting from irregularities of deposition and occurring on homocline, or on the flanks or nose of anticline—Miocene of Midway-Sunset; Eocene of Coalinga Nose.
- B. Truncated sands or fractured shale of erosional unconformity occurring on homocline, anticlinal nose, or plunging syncline. Miocene sands of Midway-Sunset and West Side Coalinga, and Miocene shale of Santa Maria Valley.

Some of the types of traps mentioned in the preceding classification deserve special mention because of characteristics either uncommon or difficult to explain.

Truncated Reservoir Produced by Erosional Unconformity. The reservoirs of sand and fractured shale truncated and sealed by unconformably overlying beds present a particular problem of migration and accumulation. If oil was generated in, and forced from, the organic muds into contiguous permeable sands soon after deposition of these sediments and, as seems most reasonable, during early stages of compaction, why was the oil not forced to the surface and lost before or during the subsequent period of uplift and erosion and before the still later deposition of the unconformable seal? Miocene beds of this type in the basin immediately adjoining the Midway-Sunset district had been buried and compacted by the weight of several thousand feet of lower Pliocene sediments before their truncated and exposed edges were covered with impermeable upper Pliocene sediments. Sufficient time had elapsed for these lower Pliocene sediments to accumulate, and sufficient structural tilt had occurred to permit this deposition and to give the exposed Miocene beds an inclination of from 5° to 30°

The presence of oil in truncated beds beneath an unconformity is commonly accepted as evidence of post-unconformity migration and accumulation, in spite of the fact that such a conclusion is in serious conflict with impressive evidence that migration, in greater part, must have occurred earlier during the burial and compaction of the pre-unconformity sediments. A commendable and inspiring attempt to reconcile these two types of conflicting evidence has been made by George E. Dorsey (33). Dorsey believes it reasonable to assume that oil trapped in such pre-unconformity strata migrated to, and accumulated in, approximately their present position during the course of burial and compaction prior to the deposition of the overlying unconformable muds which act as a seal. He points out that areas of accumulation were areas of uplift and postulates that the underground fluid level in such uplifts did not reach the surface but became static at appreciable depths beneath it, just as the underground water level in present exposed uplifts remains below surface outcrops. Such subaerial uplifts would be areas of intake for fluids rather than areas of artesian flow. During erosion, therefore, the oil accumulated on top of the underground water in an uplift would remain some distance beneath the outcrop and would thus be protected from appreciable loss. During the following submergence which provided the depositional seal of impermeable mud, the underground fluid level remained sufficiently low or the exposed edges of the oil-bearing beds became sufficiently clogged to prevent escape of much of the oil. Those interested in the problem of accumulation in pre-unconformity strata should refer to Dorsey's paper.

As Dorsey admits, this protective process requires a delicately favorable balance between the position of the underground fluid level and the rates of submergence and deposition. It also requires that previous compaction and the resulting hydraulic pressure causing fluid movement through reservoir sands had been inadequate to force the oil to the surface before underground fluid levels became adjusted to topography. Possibly this pressure affected the movement of connate water more immediately and efficiently than oil, and the final stage of migration and accumulation of oil into the trap was dependent on buoyancy acting through a longer period of time. If this be true, then there appears to be no obvious reason to assume that the oil arrived near the up-dip eroded edges of these beds until after submergence and deposition of the impermeable seal.

Accumulation in traps produced by erosional unconformities is not thoroughly understood. It has been suggested earlier in this paper that reservoir fluid movement up-dip into the trap was encouraged by leakage of water along the unconformity by reason of differential capillarity or by an outlet for the reservoir at a point outside the area of accumulation. Whatever the mechanism or the time of accumulation, it is probable that in many cases much oil and gas was lost and only a part of the original quantity of these hydrocarbons was preserved. The accompanying sketch section across the Santa Maria Valley field illustrates the relation of a 100-ft. Pliocene tar sand to the underlying erosional Pliocene-Miocene unconformity. Intervening siltstones are also oil saturated. In this area the pre-unconformity Monterey shale constitutes the only reasonable source for the oil. It seems that the tar in the overlying sand, covering many square miles, must be a residium of oil that has leaked from the underlying trap, either along the unconformity or vertically along faults known to be present.

Plunging Noses and Homoclines with Low Fluid Levels. Some sands on anticlinal noses and homoclines in several producing districts of the State have low fluid levels with the structurally highest parts of the sands dry and the oil resting on water several hundred feet down dip. This is the condition in some Miocene sands of the Midway-Sunset district and apparently in small productive areas in the highly elevated district north of the Santa Clara River in Ventura County.

The accumulation and retention of oil in the "Temblor" sand of the East Coalinga anticline occur under somewhat similar conditions. The Temblor reservoir sand crops out up the plunge of the fold. The oil, however, extends to, and seeps from, the outcrop and commercial production has been obtained from shallow wells nearby. According to Max Birkhauser,[20] who has devoted considerably study to the geology of this area, it is probable that accumulation occurred when the outcrop of the "Temblor" sand was overlapped by impermeable lower Pliocene strata, and that subsequent late Quaternary elevation and erosion of the Coalinga anticline has stripped away the Pliocene seal. Apparently the reservoir fluid pressure since that time has not been high enough to flush all of the oil from the sand.

Anticlines with Multiple Oil Zones. The structural closure of an anticline is commonly considered to be a measure of the maximum thickness of oil sand to be expected. This is true for the anticline having only a single oil sand. Where several oil sands are present and separated by impervious shale it is not unusual for their aggregate thickness to exceed considerably the amount of structural closure. The thickness from the top to the bottom of the entire producing section may be many times the amount of closure.

[20] Personal communication.

Excellent examples are several fields in the Los Angeles Basin that are famous for the number and thicknesses of their producing Pliocene and Miocene oil zones, and for their average yields per acre. The lack of any relation in these fields between estimated total closure and total thickness of oil sand, oil zones, and producing interval appears in the following tabulation.

Field	Estimated Structural Closure (feet)	Number of Zones *	Thicknesses (ft.)			Production Per Acre to January 1, 1940 (bbl.)
			Oil Sand	Oil Zones	Producing Interval	
Santa Fe Springs	600	9	2500	4525	3330–7855	280,000
Seal Beach	400	5	2675	4060	4400–9000	265,000
Long Beach	1600	6	2200	5200	3300–10,400±	396,000
Dominguez	1000	9	1350	3260	3765–7580	108,000

* A zone commonly includes several beds of sand separated by thin beds of shale.

SOURCE ROCKS

Recognition of beds that have been the source of oil is a problem regarding which petroleum geology has made little progress. Confidence that probably all commercial quantities of oil have been derived from organic matter preserved in fine-grained marine muds is justified, but our ability to determine from the present appearance and composition of marine shales their original organic character, their capacity as a source of oil, and their actual productivity is not established.

Source beds are obviously essential but our evaluation of the source quality of any marine shale section generally is based on its comparison with other shale assumed to have been a source. It is probable that occasionally our appraisal of this point is in error and that, because of this error, some exploratory projects fail to find oil, or find gas where oil was expected.

After oil is discovered in a district the problem of a source for the oil of that district receives no particular attention principally because the practical question of the presence of oil is settled and the existing scarcity of basic facts does not encourage hope for conclusive results in any study of the source of oil. Investigations such as those being conducted, however, on the identity and composition of organic matter now accumulating in different types of recent marine sediments and the importance of bacterial activity and the character of the physical and chemical changes that transpire during and after burial may in time provide acceptable evidence of the characteristics which a source rock should have.

The work of Parker D. Trask in collecting and analyzing thousands of recent sea-bottom samples from many parts of the world and of ancient sediments, principally shales, from exposed and subsurface sections in oil-producing districts has provided valuable data and has encouraged the geologist in this method of attack (Trask, P. D. 31; 32; 37b; 39a). Research institutions, such as the Scripps Institution of Oceanography at La Jolla, are conducting comprehensive investigations of the sea-bottom topography which, in many cases, appears to control the accumulation of organic muds, the organic character of these muds, and the conditions of stagnation, temperature, and decomposition common to their environment.

The problem of the source of oil found in California fields is herein approached by making rather sweeping generalizations, a method which avoids the task of collecting and appraising detailed facts and rarely provides a specific answer. The problem can better be attacked at some future time when more dependable knowledge of the life history of sediments, organic matter, and oil has equipped us to recognize and evaluate essential data. It is closely related to the present controversy on lateral migration versus local origin.

It is possible that the oil in each zone of each field has a separate and distinct source; certainly it is probable that several stratigraphic units, rather than one or two, have been the source of the oils so widely distributed in the stratigraphic section of California fields.

The oil of many fields occurs in reservoirs intimately associated with dark brown to black richly organic shale. This is particularly true of Playa del Rey, Orcutt, Santa Maria Valley, and all oil fields of the State producing from marine Miocene beds. This close association of producing reservoirs and highly organic shales offers strong support for the belief that much of the oil, particularly that in the Miocene, has originated in that general part of the section in which it now occurs.

Richness in organic content, however, may not be a dependable guide for the recognition of source beds. Trask (Trask, P. D. 37b, pp. 373-376; 37c) has made a study of the problem of evaluating several possible criteria for the recognition of source beds. His basic assumption for this study was that shales stratigraphically close to producing sands were source beds and those far removed were not. He concluded on this basis that the richness of shales in organic matter probably has little value as an index of source beds—despite the fact that beds very low in organic matter show some tendency to be poor source beds, and sediments very high in organic content show some tendency to be good source beds. Trask believes the total quantity or organic matter in a shale is the important factor rather than its richness expressed in percentage, and that a 100-ft. bed containing 1% organic matter is as good a source as a 50-ft. bed containing 2%.

This possibility, or another wherein oil may have been derived from types of organic matter now completely destroyed and not present in existing shales, permits consideration of the comparatively lean but thick Pliocene shales of the Los Angeles Basin and the San Joaquin Valley as possible source rocks for the oil produced from associated Pliocene sands.

Vertical migration through considerable rock thicknesses, as evidenced by an abnormally high stratigraphic occurrence of an oil zone, appears to have been important only in those fields in which faults are known. Even in some of these fields, particularly Long Beach, there is good evidence that oil did not migrate upward along faults but rather moved laterally through them into down-faulted younger sands.

SAN JOAQUIN VALLEY

Fig. 106, a generalized structure section across the southern part of the San Joaquin Valley portrays the stratigraphic distribution of most of the oil pools in the

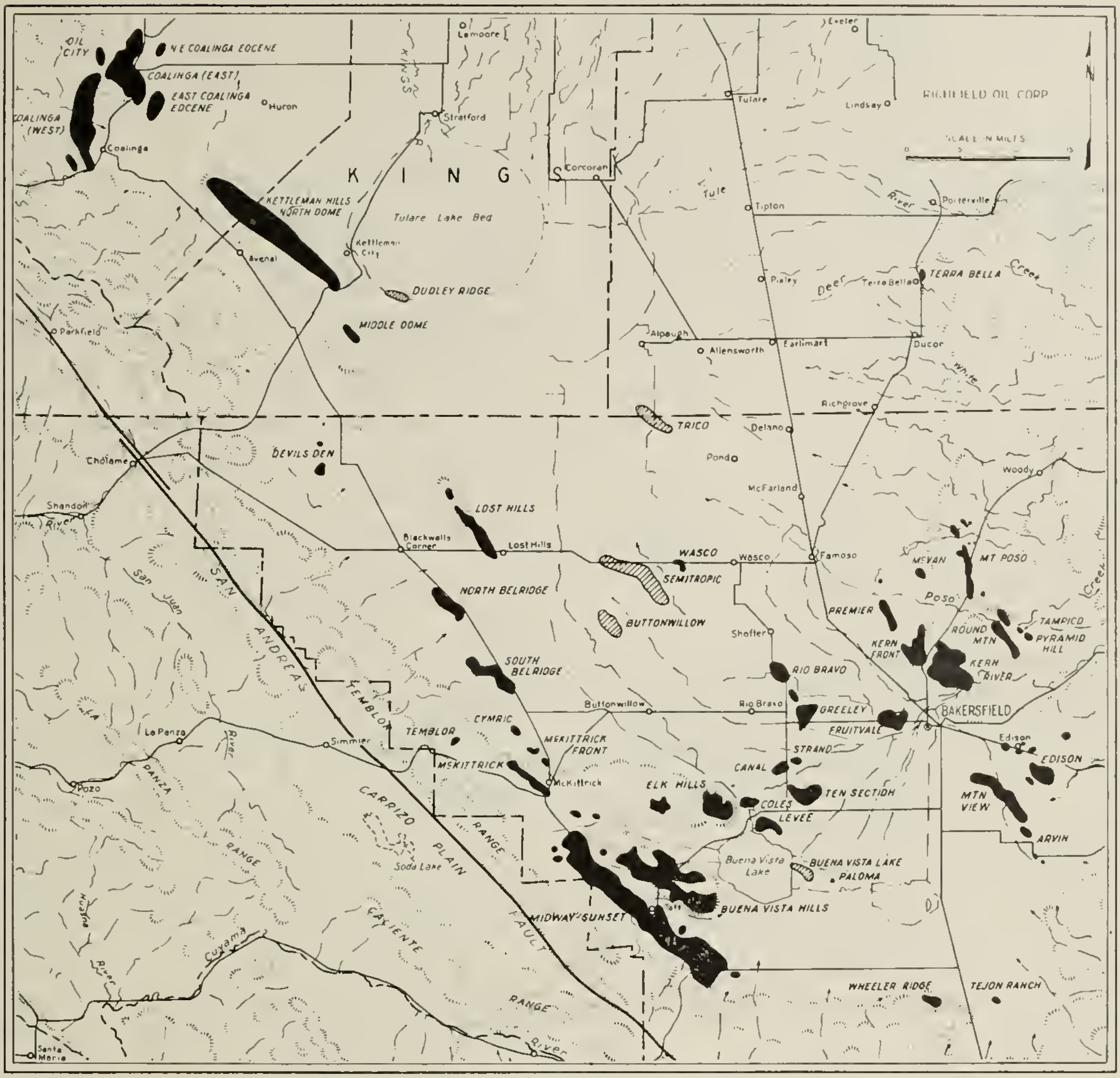


FIG. 108. Map of oil and gas fields of San Joaquin Valley.

southern part of this major district. Fig. 107 illustrates the stratigraphic positions and types of traps of other accumulations farther north in the East Coalinga and Kettleman Hills anticlines. The following few additional occurrences of oil are of comparatively minor significance but they serve to complete for this district the general picture of the stratisgraphic distribution of commercial oil pools.

Continental Lower Pleistocene and/or marine upper Pliocene sands	— Lost Hills and South Belridge.
Upper Miocene fractured shale	— South Belridge.
Upper middle and lower upper Miocene sands	— Wheeler Ridge-Tejon area.

Commercial accumulations of oil occur in both marine and continental strata and are widely distributed through 10,000 to 15,000 ft. of sediments varying in age from Cretaceous to Pleistocene. Fig. 106 attempts to illustrate the segregation of these sediments into three general groups according to their qualifications as a source of oil. These groups are:

Improbable source beds	— Continental Pleistocene, Pliocene, Miocene and Eocene (?) beds in upper and lower parts of section.
Possible source beds	— Marine Pliocene consisting generally of light-gray sediments comparatively lean in organic matter. May have been the source of Pliocene oil in Midway-Sunset, Buena Vista Hills, and Elk Hills, and in continental Kern River formation of East side fields.
Probable source beds	— Marine Miocene, Oligocene, Eocene, and Cretaceous shales. Dark-brown to dark-gray and black shales, generally rich in organic matter. The source of oil found in marine reservoirs of this age, and the probable source of oil in the continental "Chanac" formation.

The marine Miocene shale formations of the San Joaquin Valley comprise the major part of the one stratigraphic series in California which, on the basis of its rich organic character and prolific productivity, can be accepted as a major source of oil and gas. It varies in thickness from 1,000 ft. or less to at least 10,000 ft., is generally characterized by brown and black organic shale, commonly has live seepages and tar sands in outcrops, and contains sandstone reservoirs responsible for about 75% of the estimated ultimate production of known fields of this district.

Production from this Miocene series is derived principally from two major sandstone units, the Stevens zone in its upper part and the Rio Bravo-Vedder zone at the base. The Stevens zone is productive only in fields in the central part of the geosyncline although its general stratigraphic equivalents, both marine and continental, yield oil in fault traps along the eastern flank. Along the western flank in the Midway-Sunset field, lenticular sands in this part of the section, and truncated sands still higher, are productive. The Rio Bravo-Vedder zone is more extensive. It yields oil in anticlinal fields in the central part and in fault traps along the east flank of the geosyncline, and this general zone, including stratigraphically higher beds of middle Miocene age, is productive farther to the northwest in North Belridge, Kettleman Hills, and Coalinga.

The shale composing the greater part of the marine Miocene and closely associated with the producing sands is rich in bituminous organic matter. This is true also of the San Lorenzo (Oligocene) shale which immediately underlies the Vedder zone and which is the approximate age equivalent of the organic Kreyenhagen shale of the Coalinga area.

The Stevens zone is composed of alternating beds of sand and hard dark-gray to black shale and cherty shale. The shale within the sand zone, the 100 to 400 ft. of overlying shale, and the shale immediately below the zone are similar in having a dark brown to black bituminous appearance. In this regard they are much like shales of about the same age in the producing zone of the Wheeler Ridge field that have been examined with some care (Hoots, H. W. 29), have been found to yield considerable oil when heated, and to contain abundant bituminous organic matter similar in amount, character, and general aspect to that of normal laminated oil shale. The close association of such highly organic shale with producing oil sands is a strong argument for this shale having been the source.

Truncated beds of upper Miocene shale in the Midway-Sunset field, as suggested by R. W. Pack (20, pp. 70-71), are probably the source of oil found in intercalated beds of Miocene sand and in the unconformably overlying upper Pliocene buttress sands. It seems not unreasonable to suggest that Miocene shale is also the source of oil found in Pliocene and uppermost Miocene beds of the nearby Buena Vista Hills (see fig. 106).

LOS ANGELES BASIN

The accompanying chart (fig. 110) shows the positions and age relations of producing sands in the fields of the Los Angeles Basin. All of the oil of this district except a small amount from fractured schist, comes from sands and conglomerates of Pliocene and Miocene age and it will be noted from the chart that producing oil zones are restricted to the Repetto (lower Pliocene) formation and upper Miocene formations except in three fields, Inglewood, Potrero, and Long Beach, where clearly recognized faults extend through the oil zones to the surface and appear to have permitted migration into sands of the younger Pico (upper Pliocene) formation. Since known pre-Miocene rocks of this district are not of a type suggesting a probable source for oil, it is clear that the known distribution of oil justifies consideration of only the Repetto and Miocene formations as possible sources.

Evidence of varying quality suggests that both the lower Pliocene and upper Miocene formations may have been sources of oil. The upper Miocene shales are obviously rich in organic matter and are similar in this and other respects to much of the Miocene shale in other oil-producing districts of the State. These organic shales in all of the fields of Miocene production are so intimately associated with the oil sands as to constitute the only reasonable source for the Miocene oil. Fields in the western part of the basin where Miocene sediments rest directly on Franciscan (Jurassic?) schist provide almost irrefutable evidence that the Miocene shales of this section are the source of the oil found in the associated Miocene sands. In the Playa del Rey and El Segundo fields a conglomeratic sand resting directly on the schist is the main producing reservoir. It is directly overlain by 100 to 200 ft. of impervious black phosphatic and bituminous shale which is remarkably rich in organic matter, yields considerable oil when heated, and contains a generous amount of a viscous black bitumen extractable with solvents. The character and relations of this shale are described in more detail elsewhere (Hoots, H. W. 35a); its organic content has been found by Parker D. Trask [21] to exceed that of any other oil zone shale studied by him.

Although evidence that shale of the Repetto formation has been the source of oil produced from Repetto sands is not conclusive, there are two suggestive lines of evidence.

(1) Except in three fields where faults appear to have permitted leakage to younger sands, all Pliocene oil zones are restricted to the Repetto and, from one field to another, occupy similar stratigraphic positions in so far as the occurrence of porous sands permit. The oil in the Repetto could hardly have migrated upward from the underlying Miocene and everywhere attained such uniform distribution, and have halted its upward migration in the several unfaulted fields throughout the basin at almost the same stratigraphic horizon.

[21] Personal communication.

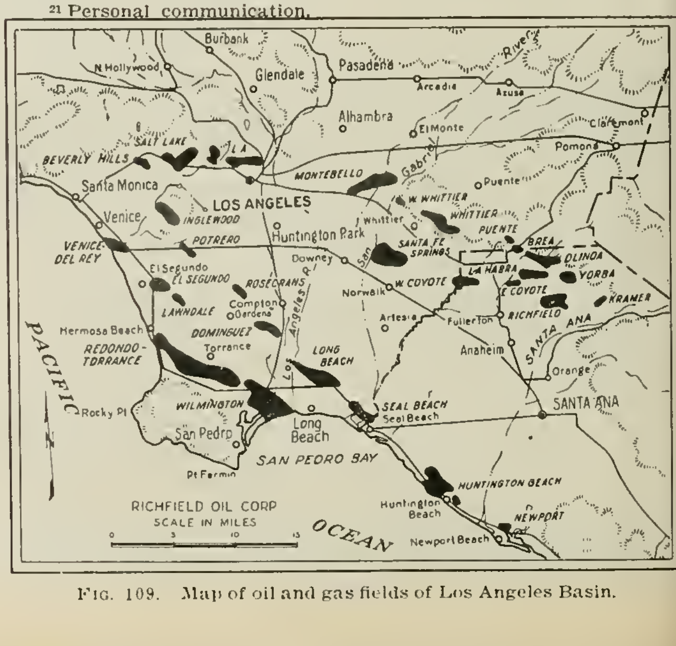


FIG. 109. Map of oil and gas fields of Los Angeles Basin.

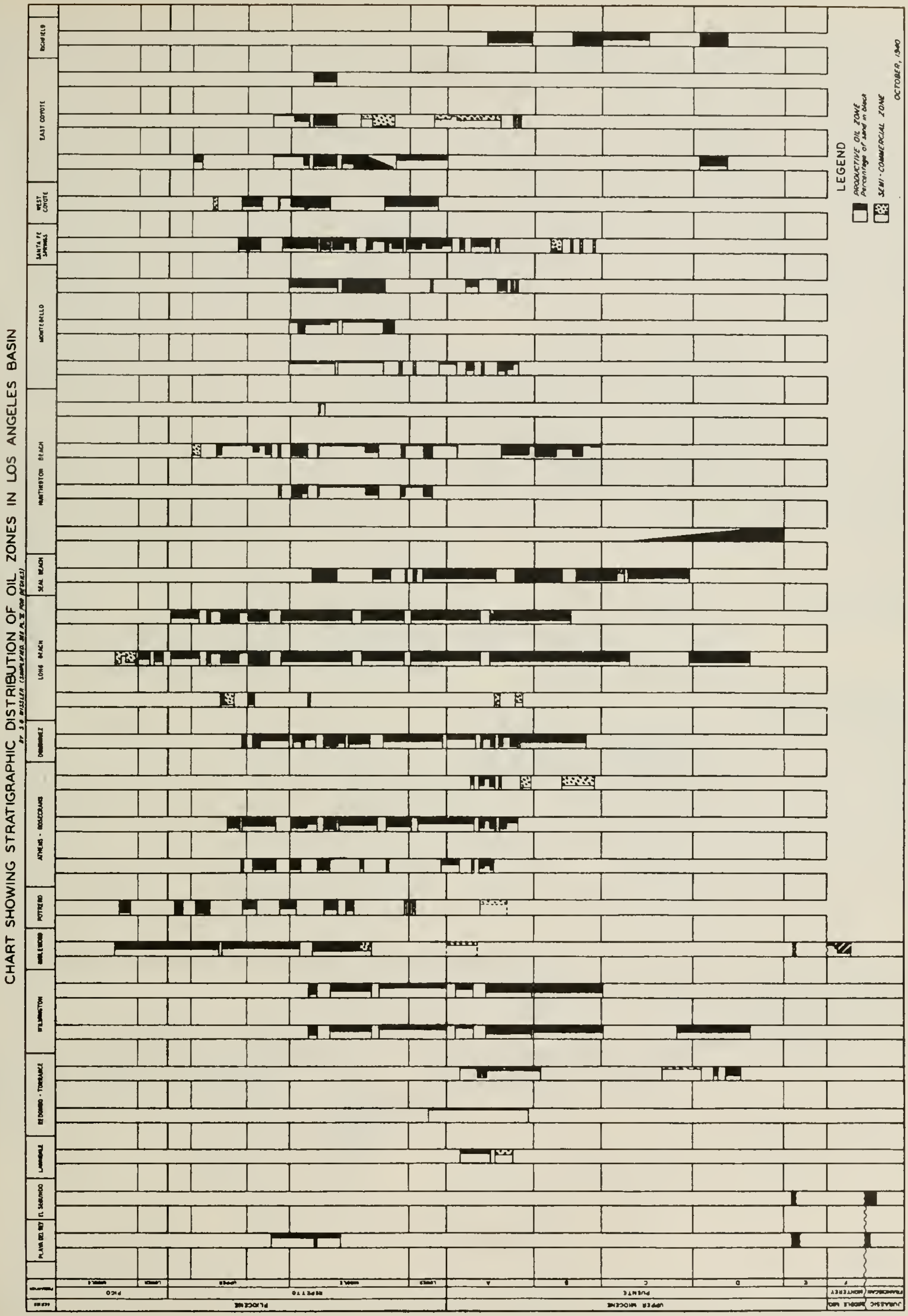


CHART SHOWING STRATIGRAPHIC DISTRIBUTION OF OIL ZONES IN LOS ANGELES BASIN
RICHFIELD
EAST COYOTE
WEST COYOTE
SANTA FE SPRINGS
MONTEBELLO
HUNTINGTON BEACH
SEAL BEACH
LONG BEACH
DOMINGUEZ
ATHENS - ROSECRANS
POTRERO
INGLEWOOD
WILMINGTON
REDONDO - TORRANCE
LAWNDALE
EL SEGUNDO
PLAYA DEL REY
LEGEND
PRODUCTIVE OIL ZONE
Percentage of sand in black
SEMI-COMMERCIAL ZONE
OCTOBER, 1940

FIG. 110.

(2) Shale in the Repetto formation of the Santa Fe Springs field, according to Trask (Trask, P. D. 36, p. 247), contains an average of 1.5% organic matter, an amount which he considers to be within the limits of the quantity of residual organic matter to be expected in an ancient source bed. He finds also that the quantity of oil in each of the lower five producing zones of this field is approximately proportional to the quantity of organic matter, a relation which could hardly exist if the oil had migrated upward from the Miocene. What seems to be another important fact is that the oil zone originally the most extensive in this field and containing the most oil is the Meyer near the top of the Repetto, and that five zones of smaller areal extent and productivity lie below it.

SANTA BARBARA-VENTURA DISTRICT

Producing oil zones are more evenly distributed throughout the thick Tertiary section of the Santa Barbara-Ventura district than in any other district of the State. They range in age from lower Eocene to middle Pliocene and through a stratigraphic column the composite thickness of which exceeds 25,000 ft. Only one or two formations comprising a fraction of this thickness are productive in any one field. The stratigraphic distribution of oil zones in various fields is tabulated below.

Pleistocene	
Pliocene	
Santa Barbara beds	
Pico formation	Ventura Avenue upper zones, Rincon, Padre Canyon, San Miguelito, Oxnard, Aliso Canyon, upper zones of Elsmere Canyon-Newhall.
Repetto formation	Ventura Avenue lower zones.
Miocene	
"Santa Margarita" formation	
Modelo (Monterey) formation	Newhall-Potrero and small fields in Sespe-Modelo Canyon area of Ventura County.
Rincon shale	Small production at Elwood.
Vaqueros sandstone	Elwood, Capitan, More Ranch (gas), Summerland, Santa Barbara Mesa, and small fields in upper Sespe Creek.
Lower Miocene to upper Eocene	
Sespe formation (non-marine)	Capitan, Elwood, Goleta, Santa Barbara Mesa, Ojai, South Mountain, Bardsdale, Shiells Canyon, Tapo Canyon.
Eocene	
Several marine formations	Simi, Tapo Canyon, and lower zones at Bardsdale and Elsmere Canyon. .

There can be but little doubt that oil in the Eocene sands of this district was derived from the closely associated dark-gray organic marine Eocene shales. The problem of the source of the oil found in Miocene and Pliocene strata appears to be the same here as in the Los Angeles Basin. Except for variations in thicknesses these two rock series in both of these districts are similar in all essential aspects. The oil in Miocene sands appears certainly to have been derived from the closely associated highly organic and bituminous Miocene shales. The origin of the Pliocene oil is less certain. The Pliocene shales are not as organic but if carefully investigated would probably offer as much evidence of having been an adequate source as do the Repetto (lower Pliocene) shales of the Los Angeles Basin.

The common occurrence of commercial oil zones in the red and green non-marine sediments of the Sespe formation perhaps is the most unusual feature of oil distribution in this district. This occurrence may be due in large part to the fact that this is the only district of the State in which extensive non-marine strata of this age occur on anticlinal folds at depths accessible to the drill. It happens, however, that its locale is a district of intense structural deformation where producing anticlines are commonly associated with faults of large displacement. Oil in the non-marine Sespe did not originate there but migrated from one of the three following possible sources: (1) Marine Sespe shale, into which the non-marine Sespe is known to grade laterally; (2) Underlying marine organic Eocene shale; (3) Marine organic Miocene or Pliocene shale in fault contact with the producing non-marine Sespe.

SANTA MARIA DISTRICT

Production in the fields of the Santa Maria district comes largely from cherty shale and sand of the Monterey (Miocene) formation, and possibly also from associated argillaceous brown shale. Minor amounts of oil are obtained in some fields from sands and sandy shale within and at the base of the overlying Sisquoc (lower Pliocene) formation. Producing zones of the various fields are tabulated below and the general rela-

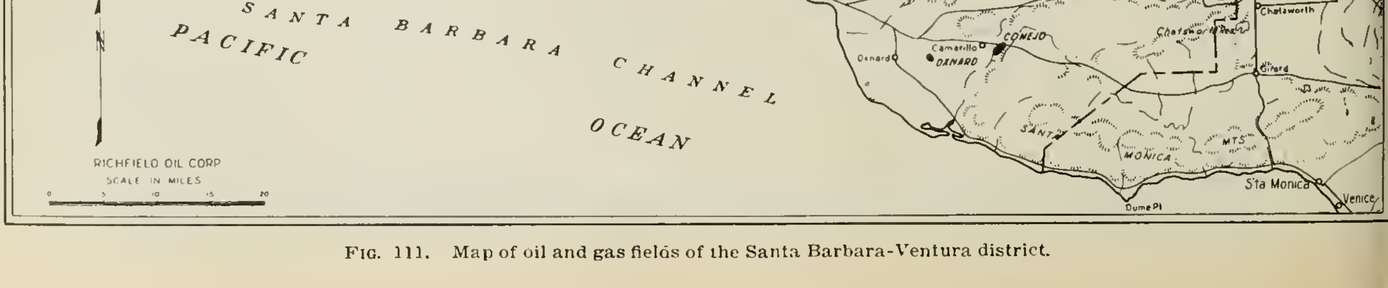
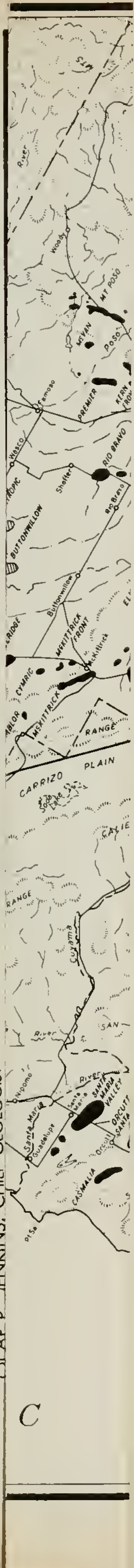


FIG. 111. Map of oil and gas fields of the Santa Barbara-Ventura district.

PLATE VI

WALTER W. BRADLEY, STATE MINERALOGIST
OLAF P. JENKINS, CHIEF GEOLOGIST

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
RICHARD SACHSE, DIRECTOR



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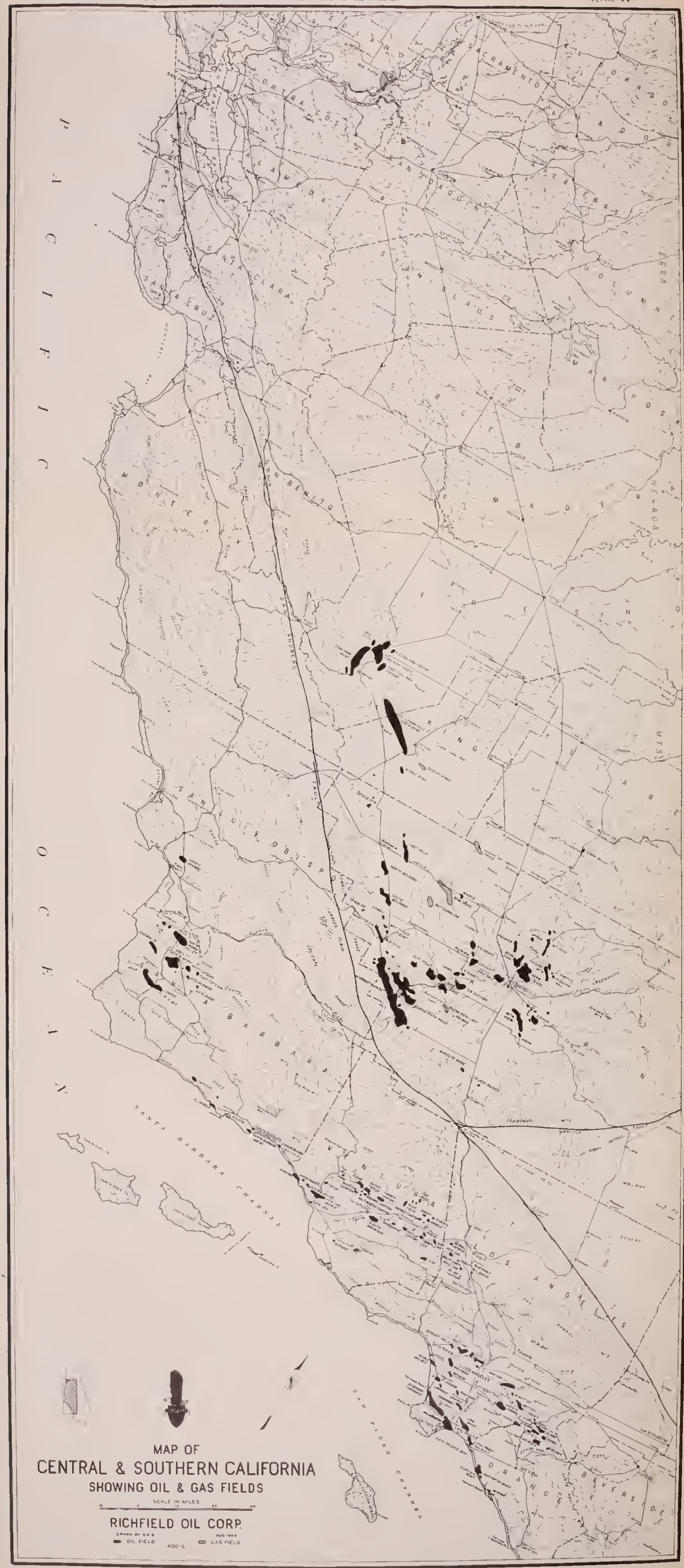

Accompanying Bulletin 118, Part Two

tions of formations are shown in fig. 113, a cross-section of the Santa Maria Valley field.

Field	*Producing Zones*
Santa Maria Valley	Monterey shale, cherty shale, and sand.
Casmalia	Monterey cherty shale, brown shale, and sand (?).
Orcutt	First zone—sand at base and within the Sisquoc formation.
	Second zone—Monterey cherty shale and brown shale.
	Third zone—lower Monterey sands.
West Cat Canyon	Sisquoc sands in northern part.
	Monterey shale and cherty shale in Las Flores area.
East Cat Canyon	Basal Sisquoc sands unconformably overlying Monterey.
Gato Ridge	Monterey cherty shale.
Lompoc	Monterey cherty shale and sand.

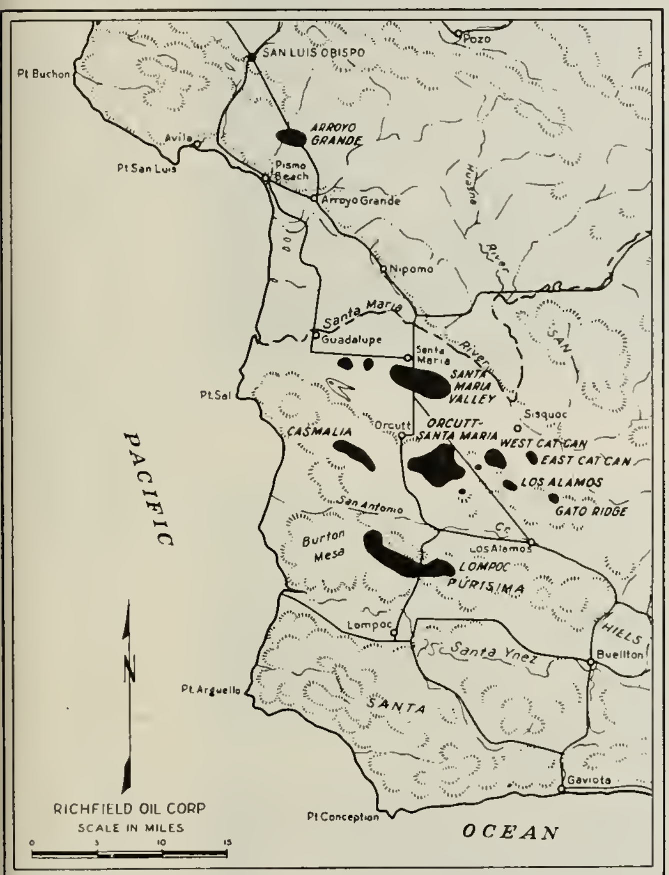

FIG. 112. Map of oil and gas fields of the Santa Maria district.

Seepages and impregnations of heavy oil and tar occur in outcrops of Pliocene and Miocene shale, siltstone, and sandstone in many places throughout the district. Burned red shale, apparently resulting from the combustion of shale previously impregnated with oil, covers extensive areas in punky Sisquoc diatomite where faults and fractures, it seems, have encouraged upward migration.

Although both the Pliocene and Miocene shales are rich in siliceous and calcareous remains of marine plants and animals, particularly diatoms and foraminifera, the Pliocene shale and diatomite generally vary in color from light gray or greenish gray to white and are comparatively lean in the primary type of bituminous carbonaceous matter. The Miocene shales are the most likely source of oil. They are generally hard to cherty, dense, and finely laminated, and when fresh are brown or dark gray to black in color. Phosphatic material is abundant in laminae, nodules, and lenses and the bedding planes commonly carry spots of oil considered to be indigenous.

The Orcutt and Santa Maria Valley Miocene oil zone contains a bituminous nodular phosphatic shale member similar in appearance and essential characteristics to the nodular oil shale which immediately overlies the basal Miocene oil zone of the Playa del Rey and El Segundo fields in the Los Angeles Basin.

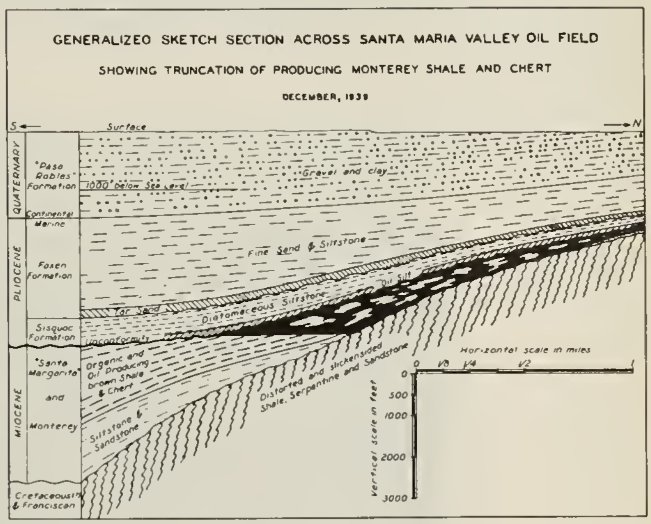

FIG. 113.

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	Monterey shale and cherty shale in Las Flores area.
East Cat Canyon	Basal Sisquoc sands unconformably overlying Monterey.
Gato Ridge	Monterey cherty shale.
Lompoc	Monterey cherty shale and sand.

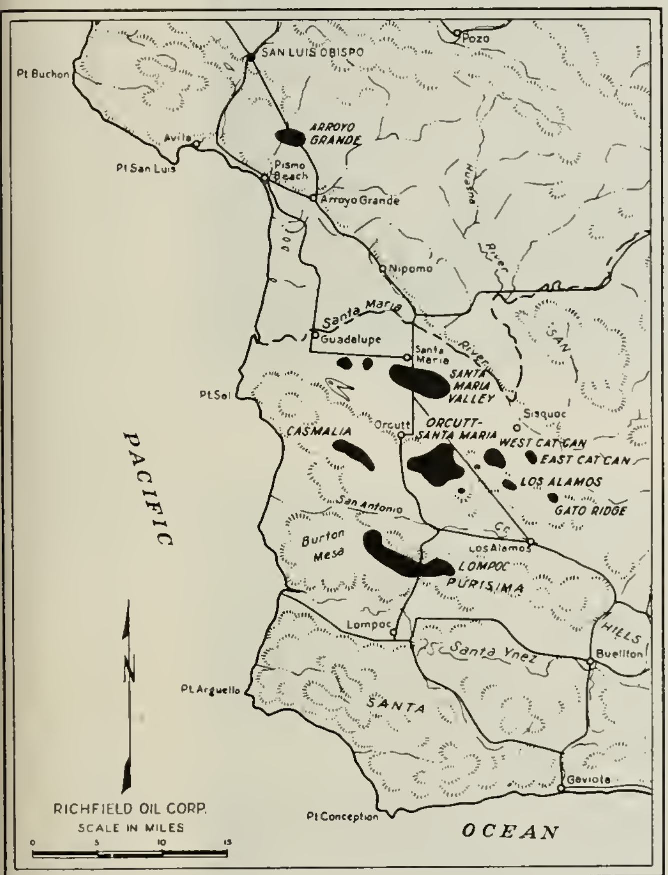

FIG. 112. Map of oil and gas fields of the Santa Maria district.

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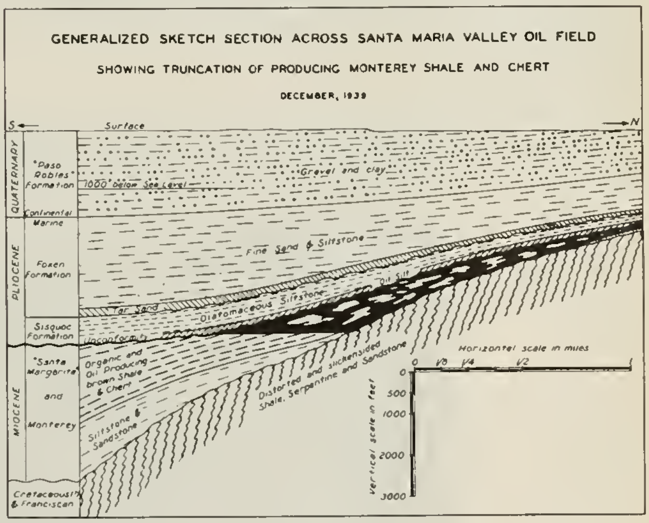

FIG. 113.

FIG. 114. Aerial view of the Santa Maria Basin, looking west. Wells south of Orcutt in the foreground. *Photograph (0-6442) by courtesy of the Fairchild Aerial Surveys, Inc.*

FIG. 115. Aerial view of the east flank of the Pico anticline south of Santa Clara River. *Photograph (0-1285) by courtesy of the Fairchild Aerial Surveys, Inc.*

GEOLOGIC FORMATIONS AND ECONOMIC DEVELOPMENT OF THE OIL AND GAS FIELDS OF CALIFORNIA

Part Three

Descriptions of Individual Oil and Gas Fields

Editorial note:

PART THREE represents the third of four divisions of Bulletin 118, and is intended to present concise descriptions of individual oil and gas fields and other significant areas in California, most of which have in part at least been tested by the drill. Each of these individual reports has been prepared by one or more recognized authorities. The reports cover, in most cases, the following items: history, significance, distinguishing features, stratigraphy, structure, productive horizons, and kind of oil and gas. Though a sincere attempt has been made to prepare a volume coordinated in the common interest of presenting briefly the significant facts, it has not been possible or advisable to maintain uniformity in style, in treatment of details, or in the length of reports, because of the large number of contributors (nearly 100). Since most of the reports are illustrated by geologic maps and sections, this part of the bulletin has become a veritable atlas of California oil-field geology. Not all the significant areas, however, have been covered by individual reports, because authors for areas could not, in every case, be found. The reader may find it necessary, therefore, to consult the carefully selected published works cited throughout Part Three. The citations have been systematically grouped to conform with the geological grouping of the reports. The full references will be found arranged alphabetically by authors in the Bibliography of Part Four; in the rest of the bulletin only citations are given. The "Citations to Selected References" and their accompanying index maps have been arranged to conform with the numbered areas on the "Outline Geologic Map of California, Showing Oil and Gas Fields" (in pocket). Since the manuscripts describing the fields and areas were prepared over a period of nearly four years, and since the industry has progressed during this time with astounding rapidity, the reader is cautioned to examine the footnotes which indicate the date when each manuscript was "submitted for publication." Later developments may have thrown more light on the subject than is recorded in this book, but it is hoped that the facts herein presented, so far as they go, will be found unalterable.

The following chapters are included in PART THREE:

CITATIONS TO SELECTED REFERENCES

By ELISABETH L. EGENHOFF*

Explanation:

In order to have ready reference to publications on the oil and gas fields of California and all other areas of particular interest in the subject matter of this bulletin, the following citations have been carefully selected, systematically arranged, and inserted in appropriate places throughout Part Three. It is intended that they should serve as an index to the final assembled Bibliography that appears in Part Four; this Bibliography is arranged alphabetically by authors, and all citations appearing in Bulletin 118 refer to it.

The index maps that accompany the classified citations are on the same scale as the large six-sheet colored Geologic Map of California (Jenkins, O. P. 38), issued by the Division of Mines in 1938 (scale 1:500,000, or 1 inch equals approximately 8 miles). On the index maps the total proved productive acreage (to June 30, 1941) is shown stippled (gas fields), or in black (oil fields), and the "fields" and "areas" (so-called for convenience, but without reference to their possible productivity) are shaded by means of diagonal lines. The numbers (1, 2, 3, etc.) appearing within the stippled, black, or shaded areas refer to the area names indicated in the captions. These names have been selected in accordance with accepted usage by the State Division of Oil and Gas. In the lower right-hand corner of each of the index maps is a number (101, etc.) that corresponds to the red number given the field on the "Outline Geologic Map of California, Showing Oil and Gas Fields", scale 1:1,000,000, or 1 inch equals 16 miles. Fields in the Los Angeles Basin are indexed in the 100 series: Ventura Basin and Transverse Ranges fields in the 200 series; Santa Maria Basin and southern Coast Ranges fields in the 300 series; San Joaquin Valley and bordering foothill fields in the 400 series; and northern San Joaquin Valley, Sacramento Valley, and northern Coast Ranges fields in the 500 series.

OUTLINE OF REPORT

* Assistant office geologist, Geologic Branch, California State Division of Mines, San Francisco.

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Allen, R. E. 34a; Independent Petroleum Association of America 40; Jensen, J. 40.

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Petroleum, Origin (*see also* **Petroleum Accumulation**)
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Petroleum, Production
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Petroleum, Properties
Allen, Jacobs, Crossfield, and Matthews 14; Bohn, J. L. 30; Garton and Lane 38; Hudson and Mabery 01; Lane and Garton 37; Melhase, J. 36; Mining and Scientific Press 00a; Mithoff, MacPherson, and Sipos 41; Prutzman, P. W. 04; 24; Taff, J. A. 34.

Petroleum, Radioactivity
Bohn, J. L. 30.

Petroleum, Recovery Methods
Arnold and Garfias 14.

Petroleum, Reserves (*see also* **Petroleum, Resources and Discoveries**)
Barnes, R. M. 40a; Collom, R. E. 34; Collom and Barnes 23; Macfarland, J. M. 31; Mills, B. 32c; 37; Minshall, F. E. 36; 37; Pack, R. W. 17; Petroleum World 41; Stockman, L. P. 41l.

Petroleum, Resources (*see also* **Petroleum, Reserves and Discoveries**)
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Cunningham, G. M. 26a; Nature 26.

Petroleum, Tideland Development
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Petroleum, Uses
Prutzman, P. W. 04.

Petroleum, Withdrawals
Ball, M. W. 16.

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Chapter VIII

Los Angeles Basin and Southernmost California

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Fraser, D. M. 31; Vander Leck, L. 21.

Inyo County

Ferguson, R. N. 18a; Vander Leck, L. 21.

LOS ANGELES CITY OIL FIELD

By E. K. Soper*

OUTLINE OF REPORT

HISTORY

The Los Angeles City oil field (also known as the Los Angeles oil field), is located in the east-central part of the Los Angeles metropolitan area, Los Angeles County. It consists of 3 distinct areas of production (eastern, central, and western) and at its maximum development occupied a narrow zone about 4½ miles long, varying in width from 1,500 feet at the west end to 800 feet at the east end. This zone extends from North Broadway, near the southwest corner of Elysian Park, westward for 3 miles to the region north of Westlake Park, where its trend curves to N. 70° W. The western 1½ miles of this strip was not continuously developed but contained 3 separate groups of wells. From the area northwest of Westlake Park to the eastern end of the field, wells were closely spaced for a distance of about 3 miles. Between the years 1892 and 1900, approximately 1,000 wells were drilled.

Discovery of the field was made in the central area by Doheny and Cannon, 1892. At present only about 100 wells in the eastern and central parts of the field are producing, from an area of about 270 acres. Average production per well has declined to less than 2 barrels per day. Most of the wells were less than 1,000 feet deep, but a few were drilled to about 1,500 feet. The deepest well in the field was probably the one located at the corner of First Street and Vermont Avenue; it reached a depth of 1,735 feet.[1]

STRATIGRAPHY

The oldest rocks exposed in the area belong to the Puente formation of upper Miocene age, which here is probably equivalent to the Modelo formation of the Santa Monica Mountains. The Puente formation, which outcrops throughout most of the area of the Elysian Park anticline, consists of four main members: (1) lower massive sandstone; (2) lower shale; (3) upper sandstone (oil bearing); (4) upper siliceous shale. The top of the Miocene Puente is marked by a zone of white or light-gray laminated diatomaceous shale, or diatomite, 20 to 50 feet thick. The total thickness of the Puente formation present in the area of the Elysian Park anticline is at least 8,000 feet. The top of the upper oil zone is about 2,500 feet stratigraphically below the top of the Puente.

Overlying the diatomaceous shale, probably with slight disconformity is a series of marine silty and sandy shales of Pliocene age, with a few very thin layers of pebbly conglomerate. The exposed thickness of these Pliocene beds is about 1,000 feet. They may be divided into a lower part (probably equivalent to the Repetto formation) and an upper part (Pico formation), separated by an unconformity. There is a lesser unconformity within the Pico beds. The upper part of the Pico is concealed beneath terrace gravels and alluvium.

STRUCTURE

The Los Angeles City field is located along the south side of a narrow zone of minor faulting and sharp folding, which occurs as one of several secondary structural features on the south limb of the Elysian Park anticline. At the east end of the field there is definite surface evidence of both normal and thrust faulting. The vertical displacement of the faults, which is nowhere great, decreases from east to west where the faulting passes into a narrow belt of sharp folding in which the strata show vertical dips and crumpling.

Several wells located in the eastern area at the extreme north edge of the belt of deformation were reported to have drilled through a fault into productive oil sands, indicating a north dip for the fault. The oil accumulation is against the fault or flexure zone on the down-dip side, and is confined to a narrow belt along the south edge of this zone. A short distance north of the productive belt, the oil sands outcrop along the crest of another secondary anticline, which, however, is not productive.

PRODUCTIVE HORIZONS

The oil-bearing strata occur in the upper sandstone member of the Puente formation. The top of the oil zone is about 2,500 feet below the top of the Miocene. The oil-producing horizons are recognizable throughout most of the field. The upper oil sand ranges in thickness from 55 feet to 300 feet, and in depth below the surface from 100 feet to 600 feet. The lower oil sand ranges in thickness from 25 to 60 feet, and occurs from 160 to 350 feet below the upper sand. Much difficulty was encountered with both bottom- and edge-water. Few wells had initial productions of more than 100 barrels per day. All the wells in the field were started and bottomed in the Puente formation.

KIND OF OIL

The oil ranges in gravity from 12° to 20° A.P.I., with an average of about 14° A.P.I.

* Associate Professor of Geology, University of California at Los Angeles. Manuscript submitted May 16, 1938.

[1] For the most complete description of the Los Angeles City field, including well data, maps, and sections, *see* Eldridge and Arnold 07, pp. 138-186; *see also* Soper and Grant 32.

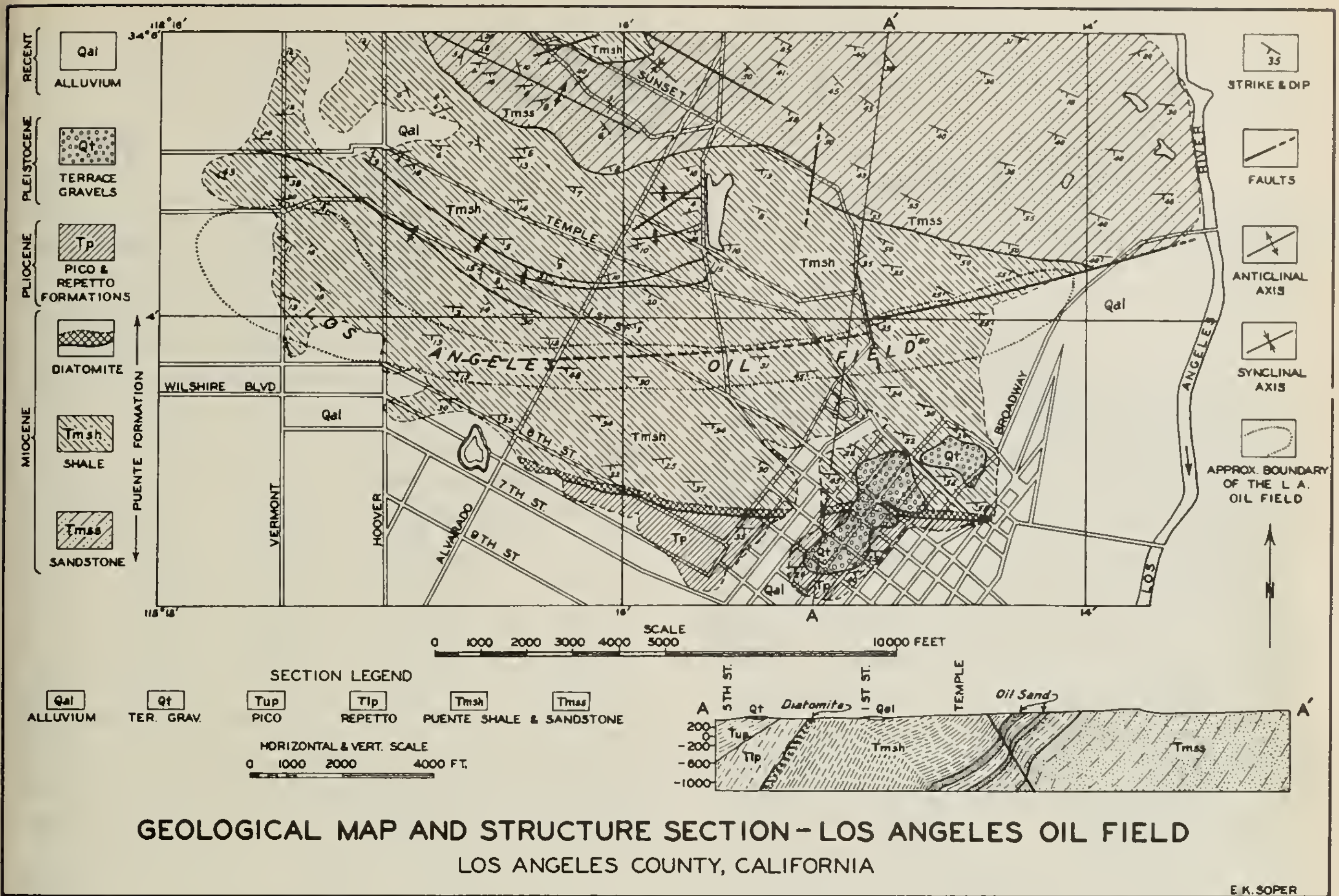


FIG. 116. Los Angeles oil field: geologic map and section.

CITATIONS TO SELECTED REFERENCES—Continued

LOS ANGELES CITY OIL FIELD (Los Angeles Oil Field)

Arnold, R. 15; Barbour, P. E. 09; Blackwelder, Thelen, and Folsom 17; Brophy, W. E. 34; Burkhart, H. W. 10; Clapp, F. G. 17; Crawford, J. J. 96; Eldridge, G. H. 03; Emmons, W. H. 21; Jones, E. C. 97; McCollough, E. H. 34; McLaughlin and Waring 14; Mining and Scientific Press 10; 11a; Prutzman, P. W. 04; 10; Soper, E. K. 32a; Taff, J. A. 34; Vander Leck, L. 21; Watts, W. L. 00.

Central Area
Eldridge and Arnold 07.

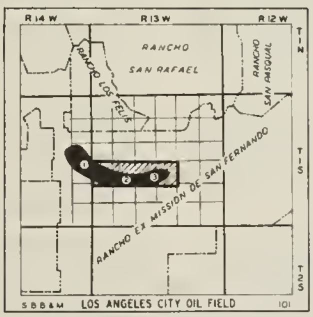
Eastern Area
Eldridge and Arnold 07.

Eastern Extension (Eastern) Area
Watts, W. L. 00, p. 45, Fig. 1.

East Los Angeles (Eastern) Area
Prutzman, P. W. 13.

Western Area
Eldridge and Arnold 07.

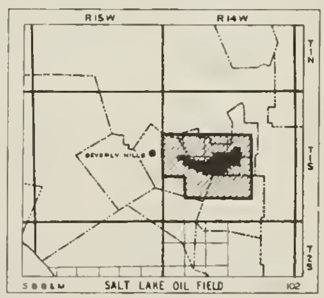
West Los Angeles (Western) Area
Prutzman, P. W. 13.



Los Angeles City oil field. Areas: (1) Western; (2) Central; (3) Eastern. (On this and the following index maps, total productive acreage to the end of June 1941 is shown either stippled (gas fields) or in black (oil fields). The "field" and "area" names used in connection with these maps are the ones accepted by the State Division of Oil and Gas. The areas indicated by diagonally ruled lines are the "fields" as arbitrarily defined by the Division of Oil and Gas; They do not indicate possible productive acreage.)

SALT LAKE OIL FIELD

Arnold, R. 06; 15; Arnold, Darnell, et al. 20; Blackwelder, Thelen, and Folsom 17; Eckis, R. 34; Eldridge and Arnold 07; Grant and Sheppard 39; Kirwan, M. J. 18; 18a;



Salt Lake oil field.

Masser, H. L. 22; 23; McCollough, E. H. 34; McLaughlin and Waring 14; Mendenhall, W. C. 05; Moran, R. B. 17; Prutzman, P. W. 10; 13; Soper, E. K. 32a; Taff, J. A. 34; Thoms, C. C. 24; Vander Leck, L. 21.

Rancho La Brea Tar Pits
Hanks, H. G. 84, p. 288; Merriam, J. C. 14a; Mining and Scientific Press 86.

Sherman (Salt Lake) Oil Field
Moran, R. B. 17; Prutzman, P. W. 10.

SALT LAKE OIL FIELD

By E. K. Soper *

OUTLINE OF REPORT

HISTORY

The Salt Lake oil field, located on the coastal alluvial plain about 2 miles south of the southern edge of the Santa Monica Mountains, is in the western part of the Los Angeles City residential district, Los Angeles County. At the height of its development the field occupied an area of about 1,000 acres, north, east, and west of the Rancho La Brea fossil pits north of Wilshire Boulevard, extending from near Highland Avenue on the east to San Vicente Avenue on the west. Now only a few derricks remain, in the area bounded by Wilshire and Beverly Boulevards and La Brea and Fairfax Avenues.

The Salt Lake field was discovered by the Salt Lake Oil Company in 1903, although some unsuccessful drilling had been done near the brea pits prior to that date. It was the last and westernmost of a chain of east-trending fields developed in the northern portion of the City of Los Angeles.[1]

From 1903 to 1912 development of the Salt Lake field was rapid and extensive, and by 1915 some 350 producing wells had been drilled. At the peak of production, attained in 1908, the field produced 4,535,800 barrels of oil from 185 wells. As production declined, the wells were abandoned. In recent years, the Los Angeles residential district has rapidly extended westward, and, as much of the area became increasingly valuable as real estate, most of the derricks were removed. Hundreds of residences now occupy parts of the area formerly productive, some of which are located directly over old capped wells. Hancock Park, embracing the area surrounding the famous Rancho La Brea fossil pits, also lies within the formerly productive area.

On January 1, 1937, only eight wells were producing, their total production amounting to 255 barrels per day.

Exploration for deeper productive oil zones was discouraged by the rapid encroachment of the residential district, and the city's adoption of regulations prohibiting or restricting drilling for oil within certain areas in the city limits. The three principal operators were the Salt Lake Oil Company, the Arcturus Oil Company, and the Rancho La Brea Oil Company. These properties were later operated by the Associated Oil Company.

* Associate Professor of Geology, University of California at Los Angeles. Manuscript submitted for publication September 15, 1938.

[1] *See* Hoots, H. W., 31, p. 131. The earliest published descriptions of the Salt Lake field are by Ralph Arnold (06) and Eldridge and Arnold (07, pp. 186-195).

STRATIGRAPHY

No rock outcrops occur in the area surrounding the Salt Lake field. The surface is covered by Quaternary alluvial deposits of sand, gravel, clay, and sandy clay from 40 to 150 feet thick, with an average thickness of 75 feet. The nearest outcrops occur along the south edge of the Santa Monica Mountains, where upper and middle Miocene marine sediments (Modelo and Topanga) dip southward beneath the alluvium. Locally, these are covered by Quaternary alluvial deposits, which in some places extend north to the Santa Monica granite and schist. What information there is available regarding the stratigraphy and subsurface structure of the field has been obtained from studies of the nearest surface outcrops; from earlier drilling to the east and northeast along the "Los Angeles anticline" described by Arnold (Eldridge and Arnold 07, pp. 193-194); from a few well cores from wells drilled subsequently in the Beverly Hills field 3 miles west of the Salt Lake field; and from drillers' logs of the old wells in the Salt Lake field. The wells were all drilled by cable tools prior to the time when cores could be obtained, and therefore there is still some doubt regarding the thickness and age of the formations drilled through, the exact nature of the structure, and the number, thickness, and geologic age of the oil sands encountered.

Pliocene sediments, resting upon eroded Miocene rocks with angular unconformity, are known to exist from exposures along the south edge of the Santa Monica Mountains west of this area, and from well records in the Salt Lake and Beverly Hills fields and other scattered localities. The Miocene-Pliocene contact is, however, nowhere exposed in the area surrounding the Salt Lake field, because of the thick mantle of alluvial deposits that covers the coastal plain. Well cores obtained in the Beverly Hills field, 3 miles west and somewhat south of the Salt Lake field, indicate a thickness there of more than 2,000 feet of upper and lower Pliocene sediments. The stratigraphic section penetrated by the wells in the Salt Lake field was considered (Eldridge and Arnold, 07, pp. 186-195) to consist of 50 to 100 feet of flat-lying Pleistocene and Recent clay, coarse sand, and gravel; 1,000 to 3,000 feet of folded Pliocene clayey and sandy shale of Fernando age, and 150 to 500 feet of oil zone also of Fernando age, consisting of fine to coarse sand interbedded with clay and sandy shale. The writer has examined a large number of old well logs from this field now in the files of the State Division of Oil and Gas, and the brief description given above of the formations penetrated contains about all the data available. The geologic age of the oil sands must be inferred from the stratigraphy of adjacent areas where more accurate data are available. In the Beverly Hills field, paleontological data obtained from well records indicate that the geologic age of the oil sands is Pliocene-Miocene "transition zone" or lowermost Pliocene (Repetto). In the Los Angeles field, east of the Salt Lake field, the age of the productive sands, at comparable depths, is known to be upper Miocene (Modelo) throughout much of the field, although it is probable that the oil sands in the wells northwest of Westlake Park are of Pliocene age. From this evidence, coupled with the lack of any reliable paleontological data to the contrary, it must be admitted that there is a possibility that some of the deeper wells in the Salt Lake field may have reached the top of the Miocene, and that the lower oil sands may be of Modelo age.

A typical well log from the north-central part of the field is given below. Other typical logs are given in Eldridge and Arnold's report (07, pp. 190-193).

Depth in feet		*Formation*
From	To	
0	30	soil and gravel
30	45	water sand
45	60	shale
60	90	water sand
90	1265	shale
1265	1275	oil, tar, and sand
1275	1420	shale
1420	1440	oil sand
1440	1730	shale
1730	1920	oil sand
1920	2020	shale
2020	2190	oil sand
2190	2270	oil sand

The most detailed description available of the subsurface structure and oil zones is an unpublished report prepared in 1917 by Joseph Jensen for the Associated Oil Company. No wells have been drilled in the field since 1917; consequently Jensen's report and structural contour map are based upon all the data available. This report and map were used by H. W. Hoots in compiling well data for his report on the geology of the eastern part of the Santa Monica Mountains (Hoots 31, pp. 130-133, pl. 33, 34). The map published in Hoots' report, based upon Jensen's map, is the one reproduced herewith.

Jensen, as quoted by Hoots (31, p. 131), believed four separate oil zones were encountered in the Salt Lake field, as follows: (1) an upper zone called the upper Arcturus zone, at depths from 650 to 1,750 feet, in the western part of the field, producing oil of 14° to 18° Baume gravity; (2) a second zone, called the lower Arcturus zone, found about 900 feet below the top of the upper Arcturus zone, producing oil of 17° to 19° Baume gravity; (3) a third zone, called the Salt Lake zone, which was encountered about 2,100 feet below the lower Arcturus zone and which was the zone from which most of the production of the field was obtained, producing oil of 9° to 22° Baume gravity; (4) a fourth zone, about 1,000 feet below the top of the Salt Lake zone, indicated by the records of some of the deepest wells, but which was never developed.

STRUCTURE

An examination of the structural contour map of the Salt Lake field shows the following structural features: (1) a prominent northwest-plunging syncline near the corner of La Brea Avenue and Third Street; (2) a southwest-plunging anticlinal nose northeast of the syncline; (3) a north-dipping monocline (southwest of the syncline and north of the brea pits), which curves around to the south in its westward portion to form a northwest-plunging anticlinal nose. The details of the subsurface structure thus are seen to be rather complex, and furthermore, it must be borne in mind that the accompanying structural contour map is necessarily based upon old well logs which, at best, are often unreliable.

The broader and more generalized features of the Salt Lake oil field structure and its probable relation to the regional structure of the area were summarized by Arnold (Eldridge and Arnold 07, pp. 193-194) as follows:

"Practically all the productive oil sands of the different Los Angeles fields lie on the southern limb of a flexure, usually a more or less well-defined anticline, whose axis extends in a westerly direction to the region approximately half a mile north of Westlake Park, where it bends about 20° to the north and extends to a point about three-fourths of a mile southeast of Colegrove and something over a mile northeast of the Salt Lake field. Here it appears to bend again to the north, probably trending about N. 60° W. In the Los Angeles city fields—that is, between the Catholic Cemetery and the Westlake Park region—the southern limb of the flexure dips normally at angles varying from 30° to 80°, while to the west, along that portion having a northwesterly trend, the dips flatten to 20° or 25°. The Salt Lake oil field is located on the northwestern flank of a minor but probably somewhat complex fold or fault, or both, developed on the comparatively low-dipping southwestern limb of the major flexure just described. * * *

"The exact nature of the local flexure is not known, but it is probably an anticline, more or less complicated by faults near the apex. Its axis extends in a general northeast-southwest direction. The logs of certain wells located southeast of the lagoon (brea pit) appear to indicate the presence of a minor anticline developed just south of the main flexure and separated from it by a fault. Still other evidence suggests a local dome-shaped structure, or quaquaversal, having its summit in the region of the lagoon."

The State Division of Water Resources published a report (Eckis, R. 34, pp. 203-204, pl. B) which contains additional interesting data regarding the subsurface structure of the Salt Lake field. This report, which describes the ground water storage and the character and capacity of the alluvial deposits of this and numerous other areas in the southern California coastal plain, contains a map (pl. B) on which are shown subsurface contours of the top of the bedrock in the area including and surrounding the Salt Lake oil field. These contours show that to the north of the Salt Lake field, between the axis, or "high," of the structure and the south base of the Santa Monica Mountains, the bedrock drops off steeply to a deep, narrow, alluvium-filled trough, and rises again, just as steeply, to the outcrops along the base of the mountains. In the deepest part of this narrow, alluvium-filled trough, the shale bedrock is about 700 feet below the surface, whereas on top of the Salt Lake anticlinal and probably faulted structure, the shale was encountered at depths considerably less than 100 feet. The narrow east-trending trough can scarcely be an erosional feature, since it trends at right angles to the direction of present and Pleistocene drainage. It is probably the result of the structural uplift (in which faulting may have played a part) along the line of the Salt Lake oil field structure. It will be noted that these more recent data on the thickness of the alluvium in this area, demonstrating the slope of the bedrock surface, do not bear out Arnold's views that the Salt Lake structure is a minor flexure developed on the southwest flank of a buried structure to the north, which he called the Los Angeles anticline.

It is also interesting to note that as early as 1905 W. C. Mendenhall (05) published a report on the underground waters of the southern California coastal plain, with maps showing ground-water contours and artesian basins. On Plate VI accompanying this report, three artesian basins are shown immediately north of the area of the Salt Lake oil field, another near Sherman, west of the Salt Lake field, and another along the northeast edge of the Baldwin Hills. Referring to the latter artesian basin, Mendenhall says (pp. 14-15):

"The interrupted ridge which extends northwest from Huntington Beach to the vicinity of Palms divides the coastal plain into an eastern and western portion. Of these, the eastern portion has much the greater area. It includes the bigger part of the Downey, Anaheim, and Santa Ana quadrangles, while the western section occupies much of the Redondo quadrangle and a part of the Santa Monica quadrangle. The ridge which separates these two sections is not a surface feature merely. It seems to be the surface expression of a broad fold in the sands and clays of the coastal plain—a fold that acts as a dam to waters seeking a way seaward beneath the surface, checking their course and tending to force them toward the surface in order to pass the obstruction. In consequence, ground-water levels are much higher above this ridge than below it, as would be true of a surface dam, and the chief artesian basin of the coastal plain, as indeed, of southern California owes its existence to it."

From Mendenhall's clear explanation for the occurrence of these localized artesian basins on the coastal plain, and from subsequent developments in the Salt Lake, Beverly Hills, and Inglewood (Baldwin Hills) oil fields, it is evident that Mendenhall's ground-water map of the area published in 1905 might have been used successfully as a guide in drilling for oil in these areas.

The value of ground-water contours and artesian basins as a guide in tracing buried geologic structures, with special reference to the area surrounding the Salt Lake field and certain other fields in California has been discussed by the writer in another paper (Soper 32a).

Recently U. S. Grant, Professor of Geology at the University of California at Los Angeles, has encountered evidence that the area to the north of the Salt Lake field has been, and is at the present time, undergoing subsidence (Grant and Sheppard 39, pp. 303-312). He has supplied the writer with the following brief summary of his findings:

"Spirit levelling carried on by the Bureau of Engineering, City of Los Angeles, indicates that a considerable area west of La Brea Avenue, south of Sunset Boulevard and north of Venice Boulevard is subsiding. The data on hand at the present time demonstrate a maximum rate of subsidence of about 0.05 ft. per year in the area centering around the intersection of La Cienega Boulevard and Melrose Avenue. The middle portion of the former total productive area of the Salt Lake oil field appears to be subsiding very much less rapidly. Although a decrease in the quantity of ground water may account for some of the subsidence, the fact that the west boundary of the sinking area terminates on the west at the line of hypothetical projection of the Newport-Inglewood zone of flexure, and the further fact that the erosion surface underlying the fanglomerate southeast of Sherman appears to be tilted northwestward suggest that the movement may be in part tectonic. A longer period of observations is needed to determine the causes with certainty. Production from wells in the Salt Lake field, now very small, does not seem to be a likely cause of the downward movement."

PRODUCTIVE HORIZONS

In the eastern part of the field only one oil zone was recognized. Wells in the northeast part of the field were 900 to 1,800 feet deep; in the southeast part, they were 1,200 to 3,200 feet deep. The deepest drilling was in the southwestern part of the field; the Arcturus Oil Company well No. 201 reached a depth of 4,360 feet, and the Gilmore Oil Company well No. 55 drilled to a depth of 3,733 feet. Two or three separate oil zones were recognized in the western part of the field. Total production to date has been about 41,000,000 barrels of oil. Initial production usually ranged from 350 barrels to 500 barrels per day, but occasionally wells were completed with initial productions up to 1,200 barrels per day.

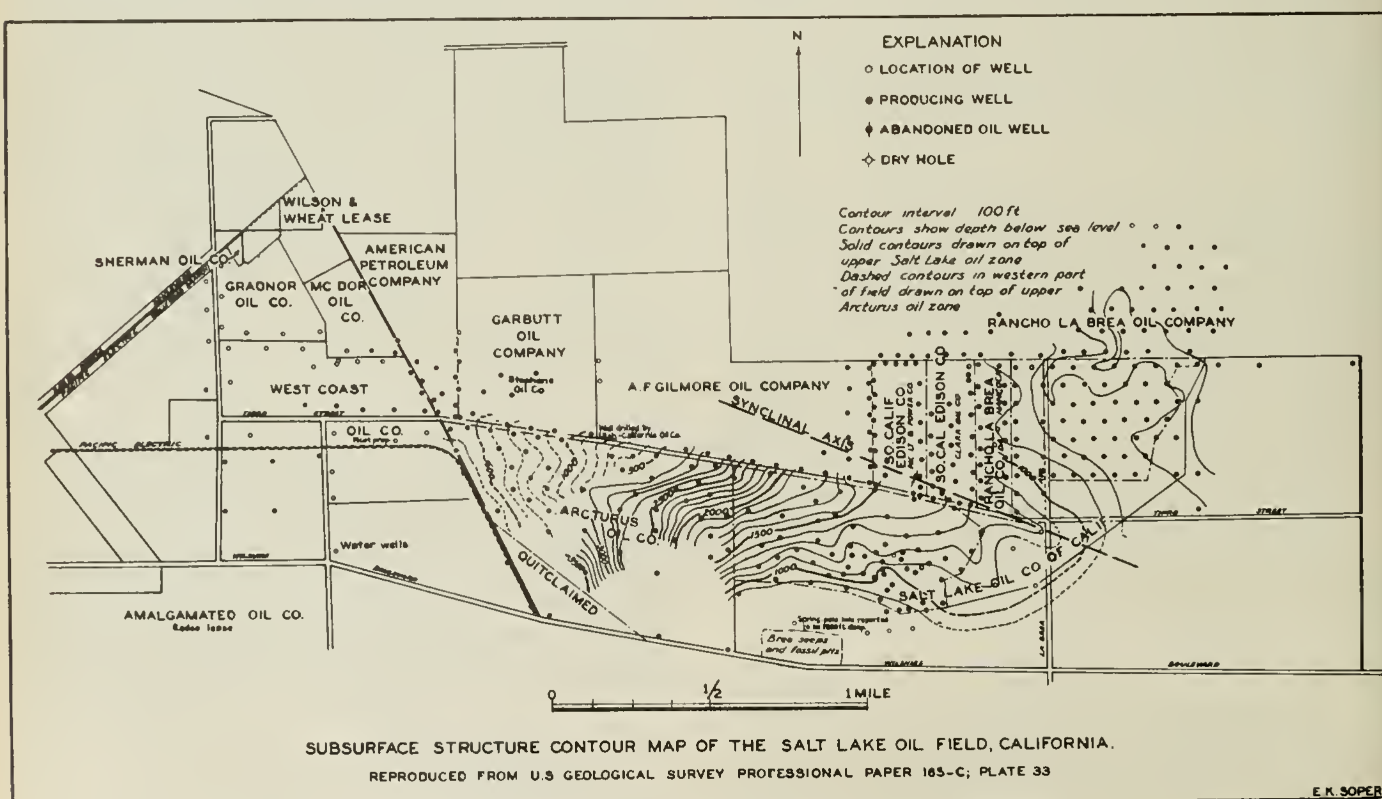


FIG. 117. Salt Lake oil field: structure map.

BEVERLY HILLS OIL FIELD

By E. K. Soper*

OUTLINE OF REPORT

HISTORY

The Beverly Hills oil field[1] is located a short distance south of the City of Beverly Hills, about 3 miles west and slightly south of the Salt Lake field, and about 2½ miles south of the Santa Monica Mountains, in Los Angeles County. It was discovered in 1908, and reached its peak production in 1912, when 246,223 barrels of oil were produced from 20 wells. The proven productive acreage totals about 130, and 32 productive wells have been drilled in the field. In addition, several dry holes have been drilled near the east edge of the field. Average daily production per well at the peak of development was only about 35 barrels, and at present the average daily production of the field is of small importance. In recent years the growth of the Beverly Hills residential district has resulted in the erection of dwelling and school buildings very close to some of the few wells still remaining on production.

STRATIGRAPHY

Throughout the Beverly Hills field the surface is covered by Recent and Pleistocene alluvial deposits. The stratigraphy, as revealed by the studies of G. D. Hanna in Fox Hills well No. 101, Rodeo lease, (Hoots 31, pl. 34; pp. 132-133) is as follows:

Formation	*Feet*
Pleistocene (marine)	- 900(?)
Pliocene, upper	900-2375
Pliocene, lower	2375-3067
Pliocene-Miocene "transition zone"	3067-3337
Miocene	3337-4970+

The strata consist of clayey shale, sandstone, and conglomerate.

* Associate Professor of Geology, University of California at Los Angeles. Manuscript submitted for publication September 15, 1938.

[1] Very little information concerning this field has been published. Most of the data given here were supplied in 1930 by Messrs. J. A. Taff, Joseph A. Jensen, and H. J. Steiny of the Associated Oil Company and are quoted by the writer from Hoots (31).

STRUCTURE

The Beverly Hills field is not on the structural trend of the Salt Lake and Los Angeles City fields, but is the northernmost of the chain of fields extending in a northwest direction across the Los Angeles Basin along the Newport-Inglewood uplift or fault zone.

The structure of the Beverly Hills field consists of a small dome with at least 150 feet, and probably 400 or 500 feet, of closure. Dips on the north flank are about 15°; those on the south flank, 45° or more. In the lower 370 feet of the Fox Hills No. 101 well, nearly vertical dips were noted in the Miocene.

PRODUCTIVE HORIZONS

The oil occurs in the lower Pliocene or Pliocene-Miocene transition zone just above the top of the Miocene. Thickness of the producing zone varies from 300 to 600 feet; the top of this zone is reached at about 2,450 feet, on top of the structure. Gravity of the oil varies from 15° to 22° A.P.I.

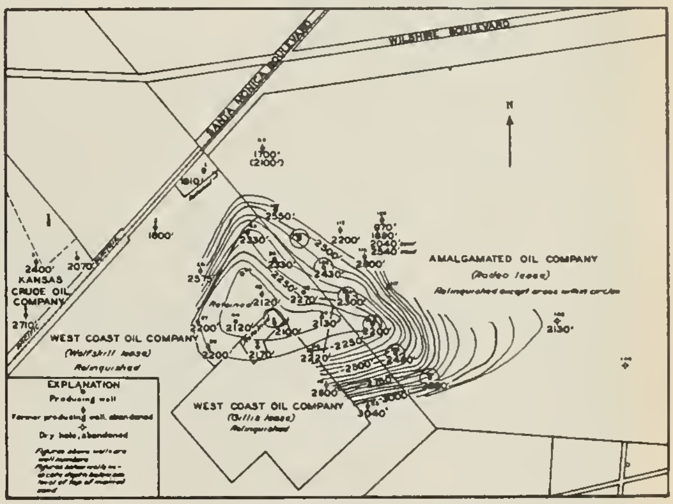
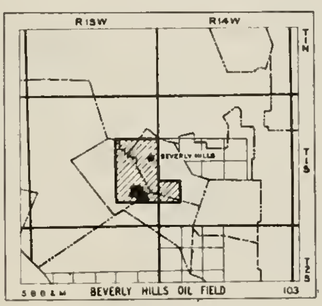


Fig. 118. Beverly Hills oil field: structure map.

CITATIONS TO SELECTED REFERENCES—Continued

BEVERLY HILLS OIL FIELD

Hoots, H. W. 31; McCollough, E. H. 34; McLaughlin and Waring 14; Thoms, C. C. 24; Vander Leck, L. 21, p. 140.



Beverly Hills oil field.

SANTA MONICA BAY

Shepard and MacDonald 38.

WESTERN AVENUE WELLS

Prutzman, P. W. 13, p. 196.

WHITTIER OIL FIELD

By W. H. HOLMAN *

OUTLINE OF REPORT

WHITTIER AREA

History

The Whittier area of the Whittier oil field is located on the southern slope of the Puente Hills immediately east of the city of Whittier, Los Angeles County. The productive area includes about 485 acres in Secs. 22, 23, and 26, T. 2 S., R. 11 W., S. B. Production is obtained from the broken strata for a distance of about 2 miles along a fault zone and in a truncated homocline immediately south of this fault zone.

The productive measures outcrop within the limits of the area, and, as a result, there are several seepages of oil and a number of brea deposits in the region. The first wells were drilled in the vicinity of these showings of oil. A commercial discovery was made in the year 1897 near the center of the present productive area, when Central Oil Company well No. 1-A was completed as a steady producer at a depth of 984 feet, pumping about 10 barrels of 18-degree gravity oil daily. The production was obtained from about 80 feet of sand which is referred to as the Third oil zone. Rapid development followed the discovery, and 6 years later there were about 100 wells drilled in Secs. 22 and 23. Although the initial yields were generally small, a few wells yielded as high has 300 barrels of oil per day. In the following 6 years, or until December 1909, the average number of producing wells remained at about 95 and the monthly production was about 60,000 barrels. This had been raised to more than 96,000 barrels in June 1917, when there were 139 producing wells and the productive area had been extended to include the north half of Sec. 26. The productive area. about 500 acres, and the amount of oil produced were then at the maximum. The number of commercial wells increased to about 163 in 1924, but the production had declined to about 72,000 barrels per month. In 1938 the same number of wells produced about 24,000 barrels per month. The cumulative production of the area was about 25,000,000 barrels up to the latter part of May 1940, at which time most of the wells were shut in.

With the exception of a few wells drilled in recent years by the rotary method, the entire area was developed by cable tools, before the advent of micropaleontology or electric logs. Thus, the structural interpretations are dependent on the use of drillers' logs and the geologic relationships of the outcropping strata.

* Geologist, Standard Oil Company of California, Los Angeles. Manuscript submitted for publication August, 1941.

Structure

The structure in which most of the oil has accumulated is essentially a southward-dipping homocline. It is downthrown along the south side of a northwestward-trending major fault zone known as the Whittier fault. Steeply dipping strata, largely Puente shale, of upper Miocene age, occur within and immediately north of the fault zone. On the opposite side the homocline consists of a slightly deformed and faulted, conformable series of siltstones, sands, and conglomerates ranging in age from uppermost Miocene to upper Pliocene. A complete section of these strata crops out. The beds of the Repetto formation (lower Pliocene) are exposed over a greater area than are the others, with the basal part of this formation cropping out near the northwestern end of the area. Within a broken zone immediately south of the main Whittier fault the Repetto beds dip very

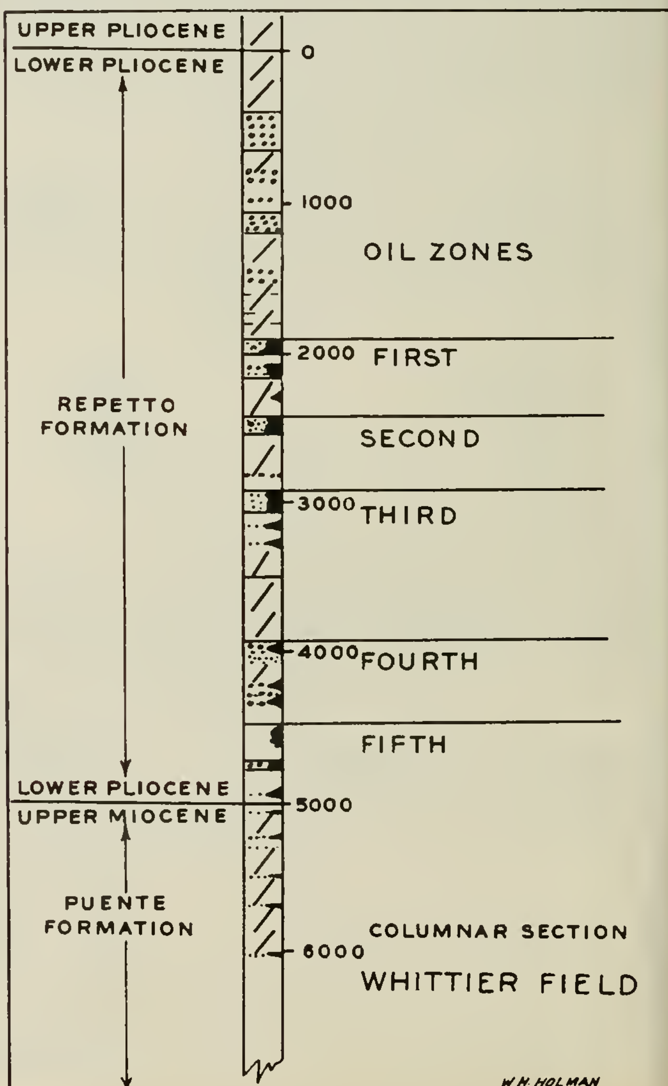


FIG. 119. Whittier oil field: columnar section.

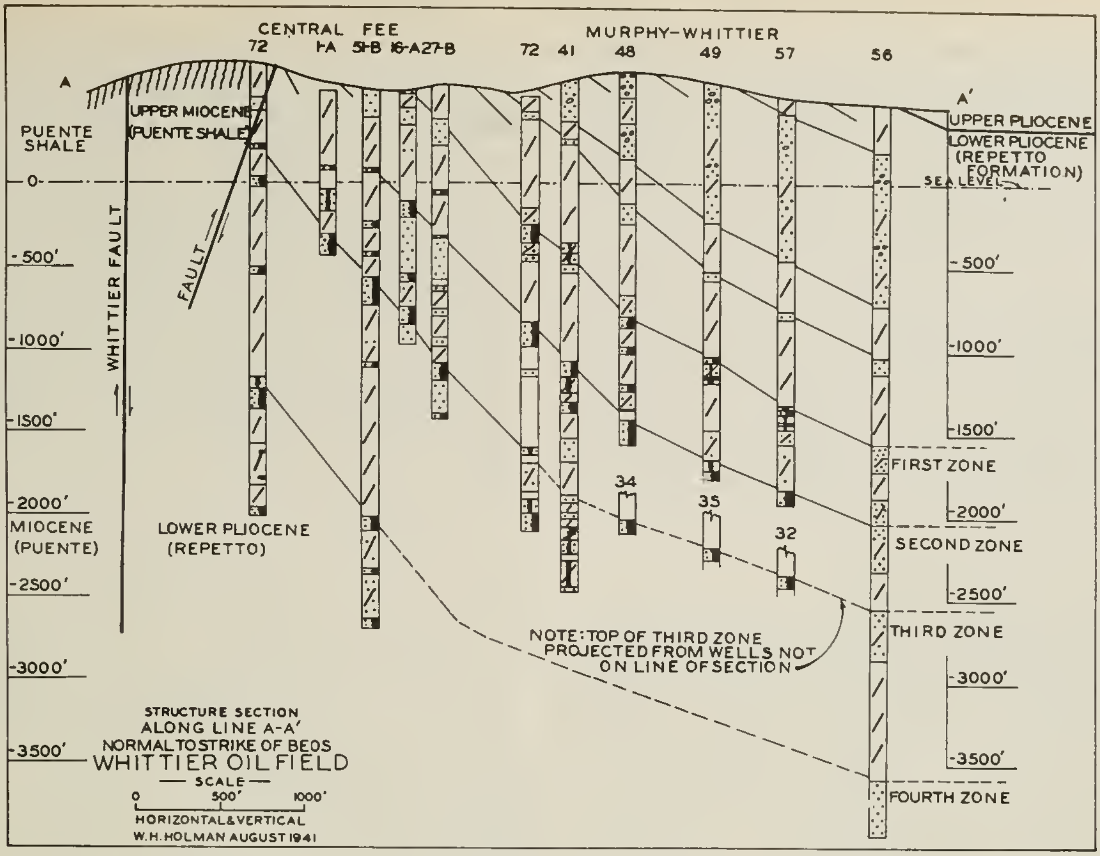


FIG. 120. Whittier oil field: structure section.

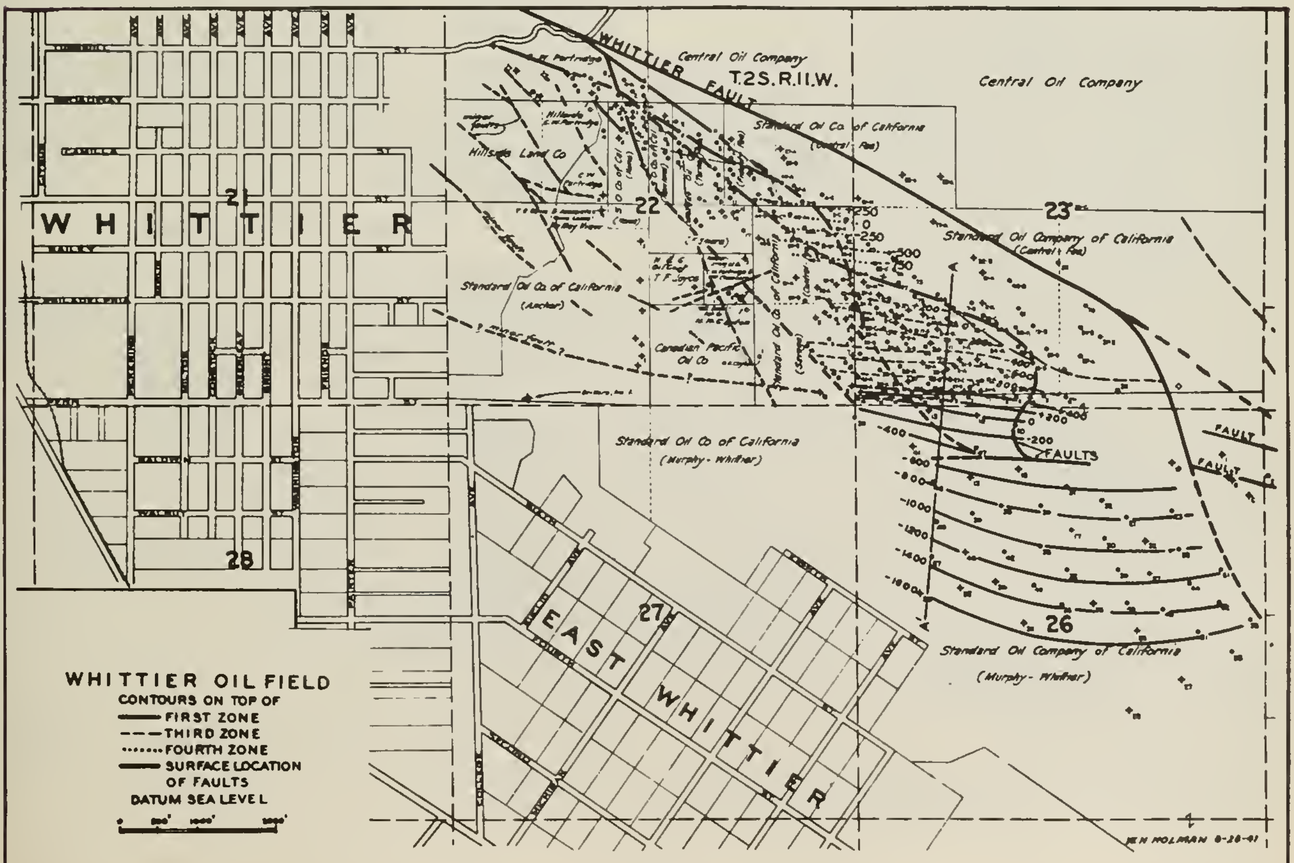


FIG. 121. Whittier oil field: structure map.

steeply and locally are overturned. The dip gradually decreases to a minimum of 30 degrees south of the fault. The trend of beds south of the fault is generally east-west, and is interrupted by a slight southward bowing in Sec. 26, where the lowest dips within the area are apparent. This suggests a gently arched structural nose which extends the productive area southward and farther west than usual from the Whittier fault. The larger part of this productive area seems to be closed effectively on the west by a southward-trending fault of slight displacement. A number of similar small faults branch off from the Whittier fault zone, and some of these likewise appear to be factors in limiting minor productive areas south of the major fault. However, the most important factor in the entrapment of the oil is the eventual sealing of the productive strata up the dip. This is effected either by their termination against the Whittier fault or by the tarry residue which occurs at their outcrop.

Stratigraphy and Productive Horizons

The producing zones of the Whittier area are found in the Puente formation, of upper Miocene age, and in the Repetto formation, of lower Pliocene age. These formations consist of a series of interbedded shales, siltstones, sandstones, and conglomerates which occur in a conformable sequence. However, production is also obtained from an older, relatively lower part of the Puente formation which lies in fault contact with upper Puente and lower Repetto beds.

The nature of the strata is known principally from the outcrops, since practically all the wells were drilled before the time of coring.

Five oil zones have been developed in the lower 3,000 feet of the Repetto formation and in the upper 1,000 feet of the Puente formation. The division of the zones is quite arbitrary over the area and has been based primarily on the presence of intermediate waters of meteoric origin. These waters were located in the early development of the field.

The tops of the First, Second, and Third zones occur about 500 feet apart stratigraphically, and the top of each appears to be determined by the presence of productive sands about 100 feet thick. The lower parts of these zones, as well as the entire Fourth and Fifth zones, are composed of relatively thin productive sands interbedded with siltstones and shales. The zones or parts thereof were usually developed individually in wells drilled in the early years, but later, when cementing was practiced, an increasing number of wells were completed with two successive zones open to production. The above group of zones has been developed by wells ranging in depth between 700 feet and about 3,200 feet.

The First and Second zones occur in the youngest, or uppermost, oil-bearing strata in the area, but they were the last to be discovered and developed. These zones occur in the southeastern part of the area and are confined practically to Sec. 26. The gravity of the oil is about 18 degrees Baume.

The Third zone has the greatest areal extent and probably has been the most productive zone in the area. It underlies the region covered by the First and Second zones and also extends farther north and west beyond the outcrop of the latter zones. The gravity of the oil averages about 19 degrees; however, from the shallowest commercial wells the gravity is as low as 14 degrees.

The Fourth and Fifth zones are not so well defined as the higher zones. The top of the Fourth zone occurs about 1,000 feet stratigraphically below the top of the Third zone, and the top of the Fifth zone is about 500 feet stratigraphically below the top of the Fourth zone. These zones were discovered early in the development of the area. They occur in steeply dipping strata along the fault zone, and are confined to a small area in the northwestern part of the field. The average gravity of the oil is about 18 degrees, ranging from 12 degrees in the shallowest wells to about 25 degrees in the deepest wells.

In addition to the five zones in the conformable sequence of strata, there are less clearly defined productive lower Puente measures in the northern part of the field. These Puente strata normally occur about 2,500 feet to 4,000 feet stratigraphically below the top of the Puente formation. They are highly contorted and upthrown, by faulting, against upper Puente and lower Repetto beds. Since these lower Puente productive strata have been faulted into contact with various oil-bearing members of the Repetto formation, the oil may have migrated from the latter. The gravity of the oil ranges from 25 to 30 degrees, which is the highest in the field. Production has been obtained at depths between 1,000 feet and 3,500 feet. No well-defined oil zones are apparent.

Kind of Oil

The quality of the oil is quite constant over the field, although the range in gravity is between 14 and 30 degrees. The oil is almost free of sulphur, is easily refined, and yields a relatively large amount of good lubricating stock.

RIDEOUT HEIGHTS AREA

The Rideout Heights area of the Whittier oil field is located at the western end of the Puente Hills and is almost entirely within the limits of the City of Whittier, Los Angeles County. The productive area includes about 50 acres in a narrow strip in Secs. 16 and 17, T. 2 S., R. 11 W., S. B.

Drilling in the area began about 1900, soon after the nearby Whittier area was discovered. Substantial production was not obtained, however, until 1919. In September of that year Whitley Oil and Refining Company well No. 1 was completed producing 250 barrels of 28-degree gravity oil a day. This completion immediately led to further drilling. The activity was greatest during the years 1924 to 1926, and in this period twelve dry holes and six productive wells were drilled. The maximum annual production of the area was reached in 1926, with 161,500 barrels of oil from fourteen wells. Early in the same year the peak monthly production of about 15,000 barrels was obtained from eleven wells. At the present time the total monthly yield of ten wells is about 3,000 barrels. The cumulative production of oil for the 22 years since September 1919 is approximately 1,567,000 barrels, mostly 22-degree gravity oil, though the range of gravity is from 14 to 30 degrees.

The dominant structural feature is the highly inclined Whittier fault trending N. 70° W. through the area. It divides a northwestward-dipping homocline of lower Pliocene and upper Miocene strata on the north from a series of southwestward-dipping lower Pliocene and upper Miocene strata on the south. Near the fault the beds dip very steeply, and in places they are overturned or sharply folded. Oil has accumulated within sands interbedded with these steeply dipping and contorted strata. The oil-bearing beds apparently are not divisible into zones which may be traced with certainty for appreciable distances within the area. Production is obtained from lower Pliocene and upper Miocene strata, and at depths ranging from 832 to 4,675 feet.

BARTOLO AREA

The Bartolo area of the Whittier oil field is located in the southern part of the San Gabriel Valley, immediately west of the Puente Hills and about 2 miles north of Whittier, Los Angeles County. Fifteen acres have been found productive in the SW¼ Sec. 4, T. 2 S., R. 11 W., S. B. The discovery was made in July 1935, when the Woodward Oil Company completed well Lapworth No. 1 at a depth of 3,167 feet, pumping about 225 barrels a day of 28-degree gravity oil. Within the year, five other operators had entered the area and two small producing wells were completed immediately southwest of the discovery well. Four dry holes were drilled nearby. This drilling activity defined the productive limits of the field.

The producing zone consists of thin beds of sand and conglomerate of upper Miocene age. These strata occur within a northwestward-dipping homocline which is concealed by the alluvial deposits in the Bartolo district. This homocline outcrops extensively in the Puente Hills, about half a mile east of the field. The localized accumulation of oil in this structure apparently is due to truncation of the producing zone by minor fault displacement.

The maximum settled production, 82 barrels of oil a day, was obtained in December 1935. Production declined rapidly, and in the year 1938 the total yield was 8,000 barrels of oil from three wells. At the present time the output is about 150 barrels of oil per month, from one producing well. Pumping has been discontinued in the other two wells due to their small yield.

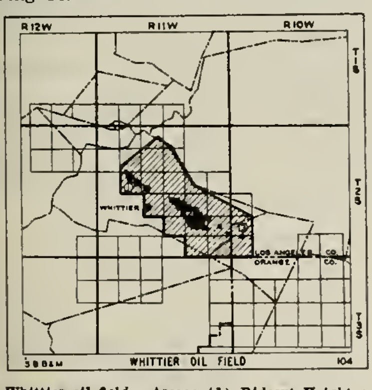
CITATIONS TO SELECTED REFERENCES—Continued

WHITTIER OIL FIELD

Arnold, R. 15; Arnold, Darnell, et al. 20; Bellemin, G. J. 40; Blackwelder, Thelen, and Folsom 17; Burkhart, H. W. 10; Emmons, W. H. 21; English, W. A. 26; Huguenin, E. 26; Kirwan, M. J. 18; 18a; 18b; McCollough, E. H. 34; McLaughlin and Waring 14; Mining and Scientific Press 10; Moran, R. B. 17; Prutzman, P. W. 04; 10; 13; Taff, J. A. 34; Thoms, C. C. 24; Vander Leck, L. 21; Watts, W. L. 00.

La Habra Canyon Area

Eldridge and Arnold 07; McLaughlin and Waring 14.



Whittier oil field. Areas: (1) Rideout Heights; (2) Whittier; (3) La Habra.

Rideau Heights (Rideout Heights) Area

English, W. A. 26.

Rideout Heights Area

Norris, B. B. 30.

Whittier Area

Eldridge and Arnold 07; Norris, B. B. 30.

BREA-OLINDA OIL FIELD

Arnold, R. 15; 31; Burkhart, H. W. 10; Eldridge, G. H. 03; Emmons, W. H. 21; English, W. A. 26; Hodges and Johnson 31; Hoots and Herold 35; Huguenin, E. 26; Lake and Phelps 25; Masser, H. L. 22; 23; McCollough, E. H. 34; Miller, H. C. 29; Prutzman, P. W. 10; Soyster, M. H. 22; Thoms, C. C. 24; Vander Leck, L. 21; Watts, W. L. 00.

Brea Canyon Area

Eldridge and Arnold 07; English, W. A. 26; Kirwan, M. J. 18; 18a; McLaughlin and Waring 14; Moran, R. B. 17; Norris, B. B. 30; Stockman, L. P. 35i; Taff, J. A. 34.

Fullerton Area

Arnold, R. 31; Arnold, Darnell, et al. 20; Burkhart, H. W. 10; English, W. A. 26; McLaughlin and Waring 14; Mining and Scientific Press 10e; Prutzman, P. W. 04; 10; 13; Watts, W. L. 00.

Fulton (Brea-Olinda) Oil Field

Blackwelder, Thelen, and Folsom 17.

Olinda Area

Arnold, Darnell, et al. 20; Clute, W. S. 26; Eldridge and Arnold 07; English, W. A. 26; Kirwan, M. J. 18; 18a; McLaughlin and Waring 14; Moran, R. B. 17; Norris, B. B. 30; Prutzman, P. W. 13; Stockman, L. P. 35l; Taff, J. A. 34; Vander Leck, L. 21.

Petrolia Area

Goodyear, W. A. 88, pp. 70-73; Hanks, H. G. 84, pp. 299-300.

Puente (Old Puente) Area

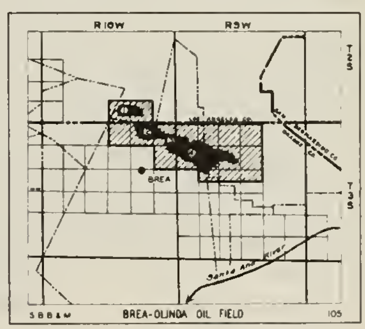
Burkhart, H. W. 10; Crawford, J. J. 96; Eldridge and Arnold 07; Emmons, W. H. 21; English, W. A. 26; Goodyear, W. A. 88; Jones, E. C. 97; Kirwan, M. J. 18; 18a; McLaughlin and Waring 14; Mining and Scientific Press 92a; Norris, B. B. 30; Prutzman, P. W. 04; 13; Stockman, L. P. 35l; Taff, J. A. 34; Watts, W. L. 00.

PUENTE HILLS REGION

Bellemin, G. J. 40; Eldridge, G. H. 03; Emmons, W. H. 21; English, W. A. 26; Kirwan, M. J. 18; Mining and Scientific Press 10; 11a; Watts, W. L. 00.

TURNBULL CANYON FIELD

California Oil World 42.



Brea-Olinda oil field. Areas: (1) Puente; (2) Brea Canyon; (3) Tonner Canyon; (4) Olinda.

PLAYA DEL REY OIL FIELD

By LOYDE H. METZNER*

OUTLINE OF REPORT

HISTORY

The Playa del Rey oil field (Los Angeles County), situated on Santa Monica Bay, extends in a northwest direction across the southern portion of the city of Venice, and southeast across the tidal marshlands of Ballona Creek into the Del Rey Hills. On the bases both of structure and the resultant history of development, the field is divided into two areas: (1) the Ocean Front, or Venice area, and (2) the Del Rey Hills area, in which only one productive zone is known.

Since surface topography furnished but vague and possibly misleading indications of the underlying structural conditions, wildcatting was carried on for nearly 9 years before oil was discovered. Following the discovery of the lower zone in August, 1929, and the upper zone in June, 1930, at Playa del Rey, development progressed rapidly in the Ocean Front area until peak productions were reached, for the latter in December, 1930, and for the former in February, 1931. The Del Rey Hills area, productive in the lower zone only, was discovered in May, 1931; but, since the structural separation between the two areas was not then known to exist, the discovery was not recognized as such until the summer of 1935, when an active drilling campaign provided new correlations.

DISTINGUISHING FEATURES

The Playa del Rey field is distinctive in that it alone in California is productive in both a basal conglomerate zone and a zone of folded sediments which owe their anticlinal curvature to deposition and compaction over an eroded ridge of basement rocks. Here a true anticline was developed on a major scale without the assistance of faulting or diastrophic folding. As the structure of this field and the conditions which influenced accumulation in the basal conglomerate zone became better known, new impetus was given to prospecting near the west edge of the Los Angeles Basin. This resulted in the discovery of El Segundo field.

* Signal Oil and Gas Company. Manuscript submitted for publication July 11, 1938.

STRATIGRAPHY AND STRUCTURE

The structure of the Playa del Ray field (Metzner 35) consists of a ridge of schist representing an old erosion surface, on the flanks and over the crest of which the oil-bearing and other sedimentary rocks of the region were deposited, to form a northwest-trending anticline or elongated dome. During the long interval of erosion prior to deposition of the sediments the schist ridge was part of a mountain system probably comparable in height and extent with the present-day Santa Monica Mountains, and similarly dissected by drainage channels.

During submergence of this ridge in upper Miocene time, an apron of schist-bearing clastics, composed chiefly of schist sand and angular schist fragments from near at hand, and quartz sand and rounded quartz pebbles, was deposited in the littoral zone at the foot of the ridge and in the embayments formed by the submerged drainage. This littoral type of deposition ended abruptly while the main ridge and many of the subsidiary lateral ridges still remained above sea level. The schist-bearing clastics are identified by Corey (36) as upper Miocene in age, and "directly correlative with Hoots' (31) 'basal Modelo Graywacke' of the Santa Monica Mountains."

Conformably overlying the basal conglomerate and sand deposits, and covering the whole of the schist ridge is a dark-brown compact nodular shale containing small but abundant lenticular streaks and nodules composed chiefly of calcium phosphate (Hoots, Blount, and Jones 35a). Because of the complete pinching out of the sand-conglomerate body and the unconformable character of the nodular shale in so far as it rests directly upon the schist, the known thickness of the former ranges from 0 to 234 feet, and of the latter from about 60 to 308 feet, within the limits of the field.

The remainder of Miocene time is represented by about 500 feet of hard, compact black shale and sandy shale, which is conformably overlain by Pliocene and Pleistocene sediments as follows (Barton 31):

Formation	*Thickness in feet*	*Lithology*
Pleistocene	150	Sand and gravel
	200	Sandy shale and clay, streaks of sand
Upper Pliocene		
Upper Pico	1,400	Shale and streaks of sand
Lower Pico	650	Shale and streaks of sand
Lower Pliocene	900	Sandy shale
	1,100	Shale with streaks of oil sand, comprising the upper oil zone
	500	Sandy shale
Upper Miocene (see text above)		

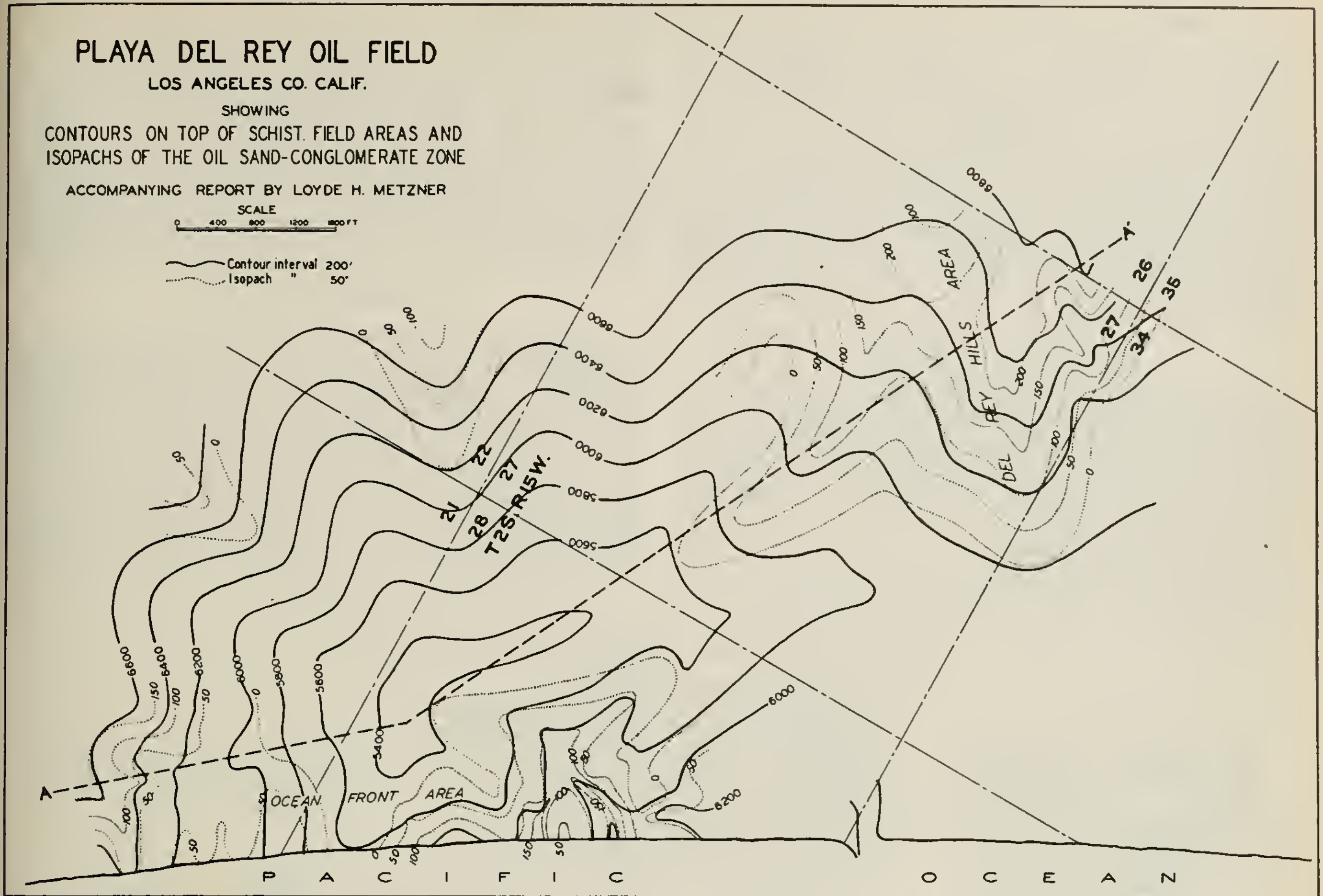


Fig. 122. Playa del Rey oil field: structure map.

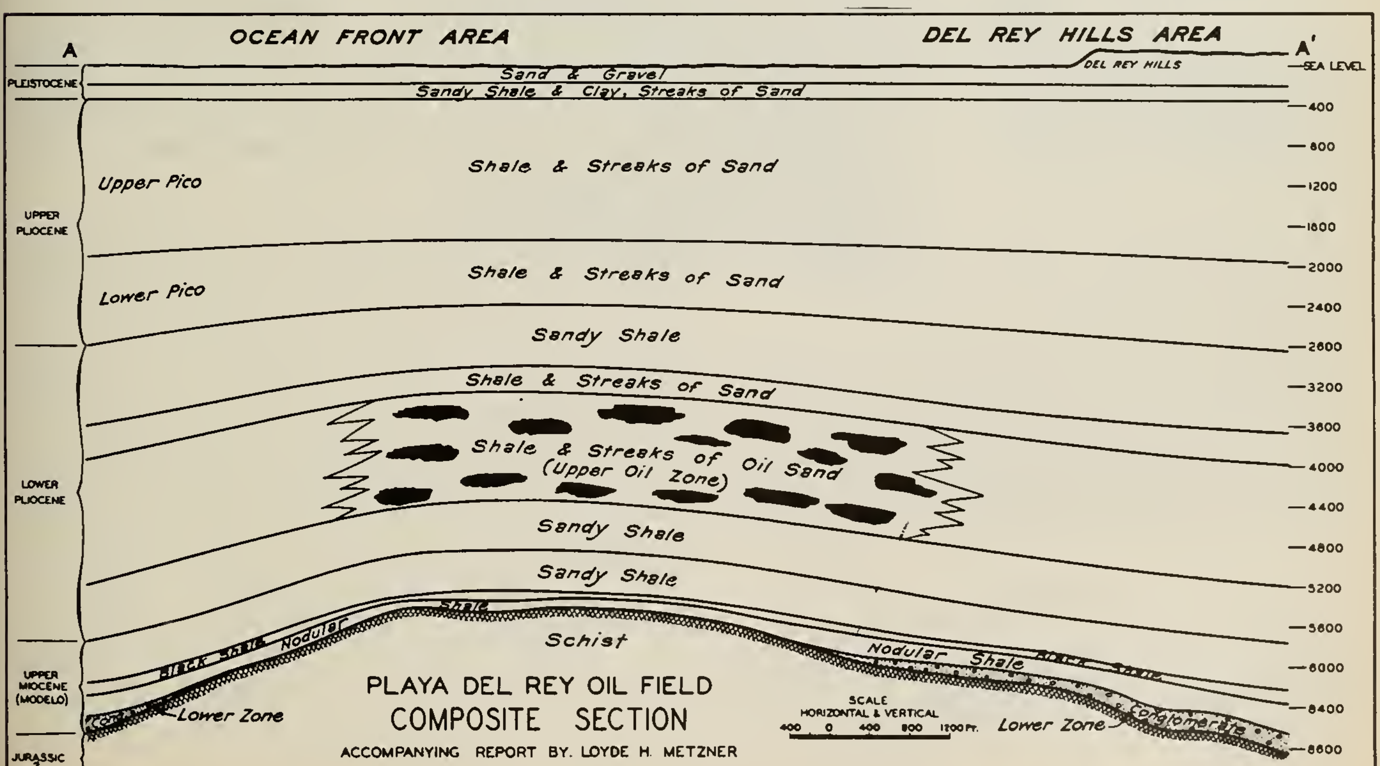


Fig. 123. Playa del Rey oil field: composite section.

The anticlinal curvature which controls the upper zone accumulation in the Pliocene beds of the Ocean Front area is believed to be chiefly depositional in origin rather than totally diastrophic, as are most anticlinal structures. The Pliocene sediments here were deposited on a surface which was itself anticlinal in shape, and which tended to impart this shape to subseqeunt sediments as they became compacted. It is probable, however, that a part of the curvature can also be attributed to a local vertical upthrust transmitted through the underlying schist ridge to the Tertiary sediments.

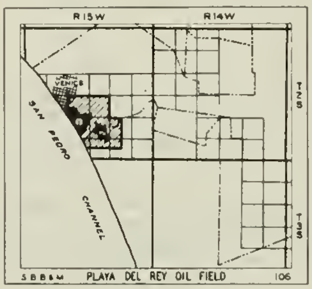
PRODUCTIVE HORIZONS

Two oil zones are productive at Playa del Rey. The upper zone, with a thickness of about 1,100 feet, consists of 10 to 20 percent oil sand interbedded with shale, and lies with its top about 900 feet below the top of the lower Pliocene formations. This zone is productive in the Ocean Front area only.

The lower zone consists of the schist-bearing clastics, or basal conglomerate, described as overlying the schist and underlying the nodular shale. Since some small quantities of oil and gas are known to occupy the discontinuous lenticular streaks and nodules within the nodular shale, and a few fractures in weathered phases of the schist, these two formations are often included as additional members of the lower zone. Oil in commercial quantities in this zone occurs only in the isolated areas previously described as embayments formed in the submerged drainage depressions in the surface of the schist, forming an ideal structural trap in each instance.

KIND OF OIL AND GAS

Initial gravities of oil from the upper zone range from 19° to 21°, and from the lower zone from 21° to 24° A.P.I., and show a tendency to increase by as much as 1.5° during the first month of production. During the early life of each area the gas-oil ratios were excessive, due in large part to the prevailing conditions of competition between the operators. The gas carries a gasoline content of about 1.5 gallons per thousand cubic feet, and the oil contains a small percentage of sulphur which is only slightly detrimental.



Playa del Rey oil field. Areas: (1) Ocean Front, or Venice; (2) Del Rey Hills.

CITATIONS TO SELECTED REFERENCES—Continued

PLAYA DEL REY OIL FIELD

Barton, C. L. 31; Hight, W. 33; Hoots, Blount, and Jones 35a; Hoots and Herold 35; Huguenin, E. 26; McCollough, E. H. 34; Millett, E. R. Jr. 35; Porter, W. W. II 38; Stockman, L. P. 34b; 34c; 35b; 35c; 35d; 35g; 35l; 36k; Van Tuyl and Parker 41.

Del Rey Hills Area

Corey, W. H. 36; Magee, J. P. 36; Metzner, L. H. 35; Petroleum World 35a; Russell, S. 30.

Venice (Ocean Front) Area

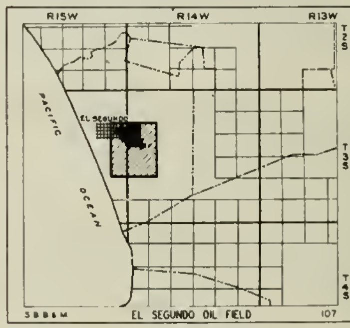
Corey, W. H. 36; Lahee, F. H. 34a; Petroleum Times 30; Soper, E. K. 32a; Taff, J. A. 34; Van Couvering, M. 30; Van Tuyl and Parker 41; Warner, T. 30.

MANHATTAN BEACH AREA

California Oil World 34c; Marshall, W. C. 34.

EL SEGUNDO OIL FIELD

California Oil World 37d; 37e; 37g; 40; 40a; Edwards, M. G. 37; Hoots, H. W. 36a; 38; Huguenin, E. 26; 37; Oil Weekly 37; 37a; 37b; 40a; Petroleum World 36a; Porter, L. E. 37; 38; 38a; Porter, W. W. II 38; 39b; Powell, E. B. 36; Sanders, T. P. 37b; Stockman, L. P. 36h; 40b; Van Tuyl and Parker 41; Wilhelm, V. H. 38.



El Segundo oil field.

EL SEGUNDO OIL FIELD

By Richard G. Reese*

OUTLINE OF REPORT

HISTORY

El Segundo field centers at the corner common to Secs. 7 and 18, T. 3 S., R. 14 W., and Secs. 12 and 13, T. 3 S., R. 15 W., S. B., Los Angeles County. It includes the west part of the town of El Segundo. The Torrance field is about 5 miles to the south, and the Playa del Rey field about 4 miles to the north.

The discovery that led to the development of this field was made by the Republic Petroleum Company in its well No. "El Segundo" 1. A flow of 350 barrels of 28° gravity oil was obtained August 30, 1935 from 68 feet of sand and conglomerate overlying schist at a depth of 7,310 feet. Subsequent development was at a relatively constant rate to August 1, 1938, at which time there were 3 drilling, 66 completed, and 7 abandoned wells. The last well was completed September 14, 1938, and since that time there has been no drilling in the field. The producing wells cover an area of 950 acres. A total of 6,500,000 barrels of oil had been produced to July 1, 1938, and a total of about 8,316,000 barrels to July 1, 1939.

SIGNIFICANCE AND DISTINGUISHING FEATURES

El Segundo is the third field in the Los Angeles Basin in which the entire local series of sedimentary rocks has been penetrated. It is one of two fields which produce from the sediments at the sedimentary-metamorphic contact, and the only one in which the metamorphics serve, in part, as a good reservoir rock. It is also the only field which has no productive measures above the sedimentary-metamorphic contact.

STRATIGRAPHY

The sedimentary section penetrated in El Segundo field is similar to that of the Lawndale field. The top 5,700 feet consists of alternating beds of sand and shale, Pliocene and younger. The bottom 450 feet of this series is essentially shale. The underlying upper Miocene section, which varies in thickness from 1,300 to 2,000 feet, is practically solid shale. The basal part is formed of 100 to 200 feet of nodular shale, below which is a basal sand and conglomerate, made up primarily of schist fragments, ranging in thickness up to 100 feet. This conglomerate is entirely absent in some places, but where present is always in contact with the Franciscan (?) Jurassic (?) schist. The variation in the Miocene thickness is attributed to overlap on the pre-Miocene schist high. The nodular shale and schist-conglomerate are considered shore-line facies of a transgressing sea and a lithologic but not a stratigraphic unit.

STRUCTURE

The surface configuration of the top of the oil zone conforms approximately to that of the eroded schist high upon which the Miocene sea transgressed. It is believed that this old land mass has remained practically stationary since deposition of the overlying sediments. Correlation of electric logs of the wells drilled during the development of the field shows that the local lows in the schist contain a thicker section of sediments than the adjacent highs, and that the Miocene section, in general, thickens away from the schist high. Contours on various datums in the Miocene section reveal progressively less closure at shallower depths, until, at a short distance above the Pliocene-Miocene contact, there is no evidence of either folding or compaction over a buried high.

There is definite evidence that some normal faulting cuts the Miocene section and extends a short distance into the Pliocene rocks. There is not definite evidence that this faulting cuts the schist. The throw of the faults ranges from 200 to 10 feet, generally diminishing in an upward direction. The trace of none of these faults can be followed across the entire field. The fault planes appear to be slightly curved surfaces, and invariably merge with the schist surface where the latter is relatively steep. It is concluded that the faulting: (1) is due to adjustment by compaction of the sediments over the schist high; (2) does not cut the schist surface; and (3) in so far as can be recognized, has no bearing on accumulation.

PRODUCTIVE HORIZON

The only producing horizon in the field occurs at the base of the sediments. It varies in depth from 6,850 feet at the crest of the structure to 7,750 feet on the south plunge. The reservoir rock is of two types, namely schist-conglomerate and schist which is locally porous as a result of fracturing, weathering, and the presence of small cavities. The latter type is found only in the west half of the field where at many productive locations it is in direct contact with impervious shale. The fact that wells showing the highest initial rates were encountered in this part of the field certainly suggests that the porous schist is more permeable than the poorly sorted conglomerate of angular schist fragments which serves as the other reservoir rock. The productivity at different locations in the field varies according to the degree of permeability of the reservoir rock rather than the thickness or structural elevation of the formation.

KIND OF OIL

The gravity of the oil ranges from 15° to 28°. As compared to the average Los Angeles Basin crude, it is a high-sulphur crude producing low octane gasoline.

* Standard Oil Company of California. Manuscript submitted for publication July 20, 1939.

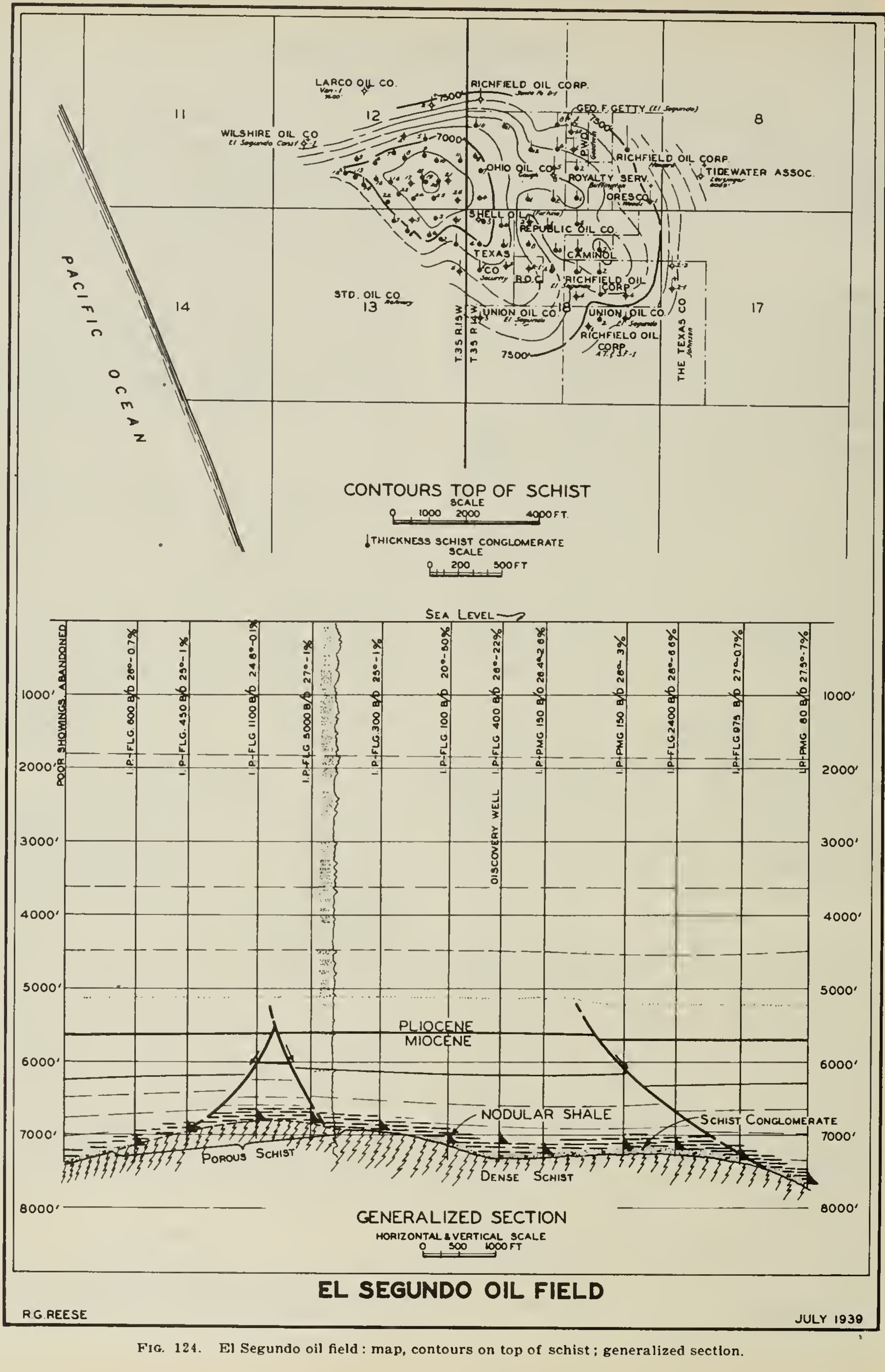


FIG. 124. El Segundo oil field: map, contours on top of schist; generalized section.

LAWNDALE OIL FIELD

By Richard G. Reese *

OUTLINE OF REPORT

HISTORY

The Lawndale oil field is located in the NE¼ Sec. 20, T. 3 S., R. 14 W., S. B., Los Angeles County. It is 2 miles southeast of El Segundo field, and 5 miles west of the Rosecrans field.

The discoveries that led to the attempted development of an oil field in this area were the San Clemente Oil Company well No. "Peck" 1, completed July 3, 1928 flowing 150 barrels of 31.4° gravity oil, followed by Smith Development Company well No. "Peck" 1, completed December 16, 1928 flowing 990 barrels of 33° gravity oil. These wells were bottomed at 5,814 and 5,897 feet respectively. A townlot drilling campaign, the like of which never has been, and probably never will be equalled, immediately followed the completion of the second well. Activity reached a peak in February 1929, at which time there were 41 drilling wells and 26 additional locations being rigged to drill. This activity was confined to an area of about 190 acres, 85 of which, held in relatively large blocks, contained but seven of the active projects. The activity had been greatly discouraged by dry holes as early as May 1929, and on July 2, 1929, seven wells were producing 2,175 barrels of oil, four wells were drilling, and 57 were idle or abandoned projects. Of the latter group, 23 had been drilled to depths in excess of 5,700 feet without finding commercial production. In the final analysis, this discovery caused 64 holes to be drilled, with a combined footage of 361,000. Seven of the holes, confined to an area of less than 25 acres and with a total footage of 41,644 produced 1,100,000 barrels of oil up to June 1, 1939.

DISTINGUISHING FEATURES

There are two features that distinguish the Lawndale field: it is a "text-book illustration" of the disastrous financial result of over-enthusiasm and haste; and its development established the existence of a new trend of folding in the Los Angeles Basin, in spite of the fact that this development cost many times the value of the oil received.

* Standard Oil Company of California. Manuscript submitted for publication August 3, 1939.

STRATIGRAPHY

The sediments penetrated in this field include 5,600 feet of Pliocene and younger sediments and 1,800 feet of upper Miocene. The top 800 to 1,000 feet are generally logged as sands and gravels. From 1,000 to 3,300 feet is essentially shale. The interval 3,300 to 4,900 feet contains 50 percent fine- to medium-grained sands occurring in 10- to 50-foot beds. The lowermost 700 feet of the Pliocene, between 4,900 and 5,600 feet, is shale containing occasional thin lenticular sand beds. The Pliocene-Miocene contact is generally considered to be at the first occurrence of laminated brown to reddish-brown shale, found at a depth of about 5,450 feet below sea-level at the crest of the field. The Miocene section is also essentially shale but contains frequent 1- to 10-foot beds of medium- to fine-grained sandstone. The shale is generally very arenaceous, except at the top, where the typical platy shale occurs. This is the datum generally used for structural interpretation.

STRUCTURE

The structure is apparently anticlinal, but may be faulted to a minor degree. In spite of the fact that so many wells were drilled in a relatively small area, the structural detail is not commonly agreed upon. This is undoubtedly because the shallowest datum common to all projects occurs at a depth of 5,600 feet in holes drilled in great haste and with little knowledge of the amount or direction of drift. The resulting interpretations vary greatly as to subsurface structural detail, but generally agree in attributing accumulation to a northwest-trending elongated dome-like structure.

PRODUCTIVE HORIZON

The only interval from which production in a volume approaching commerical value was obtained occurs within the top 300 feet of the Miocene. None of the showings cored or tested in the lower 800 feet of the Pliocene and in the Miocene below the top 300 feet furnished clean oil at a commerical rate.

KIND OF OIL

The gravity of the oil produced ranges from 29° to 32°. As compared with the average Los Angeles Basin crude, it has a medium sulphur content and a high wax content; the gasoline content is slightly lower for a given gravity.

TORRANCE OIL FIELD

By EUGENE L. DAVIS*

OUTLINE OF REPORT

HISTORY

The Torrance oil field was discovered by the Chanslor-Canfield Midway Oil Company's well Del Amo No. 1, completed June 6, 1922. Initial production at depth of 3,500 feet was 300 barrels per day of 21.6 degrees A. P. I. gravity oil.

Development of the field was slow until discovery of larger completions (up to 2,000 barrels per day) in the townlot area of Lomita, precipitated a typical townlot boom.

Peak production, 72,000 barrels per day of oil from 345 wells, was reached in May, 1924. (Musser, E. H. 25.)

A deeper zone about 1,350 feet below the top of the main zone was discovered by the Chanslor-Canfield Midway Oil Company in their well Del Amo No. 23, recompleted on July 22, 1936, at a depth of 4,887 feet, plugged to 4,400 feet. Initial production was 105 barrels per day of 26.5 degrees gravity oil.

This zone was subjected to rapid development but was found to be of limited extent and productivity. It is productive in three areas, all on the south flank: one at the extreme eastern end of the field; one in the south-central portion (Lomita); and one smaller area south of the westerly portion of the field. Some 320 wells have been drilled to this zone, their initial production ranging from nothing to 700 barrels per day. Declines have been rapid except in the rare instances where wide spacing prevailed. It is probable that this drilling was, on the whole, unprofitable.

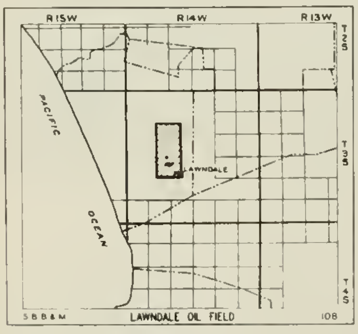
Several wells have been drilled to test the Del Amo sand interval on the north flank of the field, and two wells found thin sands containing oil and water. These holes were well located, judging by the known structure, so that prospects of commercial oil production on the north flank do not appear favorable.

At the present time (August, 1941), the productive area of Torrance appears to be connected with that of Wilmington. The main zone of Torrance includes a part of the Terminal zone of Wilmington.

Several test wells have been drilled to the underlying schist but have found the overlying schist-conglomerate to be barren or to yield high head water. These tests have been fairly well distributed on the structure and indicate that oil production from this conglomerate is unlikely.

* Chief of Production Section, Office of Petroleum Coordinator, Los Angeles. Manuscript submitted for publication March 24, 1938; revised January 27, 1942.

CITATIONS TO SELECTED REFERENCES—Continued



Lawndale oil field.

LAWNDALE OIL FIELD

Elliott, G. R. 28; McCollough, E. H. 34; Oil Bulletin 29; Petroleum World 36a; Van Couvering, M. 28.

TORRANCE (TORRANCE-REDONDO) OIL FIELD

Bermingham, J. A. Jr. 38a; 38b; Brown, C. C. 26; David, L. 40; Hight, W. 33; Hoots, H. W. 39; 39a; Hoots and Herold 35; Huguenin, E. 26; 37; 39; McCollough, E. H. 34; Miller, H. C. 29; Musser, E. H. 25; Oil Age 23; Petroleum World 36a; Shepherd and MacDonald 38; Soper, E. K. 32a; Soyster, M. H. 38; Stockman, L. P. 351; Taff, J. A. 34; Thoms, C. C. 24; Wilhelm, V. H. 39a; Williams, G. C. 38.

Lomita Area

Bermingham, J. A. Jr. 38; Sanders, T. P. 38a; Soyster, M. H. 38.

North Redondo Area

Edwards, M. G. 37.

Redondo (Redondo Beach) Area

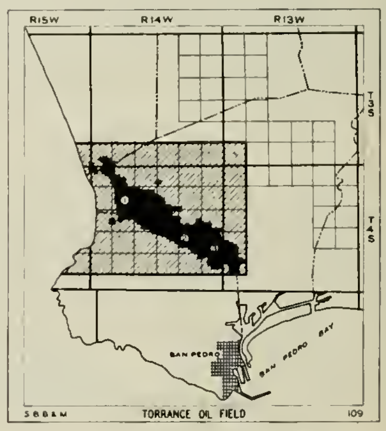
Soyster, M. H. 22; Stockman, L. P. 36g.

Torrance Area

Soyster, M. H. 22.

Vesta Area

California Oil World 41b; Hunter, A. L. 41; King and Preston 41.



Torrance oil field. Areas: (1) Redondo; (2) Lomita; (3) Joughin.

SIGNIFICANCE

The field is of secondary importance commercially. Operations have been rather unprofitable due to low productivity, small demand for the crude produced, and high maintenance costs.

DISTINGUISHING FEATURES

Absence of the highly productive lower Pliocene sands usually found in Los Angeles Basin fields and the presence of only thin, fine-grained sands in the Miocene account for the low recovery of oil, which is about 20,000 barrels per acre.

The field is the largest in areal extent in the Los Angeles Basin, being about 7 miles long by 1 mile wide and covering an area of 4,005 acres.

The gentle plunge and dips of the structure together with the progressive gradation of the oil measures from sand to shale in a westerly direction may account for the oil concentration without proved structural closure on the west.

Edgewaters are absent or not important over most of the field. Present low production, 14 barrels per day per well, is due to depletion and bad mechanical condition of the well casings. Collapsed casing in the oil zone is very common. Average water production is 6 barrels per day per well.

To January 1, 1941, about 1,200 wells have been drilled in this field. They have produced approximately 100,000,000 barrels of oil. On September 1, 1941, the 656 wells were producing 9,277 barrels per day.[1]

STRUCTURE

The Torrance anticline is a broad, gently folded structure extending in a S. 65° E. direction from its highest point at Redondo Beach. The angle of plunge is less than 2 degrees. Dips on the north flank vary up to 12 degrees; south flank dips are about 5 degrees.

There are three structural divisions of the field, approximately equal in area, and separated from each other by minor flexures in the folding, and perhaps by faulting. These are as follows: (1) the Redondo. or western area, extending from Redondo Beach to Madrona Avenue; (2) the central area south of and within the City of Torrance, including in its southern portion the townsite of Lomita; and (3) the eastern, or Joughin, area of which Western Avenue is the approximate western limit, the east end merging into the Wilmington field.

The en echelon arrangement of the minor structures of Torrance is apparently caused by lateral movement at an angle diagonal to the main pressure causing the original fold.

No proved structural closure exists on the west end. Further development in this direction is prevented by the city of Redondo Beach. The east end is apparently connected by a productive structural saddle to the Wilmington field.

[1] Personal communication from Carl Bloom, Division of Oil and Gas.

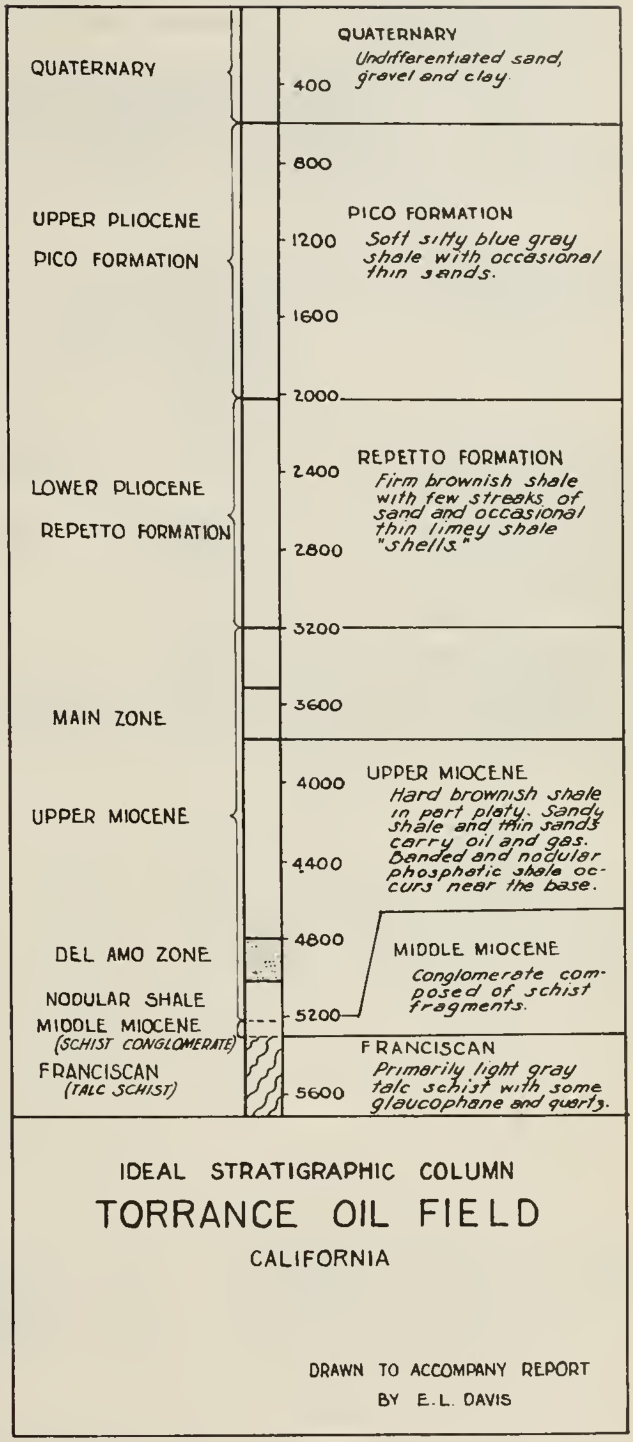


FIG. 125. Torrance oil field: ideal stratigraphic column.

STRATIGRAPHY

The sedimentary series in the Torrance field consists largely of marine formations, which are overlain by approximately 1,000 feet of Pleistocene and Recent sands and gravels.

Lithologically, the Miocene sediments indicate deposition in shallow, quiet water. Certain beds, locally, appear to be estuarine deposits. The sediments were probably derived mostly from the north and east, as the formations become progressively sandier in these directions.

IDEAL GEOLOGICAL COLUMN

Recent and Pleistocene	1000 ±	Sands, clays, gravels
Upper Pliocene—(Pico)	1000 ±	Sandy, blue shales
Lower Pliocene—(Repetto)	1000 ±	Sandy, gray-brown shales and sand
Miocene	2500 ±	Hard, brown shales with streaks and lenses of sand
	50 ±	Hard, blue-gray schist conglomerate
Jurassic (?) Franciscan		Blue-gray glaucophane and talc schist

The Pliocene-Miocene contact occurs at about 3,000 feet in the central portion of the field. The schist is found at 5,800 ± feet.

The stratigraphic column differs from that of nearby fields in that the lower Pliocene is relatively very thin and the usual productive oil sands are lacking.

PRODUCTIVE HORIZONS

The main producing horizon at Torrance occurs at the top of the Miocene formation. This zone consists of from 200 to 600 feet of principally hard, brown shales with thin beds of shaly sands and lenses of sand (15 percent).

The Del Amo zone consists of a series of shales interbedded with fine-grained compact sand. It is of middle Miocene age. It is productive only in limited areas on the south flank of the structure. It appears to be almost or entirely absent at other localities where drilled, except on the north flank of the middle and eastern parts of the structure, where thin sands bearing both oil and water are found at this stratigraphic depth.

KIND OF OIL AND GAS

The accumulation of oil appears to have been controlled by the original folding, especially by that of the subsidiary anticlines. The main zone (3,200-3,600) shows a wide variation in the amounts of oil it is capable of producing and in the gravities of oils produced. These range from 14 to 28 degrees A.P.I.

Western Area	14° to 20° A.P.I.
Central Area	16° to 28° A.P.I.
Eastern Area	16° to 22° A.P.I.

The gravity of the oil and its contents of gasoline, naphtha, and sulphur are dependent upon structural location of wells and the penetration of the oil zone. In general, the deeper sands contain the higher gravity oil.

The gravity of the oil in the Del Amo zone ranges from 26 to 30 degrees A.P.I. A U. S. Bureau of Mines analysis of a Main zone sample is as follows:

Depth: 2900-3400
Gravity of Oil: 15.3 A.P.I.
Percent Sulphur: 3.0
4.6% of 40.4° A.P.I. gasoline
40% of 30.8° to 18.1° A.P.I. lubricating distillate.

WILMINGTON OIL FIELD

By Read Winterburn *

OUTLINE OF REPORT

HISTORY

The Wilmington oil field is located in the area between the center of the city of Wilmington and the Los Angeles County Flood Control Channel in Long Beach. The accumulation probably extends under the ocean to the south and southeast, but no drilling has yet been done beyond the high-tide line.

Commercially attractive production was first proven in this field December 6, 1936, by the completion of General Petroleum Corporation well No. Terminal 1 at an initial rate of 1,389 barrels per day of 20.5 gravity oil. This well was located after a thorough seismographic survey had been made of the area. The well was drilled to a total depth of 6,814 feet, encountering schist at 6,787 feet, and before completion was plugged back to 3,625 feet and completed with 6⅝-inch casing cemented through perforations at 3,122 feet. The producing interval includes approximately 500 feet of formation in the Terminal zone, extending from the "J" marker to about 100 feet below the "AA" marker.

Completion of No. Terminal 1 initiated an intensive drilling campaign which has resulted in the completion of 914 wells. The daily production of the field under heavy curtailment is now about 81,000 barrels per day.[1]

* Petroleum Engineer, Union Pacific Railroad Company. Manuscript submitted for publication June 20, 1941.

[1] These figures are as of November 27, 1940.

STRATIGRAPHY

The following table shows the various formations encountered in the Wilmington field:

TABLE 1

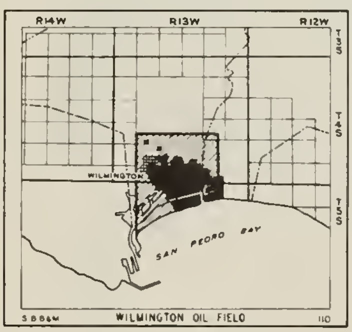
Age	Formation	Thickness	Lithology and remarks
Quaternary and Pleistocene	San Pedro	1,000′±	Fresh-water sands, gravels and clays
Pliocene	Upper Pico	800′±	Alternating sands and siltstones
Pliocene	Middle Pico	0′–200′	Sands and siltstones
Unconformity			
Pliocene	Repetto	875′–1,150′	Gray and green shales, siltstones and sands at top, grading to interbedded grayish-brown shales and fine-grained sands toward bottom
Miocene	Puente	4,100′±	Hard brown shales and sands; sands are fine and unconsolidated at top, becoming firmer and coarser grained towards bottom. Top portion contains layers of laminated diatomaceous shale
Unconformity			
Jurassic?	Basement		Schist

Since very little coring has been done in the upper 2,000 feet, the exact top of the upper Pico and the areal extent of the middle Pico have not been determined. The middle Pico is apparently overlapped in the northern part of the field. However, it is possible that a thin section of the middle Pico extends across the top of the structure.

CITATIONS TO SELECTED REFERENCES—Continued

WILMINGTON OIL FIELD

Albright, J. C. 39; 39a; 39b; Bartosh, E. J. 37; 38; 38a; California Oil World 40b; Carrey, A. A. 38; Dean, C. J. 38; Edwards, M. G. 37; Hoots, H. W. 38; 39; Huguenin, E. 26; 37; 39; Jackson, G. 41; Mead, R. G. Jr. 37; 37a; Mills, B. 38c; Nash, A. W. 38; Oil and Gas Journal 37b; Oil Weekly 37, 37b; Petroleum World 36a; 38; Porter, W. W. II 38; 39b; Sanders, T. P. 41d; Stockman, L. P. 37; 41e; 41l; Wilhelm, V. H. 38; 39a; 40; 41; 41a; Wilson, G. M. 41a; Winterburn, R. 40.



Wilmington oil field

SAN PEDRO REGION

Arnold, R. 03; Clark, A. 31; McLaughlin and Waring 14; Vander Leck, L. 21; Watts, W. L. 00; Woodring, W. P. 32a; Woodring, Bramlette, and Kleinpell 36.

Palos Verdes (San Pedro) Hills

David, L. 40a; Watts, W. L. 00; Woodring, Bramlette and Kleinpell 36.

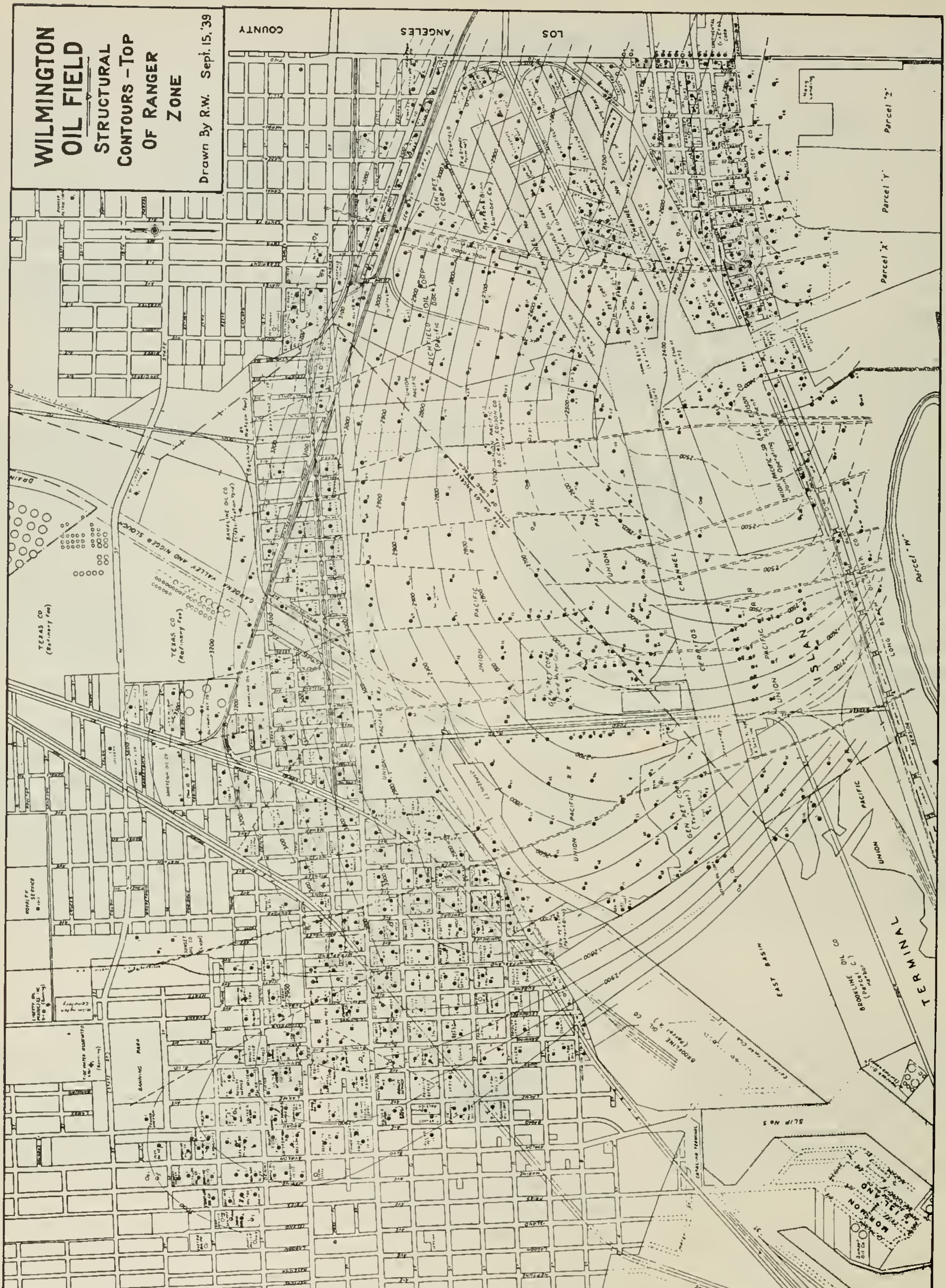


FIG. 126. Wilmington oil field: structure map.

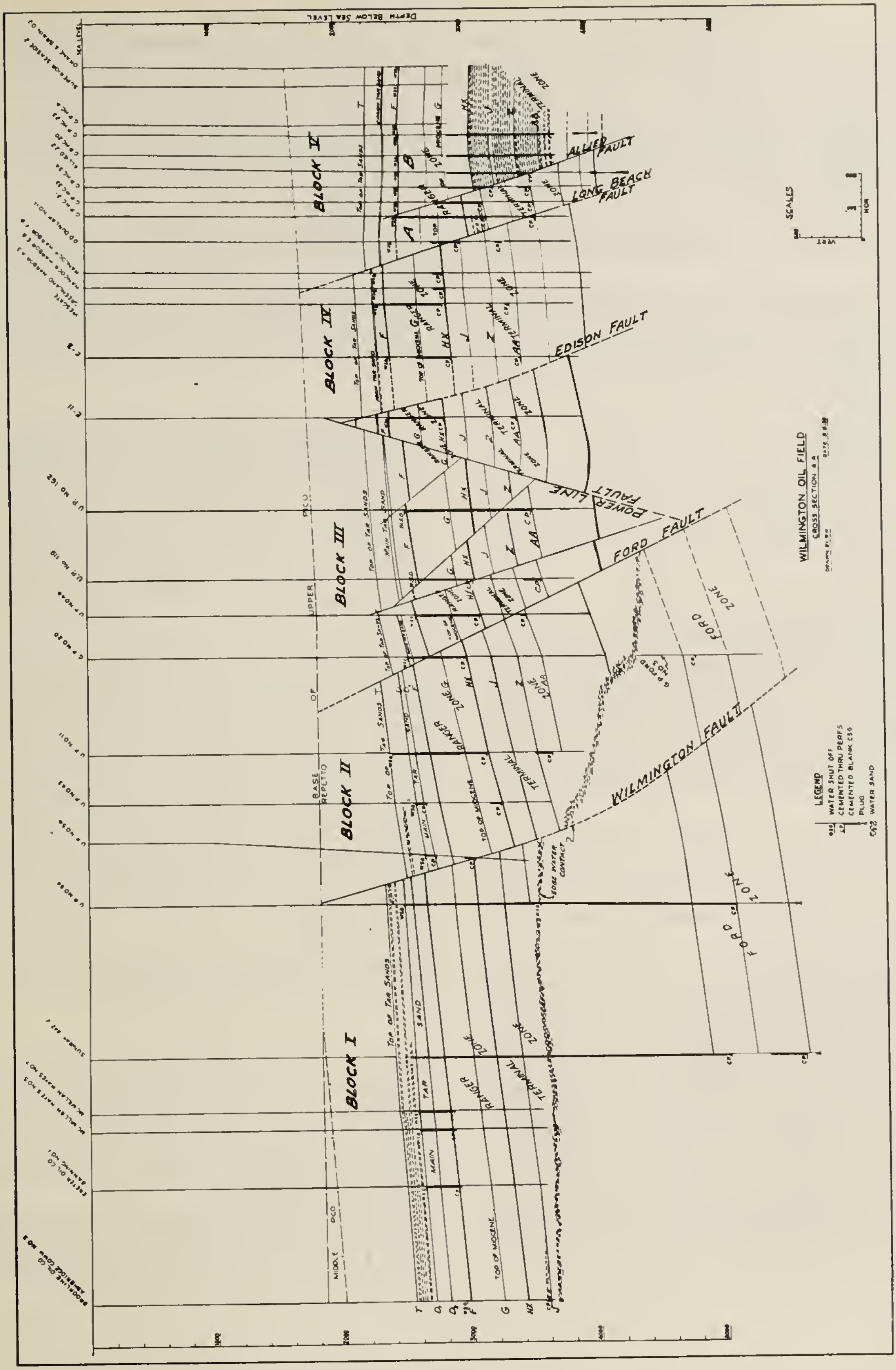


Fig. 127. Wilmington oil field: cross-section.

STRUCTURE

As shown in the structural contour map, the structure of the portion of the field so far developed is an anticlinal nose plunging to the northwest. Drilling so far has given no indication of any reversal of this plunge to the southeast. The four main faults now known trend in a northerly direction transverse to the axis, and divide the field into five structural blocks. Starting from the west the main faults are commonly referred to as the Wilmington fault, the Ford fault, the Power Line fault, and the Long Beach fault. For convenience of reference, the five structural blocks are numbered consecutively from west to east.

The five structural blocks are complicated further by minor faulting. The Allied fault on block five has had a distinct effect on accumulation in the Terminal zone. The Edison fault on block four immediately east of the projection of the Power Line fault is of relatively large magnitude near Seaside Avenue but apparently diminishes in throw rapidly to the north and has not been found to extend north of Cerritos Channel. South of Cerritos Channel the Ford fault apparently is represented by three parallel faults. The largely undeveloped area between the Ford and Power Line faults is probably complicated by faulting, which may necessitate the further division of block three into structural subdivisions.

The accompanying section extends from the northwest end of the field approximately along the axis of the fold to the middle of block four, from which point it runs obliquely down the northeast flank of the structure across block five. All the principal faults are normal faults, hading to the east, with the exception of the Power Line fault, which hades to the west. The angle of inclination of the fault planes ranges between 50 and 60 degrees from the horizontal, with a general tendency to steepen as the fault is traced northward from the axis of the structure.

The amount of apparent vertical displacement on the faults is relatively small, varying from a maximum of 350 feet at the top of the Terminal zone on the Wilmington fault to about 100 feet on the Allied fault at the same stratigraphic depth. The Wilmington fault has an apparent vertical displacement of 350 feet at the top of the Terminal zone where it crosses the Consolidated Channel. This decreases progressively southward until it is only 250 feet at Cerritos Channel. The throw of the other faults decreases to the north, some of them disappearing completely before reaching the limits of the field.

Thickness of the Repetto beds increases to a marked degree down the dip. A much thicker Repetto section is found on the downthrown side of all the faults than on the immediately adjacent upthrown block. Intervals in the Miocene are more nearly uniform throughout the field. The thickening of intervals in Repetto on the downthrown fault blocks is accompanied by progressive increase in vertical displacement on the faults with depth down to the top of the Miocene; below this horizon the displacement remains relatively constant.

This relationship of the variable thickness of the Repetto section to the structural features suggests that the folding and faulting occurred progressively during the deposition of the Repetto beds, which attained varying thicknesses, depending on the relative depression of adjacent areas during deposition.

The folding and faulting of the Repetto and Miocene beds are not reflected in the younger sediments above the unconformity.

The faults apparently are sealed and act as barriers to the movement of fluid through the sands. As a result, each of the five structural blocks is distinguished by a different gravity of oil and by a distribution of edgewater and intermediate edgewater which has no relation to that on the other blocks. At many places water sands on one side of a fault are in contact with oil sands on the opposite side.

PRODUCTIVE HORIZONS

Four productive zones have been encountered in the Wilmington field. From top to bottom these are:

1. Tar zone, between electrical markers T and F. Thickness varies from 250 to 400 feet; average 40 percent sand; gravity of oil 12 to 15 degrees A. P. I.
2. Ranger zone, between electrical markers F and HX. Thickness varies from 400 to 600 feet; 15 to 30 percent sand; gravity of oil from 12 to 25 degrees A. P. I.
3. Terminal zone, between electrical markers HX and AE. Thickness is about 1,100 feet; 50 to 70 percent oil sand; divided into upper and lower Terminal for production purposes, gravity in upper 400 feet varies from 14 to 25 degrees and in lower portion from 26 to 31 degrees. The actual point of division ranges from 400 to 600 feet below the top in different wells, depending on conditions in particular areas.
4. Ford zone, between markers AM and AW. Thickness is 750± feet; 25 to 35 percent oil sand, gravity of oil 28 to 32 degrees A. P. I. (The whole 750-foot interval is not included in any one well but represents interval from highest shutoff point to deepest penetration.)

Table 2 shows the limits of production for the various zones in each block together with the gravity of the oil and initial production rates.

KIND OF OIL

The gravity of Wilmington crude varies from 13 to 32 degrees A. P. I. Oil below 17 degrees gravity contains from 1.7 to 2.5 percent sulphur. The sulphur content decreases with increase in gravity, to range from 0.6 to 0.9 percent for 29 gravity oil. Gasoline content ranges from 8 percent for 16 gravity oil to 31 percent for 29 gravity.

The gravity of oil increases with stratigraphic depth. On each structural block the highest gravity oil in each zone is found at the highest structural position.

TABLE 2. DISTRIBUTION OF ZONES ON FAULT BLOCKS

Zone	Block I	Block II	Block III	Block IV	Block V
Tar	Upper portion wet. Main tar sand productive. 100 to 300 bbl. per day, 13° to 15°.	Entire zone saturated near axis of fold. Entire zone wet north of Anaheim. Not produced separately.	Upper portion wet at all locations below 2700-ft. contour[a]. Entire zone wet below 2950-ft. contour[a]. 300 bbl. per day, 15°.	Entire zone saturated east of Harbor entrance. Wet at lower structural elevations. Not produced to date.	Upper portion wet. Lower portion saturated between 2500 and 2600-ft. contours[a]. Entire zone saturated above 2500-ft. contour and wet below 2600-ft. contour[a].
Ranger	Saturated and productive over entire area. Not produced separately.	Saturated and productive over entire area. Water sands in bottom at lower structural positions. 50 to 2700 bbl. per day, 12° to 22°.	Saturated and productive over entire area. Water sands in bottom at lower structural positions. 50 to 2300 bbl. per day, 14° to 24°.	Productive over entire area. Water sands in bottom in northern portion. 150 to 900 bbl. per day, 16° to 20°.	Productive over entire area. Water sands at bottom at lower structural elevations. 100 to 700 bbl. per day, 14° to 18°.
Terminal	Top 250 ft. productive at lowest structural positions. Top 750 ft. productive at highest structural positions. 100 to 1800 bbl. per day, 14° to 22°.	Top 80 ft. productive at Anaheim St. 1100 ft. productive at highest structural positions. Not productive below 3000-ft. contour[a]. 200 to 8000 bbl. per day, 17° to 31°.	Top 400 ft. productive at 2750-ft. contour[a]. Wet at 2850-ft. contour[a]. Entire zone productive south of Cerritos Channel immediately east of Ford fault. 400 to 8000 bbl. per day, 21° to 31°.	Entire zone productive above 2500-ft. contour[a]. Intermediate edge waters between 2500 and 2700-ft. contours[a]. Edge of accumulation near 2700-ft. contour[a]. 600 to 7500 bbl. per day, 18° to 29°.	Entire zone saturated above 2450-ft. contour[a] and wet below 2600-ft. contour[a] on block VA. Upper 560 ft. wet at all locations drilled to date. Lower 540 ft. saturated above 2470-ft. contour and wet below 2500-ft. contour[a] on block VB. Gravity 24° to 29°.
Ford	Productive inside of 2850 ft. contour[a]. 100 to 500 bbl. per day, 28° to 30°.	Productive on Ford lease north of Cerritos Channel. Undrilled elsewhere. 600 to 900 bbl. per day, 29° to 32°.	Not drilled.	Not drilled.	Cores indicate sands to be wet in block VB. Probably productive at higher structural positions. Not drilled in block VA.

[a] All contours referred to in this table are subsurface structural contours on top of Ranger zone.

INGLEWOOD OIL FIELD

By Herschel L. Driver *

OUTLINE OF REPORT

HISTORY

The Inglewood oil field lies near the northwestern extremity of the Los Angeles Basin along a line of folding extending in a southeasterly direction to Newport. The productive area comprises 875 acres in portions of Secs. 7, 8, 16, and 17, T. 2 S., R. 14 W., S. B. The discovery well, No. "Los Angeles Investment" 1-1, completed by the Standard Oil Company of California on September 28, 1924 at a depth of 2,134 feet, had an initial production of 145 barrels of oil per day. This well is near the southernmost edge of the field. Between September 1916 and the discovery date, five adjacent wells had been drilled and abandoned at depths ranging from 4,500 to 6,757 feet. Four of these wells, the Bartola Oil Company well No. 1, Standard Oil Company (California) Nos. "Cienega" 1 and 2, and 57 Petroleum Corporation No. "Casserini" 1, were located within half a mile of the present limits of production. The fifth well, Amazon Drilling Company well No. 10, later known as Pacific Oil Company No. "Baldwin" 1, was located about a mile from present productive limits. Before the end of 1924, the Mohawk Oil and Gas Syndicate well No. 1 was completed at a depth of 2,344 feet near the western edge of the field. The initial production was 250 barrels of oil per day. Very rapid development followed, and by September 1925 there were 150 productive wells in the field. (Huguenin, E. 26b)

SIGNIFICANCE

This field has been developed with the aid of modern methods such as rotary drilling, aerial photography, lithologic and paleontologic evidence derived from cores, electric logs, and formation tests. Except for approximately 22 acres, the proven acreage is leased by the Kettleman and Inglewood Corporation, the Standard of California, Tide Water Associated, Shell, and The Texas oil companies; so the disadvantages of townlot conditions have largely been avoided. The presence of comparatively shallow oil zones and the possibilities of deeper zones make this field especially attractive.

DISTINGUISHING FEATURES

The Inglewood field lies within the Baldwin Hills, the most prominent topographic feature along the line of uplift from Beverly Hills to Newport. In conformity with the Pliocene productive area in the Old Field of Huntington Beach and in the other fields along this direction of folding, oil accumulation in the Inglewood field is influenced by a major zone of faulting that trends northwest; and the highest portion of the field, both topographically and structurally, lies east of this zone of faulting. Unlike the other fields along this structure, however, most production in the Inglewood field is west of the major faulting, and is not under the structurally highest portion of the field. The sediments down to and including the uppermost Repetto are structurally higher at the crest of this field than in any other field along the line of folding. The top of the uppermost oil zone is within stratigraphically higher beds than any other productive oil zone within the Los Angeles Basin.

STRATIGRAPHY

The rocks which have been penetrated by drilling within the Baldwin Hills area are confined to Miocene and post-Miocene.

Miocene has been reached in the Southwest Oil and Development Company No. "Baldwin Hills" 1, Baldwin Oil Company No. "Monrovia" 9, Kettleman and Inglewood Corporation No. "Rubel" 17, Standard Oil Company of California No. "Baldwin-Cienega" 105, Western Consolidated Oil Company No. "Smith" 1, Federal Oil Company No. "Smith" 1, and Bush Oil Company No. "Sentous" 1. Most of these wells penetrated less than 200 feet of Miocene, and none of them penetrated as much as 600 feet except the Bush well, where about 1,325 feet of these rocks were drilled into before the well was completed. The *Valvulineria californica* zone of upper-middle Miocene age (Luisian stage[1]) was reached in the lower portion of the Bush well, but no evidence of schist was noted. The Miocene consists essentially of dark-brown laminated and massive shale interbedded with minor amounts of sand. These sediments are in normal contact with the overlying Pliocene beds.

The Pliocene is commonly divided into two major parts: the Repetto formation, and the overlying Pico formation. Each of these divisions may be divided into numerous microfaunal zones. The Repetto formation is about 3,150 feet thick, and grades faunally and lithologically from the underlying brown shales, through massive brownish-gray shale and sandy shale, to become interbedded with greater quantities of sand as the top of the formation is approached.

The Pico formation is about 1,700 feet thick at the crest of the Inglewood field, and grades faunally and lithologically upward through massive sand and brownish-gray sandy shale to olive-gray argillaceous silt with seams of sand. Laminated olive-gray and olive-brown shale is present in the upper portion of the formation. Uppermost Pico argillaceous silts and seams of sand outcrop just east of the Inglewood fault, throughout most of the northern portion of the eastern block, in a few localities at the northwestern end of the western block, and in one locality at the northwestern tip of the central graben. Foraminifera and occasional molluscs

* Standard Oil Company of California. Manuscript submitted for publication May 26, 1938; revised November 25, 1940.

[1] Kleinpell, R. M. 38.

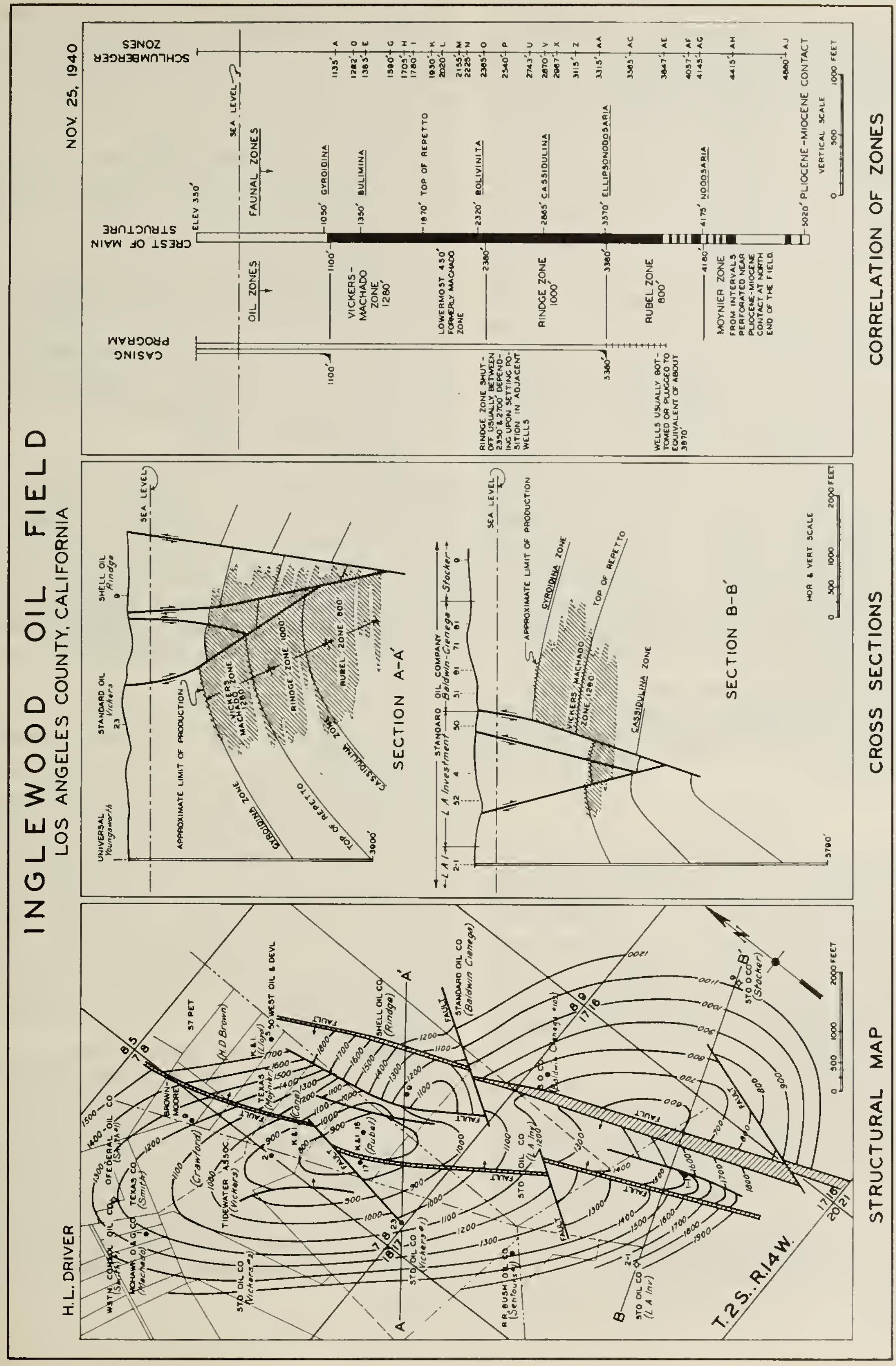


FIG. 128. Inglewood oil field: structure map; cross-sections; correlation of zones.

are present in the quarry at the northwestern end of the hills. Elsewhere, the outcrops of Pico sediments are commonly weathered to a buff color, and the evidence of foraminifers is often limited to molds or limonitic casts. Scattered buff, irregular limestone concretions are present at various localities within the Pliocene outcrops. Surface and subsurface evidence shows some lateral variation in the thickness of sand bodies.

The Pleistocene is conformably deposited over the Pliocene in the western block, but is unconformable in the eastern block[2]. The sediment varies appreciably laterally, but typically consists of grayish-tan sandy clay interbedded with coarse, loosely consolidated sand. Above these sediments occur calcareous sandstone, cross-bedded and lenticular coarse gray sand, gravel, and conglomerate, and arkosic gray and brown sand that grades upward into red soil. The calcareous sandstone at the reservoir site near the northeastern edge of the hills contains molluscs which have been identified[3] as lower San Pedro (Pleistocene) in age. The uppermost red material is locally indurated and forms the rimrock sandstone (Robertson and Jensen 26a) as typically exposed in the south-central part of the hills. The Pleistocene covers all of the central graben, nearly all of the western block, the southern part of the eastern block, and forms a cap on the hills in the northern part of the eastern block. The thickness over the productive area west of the Inglewood fault varies from 80 feet to 200 feet. The thickness over the productive area of the eastern block is about 90 feet. Thinning takes place in a northerly direction, and thickening takes place in a southeasterly direction.

Recent alluvium and stream terrace deposits occur as sandy black and reddish clay soils, and cover the crest and southern slopes of the Baldwin Hills. The plains east, north, and west of these hills are covered by gray and black sandy loam.

STRUCTURE

The main portion of the field is within a northwest-trending anticline, the crest of which has been dropped between faults. The easterly fault bounding this graben has been referred to as the Inglewood fault. Its position is marked at the surface by an escarpment along which Mr. G. B. Moody[4] has measured a vertical displacement of about 275 feet. The direction of striae in numerous cores indicates the larger component of movement to be horizontal. A horizontal displacement of as much as 1,500 feet has been estimated[5]. This fault dips 60° to 80° west.

Evidence for the major movement of the eastern block in a southerly direction with reference to the western area is supported by the topographic configuration at the northern end of the hills, and by the accumulation of oil in the eastern block south of the main accumulation in the western area. It is probable that the oil originally accumulated in one anticlinal fold which was later faulted. The oil accumulation within the eastern block was then originally within a structurally lower portion of the main oil body, thus accounting for the smaller production within the structurally higher eastern block.

The western side of the graben is terminated by a fault whose vertical displacement amounts to about 30 feet at the surface and about 160 feet in the vicinity of the Vickers-Machado oil zone. The dip of the fault at the surface ranges from 67° to 85° east and becomes less steep with depth.

The faults bounding the graben are offset by cross-faults. Subsurface data indicate this graben to be further complicated by a horst and by other grabens created along faults trending in a general northwest direction. Additional faults are present in the northwestern portion of the field. The northeastern boundary of the Baldwin Hills is marked by a fault scarp which is offset by the Inglewood fault, thus dating the latter fault as younger. All of these faults are normal.

Topography reflects the main structural features. Streams have cut steeper-walled and deeper channels through the northern portion of the hills than in the less abrupt southern portion. Apparently, the northern portion of the area has been subjected to earlier and greater uplift.[6] Beds within the quarry at the northwestern edge of the hills strike N. 10° E., and dip 35° W. Elsewhere, surface evidence indicates gentle dip. The angle of bedding tends to increase with depth, but, except where there has been local contortion, does not generally exceed 30°.

PRODUCTIVE HORIZONS

There are three main productive oil zones in the Inglewood field.

The Vickers-Machado is the uppermost; its crest is about 1,450 feet below the surface in the main portion of the field, and as high as 1,200 feet, east of the Inglewood fault. The first production from this zone was by Standard Oil Company (California), now Standard Oil Company of California, No. "Los Angeles Investment" 1-1, the discovery well of the field. The lowermost 450 feet comprise the former Machado oil zone. Edgewater between these two productive measures has encroached from the west and now has extended even into wells near the crest of the structure. The Vickers-Machado zone includes the lower 770 feet of Pico and the upper 510 feet of Repetto sediments.

The Rindge zone immediately underlies the Vickers-Machado zone, and extends for a maximum interval of 1,000 feet. The top of the zone was arbitrarily selected about 1,280 feet below the top of the Vickers zone, but actually is dependent upon the total depth of adjacent Vickers-Machado zone wells. The first production from the Rindge zone was in July, 1925, by Shell Oil Company No. "Rindge" 9, where, because of faulting, portions of this zone and the Vickers-Machado zone were produced together. Production is confined to the upper few hundred feet of the zone because of the presence of bottom water.

[2] Moody, G. B. Surface geology of the Baldwin Hills, Los Angeles County, California, *unpublished report*, January 22, 1935.
[3] Tieje, A. J. *Unpublished manuscript*, 1926.
Grant, U. S. IV. *Unpublished report*, 1935.
Clark, B. L. *Unpublished report*, 1935.
[4] *Op. cit.*
[5] Cunningham, G. M. Geology of Baldwin Hills, *unpublished report*, July 22, 1925.

[6] Moody, G. B., *op. cit.*

The Rubel zone immediately underlies a 60-foot shale body at the base of the Rindge zone. Its maximum thickness, by agreement between the operators and the California State Division of Oil and Gas, is 800 feet. The first production from the zone was in August, 1934, by Kettleman and Inglewood Corporation No. "Rubel" 17. Production is confined to the upper few hundred feet, because of the presence of bottom water.

Deeper production obtained from intervals perforated near the Pliocene-Miocene contact has been referred to as Moynier zone oil. The discovery well and sole producer is E. K. Allison Syndicate No. "Moynier" 1, now Southwest Oil and Development Company No. "Baldwin Hills" 1, completed at a depth of 6,466 feet in September 1932. Production from this zone averaged 10 barrels per day during 1937.

The deepest production is that obtained from the Bush Oil Company No. "Sentous" 1, which was completed on September 6, 1940, at a rate of about 120 barrels of oil per day. The Sentous zone, as opened to production within this well, is stratigraphically the deepest oil zone developed within the Los Angeles Basin, except for oil which migrated into schist.

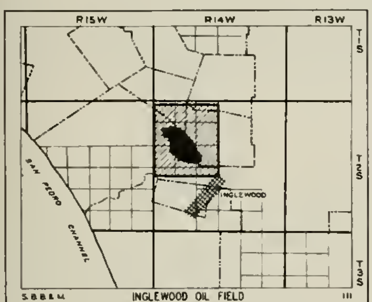
The lateral limits of zones below the Vickers-Machado have not been established definitely. Present production east of the Inglewood fault is confined to the Vickers-Machado.

KIND OF OIL AND GAS

The gravity of the oil ranges from 13° to 38°. The gas-oil ratio is comparatively low, averaging less than 500 cubic feet per barrel of oil.

Average Crude Oil Analysis

Zone	Gravity From	Gravity To	Gravity Average	Percent Wax	Percent Sulphur	Viscosity at 100°	Viscosity at 130°
Vickers-Machado	13.0°	29.3°	20°	0.32	2.35	391.0	---
Rindge	20.0°	38.0°	29°	---	1.43	---	478
Rubel	20.0°	35.6°	30°	1.70	0.91	41.0	---
Sentous	31.9°	dry	---	2.76	1.03	46.4	---



Inglewood oil field.

CITATIONS TO SELECTED REFERENCES—Continued

INGLEWOOD OIL FIELD

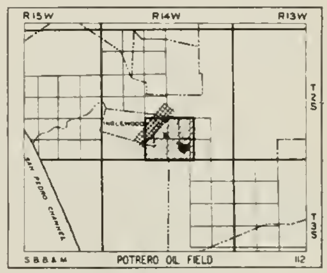
Brown, C. C. 26; California Oil World 40f; 41b; 42; Clute and Perry 25; Dunlap, W. E. 40; 41; Hight, W. 33; Hoots, H. W. 32b; Hoots and Herold 35; Huguenin, E. 26; 26a; 26b; 37; Jensen, J. 27a; Jensen and Robertson 28; Kirwan, M. J. 18; 18a; McCollough, E. H. 34; Petroleum World 35; Robertson and Jensen 26; 26a; Stockman, L. P. 34; 35i; 41f; 41l; Taff, J. A. 34; Thoms, C. C. 24; Tieje, A. J. 26; Vallat, H. E. 41a; Vander Leck, L. 21; Van Tuyl and Parker 41; Wilhelm, V. H. 41; 41a; Woodward, A. F. 40; 41.

Baldwin Hills (Inglewood) Oil Field

Taff, J. A. 34; Tieje, A. J. 26; Van Tuyl and Parker 41; Willett, G. 37.

POTRERO (CYPRESS) OIL FIELD

Eaton, J. E. 27c; Hoots, H. W. 39; Huguenin, E. 26; Jensen, J. 27a; Jensen and Robertson 28; McCollough, E. H. 34; Taff, J. A. 34; Wagy, E. W. 27.



Potrero oil field.

POTRERO OIL FIELD

By ROBIN WILLIS* AND RICHARD S. BALLANTYNE, JR.*

OUTLINE OF REPORT

INTRODUCTION

The Potrero oil field of the Los Angeles Basin district lies in Secs. 27, 28, and 34, T. 2 S., R. 14 W., S. B., about 10 miles southwest of the center of the city of Los Angeles, in Los Angeles County. It is the second from the north in the line of fields extending from Culver City to Huntington Beach along the Inglewood fault zone. It is the smallest of these fields, in the area covered, the number of wells, and the amount of oil recovered, though it is on a large fold. It displays, however, some interesting geological features, and it is also noteworthy for the high gravity of its oil. There are now some 26 producing wells in the field (June, 1941), whose daily yield is about 2,500 barrels per day of oil ranging from 32 to 51 degrees gravity. Discovered in 1927, the field has yielded more than 3,600,000 barrels of oil.

STRUCTURE

The Potrero field was first recognized as a structural dome by the topography, which shows a very broad uplift with a definite oval outline, bounded by gentle tectonic slopes. This expression is less pronounced than that of most of the oil fields on the Inglewood-Newport uplift, and is obscured by two fault scarps along which the relief is more prominent than on the tectonic slopes. The curve of the dome is best evidenced on the north, northeast, and east. On the southeast it is slight but definite, but on the northwest there is little topographic evidence of closure, before the surface rises to the much higher arch of the Baldwin Hills, which reflects the Inglewood oil field. The two fault scarps mark the lines of the Townsite and Potrero faults. The former faces west, and shows a 25-foot offset in the surface across a broad, gentle draw. Northward it increases in prominence to become the main fault in the Inglewood field. The Potrero fault scarp also faces west, and cuts through the center of the structure. On the Potrero Country Club it has a relief of about 60 feet. Both scarps trend approximately N. 25° W. Thus the topography outlines the most important structural features of the field, namely, the dome and the two larger faults.

The Dome

The Potrero oil field lies on a closed anticline or dome, on a fold which strikes approximately N. 65° W., and is distinct from both the Baldwin Hills fold to the northwest and the Athens fold to the southeast. The crest lies under the NE¼ Sec. 34.

Within the productive area along the crest of the fold the structure is exceptionally broad and gentle, at least to a depth of 7,000 feet. Except locally, along the faults, the dips do not exceed 15 degrees, and average less than 8 degrees. On the flanks higher dips probably occur, but there is no accurate control by which to determine them. The fold plunges about 5 degrees to the northwest. The southeast plunge is not defined. The northeast flank is slightly steeper than the southwest flank.

The Faults

Three faults divide the dome into four blocks, each of which contains a distinct accumulation of oil. These may be designated as: (1) the Cypress block, which lies east of the Potrero fault; (2) the Potrero block west of the Potrero fault; (3) the Townsite block, which lies west of the Townsite fault; and (4) the minor Townsite block between the Townsite fault and the minor fault to the east. Accumulations occur in the crest of the dome and along the axis of the fold against the faults.

Potrero Fault. This is the largest and most prominent fault. It cuts through the center of the dome slightly west of the apex, striking N. 25° W., and hading to the southwest at an average angle of 8 degrees from the vertical. It is somewhat flatter near the surface, and steepens downward. The apparent displacement is normal in character, and the throw at the crest of the fold is about 270 feet, down on the west. It is likely, however, that the horizontal component of displacement is the more important. The axis of the anticline in the Potrero block appears to have been displaced about 1,200 feet to the northwest, relative to the Cypress block, and most of the slickensides observed in fractured cores lie at low angles.

This fault is a zone composed of minor displacements, of which three or more show stratigraphic throws of 25 to 115 feet on core and electric logs. There is probably a large number of minor slips. Within the fault zone the beds are strongly broken, sheared, and slickensided. Nearly all of the sands cored within the fault zone itself are saturated with oil, but no oil can be produced from them, presumably because of inadequate drainage area. This suggests that the fault zone has acted as a conduit for the oil, which has found its way up from deeper source beds into the more favorably located sands. The fault zone is between 100 and

* Geologists, Basin Oil Company. Manuscript submitted for publication June 30, 1941.

200 feet wide, and wells penetrating it are in it for a vertical distance of 1,000 to 1,400 feet. Drilling through it requires care, as some wells have had trouble in preventing the diversion of the hole down the sheared fault zone.

Townsite Fault. The Townsite fault is next in importance. It lies about a quarter of a mile west of the Potrero fault and strikes nearly parallel to it. Unlike the Potrero fault, however, displacement on the Townsite fault is reverse in character. The hade is to the east, the downthrown block is on the west, and wells drill through the fault from the eastern to the western block. Its topographic expression is to the west of its subsurface trace. To the northwest the strike of this fault lines up with the trace of the main fault through the Inglewood (Baldwin Hills) oil field, and it is likely that the two are continuous. The latter, where known from well logs, is normal in character. It is suggested that the main Inglewood earthquake rift, at depth, strikes more to the northwest than the Potrero and Townsite faults, that these converge at depth into this rift, and that as these en echelon surface features cross the rift their character changes northward from reverse to normal. The Basin well No. "Potrero" 2 encountered faulting at about 8,100 feet and was still in sheared shale, dipping 65 degrees, at 9,923 feet. The character of this section suggests that it may be the main rift below the point of convergence of these two faults.

The stratigraphic throw on the Townsite fault is about 100 feet. Here also the main component of displacement is probably horizontal. As contoured on the accompanying map, the axis of the fold is offset some 600 feet, and slickensides are predominantly low-angle in the cores.

The character of this fault, as revealed in the only electric log of a well penetrating it, is significant as it is typical of many of the so-called "faults" which form barriers adequate to effect accumulation along the Inglewood-Huntington Beach trend. This log, of the Beloil No. "Castlebury" 1 well, shows that the well is in the fault zone for a vertical distance of 340 feet, though the stratigraphic throw is only 100 feet. In this interval the shale is strongly broken and sheared, but each bed, greatly thickened, is represented, and no actual duplication can be recognized. The so-called fault, therefore, is actually only a very sharp drag fold, so far as stratigraphic displacement of the beds is concerned, but it has been strongly sheared, probably in the development of the horizontal offset.

Below 4,500 feet this fault serves as a barrier sufficient to cause accumulation in the block west of it.

Other Faults. East of the main Townsite fault several wells encountered oil saturation and obtained production at shallow depth, indicating a further barrier between them and the structurally higher Potrero block. In the Basin well No. "Transwestern" 1, a normal fault on which 80 feet of beds were cut out was encountered just east of Prairie Avenue at a depth of 2,300 feet. A similar normal fault appears near the bottom of the Sunset well No. "Inglewood Community" 2 log at approximately the same location. Both wells are slant holes on which surveys are available. To pass east of the Associated well No. "Prairie" 2, this fault would have to strike northeast as shown on the contour map. This is all that is known concerning it, but it appears to have been adequate to trap oil which came across the Townsite fault at shallower depth, above the level at which that fault is a seal.

A fourth fault is shown in the cross-section B-B (see accompanying sections). It does not appear on the map, as it runs into the main Potrero fault above the level contoured. It is a normal fault, approximately parallel to the main break but dipping to the east and converging with it at a depth of 2,700 feet, just above the level of the highest production. It has no bearing, therefore, on the accumulation of oil, but is of interest in showing the character of the structure. It has been recognized in the electric logs of most of the Basin wells. Its throw, only 30 feet near the surface, increases downward to nearly 100 feet.

Other faults have been observed in comparing electric logs of the deeper wells, but there is insufficient information to determine their strike and hade. Most of these are probably related to the main Potrero fault.

STRATIGRAPHY

The following generalized stratigraphic column is taken from that compiled by Stanley G. Wissler, of the Union Oil Company, from micro-faunal data accumulated throughout the life of the Potrero field.

Formation	*Thickness in feet*	*Depth (in feet) in Basin Oil Company well No. "Potrero" 2*
Pleistocene	850	850
Pliocene		
Pico		
Upper	1100	850–1950
Middle	1050	1950–3000
Lower	500	3000–3500
Repetto		
Upper	1825	3500–5325
Middle	1715	5325–7040
Lower	550	7040–7650*
Upper Miocene		
Upper Puente	850+	7650–8500+

* Faulted interval, includes 60-foot duplication.

The character of the formations and the correlation of the intervals which have yielded commercial quantities of oil with the electric log of the well chosen as the type section are shown in the accompanying log of the Basin Oil Company well No. "Potrero" 2.

Miocene

To date only the upper Miocene has been definitely recognized at Potrero. The section of known age includes some 300 feet of hard sand of low permeability, with some shale, overlain by 550 feet of indurated shale and fine hard sandstone. The former correlates with the O'Dea zone of the Rosecrans field, and is the highest productive horizon in the Miocene along this line of fields. At Potrero its permeability is very low, due apparently to a high silt content. This area is thought to have been the center of the depositional basin at that time.

Basin Oil Company No. "Potrero" 2 drilled an additional interval of 1,200 feet of strongly faulted beds, below these beds, and encountered some rather permeable sand between 9,600 and 9,900 feet. Owing to the faulting, and complete lack of micro-fossils in the cores, these beds have not as yet been correlated with sections of known age. It appears unlikely that the middle Miocene was reached.

Repetto

The lower Repetto is similar to the uppermost Miocene beds in character. It is only slightly softer, and is predominantly shaly, with a few thin sands which, though locally saturated, have not yet yielded commercial production. These correlate approximately with the lower Zins zone of the Rosecrans field.

The basal 170 feet of the middle Repetto are shaly, and resemble the lower division. Above this the beds are less indurated. The shales are more massive and less distinctly bedded, and the sands are friable and much more permeable. The sands predominate in this interval; they occur in fairly thick beds, and include several important oil zones.

The lower half of the upper Repetto is more shaly and the sands are distributed in thinner beds throughout the section. Most of the latter carry oil, at least locally, and some are highly saturated and form widespread zones. The upper half of this series consists of thick sand bodies divided by thinner beds of shale. The sands are coarser than in the lower half, and also carry important zones.

Some paleontologists place the top of the Repetto somewhat lower in the section, but their correlation of the beds with those of other areas is essentially the same.

Pico

The lower Pico is similar to the upper Repetto. To date it has yielded no commercial production, but in the thinner sands found in the more shaly intervals there is some saturation.

The middle Pico is divided into three distinct stratigraphic units. The bottom 200 feet are made up of fine, loose sand in thick beds with thin streaks of shale, and contain the shallowest of the oil-producing zones. This zone correlates closely with the Vickers zone of the Inglewood field and the upper Wilbur zone of the Signal Hill field, the youngest producing sands of the region. The central part of the middle Pico is a thick bed of conglomerate, which ranges from 300 to 350 feet in thickness.

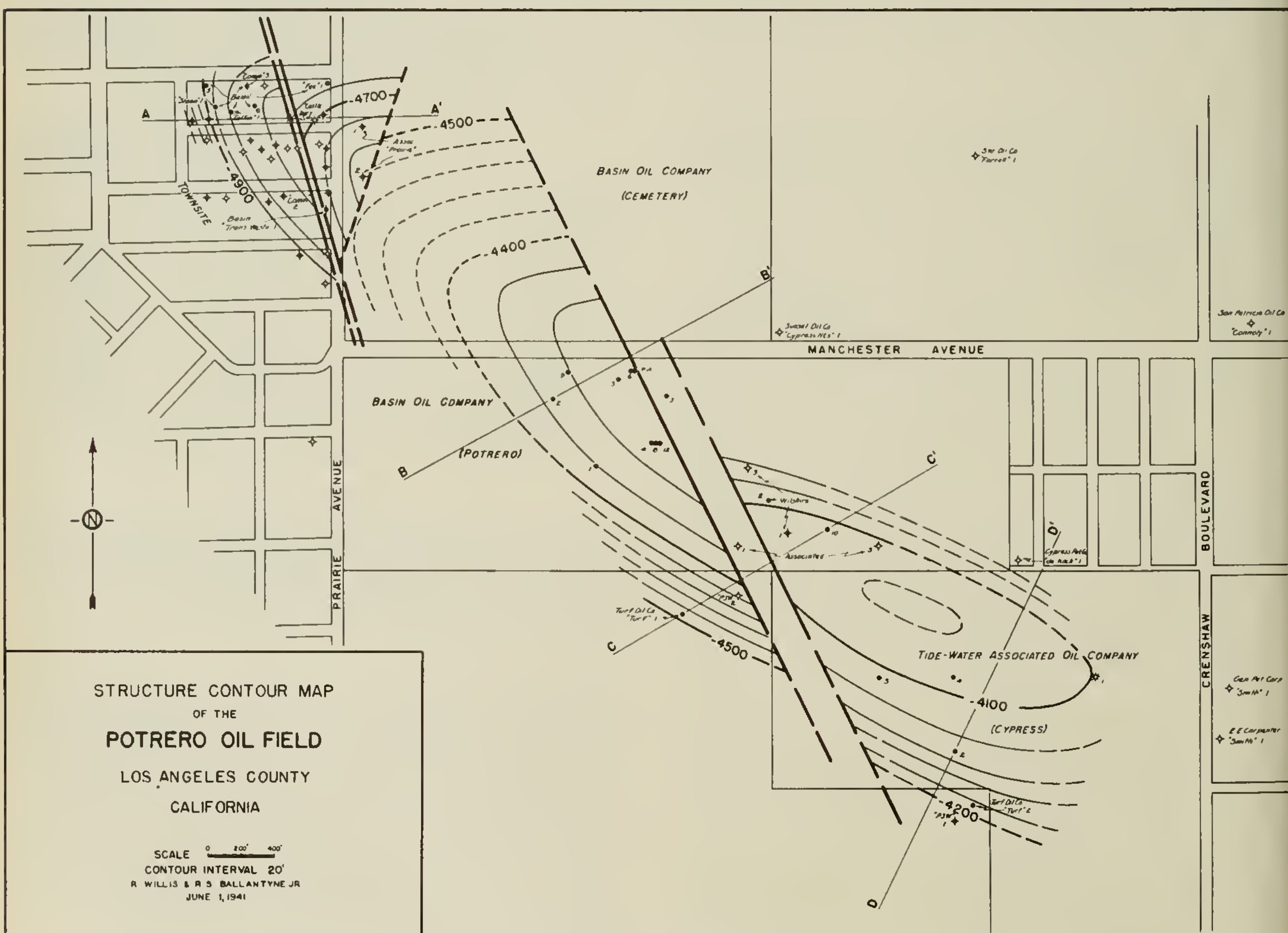


Fig. 129. Potrero oil field: structure map.

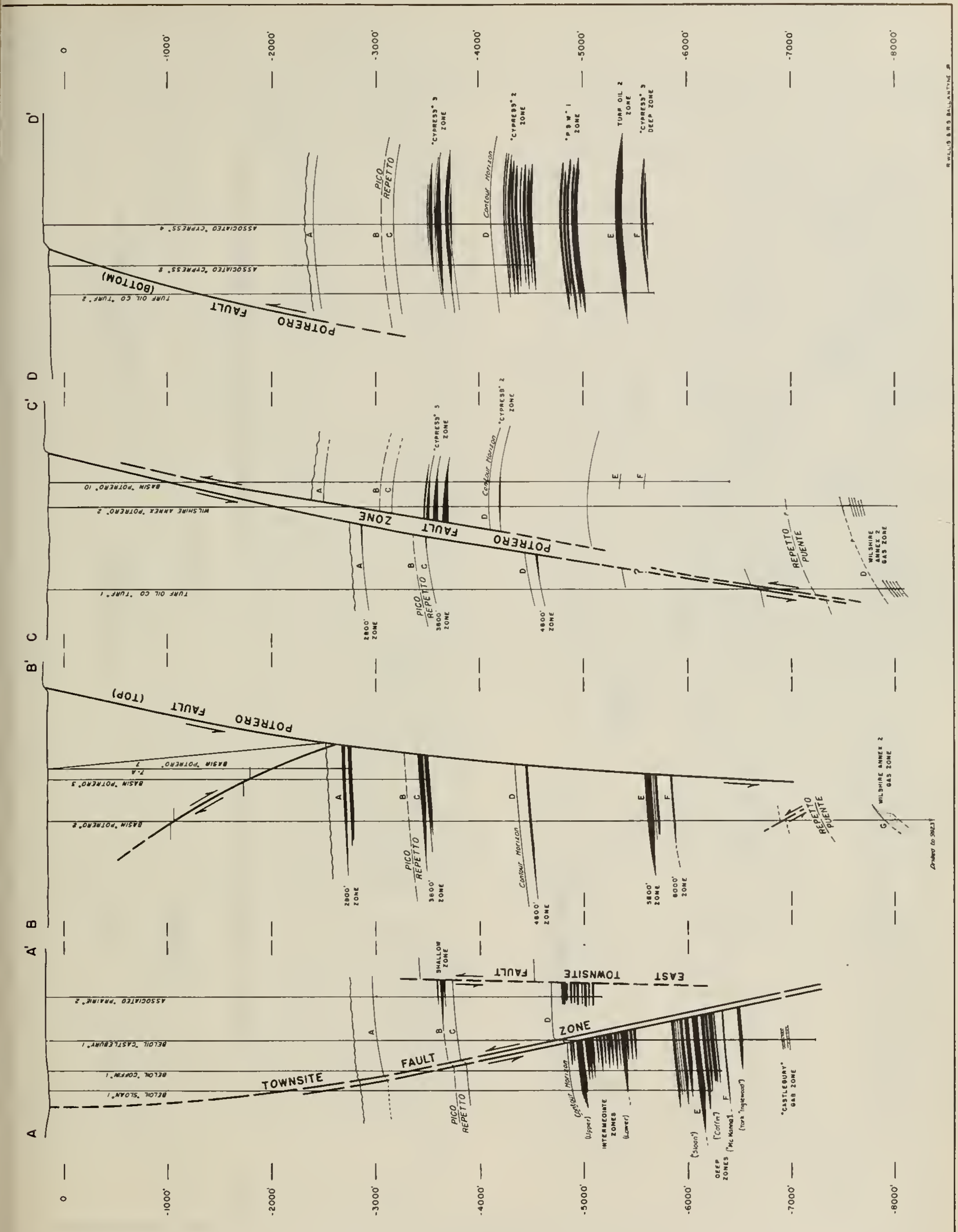


Fig. 130. Potrero oil field: structure sections.

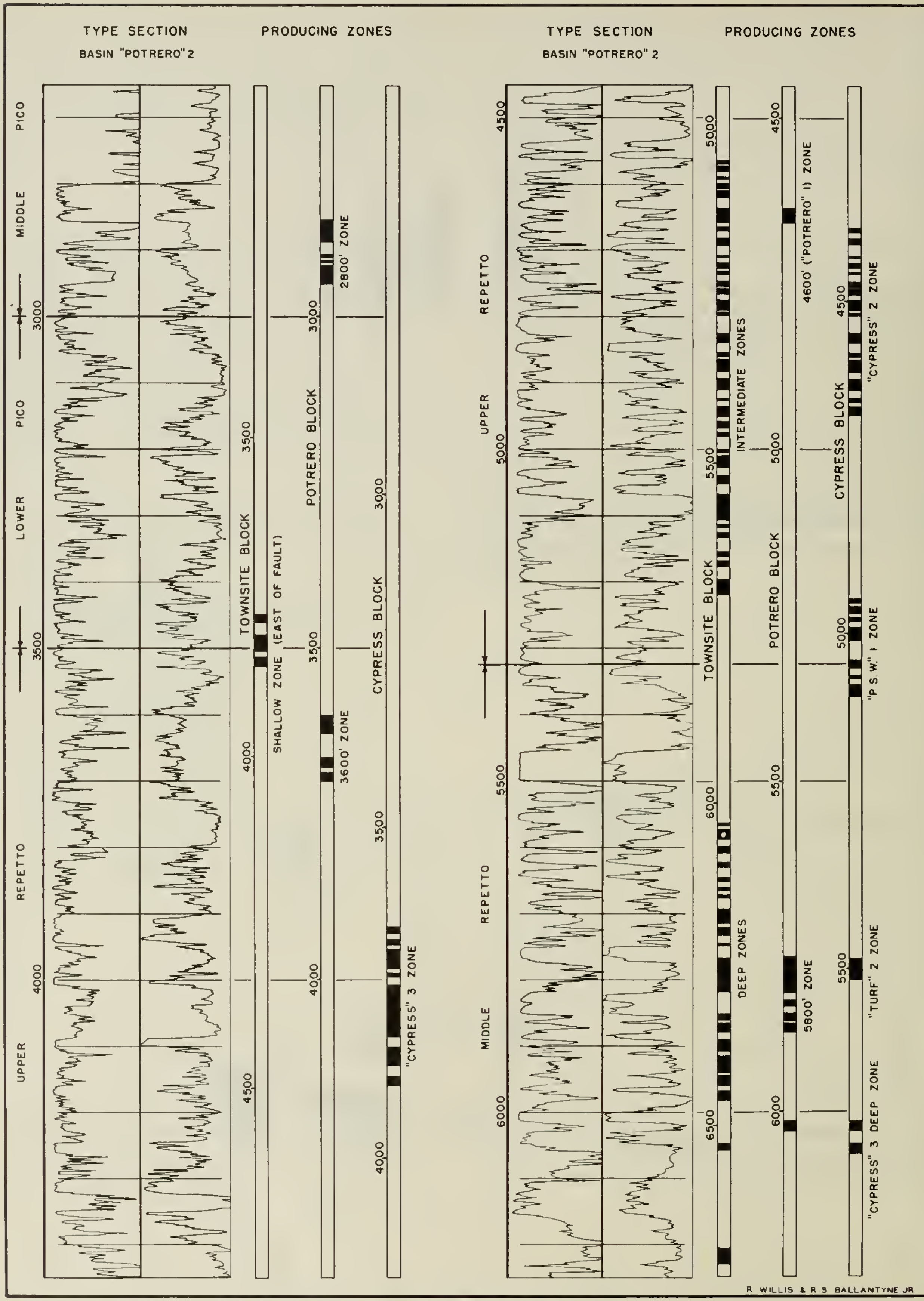


FIG. 131. Potrero oil field: Schlumberger logs.

Appearance of beds on the flanks and down the plunge of the fold, which are absent on the apex, directly under this conglomerate, suggests the presence of an unconformity.

The top 500 feet of the middle Pico are mainly soft greenish clay-shales. The upper Pico is quite sandy, and carries fresh water to a depth of 1,800 feet.

Pleistocene

This group consists of surface sands, gravels, and clays, from which the city of Inglewood obtains its water supply.

Oil Sands

As the gravity of Potrero oil is high, ranging from 32 to 51 degrees, the sands are very light in color, and it is difficult to distinguish the oil sand from water sand in cores. The carbon tetrachloride "cuts" range from light straw to light amber in color, and some sands with a high gas content show practically no cut.

Analyses show that the porosity of the less consolidated sands of the Pliocene ranges from 23 to 35 percent, and the permeability from 200 to 700 millidarcys. In the Miocene the porosity seldom exceeds 18 percent, and the sand is very "tight" the permeability rarely reaching 40 millidarcys.

There appear to be two distinct classes of oil sand, distinguished by their saturation, productivity, and extent. Though considerable intervals, locally measuring several hundred feet, contain some oil on the crest of each local structure, only a few of the sands have a high degree of saturation and wide drainage area. In the early development of the field there were no means of distinguishing between these, and large intervals were opened. As a result, wells came in for big initial production, but declined rapidly and soon went to water. Electric logging and core analysis have since provided criteria for differentiating between them, and it is now possible to select only the most prolific zones and to exclude even thin intermediate water-bearing stringers from the intervals opened to production.

It may be that carefully drilled wells, close to the faults on the axis of the fold, may eventually produce considerable oil from the secondary sands, but at present almost all production comes from the primary zones, and these will undoubtedly yield the bulk of the production of the field.

In only two or three cases do primary zones occur in the same sand body in more than one structural block, though in a general way oil saturation is found in the same parts of the section in all of them. This shows that accumulation has been subsequent to the faulting, otherwise oil would occur in the same beds on either side of the displacements. The faults probably developed simultaneously with the growth of the anticline, and they may have had an important function as channels up which oil could migrate. Accumulation in individual beds probably depended on the effectiveness of the fault seal opposite each sand body.

PRODUCTIVE AREAS AND ZONES

Cypress Block

History. The Cypress area is the largest of the four pools of the Potrero field, and was the first discovered. It includes the crest of the dome. The developed area covers about 60 acres.

Spasmodic wildcatting, based on topographic evidence of structure, culminated in the discovery of commercial production by the Tide Water Associated Oil Company. Their No. "Cypress" 1 was tested from October, 1927, to April, 1928, at various depths. It finally blew out of control, and has never since produced successfully. The first commercial well was the same company's No. "Cypress" 2, completed April 11, 1928, flowing 1,049 barrels per day of 47.2 degrees oil.

Drilling in this block was continued through 1932 by the Associated and Wilshire Annex Oil Companies, and resulted in six successful and four nonproductive wells. The former company's No. "Cypress" 4 was completed December 3, 1937. Drilling was resumed in 1940 by the Turf Oil Company and has continued to date with three new completions and one recompletion. No. "Cypress" 3 has been the most prolific well in the field. It has yielded more than half a million barrels of oil.

Productive Zones. The record of the zones which have been produced in each block is shown in Table 1. (See also cross-sections and electric log.)

The most prolific of all zones in the field to date is the Cypress No. 3 zone, the shallowest developed in this block. The sand bodies of this zone are thicker and coarser than in most, hence water encroachment has been easier, particularly on the flanks. That this zone still contains much recoverable oil is shown by the comparatively recent completion of Basin Oil Company's No. "Potrero" 10 for an initial production of 250 barrels per day of 51 degrees oil, early in 1941.

TABLE 1. RECORD OF PRODUCTIVE ZONES

	Interval in Basin No. "Potrero" 2	Wells completed in zone	Present producers	Gravity of oil (degrees)	Production: Barrels of oil
Cypress Block					
Cypress No. 3 zone	3925-4160	5	2	46-51	644,000*
Cypress No. 2 zone	4660-4870	1	1	47	308,000*
P. S. W. No. 1 zone	5230-5375	1	0	43	126,000
Turf No. 2 zone	5770-5800	1	1	46-48	12,000***
Cypress No. 3, deep zone	6015-6065	1	1	46	35,000**
Wilshire-Annex No. 2 zone	8250-8514	2	2	46-48	46,000*
Townsite Block					
Intermediate zones					
Upper zones	4560-4910	6	1	37-41	415,000*
Lower zones	5000-5270	5	1	38	35,000*
Deep zones					
Sloan zone	5560-5885	6	3	34-36	550,000*
Coffin zone	5895-6000	1	0	38	72,800
McKanna zone	6050-6100	1	0	35	15,000
York, Inglewood zone	6160-6210	2	0	38	60,000
Castlebury gas zone	6550-6620	1	1		
East Townsite Block					
Shallow zone	3440-3525	5	0	46	39,000
Intermediate zones	4665-5110	3	0	37-39	46,000
Potrero Block					
2800-foot zone	2855-2950	6	6	32-34 }	850,000** (4 wells in both zones)
3600-foot zone	3600-3700	5	5	45 }	
4600-foot zone	4633-4657	1	1	48	178,000**
5800-foot zone	5770-5880	3 }	1	43	148,000**
6000-foot zone	6015-6030	2 }			

* To October, 1940. ** To June, 1941. ***To April, 1941.

The Cypress No. 2 zone is in a stratigraphic interval which has yielded commercial oil in all four blocks. The primary saturation, however, covers a narrower interval than in the Townsite area, and the top of it lies just below the very prolific stringer which constitutes the entire 4,600-foot zone in the Potrero block. The sands of this zone are thin, and the section is predominantly shaly.

The P. S. W. No. 1 zone has not been opened on the higher part of the structure, but was produced only from this well, far down on the south flank, hence it still probably contains valuable reserves. The same is true of the Turf No. 2 zone, recently opened in approximately the same structural position. In the latter, and probably in most zones in this block, accumulation extends to a lower level on the south flank of the structure than on the north. Basin No. "Potrero" 10 is 30 feet higher structurally at this horizon than the Turf producer, yet it found no saturation in the zone. So far as is known, there is no fault barrier between the two. This sand is the only single sand body to carry a primary zone in each of the three main productive areas. It correlates with the main sand of the 5,800-foot zone in the Potrero block, and that of the Sloan zone in the Townsite block.

The Cypress No. 3 deep sand, discovered in No. "Cypress" 4, was first commercially produced in No. "Cypress" 3. The electric logs of these wells and of the Turf Oil No. 2 indicate that there may be other primary zones in the Cypress block below 5,000 feet, as yet untested. These were not saturated in Basin No. "Potrero" 10, but this well showed saturation in untested sands between 2,600 and 3,600 feet, not present in the Cypress wells. This indicates that the crest lies farther south in the deeper zones than it does in the shallower, probably due to the slight asymmetry of the fold, which is steeper on the north flank.

The Wilshire Annex Oil Company No. "Potrero" 2 discovered production in the Miocene in February, 1935. The yield has been mainly gas, with a little 47 degrees oil. Initial pressures were very high, and in spite of the low permeability of the sand the decline of the well has been very gradual.

Turf Oil Company well No. 1 is thought to have crossed the Potrero fault above the level of this zone and to be producing also from the Cypress block. Its production is similar to that of the Wilshire Annex well.

Townsite Blocks

History. The Townsite discovery well, Graham-Loftus No. "Blinn" 1, closely followed the Cypress discovery. It was tested May 8, 1929, but was never successfully produced. Intense townlot activity ensued during 1929 and 1930, decreasing in 1931 and dying in January, 1932. The first commercial completion was the Sunset Oil Company well No. "Inglewood Community" 3, which produced 1,835 barrels of 38.5 degrees oil per day. Thirty-four wells were drilled, and 22 were productive. Nine of these produced more than 50,000 barrels of oil. The number of profitable wells, therefore, was small, and though this area has yielded more than a million and a quarter barrels, it will probably never repay the cost of its development. It covers between 40 and 50 acres.

After 1932 a few wells continued to produce. Beloil Corporation Ltd. gradually acquired all of the active wells, and is now operating seven, six of which are small pumpers. The No. "Castlebury" 1 was recently deepened to the base of the middle Repetto, at 7,400 feet, and completed as a gas well at 7,100 feet. Initial production was 1,100,000 cubic feet of gas per day, with about 25 barrels of 37 degrees oil.

Productive Zones. Owing to the character of the development, it is difficult to determine which sands actually yielded the bulk of the production in the Townsite blocks. Wells were completed at all levels. No two wells set casing at the same point, and the intervals opened to production ranged from a few feet to as much as 300 feet, with one case on record of more than 500 feet. The successful producers, however, were confined to certain parts of the section and these have been summarized in Table 1.

The shallow-zone production occurs only east of the main Townsite fault, in the east Townsite block. The oil sands lie at the very top of the Repetto, and this is the only block from which these particular beds have produced. Actually the recovery was small, and no profitable wells were completed in them, though the Getty P-1 had an initial production of 1,900 barrels per day of 46.5 degrees oil. It seems likely that the drainage area between the two faults was too small for sustained production, or that the water drive essential to long life was cut off by the Townsite fault on the west, so that when the high initial gas pressure was exhausted production ceased.

More wells were completed in the intermediate zones than at any other level. It appears likely that there were two primary sand bodies in this interval, one approximately at the horizon of the 4,600-foot zone of the Potrero block, and one about 600 feet lower, which is not productive elsewhere. The former yielded the Seeberg and No. "Community" 3 wells which started the townlot boom. The latter was opened, together with poorer sands above and below it, in the Hassen and Harbrecht wells. The recent electric log of the Castlebury well shows that this sand still contains good saturation, and when opened it produced at the rate of 350 barrels per day, but went to water in less than a week. This is thought to be due to the proximity of the old holes in which a larger interval was opened, and which act as channels for water into this zone. It illustrates the difficulty of getting clean production today from any part of this riddled block.

In the east Townsite block a little production was recovered from the intermediate zones, but the wells were short-lived.

The deep zones have been divided on the basis of the intervals in which certain wells were completed. By far the most profitable is that from which the Sloan and York "Fee" wells produced. This includes the sand corresponding to the Turf No. 2 and 5,800-foot zones in the other blocks. Recent electric logs still show good saturation in this sand, and it probably yielded the bulk of the production taken from the larger interval.

The Coffin and York-Inglewood zones show only fair saturation on these electric logs, and are not considered primary zones. The successful production of a single well in each of these indicates the possibility for profit in other sands of secondary character, in well-located wells which can be recompleted by carefully selected gun-perforating, after the primary zones have been exhausted. The Coffin well came in for more than 1,000 barrels per day.

The fact that the Townsite blocks produced about the same amount of oil as has been recovered from each of the other two to date, in spite of the methods used in developing it, indicates that it might, with careful engineering, have proved capable of a much larger yield. Even so it is thought that some additional drilling, away from the older wells, with selective completion in the primary zones, may still prove profitable.

Potrero Block

History. The Potrero block, situated between the Cypress and Townsite areas, was the last to be discovered. The first completion was Basin Oil Company well No. "Potrero" 1, which came in May 26, 1938, for 515 barrels of 48 degrees oil through 10 feet of perforations in a sand less than 25 feet thick. Since then eleven wells have been completed, of which nine are still producing. No. "Potrero" 2 is now testing the deeper zones. The Trans-Western well, whipstocked from the Townsite under the cemetery to the 5,800-foot zone, is idle. Two of the Potrero wells were also directed under Manchester Avenue, and extended the productive area of the upper zones under the cemetery.

As of June 1, 1940, this block has produced some 1,177,000 barrels of oil, the largest single well, Basin Oil Company's No. "Potrero" 3, yielding 258,000 barrels. The developed area covers about 40 acres.

Productive Zones. The 2,800-foot zone is the shallowest developed in the field, and one of the most prolific. It also yields the lowest gravity (32 to 34 degrees) oil. It contains very little gas, but core analyses show a remarkable saturation, the oil content actually exceeding the water content in the better samples. Due to the high formation pressure and shallow depth wells flow with almost no gas. This horizon is not productive in the other blocks, though there is some saturation in it in the Cypress area.

The 3,600-foot zone is comparable in yield and productive area with the top zone. No. "Potrero" 3 was completed in it, and to date is the best producer in the block. In four wells these two zones have been opened together. None has been permitted to produce at a greater rate than 450 barrels per day, but their probable potential may be estimated by the performance of No. 8 when part of the crown block was dropped and knocked a nipple off the casing. The well blew out, filled two cellars, and put an undetermined amount of oil on the golf course in the hour and a quarter before it was brought under control. The estimated rate of flow was at least 6,000 barrels per day.

The 4,600-foot zone, opened only in Basin No. "Potrero" 1, contains only a single stringer of highly saturated sand which averages about 20 feet and shows a maximum thickness of 24 feet in the wells penetrating it. In 3 years this well has produced 178,000 barrels, and is still yielding more than 100 barrels per day, with no appreciable decline. The width of the productive strip limits its potential drainage area to about 15 acres. Its yield to date, therefore, has been not less than 500 barrels per acre foot.

The 5,800-foot zone includes one large sand body, already noted as productive in the other blocks, with thinner stringers below. The thin sand at 6,000 feet has been opened with these, in two of the three wells to this level. The thinner beds, though apparently holding only secondary saturation, showed good initial production in Basin No. "Potrero" 2 and 4 wells, and though they did not repay the cost of these wells, they showed the possibilities in the secondary zones. The main sand, opened in No. 2 and in the Trans-Western well, has proved disappointing, possibly due to local conditions of faulting and drainage.

Electric logs have shown considerable thicknesses of oil sand with secondary saturation in this block, particularly between the upper two zones, and these may be made to yield additional reserves, at small expense, by gun-perforating in the well highest on structure, after the primary zones are exhausted.

DRILLING AND PRODUCTION PRACTICE

In the Potrero field 1,000 feet of surface casing is set to protect the shallow fresh-water sands. Wells have been drilled to a great variety of depths below this point, and casing programs have not been standardized. Practices in the Townsite area have already been touched upon. Casing was set above the zones, and wells were completed either with long perforated liners or with open hole below the shoe. Some of the latter were among the best producers. More recently, however, the need for selective completion has been recognized. Casing is now usually set through the productive interval, often through more than one zone. The section is carefully examined by electric log and core analysis, and the intervals showing the highest saturation are opened by gun perforating.

As the leases are held in large blocks, there is practically no offset problem in the field today. This permits the spacing of wells with a view to obtaining the maximum ultimate production at the least expense. As indicated in Table 1, there are several zones in which only one well has been completed, giving each a drainage area of 20 to 40 acres. The closest spacing in the Cypress and Potrero blocks is about one well to 10 acres.

Nearly every successfully completed well in the field flowed at the outset. Gas-oil ratios have varied greatly, from as low as 200 cubic feet per barrel to 3,000 or more cubic feet per barrel. In the Miocene they are much higher than this. In the Townsite area all wells but the Castlebury are now pumping, as are the older wells in the Cypress block. In the Potrero block six of the nine producers are now on the compressor, flowing on the same system by the intermitting method whereby gas is supplied alternately to one well after the other by electric timing devices. The other three wells are still flowing.

DOMINGUEZ OIL FIELD

By S. GRINSFELDER *

OUTLINE OF REPORT

HISTORY

The Dominguez oil field, one of the important oil fields of the Los Angeles Basin, is situated 14 miles south of the City of Los Angeles, in Los Angeles County. Dominguez was discovered in September, 1923, when the Union Oil Company of California completed its well "Callender" 1-A at a depth of 4,068 feet for an initial production of 1,193 barrels per day of 32° A.P.I. gravity oil.

The history of this field has been one of systematic development, made possible through the cooperation of the four principal operating companies and the fairly large size of the productive leases. By January 1, 1941, a total of 324 wells had been drilled, of which 44 had been abandoned. To this date, 121,800,000 barrels of oil have been produced; during the month of January 1941, an average of 20,151 barrels per day was produced by 214 wells under curtailment. The lateral area developed includes approximately 1,000 acres. In the vertical section penetrated between 3,750 and 7,600 feet, eight oil zones have been delineated. An average of four strings of tools has been in continuous operation since 1938.

The estimated future production for Dominguez places this field as the fourth largest reserve in the Los Angeles Basin.

STRATIGRAPHY

Paleontologists have detected two disconformities and one unconformity above the top of the oil-producing zones, but no unconformities have been noted below the top of the uppermost oil zone.

The sequence of sedimentation within the developed area is remarkably consistent from the top of the First Callender zone to the top of the Eighth Callender zone. Beds having a thickness of 20 feet or more are traceable throughout the field, and, in many instances, thinner beds can be traced without difficulty.

There are only minor changes in the character of the sediments within the oil zones. This applies not only laterally, but also to the range in the vertical column. The sands in the Repetto become slightly coarser in texture to the southeast. A more marked change occurs in the shales in the vertical column. The soft, firm to medium-hard greenish-brown shale occurring in the First to Fifth Callender zones becomes harder and darker in color in the middle of the Fifth Callender zone. Many of the shales below the Fifth Callender zone are either brownish-black or black in color. Both the shales and sands are harder and show increased compaction with depth.

A significant feature pertinent to the thickness of sediments is that each bed in the central downthrown block is relatively thicker than those in the upthrown east and west blocks. It is believed on the basis of the data available that continued deposition occurred during this period of movement displacing the central block.

One of the deepest wells to date, the Union Oil Company "Callender" 50, was drilled to a depth of 10,435 feet, approximately 4,700 feet below the top of the Miocene. This is not equivalent to 4,700 feet of stratigraphic penetration below the top of the Miocene, however, for the faulting perceptible in cores from "Callender" 50 is of unknown magnitude.

STRUCTURE

The local structure of the Dominguez field is a faulted anticline; it is genetically associated with the forces that formed the Newport-Inglewood line of uplift. Dominguez Hill, which rises 150 feet above the floor of the basin, gives surface expression to the underlying structure. Mapping on a series of subsurface horizons indicates that the effect of the tectonic forces forming the structure was progressively greater with depth. Mapping on horizons as deep as 4,000 feet reveals an elliptical anticline with a northwest-trending axis, steep flank on the southwest, with dips of from 15° to 20°. Below 4,000 feet the effects of faulting become evident, and with depth develop as (1) a system of high-angle faults transverse to the anticlinal axis, and (2) a system of relatively lower-angle thrust faults. The high-angle faults have some measurable apparent vertical displacement, although it is believed that the main movement on these lines of shearing is roughly parallel with the Inglewood rift. The maximum apparent vertical throw that has been measured is 200 feet. The dip of the planes of thrust faulting steepen from approximately 30° on the crest of the structure to 75° on the southwest flank.

Aside from the complicated fault system developed below 6,000 feet, a conspicuous structural feature is the development of a graben in the central part of the productive area.

The detection of faulting has been aided greatly by a detailed micopaleontological study.

The effect of faulting on production down to the Fifth Callender zone (approximately 5,100 feet) is not as great as it is below this depth. The production characteristics of wells affected by faulting are (1) low rate of production, or (2) an abnormal presence of salt water. A preliminary study from microphotographs indicates that sands from wells in proximity to faulting and having low permeabilities have been subjected to crushing of the sand grains. The crushed material has partially filled the otherwise normal pore space.

KIND OF OIL

Dominguez crude varies from 29° to 33° A.P.I. gravity. It may be characterized as a low sulfur, high gasoline-content crude of asphalt base. The oil produced from the different zones is of essentially the same type, and analysis of the crude does not aid in zone identification.

* District Engineer, Dominguez District, Union Oil Company of California. Manuscript submitted for publication February 14, 1939. Revised by Mr. W. S. Eggleston August 12, 1941.

TABLE I

Stratigraphic Column and Producing Zone Characteristics, Dominguez Oil Field

Age	Formation	Division	Thickness (feet)	Oil zone	Depth, feet	Thickness (feet)	Percent SD	Remarks
Recent and alluvium			40±					
Pleistocene	Palos Verde		135±					Disconformity at base?
	San Pedro		495					Disconformity at base?
Pliocene		Upper	1144±					Unconformity at base.
	Pico	Middle	760±					
		Lower	334±					
				Gas zone	2650–3750	1100		
		Upper	1243±	First Callender	3750–4155	405	51	Top First Callender 770 feet below top of Repetto.
				Second Callender	4155–4343	188	58	
	Repetto	Middle	1208±	Third Callender	4343–4713	370	62	
		and	353±	Fourth Callender	4713–4953	240	71	
		Lower		Fifth Callender	4953–5667	714	48	
Miocene				Sixth Callender	5667–6091	424	35	Top Sixth Callender zone equivalent to top of Miocene.
		Upper	4723	Seventh Callender	6091–6636	545	55	
				Eighth Callender	6636–7461	825	58	

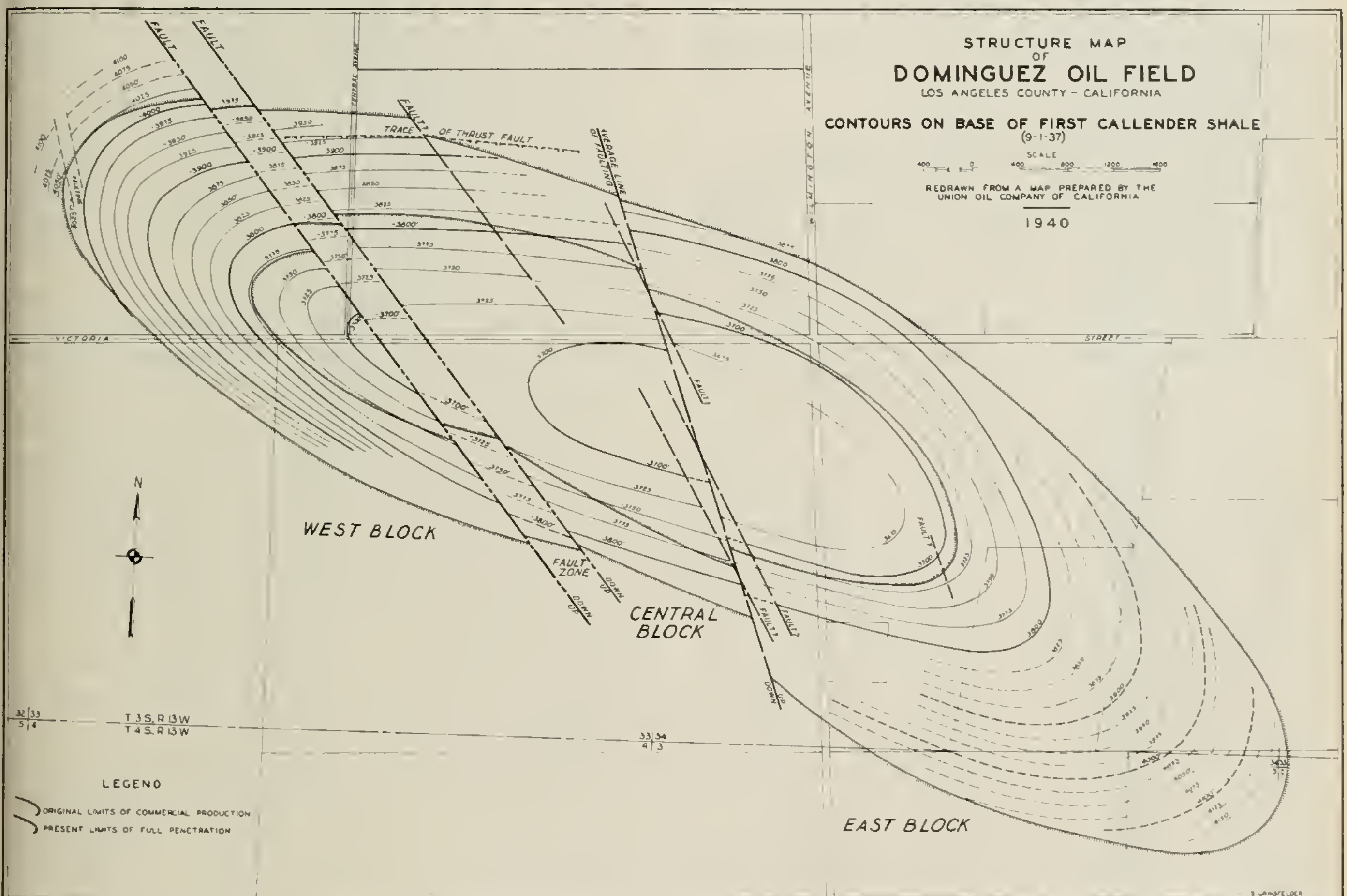


FIG. 132. Dominguez oil field · structure map.

LONG BEACH OIL FIELD

By Harry P. Stolz *

OUTLINE OF REPORT

HISTORY

The Long Beach oil field is located approximately 20 miles south of the City of Los Angeles, within the corporate limits of the cities of Long Beach and Signal Hill, Los Angeles County. Originally called the Signal Hill field, and often still referred to as such, it derived its original name from an outstanding topographic feature, Signal Hill, which rises to an elevation of 365 feet above sea level; from the top of this hill, it is related, the early Spaniards signalled ships at sea.

The area surrounding Signal Hill, just prior to the era of initial development, consisted of large tracts of land interspersed with many subdivisions. Although streets had been laid out, and in some cases subdividing actually completed, only a few residences had been built. Most of the land was used for the growing of grains and vegetables.

The first development within what is now known as the field proper, was initiated by the Union Oil Company of California. That company drilled its No. "Bixby" 1 well southeast of the intersection of Wardlow Road and American Avenue, in 1916. The well was drilled to a depth of 3,449 feet, but no commercial showings were noted and the well was subsequently abandoned. Further development was delayed until the Shell Oil Company commenced operations on its well No. "Alamitos" 1, located on the northeast corner of Hill and Temple Streets. This well was completed June 25, 1921, at a depth of 3,114 feet, with a water shut-off at 2,724 feet; initial production was 600 barrels per day of 22° gravity, 0.4 percent cut. The completion of No. "Alamitos" 1 as the discovery well of the Long Beach oil field presaged a scene of extensive townlot drilling, preceded only by the campaign of the Huntington Beach oil field, which had been discovered in 1920. Derricks sprang up over night; previously unheard-of bonuses and royalties were asked and received, free transportation was provided from Los Angeles and surrounding areas, and tents were erected wherein the prospective prospectors were beguiled by silver-tongued promoters.

The first stage of development of the field was confined to the south and east flanks of Signal Hill proper. The second stage of development was marked by the completion of Shell Oil Company well No. "Horsch" 1 on October 26, 1921. This well was located on the north flank of Signal Hill, and its completion caused the scene of intensive drilling to be shifted from the south and east flanks to the north and west flanks of the hill. Soon thereafter, the General Petroleum Corporation's well No. "Black and Drake" 1, located southeast of the intersection of Willow and Walnut Streets, came in out of control. This blow-out was the first indication that prolific production could be expected, and soon derricks were rising at a considerable distance northwest of the discovery well. By the end of 1922, as a result of completions of such wells as Shell Oil Company's No. "Cresson Community" 1 and the Texas Company's No. "Davidson 50-50" 1, the field was extended to the northwest, until it had a length of more than 3 miles. Gradually, deeper formations were exploited, so that by 1923 prolific oil-bearing horizons were practically insured to a depth of 5,000 feet. In the Fall of that year the field reached a peak production of 259,000 barrels per day.

In 1924 the proven area of the field extended from State Street to American Avenue; the flowing life of the wells which were then on production was apparently over, and many of them were placed on the pump. However, in 1925, a new spurt of development occurred in the northwest extension, or Los Cerritos area, northwest of Wardlow Road.

In 1927 a deep drilling campaign was initiated with the completion of the Richfield Oil Company well No. "Hass" 8. Located in the Lovelady area southeast of the intersection of Willow Street and Orange Avenue, and drilled to a depth of 5,317 feet, the well was completed November 18, 1926, at an entire rate of 2,500 barrels of oil per day. By 1929 more than 300 deep-zone wells had been drilled, some of which penetrated productive formations to a depth of more than 7,500 feet. Of particular interest was Shell Oil Company's No. "Nesa" 11, drilled to a depth of 9,280 feet, and unsuccessfully tested from 9,144 to 9,280 feet. The well indicated the existence of oil-bearing formations to what was at that time an unprecedented depth.

In 1936 a new extension (Hilldon area) of the field, located northwest of the productive area and south of the Cherry Hill fault, was discovered.

In 1938 the De Soto Oil Company drilled a well in the Lovelady area to a depth of 10,157 feet and discovered a new deeper zone, termed the De Soto zone. The well was completed flowing December 8, 1938, and subsequently put on gas lift for an initial production of 300 barrels per day of 28.9° gravity 0.3 percent cut, producing from the interval between 9,760 and 10,157 feet. The completion of this well indicated the existence of commercial production to even greater depths, in spite of the relatively poor structural location.

Since discovery, the field has been the scene of extensive townlot drilling, and its production has been remarkably sustained. To the end of 1938, the recorded production was 614,500,000 barrels of oil, produced

* Stanley and Stolz, Los Angeles, California. Manuscript submitted for publication July 10, 1939.

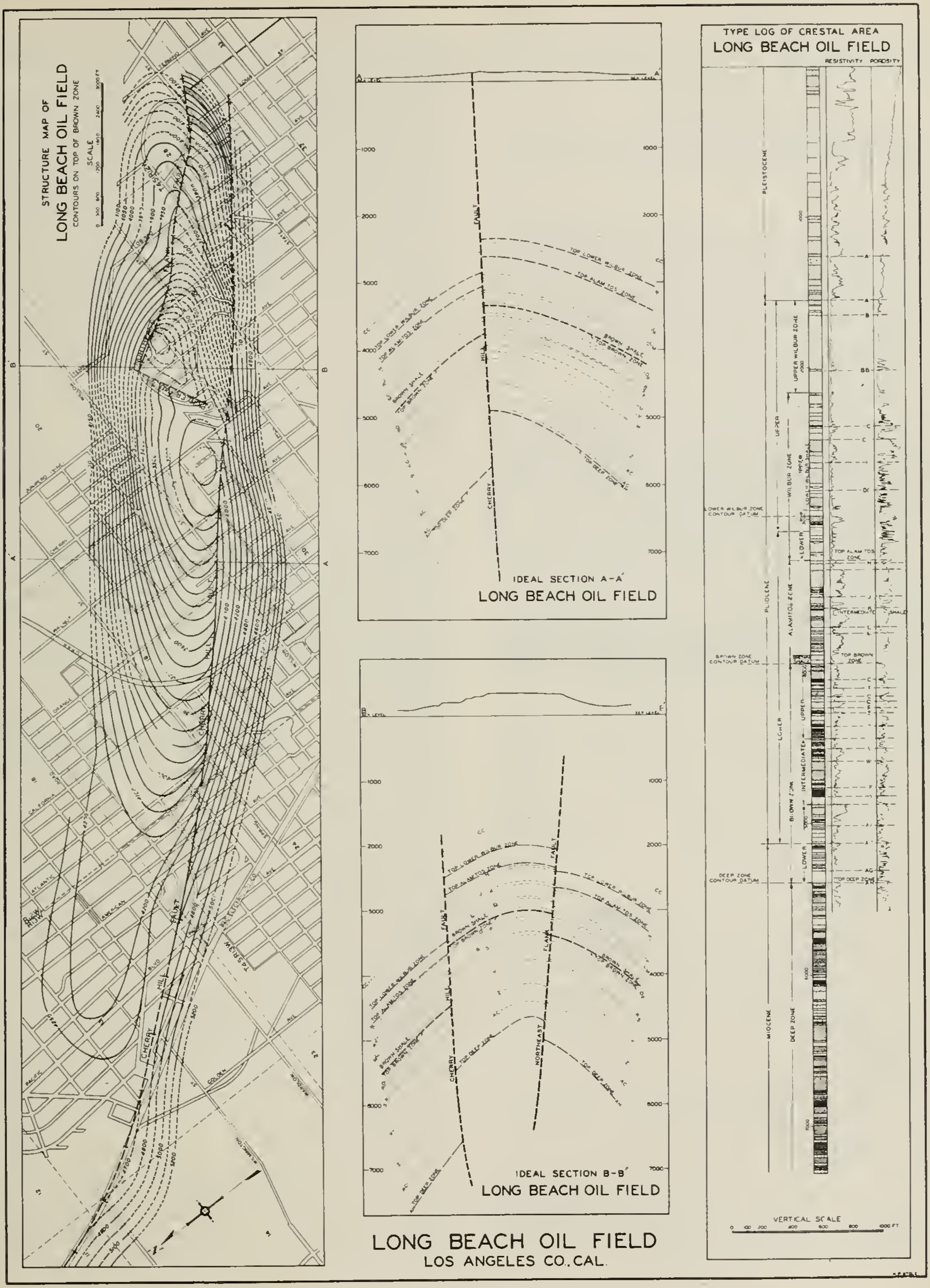


FIG. 133. Long Beach oil field; structure map; ideal sections; type log of crestal area.

from an area of 1,400 acres, resulting in an average total recovery of 440,000 barrels per acre. This enormous recovery is due to the close spacing of wells and the great thickness of productive horizons.

STRATIGRAPHY

The formations exposed at the surface are loosely consolidated sands and gravels of Quaternary age.

Pleistocene

The Pleistocene has been divided into Inglewood, upper San Pedro, and lower San Pedro formations. At the apex of the field the Pleistocene extends from the surface to a depth between 1,000 and 1,500 feet. The strata of the Inglewood formation make an unconformable blanket over most of the Long Beach oil field; they consist of reddish-brown nonfossiliferous beds from 5 to 20 feet in thickness, cemented in places, argillaceous on top, and sandier at the base.

The San Pedro formation consists of sands, gravels, and clays, the strata of which vary in thickness. The sands and gravels are often cross-bedded and interbedded with sands and clays. It is reported that a marine shallow-water fauna is found in the upper San Pedro. On the north flank of the structure, upper San Pedro fossils and mammal bones were found in deep trenches dug for sewers. Mastodon remains were found on the Cal-Mex property of the Apex Petroleum Corporation, Ltd., on the south flank of the structure, north of the cemeteries.

Because the shallow core data are insufficient, the contact between the Pleistocene and Pliocene has not been definitely placed; it is possible that the Pleistocene lies unconformably on beds of the Pliocene.

Pliocene

The Pliocene is approximately 3,600 feet in thickness, and consists of alternating beds of sand, sandy shale, and shale, with occasional streaks of hard shell. The sands vary from fine, micaceous, flour-like sand, to very coarse-grained pebbly sand. The shales are mostly organic, largely brown and brownish-gray in color, with some beds of bluish-gray.

The Pliocene is divided into upper Pliocene (Fernando or Pico) and lower Pliocene (Repetto).

Upper Pliocene. The top of the Pliocene is represented by a shale complex 600 feet in thickness (upper Wilbur shale) consisting principally of fossiliferous, slightly sandy shales with thin streaks of sand. Below this shale complex is a series of alternating shales, sandy shales, and medium- to coarse-grained, loose sands and shells aggregating 1,150± feet in thickness, with shales predominant.

This series is also called the Wilbur zone. The bottom of the latter sequence represents approximately the base of the upper Pliocene, according to micropaleontological correlation.

The lower sands of the upper Pliocene were found commercially productive in portions of the crestal area and on the southwest flank of the structure. These shallowest productive sands of the field, 250± feet in thickness, are known as the lower Wilbur zone.

Lower Pliocene. The most important of the productive formations of the field are included in the lower Pliocene and are divided into two zones, the Alamitos and the Brown.

The Alamitos zone is composed of alternating sands, argillaceous sands, sandy shales, dark-gray and brown shales, and occasional hard shells, aggregating a thickness of 650± feet. The sands vary from medium- to coarse-grained and pebbly, some being micaceous and others slightly carbonaceous. There is little appreciable difference in appearance between the strata of the Alamitos zone and those of the Wilbur zone, except that in the Alamitos zone the sandy character increases somewhat and there is a greater proportion of sands than shales. The zone has been divided into the following sub-zones:

Name of Sub-Zone	*Stratigraphic Thickness in Feet ±*
Alamitos shale	30
Alamitos sand	20
H-I shale	45
I sand	175
J-K shale	70
K sand	125
L-M shale	40
M sand	150

Overlying the Brown zone, and at the base of the Alamitos zone, a shale body 70± feet in thickness occurs. This shale contains a distinctive micro-fauna and usually has a very hard shell several feet thick at its base; it has afforded a very convenient key horizon throughout the field, definitely determined by micropaleontological examination and interpretation of most drillers' logs. Termed the Brown shale, it is now used as the base for most of the correlations throughout the field.

The Brown zone is 1,450± feet in thickness; it extends to approximately 250 feet below the Pliocene-Miocene contact, which has been determined by micropaleontological examination of cores recovered from several wells. The zone has been divided into upper, intermediate, and lower Brown zones.

The upper Brown zone, about 500 feet in thickness, is distinguished by thick bodies of fine- to coarse-grained pebbly sands with occasional sandstone, shells, and alternating beds of dark-brown fossiliferous shales and sandy shales. It probably represents the most prolific portion of the Pliocene.

The intermediate Brown zone, also about 500 feet in thickness, is lithologically quite similar to the upper Brown zone. It has been frequently exploited simultaneously with the upper Brown zone, and in combination these zones represent the sandiest portion of the Pliocene in the field. Water encroachment has been more rapid in the intermediate Brown zone than in the upper Brown zone, and has accounted for the present classification.

The lower Brown zone, about 500 feet in thickness, is much more shaly than the upper portions of the Brown zone. The shales range from dark-brown fossiliferous material at the top to very dark and almost black at the bottom. The sands in general are finer grained and sometimes silty, and often well cemented.

Miocene

The top of the Miocene is some 250 feet above the base of the lower Brown zone. The actual Pliocene-Miocene contact may be unconformable or transitional. The Miocene is more indurated and interbedded than the Pliocene and is composed of sand, silts, and shales. The sands are harder than those of the Pliocene, on the whole finer and more distinctly bedded, more micaceous and often very carbonaceous, some being very tightly cemented. The shales are generally hard and carbonaceous, dark-brown or black colored, sometimes laminated and interbedded with thin partings of fine sand or silt. At depth these formations show a considerable amount of fracturing and slickensiding, possibly as a result of compaction.

The present known productive zones in the Miocene are the Deep zone and the De Soto zone.

The Deep zone lies wholly within the Miocene; its top has been arbitrarily chosen to correspond with the base of a distinctive shale bed identified by the AH marker on electrical logs; many of the lower water shut-offs of the Deep zone wells were obtained in this shale. The Deep zone underlying the crestal portion of the field has been exploited to a thickness of 2,500 feet, corresponding to an approximate depth of 7,500 feet below sea level. On the other hand, it appears that only the upper half of the Deep zone underlying the area to the south of the Cherry Hill fault has been produced, because of the substantial downthrow of this structural block. It is probable that the full productive thickness of this zone has not been definitely established.

The De Soto zone has only been exploited in the discovery well (De Soto Oil Company No. 1) south of Cherry Hill fault and in a relatively poor structural position. It is believed that all of this zone likewise lies within the Miocene. The total thickness of the Miocene sediments in the field has not been determined, but may exceed 15,000 feet, in depth.

STRUCTURE

The Long Beach structure is located on a tectonic line crossing the Los Angeles Basin from northwest to southeast, which is often referred to as the Newport-Beverly uplift. This uplift is also marked by the productive fields of Newport, Huntington Beach, Seal Beach, Dominguez, Rosecrans, Potrero, Inglewood, and Beverly Hills. On the surface this line of uplift is indicated by a general line of low hills; the more pronounced uplifts or domal structures are Long Beach, Dominguez, and Inglewood.

The topography of the Long Beach structure is due in large part to Recent tectonic movements. A scarp, which faces southwest, that of the Cherry Hill fault, can be followed for practically the entire length of the field from the Hilldon area to south of State Street. The main topographic feature is, of course, Signal Hill; another is the isolated Reservoir Hill at the southeast end of the field.

The Long Beach field structure is a faulted, narrow, asymmetric anticline trending northwest, divided into distinctive areas by faulting. The major axis of the anticline has a general trend of N. 55° W., and crosses approximately through the crest of Signal Hill. Its plunge is gentler to the northwest than to the southeast, where it plunges from 10° to 15°.

The dips of the beds comprising the southwest flank are in general steeper than those on the northeast, dipping 40° to 45°, as compared with the 15° dip of the beds of the northeast flank.

The main faults in the field are the Cherry Hill fault and the Northeast Flank fault; they have been delineated by the subsurface data. A cross fault, the Pickler fault, has been postulated upon differences of productivity of wells.

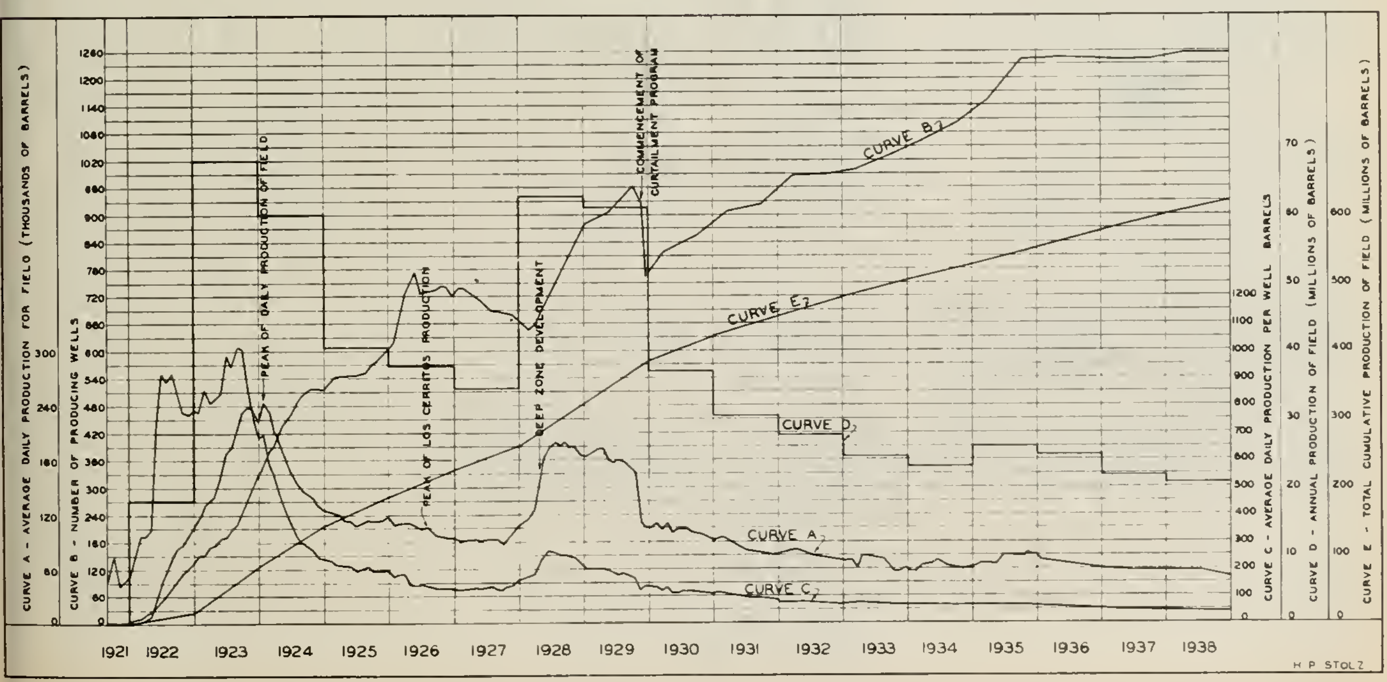
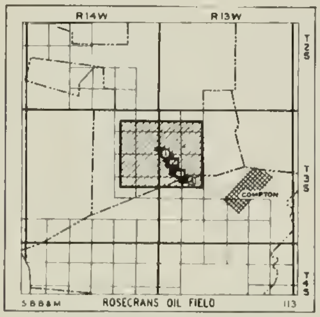


Fig. 134. Long Beach oil field: production graphs.

The Cherry Hill fault extends the entire length of the field with a maximum throw of 1,000 feet; the Northeast Flank fault extends from the east end of the field northwest to the Shell Oil Company Goddard lease where it is seemingly cut off by the Pickler fault; its maximum throw is 500 feet. The attitude and exact location of the Pickler fault are not yet known.

Minor faults are believed to exist parallel to the main faults and across the apex of the structure; but their exact location and extent are unknown. Information indicating faulting in the deeper Miocene beds is meager, but such faulting should be expected, since it is known to occur in other fields of the Los Angeles Basin.

CITATIONS TO SELECTED REFERENCES—Continued



Rosecrans oil field. Areas: (1) Athens; (2) Central; (3) Main Street; (4) South Rosecrans.

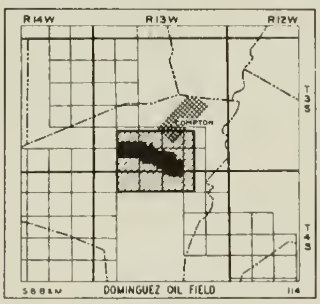
ROSECRANS OIL FIELD

Atwill, E. R. 40; Brown, C. C. 26; California Oil World 40b; 40g; 41b; Hight, W. 33; Hoots, H. W. 38; 39; Hoots and Herold 35; Huguenin, E. 26; 37; 39; Jensen and Robertson 28; McCollough, E. H. 34; Musser, E. H. 25a; Oil Weekly 37a; Stockman, L. P. 35i; 41c; Taff, J. A. 34; Thoms, C. C. 24; Vander Leck, L. 21, p. 140; Van Tuyl and Parker 41; Watts, W. L. 00; Wilhelm, V. H. 38; 39a; 41.

Athens Area
Wilhelm, V. H. 41; 41a.

Athens-Rosecrans (Rosecrans) Oil Field
Wilhelm, V. H. 38.

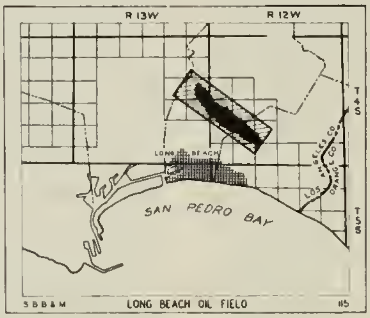
Rosecrans Area
Wilhelm, V. H. 41a.



Dominguez oil field.

DOMINGUEZ OIL FIELD

Atwill, E. R. 40; Bravinder, K. M. 42; Brown, C. C. 26; Dodd, H. V. 26; Eaton, J. E. 26c; Hight, W. 33; Hoots, H. W. 32a; Hoots and Herold 35; Huguenin, E. 26; 37; 39; Jensen and Robertson 28; Kirwan, M. J. 18; 18a; Masters, E. W. 38; McCollough, E. H. 34; Miller, H. C. 29; Oil and Gas Journal 41c; Oil Weekly 37; 37b; Sanders, T. P. 37d; Stockman, L. P. 34; 35i; 36i; Swigart, T. E. 24; Taff, J. A. 34; Thoms, C. C. 24; Uren, L. C. 37; Wilhelm, V. H. 38.



Long Beach oil field.

LONG BEACH OIL FIELD

Arnold and Loel 22; Brown, C. C. 26; Case and Keyes 23a; 24; Crown, Pierce, and Howard 32; Graser, F. A. 40; Hight, W. 38; Hoots, H. W. 32a; Hoots and Herold 35; Huguenin, E. 26; 37; 39; Masser, H. L. 22; 23; McCollough, E. H. 34; Miller, H. C. 29; Mills, B. 28; Mining and Oil Bulletin 23; Oil Weekly 37a; Prutzman, P. W. 13; Roberts, D. C. 27; 29; 30a; Roberts and Sweeney 30; Schwennesen, Overbeck, and Dubendorf 23; 24; Shayer, F. J. 23; Soyster, M. H. 22; Soyster and Van Couvering 22a; Stockman, L. P. 35i; Taff, J. A. 34; Thoms, C. C. 24; U. S. Geological Survey 34; Uren, L. C. 37; Van Couvering, M. 23; 26a; Van Tuyl and Parker 41; Willis, R. 38.

Frog Pond Area
Crown, Pierce, and Howard 32.

Hill District
Case and Keyes 23a; Roberts, D. C. 27.

Hilldon Northwest Extension
Hoots, H. W. 38; 39.

Los Cerritos Area
Crown, Pierce, and Howard 32; Jensen and Robertson 28; Van Tuyl and Parker 41.

Los Cerritos Extension
Jensen, J. 27a.

Lovelady Area
Case and Keyes 23a; Crown, Pierce, and Howard 32; Roberts, D. C. 27.

North Side Area
Crown, Pierce, and Howard 32.

North West Extension District
Case and Keyes 23a; Roberts, D. C. 27.

Painted Hills Area
Crown, Pierce, and Howard 32.

Pepper Drive and Wardlow Road Area
Crown, Pierce, and Howard 32.

Signal Hill Area
Cabeen and Kelly 41; California Oil World 37f; 38c; Crown, Pierce, and Howard 32; DeLong, J. H. Jr. 41; Hoots, H. W. 39; Jay, M. 31; Jensen, J. 27a; Killick, V. W. 22; Lamp, The 23; Masser, H. L. 23; Oildom 23; Reed, R. D. 32; Russell, S. 31; Shayer, F. J. 38; Stockman, L. P. 35i; Vander Leck, L. 21; Wilhelm, V. H. 38; 39a.

Southeastern District
Case and Keyes 23a; Roberts, D. C. 27.

State Street and Obispo Avenue Area
Crown, Pierce, and Howard 32.

West Central District
Case and Keyes 23a; Roberts, D. C. 27.

LONG BEACH HARBOR AREA

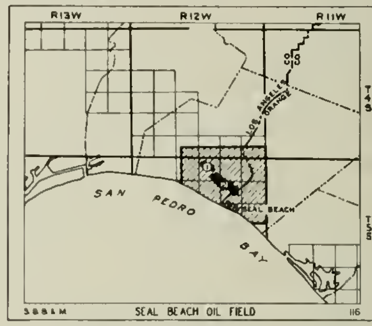
Grasser, B. A. 38.

SEAL BEACH OIL FIELD

Barnes and Bowes 30; Cadle, A. 28; Copp, W. W. 27; Copp and Bowes 27a; Hight, W. 33; Hoots, H. W. 32a; Hoots and Herold 35; Huguenin, E. 26; 37; Jensen, J. 27a; Jensen and Robertson 28; Miller, H. C. 29; Stockman, L. P. 35i; Taff, J. A. 34; Wagy, E. W. 27.

Alamitos Heights (Alamitos) Area
Cunningham and Hardy 27; Eaton, J. E. 27; 27a; Hight, W. 33; Jensen, J. 27; McCollough, E. H. 34; Rogers, R. G. 27; Wagy, E. W. 27.

Seal Beach Area
Cunningham and Hardy 27; Jensen, J. 27; McCollough, E. H. 34.



Seal Beach oil field. Areas: (1) Alamitos Heights; (2) Seal Beach.

SEAL BEACH OIL FIELD

By Glenn H. Bowes*

OUTLINE OF REPORT

HISTORY

Seal Beach oil field is located about 3 miles east of the center of the town of Long Beach, between the Long Beach and Huntington Beach oil fields, in Los Angeles and Orange Counties. It is one of the prolific producers of the Newport-Inglewood line of folding, which extends northwest for 40 miles across the Los Angeles Basin.

Wildcatting was done in the vicinity of Seal Beach for more than 5 years, at the expense of 13 dry holes, prior to discovery. Commercial discovery was made in August, 1926, by Continental Oil Company (Marland Oil Company) well No. "Bixby" 2, which was completed flowing 1,240 barrels per day of 23.8° gravity clean oil from a depth of 4,427 feet. The field production peak of 75,000 barrels a day was attained in June, 1927, and was largely controlled by rapid development of the townlot area of Alamitos Heights. This peak was followed by lesser peaks of 70,000 and 50,000 barrels a day, which were reached in September, 1927, and July, 1929, respectively.

STRATIGRAPHY

The stratigraphy of the Seal Beach field is similar to that of other fields along the Newport-Inglewood line of folding.

The most recent formations consist of 1,200 feet of soft, bluish-gray silts and clays containing streaks of loosely consolidated sands and gravels of Pleistocene and upper Pliocene age. These beds lie on interbedded sands and bluish-gray shales grading downward to brownish-gray shales of Pliocene age, which have a thickness at Seal Beach of 5,000 feet. It is within the lower 1,450 feet of Pliocene and the upper 900 feet of Miocene that the major oil accumulations occur.

The Pico and Repetto formations are represented along the axial area by thicknesses of 2,900 and 2,500 feet respectively. Off structure in a northeasterly direction, Pliocene sediments thicken greatly. The upper 1,325 feet of the Repetto formation thickens more than 700 feet in an off-structure distance of 2,450 feet.

The Repetto lies on rocks of Miocene age (Puente formation) with no discordance in dip. Puente strata have been penetrated approximately 3,200 feet. The upper 2,000 feet of this formation consists of medium-grained to silty sands interbedded with brown and black platy to massive shales. The lower 1,200 feet differs from the upper 2,000 in that the sands are harder and have a denser appearance. The shales are also harder and much darker.

STRUCTURE

The oil fields along the Newport-Inglewood line of folding are similar structurally, most of them being contained in elongated domes which were formed by folding and contemporaneous faulting.

The productive structure of Seal Beach field consists of two elongated domes separated by a non-productive saddle. The subsurface contours on the accompanying figures represent the top of the Selover zone, the best marker at the base of the relatively thick Selover shale. As the map shows, a fault trending parallel to the fold cuts the structure lengthwise. This fault dips with a high angle to the northeast, and in the easterly dome, where the oil zones are well defined on each side, it is known to have a downward displacement of 150 to 200 feet. In the smaller westerly dome the amount of vertical displacement is less, but the fault terminates production. Producing wells indicate that there is no interwell relation between producers on opposite sides of the fault.

It is probable that the Seal Beach fault has been an avenue of migration, at least to some degree. This is suggested by the fact that oil occurs slightly higher stratigraphically in the eastern dome than in the western dome, where the lithologic breaks are practically identical.

It is of interest to note the extent to which the subsurface structure is reflected in the physiography of the area. Alamitos Heights and Landing Hill, which attain elevations of 80 and 60 feet respectively, are terminal remnants of a topographic swell which was produced by the later stages of diastrophic activity; here Pleistocene sediments occur very close to the surface. These slopes indicate the nature of the folding since the deposition of the Timms Point formation. San Gabriel River is antecedent to the later stages of folding and was probably more or less controlled by the saddle between the two high parts of the structure.

The Seal Beach fault is also reflected in the topography, although it is not so apparent as the arching. The low scarp slightly offsetting the surface of Landing Hill together with the small fault valley and scarped hill through Alamitos Heights and Recreation Park all occur on a northwestward-trending line and constitute the surface evidence of the Seal Beach fault. This fault may also be traced farther to the northwest beyond the arched surface of Seal Beach to the eastern extremity of the Long Beach structure where it is well defined by a scarp.

It is believed that faulting along the Seal Beach anticline is more or less contemporaneous with the folding. Topographic evidence and subsurface structure suggest that movement along the fault was generally in a vertical direction; it is not known to exceed 200 feet. Although displacement is slight, the faulting probably increases with depth; the folding also increases downward, as indicated by the steeper dips at depth, and the

* Continental Oil Company. Manuscript submitted for publication February 8, 1938.

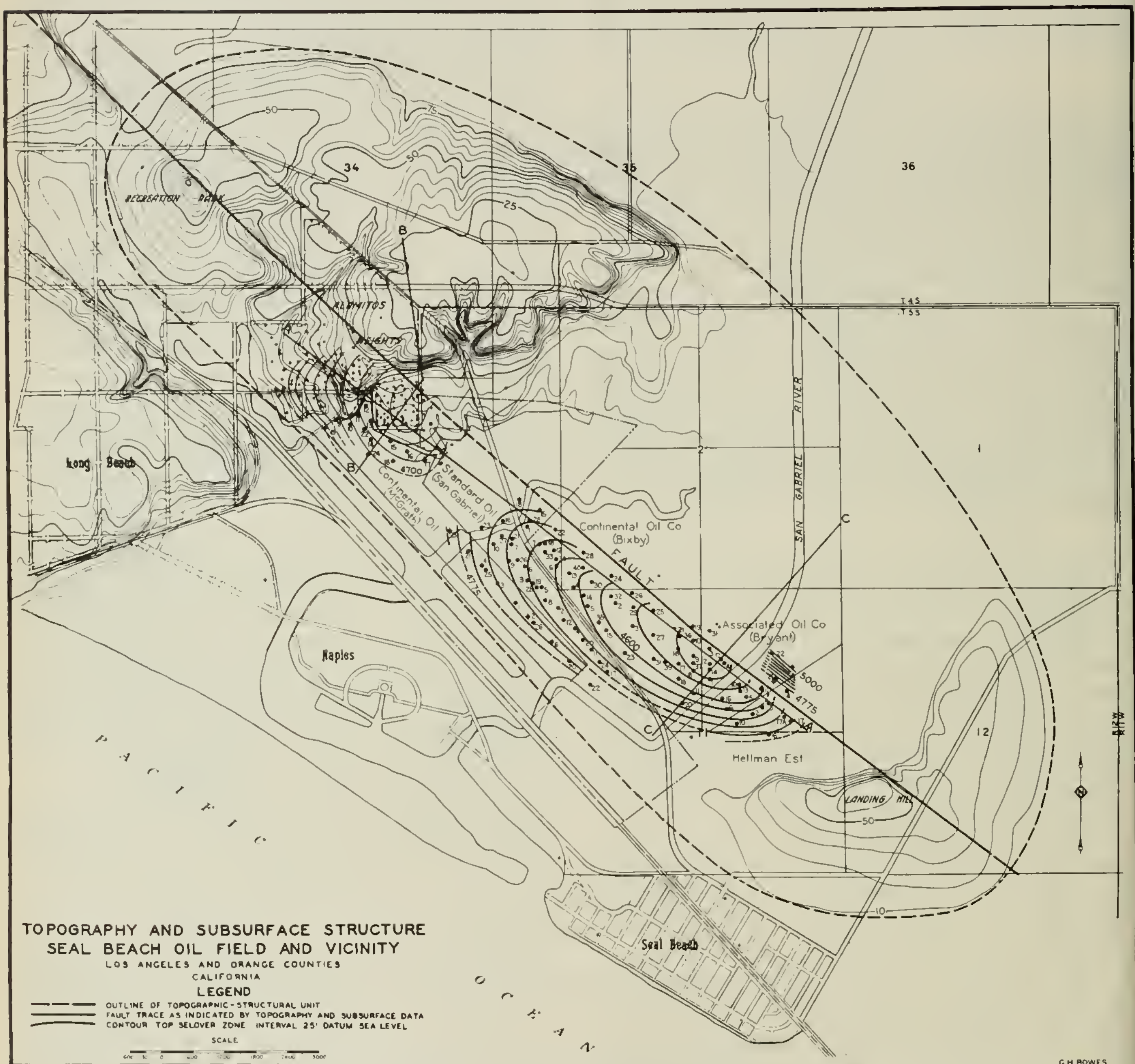


FIG. 135. Seal Beach oil field: topography and subsurface structure.

off-structure thickening of lower Pliocene beds. Structural and stratigraphic conditions suggest that diastrophic activity began before the deposition of lower Pliocene sediments.

PRODUCTIVE HORIZONS

The oil zones of Seal Beach oil field, with the exception of the Deep zone and the lower portion of the McGrath zone, are highly prolific. The Wasem zone has the greatest areal extent, and the Bixby zone the least, the latter being present only in the eastern dome. The accompanying columnar section shows lithology and maximum thicknesses of oil zones at Seal Beach, and the cross-sections show the approximate original extent of these oil zones. Wells producing from the prolific zones were drilled to various depths between 4,400 and 6,900 feet.

The Seal Beach field is 11½ years old, and has produced 79,065,224 barrels of oil from 249 wells to January 1, 1938.

At present the field is producing 9,420 barrels of oil per day, of which 7,670 barrels are from the main eastern dome.

Zone	*Initial yield barrels per day*	*Initial gravity*	*Gas content gal. per M. C. F.*	*Initial gas-oil ratios, cubic ft. per barrel oil*	*Gas content oil per cent*
Bixby	1,800	22°-25°	1	500	14.5
Selover	2,000	25°-28°	2-4	1,100	22.5
Wasem	2,000	28°-32°	1-4	1,400	28.0
McGrath	1,000	28°	4	1,600	29.0

Eighteen of the wells have produced in excess of 1,000,000 barrels of oil, and seven have exceeded 1,500,000 barrels.

The proved area includes 440 acres; past production per acre is 179,694 barrels.

Total Field Production

Zone	*Production barrels*	*Proved acreage*	*Production per acre barrels*
Bixby	6,284,693	175	35,912
Selover	21,172,300	400	52,931
Wasem	42,428,107	440	96,427
McGrath	9,180,124	250	36,720
Total	79,065,224	440	179,694

It is estimated that the Seal Beach field has a future production of 21,000,000 barrels, and will ultimately produce 100,000,000 barrels of oil.

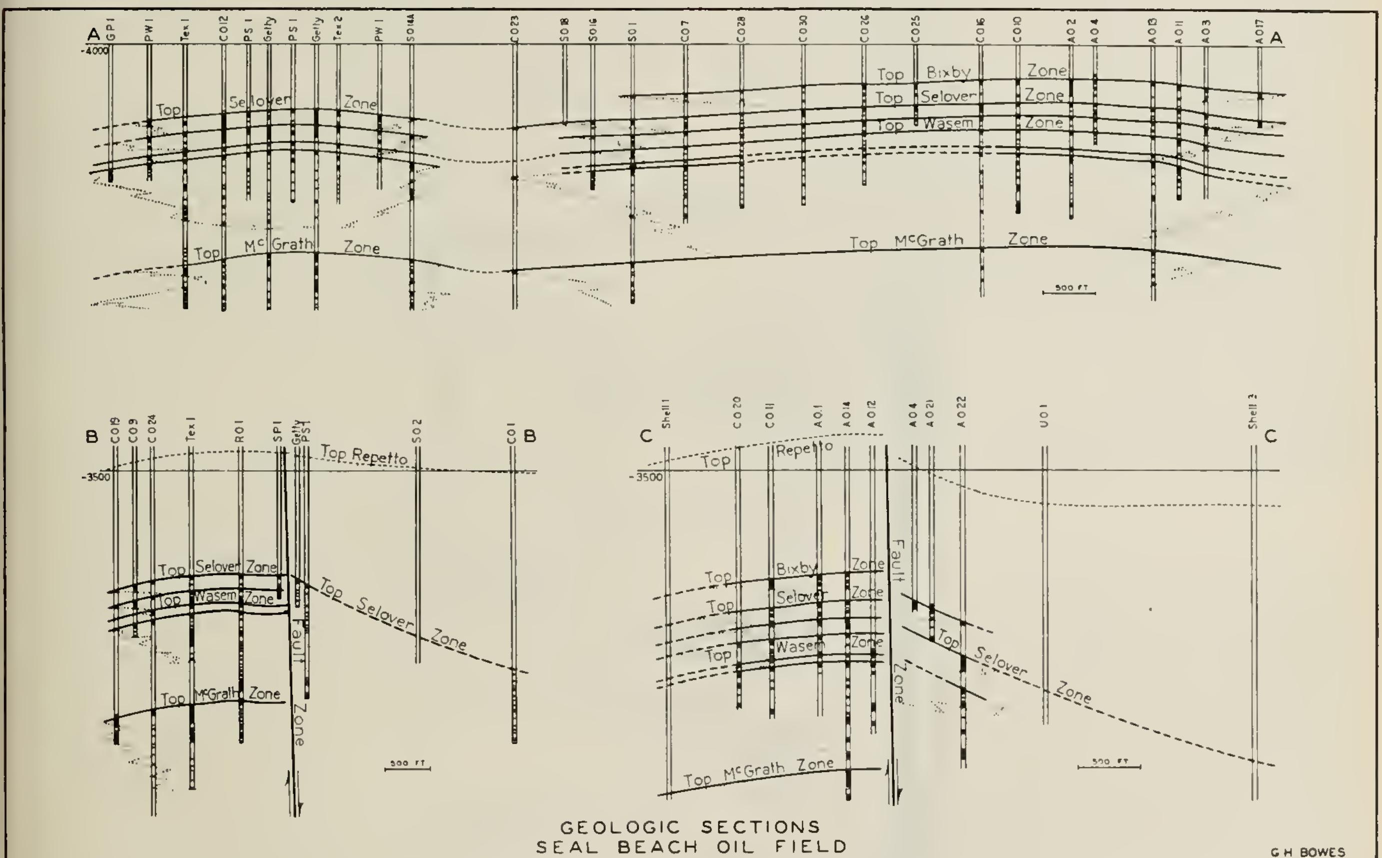


FIG. 136. Seal Beach oil field; geologic sections.

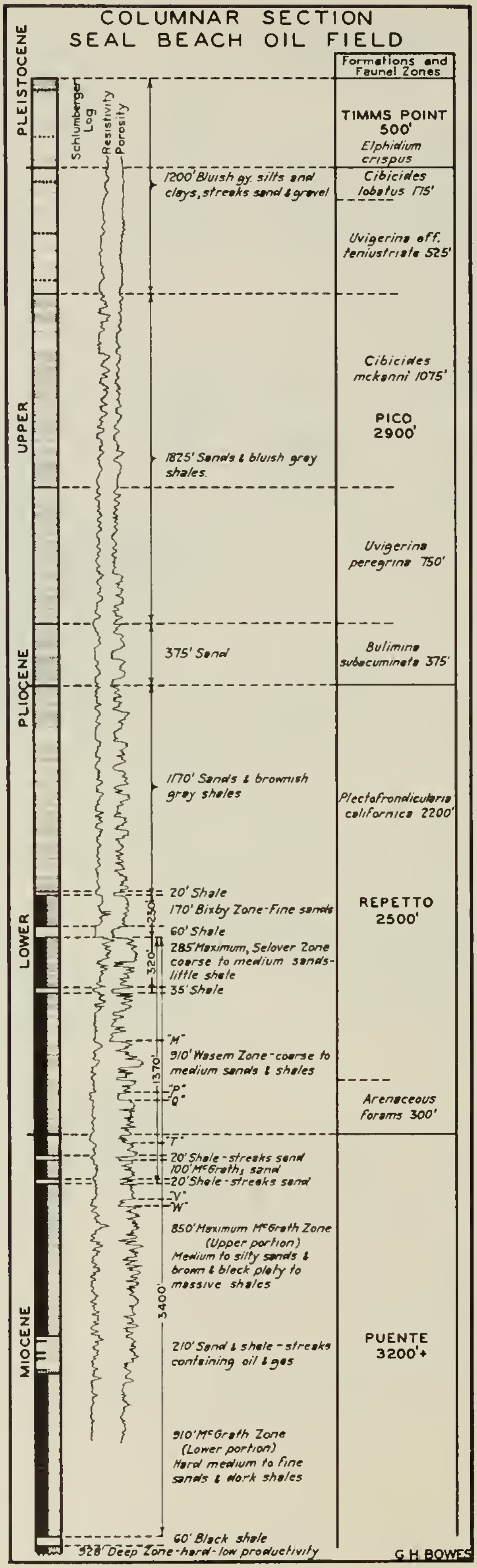


FIG. 137. Seal Beach oil field: columnar section.

HUNTINGTON BEACH OIL FIELD

By D. K. Weaver * and V. H. Wilhelm **

OUTLINE OF REPORT

HISTORY

The Huntington Beach oil field is situated 41 miles southeast of the town of Los Angeles on a high point on the coastal fold close to the south edge of the Los Angeles Basin, in Orange County. Its presence was suggested by gas encountered in water wells, and by the relatively high topography, which was believed to have a direct relation to underground structure.

Huntington Beach is probably the most complex field in the Los Angeles Basin, and has many structural problems yet unsolved. It may be said to consist of four separate fields (the Old field, Main Street field, Surf area, and Townsite Tideland area, which includes the Barley field) inasmuch as each is situated in a fault block, and each has distinctive characteristics as to productive zones.

The Standard Oil Company of California drilled the discovery well, No. "Huntington Beach" A-1, completed May 24, 1920, at 2,199 feet for an initial production of 45 barrels per day of 14° gravity oil. Added impetus was given the development of the field by the completion of Standard Oil Company well No. "Bolsa Chica" 1 November 13, 1920, at a depth of 2,549 feet. This well, from which the Bolsa zone derives its name, had an initial production in excess of 2,000 barrels per day of 25° gravity oil, and has produced over 4,000,000 barrels of oil to date.

A considerable portion of the Old field consisted of town lots which were acquired by small companies. This resulted in very close well spacing, and Huntington Beach became the first townlot oil field in California.

On April 24, 1921, the Eddystone Oil Company, now the Shell Oil Company, brought in its No. "Ashton" 1 from a deeper zone in the northern portion of the field. This well made an initial production of 1,300 barrels per day from a depth of 3,445 feet. The discovery of the Ashton zone extended the proven area of the field about half a mile down dip to the northeast. By the end of 1923, the area east of the main fault, the Old field, was almost entirely developed.

The Main Street area was developed simultaneously with the Bolsa zone development of the Old field. Bolsa zone production extended continuously from the Old field across the fault into the Main Street area. Ashton zone production, however, is terminated on the southwest by the fault.

The completion of three wells by the Standard Oil Company in the so-called Barley field prior to 1924 directed attention to possibilities of production from the Townsite area. The presence of an arch in stratified beds along the ocean bluff, together with the subsurface contours in the Barley field, indicated the presence of a structure lying partially under the Townsite and partially under tidelands. Wilshire Oil No. "H.B." 1 was the first well drilled to the Jones sand in the Townsite area. However, while Wilshire Oil Company was testing this horizon, Superior Oil Company No. "Jones" 1 was completed at 3,063 feet, producing 472 barrels per day of 17.6° gravity oil. The Wilshire Oil Company well was unproductive in this zone, and was deepened to 4,074 feet. On September 14, 1926, Wilshire No. "H.B." 1 was completed as the discovery well of the lower zone with an initial production of 700 barrels per day of 24.6° gravity oil. Another intensive townlot drilling campaign ensued during which a heavy oil zone was discovered between 1,900 and 2,200 feet. This zone was unconformable with the lower strata, and produced oil of 13° to 15° gravity. The high percentage of sand accompanying oil from this tar zone made production unprofitable.

Information obtained from drilling in the Townsite area indicated that the axis of the dome was under the ocean parallel to the shore. With the development of directed drilling, the large structure a short distance off-shore became a point of interest to many operators. The first well whip-stocked under the tidelands was McVicar and Rood's No. "Vicaroo" 1. This well was completed January 1, 1933, flowing 700 barrels daily from a depth of 4,450 feet. Intensive development of the tideland pool followed the completion of Wilshire Oil Company No. "H.B." 15, July 17, 1933, flowing 4,800 barrels daily with 4,000 M.c.f. of gas. Approximately 90 wells were drilled into the tideland pool before the practice was halted by legal action on the part of the State of California.

STRATIGRAPHY

Sediments encountered in the Huntington Beach field range from Pleistocene to middle Miocene. There is about 700 feet of unconsolidated sands and gravels of Pleistocene age followed by 1,200 feet to 1,300 feet of blue shales and sandy shales of the upper Pico (Pliocene). The tar or Bolsa zone roughly marks the top of the Repetto, or lower Pliocene, which is 1,350 to 1,450 feet thick. The Repetto consists of shale with sand streaks and some thin shells, and contains the upper Ashton zone of the Old field and the Jones sand of the Tideland pool. The lower Ashton zone in the Old field and the lower zone of the Tideland pool constitute the known producing horizons of the Miocene. Generally, the Miocene sediments are brown, massive, and thin-bedded "poker-chip" shale, with oil sands and sandy shales carrying oil. The lower zone of the Tideland area consists of more than 600 feet of almost continuous sand.

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* Wilshire Oil Company, Inc.

** The Texas Company. Manuscript submitted for publication June 16, 1938.

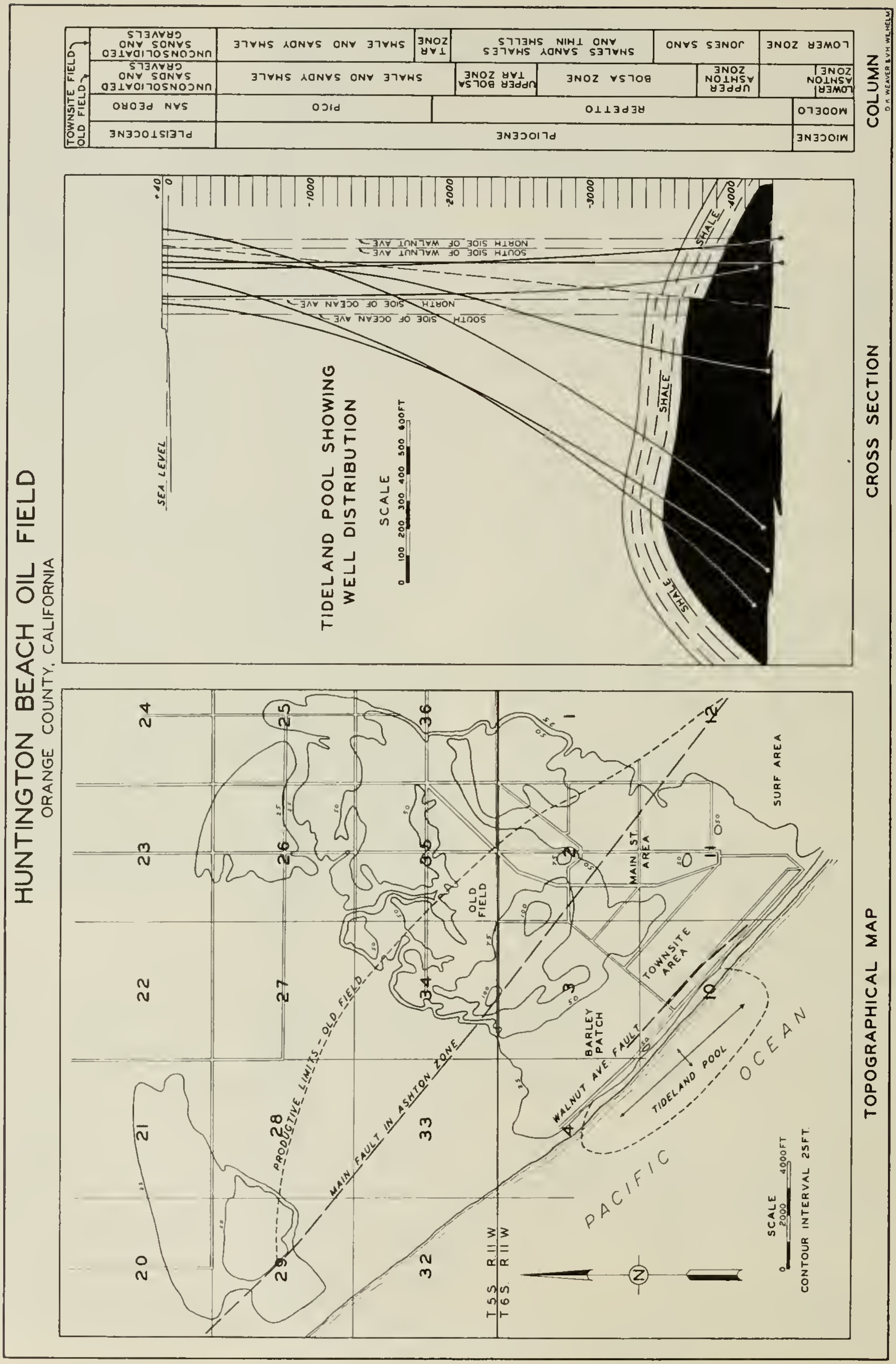


FIG. 138. Huntington Beach oil field: topographic map: cross-section.

STRUCTURE

The Old field of Huntington Beach, situated the farthest inland, is a homocline with production on the higher parts of northeast-dipping strata. This area is cut off from the southwest by a thrust fault trending northwest, the hade of the fault being approximately 60° to the southwest. The Old field has been faulted down approximately 260 feet with regard to the block on the southwest.

The Main Street area is an asymmetrical anticline with its axis parallel to the main Huntington Beach fault. In this block, the Miocene formation is apparently unconformable, rising to the southeast until it outcrops at Newport Beach.

The Surf area is a monocline sealed on the southwest by a fault paralleling the main Huntington Beach fault. This area has a very thin producing horizon with high head-waters immediately above and below the sand. Lenticularity and minor faulting complicate the underground structure.

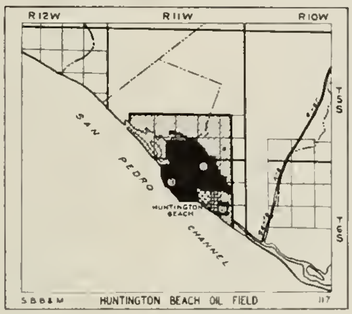
The Townsite-Tideland pool is in an elongated asymmetrical dome whose axis roughly parallels the coastline, turning shoreward to the northwest. Dips on both flanks are 10° to 12°, except in a fault block on the southeast end, which has dips as high as 35° to 40°. The subsurface axis lies about a quarter of a mile oceanward from the mean high-tide line. One large fault known as the Walnut Street fault parallels the axis, and the structure is further complicated by cross-faulting.

Tests made to date indicate that deep zone possibilities for this field are not great, probably because of its location near the edge of the basin. The greatest stratigraphic depth drilled (9,054 feet) was the middle Miocene, in the Townsite area.

The Huntington Beach field ranks third in importance in the Los Angeles Basin, both in estimated production and production to date. Oil from this field is of asphaltic base varying from 13° to 30° gravity, with a sulphur content of 1.35 percent.

Estimated ultimate gross reserves	350,435,000	barrels
Production to January 1, 1938	259,298,000	barrels
Estimated remaining reserves	91,137,000	barrels
Productive acreage	2,050	
Present total producing wells	660	

CITATIONS TO SELECTED REFERENCES—Continued



Huntington Beach oil field. Areas: (1) Old Field; (2) Surf; (3) New Field

HUNTINGTON BEACH OIL FIELD

Arnold and Loel 22; Brown, C. C. 26; Case, J. B. 21; Case and Wilhelm 23b; Collom, R. E. 21c; Dolman, S. G. 27; Eaton, J. E. 27b; Gale, H. S. 33; 34; 34a; Gester, S. H. 24; Graser, F. A. 26; Grizzle, M. A. 23; Hoots and Herold 35; Huguenin, E. 26; 39; Jensen, J. 27a; Jensen and Robertson 28; Lamp, The 23; Masser, H. L. 22; 23; McCollough, E. H. 34; Miller, H. C. 29; Oil Weekly 40c; Robertson, G. D. 22; Soyster, M. H. 22; Stockman, L. P. 35i; Taff, J. A. 34; Thoms, C. C. 24; Uren, L. C. 37; Vander Leck, L. 21; Weaver, D. K. 37.

NEWPORT OIL FIELD

By Frank S. Parker*

OUTLINE OF REPORT

HISTORY

The Newport field includes two small areas of barely commercial production, the Newport Beach area and the Mesa area, and a number of other small areas and single wells where quantities of oil were obtained which must be regarded as more than simply good showings. The whole comprises an area of about 7 square miles on Newport Mesa and the adjoining flats at the west end of Newport Bay, Orange County. The actual area of proven production probably amounts to only 80 acres, from which 154,000 or more barrels of oil have been obtained. Practically no oil has been produced since 1931 and all the old producers are abandoned.

The tar sands and seeps at the mouth of Newport Bay were known for many years, but the first attempt at production in this area seems to have been the Walker Brothers dry hole, drilled in 1903 or 1904 to about 200 feet at the cropping of the tar sands. This well was followed in the next 15 years by a number of wildcats, most of them drilled along the east edge of the Mesa near Newport Lagoon. Almost all had good showings, but they were accompanied by water. The Newport Bay Oil Company No. 3, drilled in 1909, was reputed to have produced a total of 300 barrels of 9 to 10 degree gravity oil, and the "Liberty" No. 1, drilled in 1918, is said to have produced as much as 60 barrels per day of 14 degree gravity oil for a short time before going to water. In 1922 and 1923 Fulkerson et al. drilled their No. 1 on the flats at the west end of Newport Bay to a depth of 1,750 feet. This well, when plugged back to 775 feet and perforated, flowed 15 barrels of oil per day with much water. This was the discovery well of the Newport Beach area. It was followed in the next 3 years by nine producers, two of them noncommercial, and one unsuccessful well in the immediate vicinity of the Fulkerson well. Five small producers, the rather closely spaced South Basin Company wells, were drilled a quarter of a mile to the west. Of this last group, only No. 5 was a satisfactory commercial well. Its initial production was 70 to 100 barrels of oil per day from the sands between 975 and 1,224 feet.

During this activity, early in 1925, Barnett Rosenberg completed "Mesa" 1 for 185 barrels of 11 degree gravity oil per day from 10 feet of oil sand at 629 feet, discovering the Mesa area. This well, later the Julian "Mesa" 1, produced 1,200 barrels in 10 days, then started showing water; in 8 months' production had fallen to 32 barrels of oil and 40 barrels of water per day. Eight other small producers were drilled within an area of about 25 acres.

Two dry holes were drilled immediately to the south of the Mesa area. The Interstate "Mesa" 1, about a quarter of a mile west, drilled in 1918 to 3,335 feet, was plugged back to 690 feet to produce 30 barrels of 11 degree gravity oil and 50 barrels of water per day. The Interstate "Mesa" 2 was drilled to the same sand. About a quarter of a mile west of the Interstate "Mesa" wells, the Sunland Oil Association No. 1 was drilled to a depth of 881 feet, and produced 10 to 12 barrels per day of 13 degree gravity oil cutting 14 percent. This well was offset by two unsuccessful wells. At about this time a shaft was driven to a depth of 350 feet half a mile east of the Newport Beach area, to a shallow, heavy oil sand. Several previous wells had encountered this sand and in one well it yielded asphalt so viscous as to plug the hole and prevent drilling until thinned by kerosene. A small production was obtained from the shaft by steam-heating the 8 degree gravity asphalt which seeped into the drift, and pumping it to the surface with a steam pump. Unlike most other enterprises in this area, there was little trouble with water. However, mechanical difficulties and costs of operation prevented commercial success of this venture.

The first records of production obtained by the Division of Oil and Gas were for the last half of 1924, during which the field produced 20,250 barrels of oil (the largest amount for any like period) from four wells of the Beach area. Few of the wells produced continuously and never more than 12 wells were productive at the same time. Water was produced from the start and the total reported production of 154,322 barrels of oil was accompanied by 109,594 barrels of water.

The production and noticeable showings in the shallow sands have encouraged deeper exploration sporadically from 1907, when the Newport Bay Oil Company drilled to 3,440 feet at the east edge of the Mesa, until the present summer of 1940 when the Thompson well was drilled to 5,645 feet about a mile north of the Mesa area wells. These deeper holes have tested the upper Miocene and much of the middle Miocene. One or two probably reached the lower Miocene. Up to the present time the showings in the deeper beds have not proved productive.

The Newport field is one of the few fields of the Los Angeles Basin that have been commercially unsuccessful in spite of copious showings and strong surface evidence of oil. This was doubtless due in part to the poor market for the class of oil produced and the very haphazard operations, but principally it was due to the rapid incursion of water. However, the area has interest for its geologic features out of proportion to its economic value.

* Geologist, Los Angeles, California. Manuscript submitted for publication November 9, 1940.

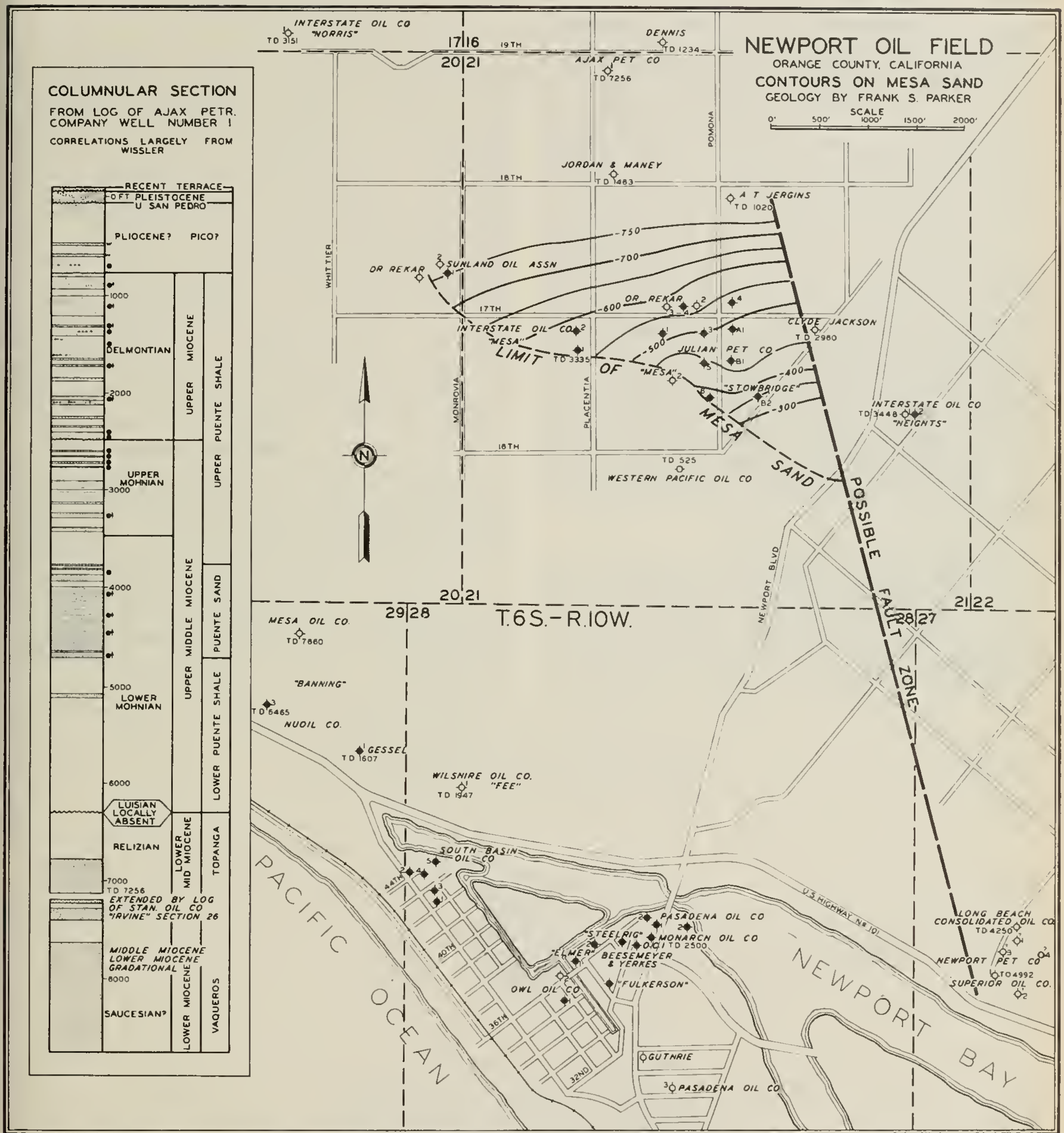


FIG. 139. Newport oil field: columnar section; structure map.

STRATIGRAPHY

The Newport area shows evidence of having been a marginal area of deposition throughout late Tertiary history. Surface data from the exposures along the margins of the Mesa and from the nearby San Joaquin Hills show evidence of unconformity between all formations above the lower Miocene as well as diastems within the formations. In the Newport Beach area, the Recent sands lie on upper Miocene (Delmontian stage)[1]. In the Mesa area (see columnar section) the surface rocks are Recent (?), overlying the slightly tilted and folded Pleistocene (upper San Pedro), which is unconformable on Pico. The Repetto is absent at this locality, but is present 2 miles or more to the northeast. The Pico lies on the upper Miocene which is more steeply tilted and partly eroded. To the east along Newport Lagoon can be seen the Repetto unconformable on upper Miocene, which is unconformable on the upper middle Miocene (Mohnian and Luisian stages), which is in turn markedly unconformable on the shales and sandstones and volcanics of the lower middle Miocene (Relizian stage). The stratigraphy is further complicated locally by intrusions, into the upper Miocene and upper middle Miocene, of sandstone dikes and sills of material thought, on the basis of its mineral content, to be of lower middle Miocene age. Along the south margin of the Mesa, these dikes and sills are tar saturated. They may have been the producing horizon in the Newport Petroleum Company shaft.

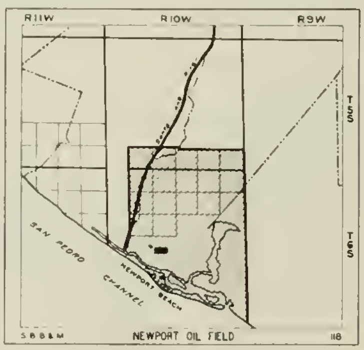
STRUCTURE

Were enough known about it, the structure of the area should be discussed formation by formation, as it is evident that a marked disparity exists between formations in amount of folding and faulting. In general, the regional dip is northwest, with the larger folds plunging west to northwest. The subsurface structure is difficult to interpret from well logs both because of their sketchy character and because some oil sands may be intrusive sandstone sills and not truly correlative from place to place.

Faults with a few feet to a few hundred feet of throw in Miocene beds are visible in the bluff at the south margin of the Mesa. Faults of large displacement are present in the San Joaquin Hills. The writer suggests that the faulting and overlap has had more influence on oil accumulation in this district than the folding. A broad anticline plunging northwestward, visible at the prominent point at the east edge of the Mesa, has been projected by some geologists as the controlling structure of the Mesa area; and another fold, exposed at the east end of Newport Harbor, as the control for accumulation in the Newport Beach area. To the writer, accumulation in the Mesa area appears to be due to closure on the south by overlap of Pico beds on a northwest-dipping unconformity across the upturned edges of north-dipping upper Miocene beds, and closure on the east by a fault which drops upper Miocene beds against upper middle Miocene beds. The accumulation in the Newport Beach area is not so readily explained, as insufficient data are available to prove or disprove fault and overlap control. The dip in this vicinity appears to be principally westward, and the small north to northwest faults at the edge of the Mesa may extend southward to intersect a fault which would be the continuation of one of the faults visible in the cliffs at the mouth of the bay; or the beds of the upper Miocene may be lenticular as suggested by the thick producing section with little bottom water in the South Basin wells, as compared to the thin section above bottom water in the more easterly wells of the Newport Beach area.

[1] The identification of the Miocene stages was furnished by S. G. Wissler.

CITATIONS TO SELECTED REFERENCES—Continued



Newport oil field.

NEWPORT (NEWPORT BEACH) OIL FIELD

Bruff, S. C. 40; Huguenin, E. 26; Kirwan, M. J. 18a; McCollough, E. H. 34; McLaughlin and Waring 14; Meek, C. E. 28; Soyster, M. H. 22; Thoms, C. C. 24; Vander Leck, L. 21; Van Tuyl and Parker 41; Watts, W. L. 00.

WEST MONTEBELLO AREA OF THE MONTEBELLO OIL FIELD

By Harry P. Stolz * and A. F. Woodward *

OUTLINE OF REPORT

HISTORY

The West Montebello area is located at the north edge of the town of Montebello about 12 miles east of Los Angeles, Los Angeles County. The field is approximately 1½ miles long and half a mile wide, and lies for the most part in a subdivided area within the Montebello city limits, on the southwest edge of the old Montebello oil field, which was discovered in 1917.

The Montebello oil field, as a whole, has been developed upon an anticlinal structure, the axis of which is arcuate in shape, trending slightly north of east, and finding its general expression in the topographically prominent La Merced or Montebello Hills.

The earlier developments in the field found three productive oil zones in the Pliocene formations, and these have furnished the bulk of the oil produced between 1916 and 1937 inclusive. A fourth zone was discovered in the lower Pliocene on the southwest edge of the old field in the latter part of 1930. Only one well (Kern Oil Company's No. "Monterey" 15), however, has produced any amount of oil from this zone.

Developments in the latter part of 1937 and the early part of 1938 in the southwestern portion of the old field proved the existence of the upper interval of a fifth productive zone lying within, but close to the base of the Pliocene. To date, the lower interval of the fifth, as well as the sixth, seventh, and eighth zones, all within the Miocene, have been developed in this area.

The discovery of the West Montebello area is generally credited to Kern Oil Company, Ltd., well No. "Monterey" 20. This well originally had been completed on September 28, 1936, in the second zone of the old field for an initial production of 55 barrels per day, 23.2° gravity, from the producing interval 3,430-3,710 feet. The well was deepened in the latter months of 1937, and on December 30, 1937, was completed with an initial production of 986 barrels per day, 40.0° gravity from the producing interval 6,221-6,353 feet—which interval is now identified as the Six-One zone.

The second producer in the area was Kern Oil Company, Ltd., well No. "Monterey" 24, completed on April 18, 1938, for an initial production of 1,628 barrels per day, 36.0° gravity from the Five-One and Five-Two zones between the depths of 5,408 and 5,781 feet, marking the discovery of the productivity of those respective zones in this area.

On May 15, 1938, three wells were completed, namely: (1) Kern Oil Company, Ltd., No. "Monterey" 25 (initial production 1,473 barrels per day, 38.0° gravity, Five-One zone—producing interval 5,709-5,790 feet); (2) McVicar-Rood No. "Manz" 1 (initial production 2,285 barrels per day, 34.9° gravity, Five-One and Five-Two zones—producing interval 5,375-5,575 feet and 5,719-5,780 feet respectively); and (3) Union Oil Company No. "Paul J. Howard" 1 (initial production 907 barrels per day, 32.4° gravity, 51 percent cut—Five-Two zone—producing interval 5,641-5,715 feet).

On May 26, 1938, the Union Oil Company well No. "Wilcox" 1 was completed as the second producer in the Six-One zone, extending the proven limits of that zone to the southeast. Its initial production was 1,071 barrels per day, 36.2° gravity from the producing interval 6,138-6,248 feet.

Completions in the fifth and sixth zones continued at a progressively rapid pace. By November, 1938, there were 26 wells producing from those zones or a portion thereof.

The Hathaway Oil Company well No. "Dore" 1 was the discovery well of the seventh zone. Completed on November 17, 1938, for an initial production of 475 barrels per day, 35.0° gravity from the interval 7,005-7,184 feet, this completion extended the productive limits of the field south of Beverly Boulevard.

The discovery of the eighth zone is credited to the Union Oil Company well No. "La Merced" 30, completed April 17, 1939, for an initial production of 710 barrels per day, 35.2° gravity, drilled to a total depth of 8,468 feet, plugged back and producing from the Eight-One zone in the interval 7,551-7,630 feet. Again the productive limits of the field were extended and still deeper production assured over all of that portion of the developed field.

The development of this field was, and continues to be, a progressive one; that is to say, as wells in the several portions of the field have penetrated deeper, new prolific oil and gas zones have been discovered. Owing to the depletion of the upper zones of the Miocene, and probably also in part to lease and offset requirements,

* Stanley and Stolz, Los Angeles, California. Manuscript submitted for publication January 20, 1940.

the deepening of the wells producing in such zones, together with the drilling of new wells to the more recently discovered deeper Miocene zones, has extended throughout the field. The deepest productive zone yet encountered is the so-called eighth zone. The deepest stratigraphic penetration to date is in the Union Oil Company well No. "La Merced" 30, which was drilled to a total depth of 8,468 feet and was plugged back to 7,630 feet, the latter depth coinciding with the approximate base of the productive sands in the lower eighth zone. Apparently the measures encountered between approximately 7,630 feet and 8,468 feet were unproductive at this location; however, the sands encountered in No. "La Merced" 30 within this interval may be productive at locations situated higher on the structure.

STRATIGRAPHY

Pleistocene. Alluvial deposits of gravel, sand, and silt are found at the surface in the West Montebello area. A few outcrops exposed along the southwest side of La Merced Hills in the northeast part of the field may, however, belong to the upper Pico (upper Pliocene) formation. The upper Pliocene is probably covered by only a few hundred feet of Pleistocene alluvium in the central part of the field, and in the southwest area it is doubtful if the Pleistocene exceeds 500 feet in thickness.

Pliocene. The Pliocene is approximately 5,300 feet thick. The upper 2,000 feet consists principally of gray shale and sandy shale with a few conglomerate beds. The lower Pliocene is composed of a series of interbedded brown shales, sandy shales, sandstones, and conglomerates. Sandy conglomeratic beds varying in thickness from 20 to 250 feet make up approximately 25 percent of the lower Pliocene section.

Pliocene-Miocene Contact. The Pliocene-Miocene contact has been placed by some micropaleontologists in the shale body between the Five-One and the Five-Two zones, while others, using somewhat different microfossil criteria, place the contact about 100 feet lower, in the Five-Two zone. Assuming the contact to be in the shale overlying the Five-Two zone the top of the Miocene is encountered at subsurface depths varying from about 5,550 feet to 5,700 feet in the main part of the field.

Miocene. Most of the wells have penetrated approximately 2,000 feet of Puente (upper Miocene) formation. The deepest well in the field (Union Oil Company No. "La Merced" 30) which was drilled to 8,468 feet, penetrated over 2,750 feet of Miocene.

The upper Miocene section consists of a series of interbedded sands and shales of widely varying thicknesses. The sands in general are fine- to medium-grained and often shaly. The shales are hard to medium hard and somewhat platy to massive. They are gray to dark-gray in color with some of brownish-gray color between the fifth and sixth zones. Streaks and pockets of fine-grained sand are common in most of the shales. A few thin hard layers or "shells" of indurated or cemented material are common in some parts of the section.

The Miocene sands, as a general rule, become more shaly on the east nose and on the north flank of the structure, with the exception of the Six-Two and the Eight-Two zones, which are more shaly to the west.

Lenticularity of beds due to lateral change in deposition is common in particular in the fifth and upper sixth zones. In some cases thick sands are replaced almost entirely by shales in comparatively short distances. The lower zones, however, show less lenticularity and most of the prominent sands and shales can be traced throughout the field. This fact would seem to indicate that the lower Repetto (Pliocene) and upper Puente (upper Miocene) sediments were deposited under somewhat varying conditions such as might be found along an irregular shore line, while the lower part of the section probably was deposited under conditions more uniform throughout the area.

STRUCTURE

The subsurface evidence revealed by wells drilled to date in the West Montebello area indicates that the productive zones and associated sediments of lowermost Pliocene and upper Miocene ages have been folded into an anticline which does not conform with that developed in the Pliocene formations of the old Montebello field. It would appear that this condition is due to a phase of crustal folding which started during the late Miocene and continued for a short time into the early Pliocene, followed perhaps by a period of quiescence and erosion prior to the deposition of the upper Repetto and Pico formations of Pliocene age. A post-Pliocene period of folding in which the stresses may have acted from a somewhat different direction resulted in the development of the main anticlinal structure of the old Montebello field. The apex of the West Montebello anticline in the Miocene beds is approximately 2 miles southwest of the apex of the Pliocene structure of the old field, and its axis lies to the south of the Pliocene axis.

The West Montebello area must be considered as a separate unit, at least in the producing measures of the Miocene, despite the fact that its structural history is closely identified with that of the Montebello uplift as a whole.

The accumulation of oil and gas in the West Montebello area is directly related to an anticlinal dome in the lower Pliocene and upper Miocene sediments. The axis of this anticlinal structure trends almost due east. In general the north flank dips from 5°-6° and the south flank dips 6°-8°. The dip of the beds on the south flank is comparatively uniform from the fifth to the eighth zones while on the north flank the dip of the beds of the upper zones is slightly less than that of the lower zones. This is particularly true on the northeast part of the structure where the beds of the upper fifth zones dip from 2°-3° and those of the sixth, seventh, and eighth zones dip from 7°-8°. Steeper dips will probably be encountered farther down on both the north and the south flanks as the field is extended laterally. This is evident on the south flank in the vicinity of the Star Petroleum Company No. "Community" 1 where the dips exceed 12°. The east nose plunges approximately 5° and the west nose approximately 4°.

The axial plane, drawn through the axes of successively lower horizons, is tilted slightly to the south. This tilt or hade of the axial plane is as high as 10°-12° in the upper zones in some parts of the field. The hade decreases with depth and in the eighth zones the axial plane is almost vertical.

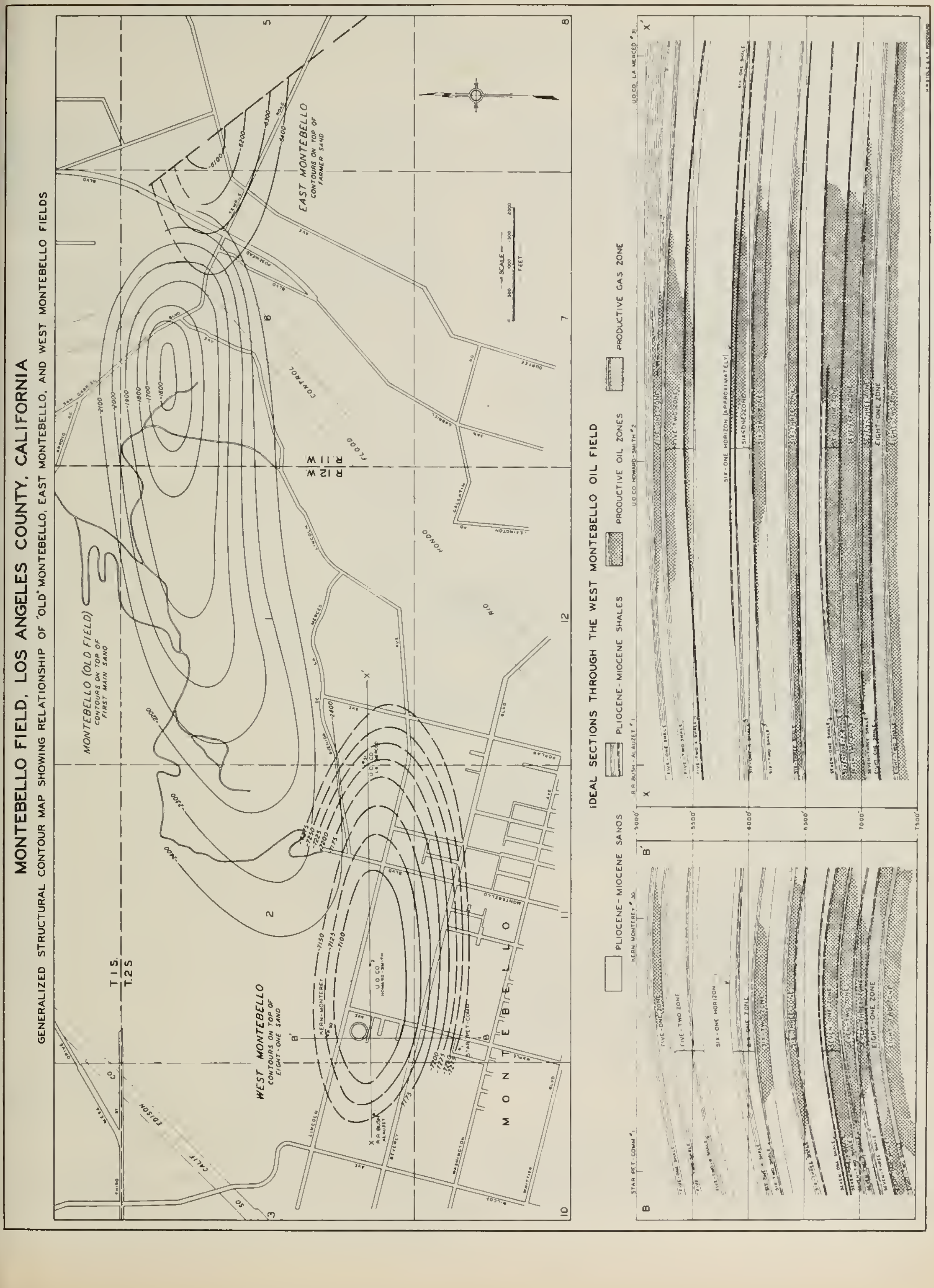


Fig. 140. Montebello oil field: generalized structure map, showing relationship of "old" Montebello, East Montebello, and West Montebello fields; ideal sections through the West Montebello oil field.

The closure on the structure is not definitely known at present, particularly because of insufficient data regarding the north flank. Evidence suggests, however, that there is over 250 feet of closure in the eighth zones. The closure is apparently considerably less in the fifth zones where the beds flatten to the north.

No marked unconformity is apparent between the Pliocene and Miocene formations in the West Montebello area. A very slight change of dip, however, between the lower Pliocene and upper Miocene is evident on the north flank of the structure. The base of the Pliocene in the Ridge Oil Company No. "Club" 1 wildcat well three-fourths of a mile northwest of the field is marked by a few feet of basal conglomerate. This conglomerate is composed of fragments of platy shale in a coarse sandy matrix. The coarse sand is typical of the lower Pliocene, while the shale fragments contain micro-fossils diagnostic of upper Miocene age.

What appears to be a marked unconformity occurs in the lower part of the Pliocene section about 300 feet above the top of the Miocene in the central part of the field. This unconformity appears to be at the base of a 200- to 300-foot series of coarse conglomerate beds. The base of this series is irregular, but in general it is from 250 to 300 feet above the top of the Miocene at the west end of the field and from 400 to 550 feet at the east end. This sharp change from coarse conglomerate to shale along a contact which represents a rather irregular surface suggests deposition of a basal conglomerate on an erosional surface. An apparent thinning to the west of the lowermost Pliocene below the conglomerate series may have been the result of erosion. An angular unconformity is evident also from the fact that contours drawn on the fourth zone, which lies immediately above the conglomerate series in the northeast part of the field, conform with the general structure of the southwest nose of the old Montebello field and not with the underlying West Montebello structure.

No faults of major importance have been found to date in the West Montebello area. Evidence of minor faulting in the upper part of the Five-One shale has been noted in cores from a few wells on the northeast flank of the field and may account for some of the irregularities in thickness of the Five-One shale and the Five-One zone in this area.

PRODUCTIVE HORIZONS

The present known petroliferous section in the West Montebello area is approximately 2,200 feet thick. The upper 200 to 300 feet lies in the lower part of the Repetto formation of Pliocene age, while the underlying 2,000 feet is in the Puente formation of Miocene age.

Productive sand intervals have been divided into four different zones, heretofore referred to as fifth, sixth, seventh, and eighth zones. These zones have in turn been divided into various sub-zones.

Pliocene

Five-One Zone. The top of the Five-One zone is found at subsurface depths ranging from 5,440 to 5,630 feet. The sand is in general from 60-100 feet thick, but in some areas changes laterally into shale and is almost entirely absent.

The productive limits of the Five-One zone are confined to an area approximately half a mile long and a quarter of a mile wide in the north central part of the field.

Miocene

Five-Two Zone. The top of the Five-Two zone is found at subsurface depths ranging from 5,540 to 5,720 feet. The zone ranges from 160 to 260 feet in thickness, and is composed principally of interbedded sands and shales. It thins toward the west where the top portion becomes predominantly shale, notably on the south flank.

The productive limits of this zone are approximately the same as those of the Five-One zone.

Six-One Zone. The top of the Six-One zone is found at subsurface depths of 6,100 to 6,330 feet. The zone is 200 feet thick in the central area, and thins to 120 feet at the west end and to 160 feet at the east end. The zone is composed of interbedded sands and shales and becomes progressively more shaly from west to east and from south to north.

Several wells on the crest of the structure produced from the Six-One zone for a short period, but were later deepened to the more prolific sands of the Six-Two and Six-Three zones.

Six-Two Zone. The top of the Six-Two zone is found at subsurface depths of 6,320 to 6,560 feet. The zone is 120 feet thick in the central area, but thins to 50 feet to the east, where the lower part becomes sandy shale. The sand lenses out entirely at the west end of the field.

Although the zone is apparently productive on the crest of the structure over an area approximately two-thirds of a mile long and a quarter of a mile wide, comparatively few wells have been completed in this sand.

Six-Three Zone (Masser). The top of the Six-Three zone is found at subsurface depths from 6,620 to 6,850 feet. The zone is 60 to 80 feet thick in the east and central parts of the area, but thins to 30 feet in the southwest part.

The Six-Three zone is known to be productive over an area approximately three-fourths of a mile long and a quarter of a mile wide, but the limits of production have not yet been definitely determined.

Seventh Zone (Hathaway). The top of the seventh zone is found at depths of 6,920 to 7,080 feet. The zone is approximately 400 feet thick and consists of a series of interbedded sands and shales, which have been divided into three sub-zones; the Seven-One, Seven-Two, and Seven-Three. A few wells have been completed with almost the entire 400-foot zone open, while others produce from only a portion of the zone. Approximately 15 wells have been completed in the seventh zone, but many of these were subsequently deepened to the eighth zone.

Eight-One Zone. The top of the Eight-One zone is found at subsurface depths of 7,350 to 7,550 feet and varies from 100 to 120 feet in thickness. The zone is predominantly sand with a few thin interbedded shales in the upper part. It is fairly uniform in both thickness and lithology throughout the field.

Evidence seems to indicate that the Eight-One zone is primarily a gas reservoir within that portion of the field above the 7,220 sub-sea contour as based on the Eight-One horizon (top of Eight-One sand). Some wells, located high on structure, with the Seven-Three zone open, produce considerable gas, generally attributed to leakage from the Eight-One zone as the result of faulty cement jobs.

The present productive area of the Eight-One zone is over 1½ miles long and half a mile wide, and its limits have not yet been defined.

Eight-Two Zone. The top of the Eight-Two zone is found at subsurface depths of 7,490 to 7,650 feet. The zone varies from 90 to 120 feet in thickness and is composed predominantly of sand with numerous thin interbedded shales.

The eastern and southern limits of production have been roughly determined, but to date insufficient drilling has been done to outline the north and west limits. The extent of the productive area of this zone, however, is less than that of the Eight-One zone.

Porosity—Permeability

The average porosity and permeability of the oil-bearing sands in the central part of the field are as follows:

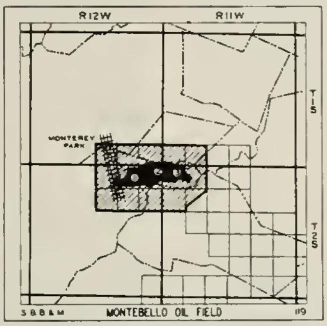
Zone	*Average Porosity (Percent)*	*Average Permeability (Millidarcys)*
5th	27.0	400
6th	27.0	250
7th	23.5	125
8-1	20.0	80
8-2	22.0	100

These figures indicate a decrease in both porosity and permeability of the sands with depth. Additional evidence also shows that higher permeabilities are found in some of the sands of upper oil zones in the eastern part of the field.

PRODUCTION

On January 1, 1940, there were 160 wells producing in the field. The total potential production was estimated at 83,700 barrels of oil per day, but under curtailed operations, the daily production was limited to 22,000 barrels per day, or an average of approximately 135 barrels per well. The total gas production was over 97,000,000 cubic feet per day, or an average gas-oil ratio of over 4,000 cubic feet of gas per barrel of oil.

CITATIONS TO SELECTED REFERENCES—Continued



Montebello oil field. Areas: (1) West Montebello; (2) Montebello; (3) East Montebello.

MONTEBELLO OIL FIELD

Arnold, R. 15; Atwill, E. R. 40; Augur, I. V. 20a; Hight, W. 33; Hoots, H. W. 39; 39a; Hoots and Herold 35; Huguenin, E. 26; 37; 39; Kirwan, M. J. 18; 18a; Masser, H. L. 22; 23; Petroleum World 36a; Soyster, M. H. 22; Stockman, L. P. 33a; 34; 35a; 35b; 35e; 35k; 36j; 39d; 39h; Taff, J. A. 34; Thoms, C. C. 24; Vander Leck, L. 21; Wilhelm, V. H. 39a.

Bartolo (East Montebello) Area

Hoots, H. W. 36a.

West Montebello Area

Huguenin and Stolz 40; Preston and King 39; Wilhelm, V. H. 40.

MONTEBELLO AREA OF THE MONTEBELLO OIL FIELD

By RICHARD G. REESE *

OUTLINE OF REPORT

LOCATION AND HISTORY

The development of oil in and adjacent to La Merced Hills is in three separate structural traps. They are referred to as the Montebello (discovered February 28, 1917), East Montebello (discovered August 16, 1933), and West Montebello (discovered January 2, 1938) areas. The following discussion pertains to the Montebello area only. It is the central part of the developed region, and is still confined, largely, to the area described by Irving V. Augur (20a) in his report.

The Montebello area of the Montebello field is located in Los Angeles County, about 5 miles east of the Los Angeles City Hall and about 1 mile north of the town of Montebello. It occupies the southeast end of La Merced Hills and extends eastward into the valley of the Rio Hondo. It is confined to Sec. 6, T. 2 S., R 11 W., S. B., and Secs. 1 and 2, T. 2 S., R. 12 W., S. B.

The recommendation that a well be drilled in this area was made as the result of geological studies. It was concluded from these studies that an anticlinal fold was present and that the oil-producing rocks of the Whittier and Los Angeles fields were older than those exposed in La Merced Hills and should, therefore, be encountered at a drillable depth in La Merced structure.

The discovery well, Standard Oil Company No. "Baldwin" 1, located in the north-central part of the area, was spudded with rotary tools December 6, 1916, and completed with cable tools February 28, 1917. The initial production was at the rate of about 350 barrels daily of 23.7 degree gravity oil cutting 1.6 percent. The production was obtained from the interval between 2,243 feet, where the 13-inch casing was cemented, and 2,395 feet, the bottom of the hole. The development prior to April, 1920, following the discovery is covered by Mr. Augur in his report. The peak monthly production was that of June, 1919, when 1,144,000 barrels were produced. Subsequent development, from 1920 to the present time, was at a relatively slow rate, the final result being a small extension of the field in a westerly direction. The productive area is about 980 acres, and 214 wells are producing at a curtailed rate of 94,614 barrels per month. The total accumulative production for the area as of October 1, 1940, was about 104,750,000 barrels.

* Standard Oil Company of California. Manuscript submitted for publication November 25, 1940.

STRATIGRAPHY

Pleistocene sands and conglomerates are exposed at the surface irregularly around the periphery of the area. They overlap the upper Pliocene silts and fine sands which are exposed along the axis and at the crest of the anticline. The Pico (upper Pliocene)—Repetto (lower Pliocene) contact is found at a depth of about 800 feet on the crest of the fold, or about 1,250 feet above the top of the first main sand of the First oil zone.

The Repetto is essentially sand and conglomerate and contains all the productive zones of the Montebello area. It is extremely lenticular, and except where wells are closely spaced and detail logs are available, correlations within this member are very hazardous. No well at the crest of the area has drilled through the Repetto into the Miocene, so that its thickness here is not known. Standard Oil Company well No. "Baldwin" 82, the deep test located far out on the west plunge, found about 4,700 feet of Repetto. Generally, it increases in thickness in a northwesterly direction. Between the crest of the East Montebello area and the southeast side of the Montebello area the thickening within the Repetto is at such a rate that the west plunge of the East Montebello structure, at the base of the Repetto, gradually flattens and finally becomes the east plunge of the Montebello area at progressively higher datums. This condition is shown graphically on the longitudinal section.

The Miocene has not been penetrated in the Montebello area proper except at locations which now appear to be on the flank of either the East or West Montebello area. The structural interpretations of the Miocene development in these two areas have discouraged Miocene exploration in the Montebello area proper. Without further deep drilling in the area there is little that can be said relative to this formation, except that it is now generally considered to be of no economic interest.

STRUCTURE

The sediments from which the oil is produced are generally coarse grained and so lenticular that reliable stratigraphic marker beds are lacking. For this reason, together with the fact that relatively few cores have been taken for detailed foraminiferal correlations, it is difficult to know whether structure or merely the configuration of some textural change which does not necessarily represent a stratigraphic marker is being interpreted. The one horizon, however, which is generally logged and which appears to represent a true stratigraphic marker is the first main sand of the First zone. This is the datum commonly used for contouring, and the one upon which the following structural interpretation is based.

The structure is an elongated anticlinal fold, the crest of which lies beneath the Standard Oil Company's Temple lease. The trend of the axis from the crest easterly is about due east, and the east plunge is relatively sharp or at an angle of about 25 degrees. The trend of the axis westerly from the crest is due west for a short distance but curves southerly into a gentle arc which finally has a trend of about S. 60° W. at the west end of the area. The flanks within the productive limits of the area dip at an angle of about 15 degrees at the west end of the area, but steepen in an easterly direction, and at the east end of the area dip at an angle of about 35 degrees. Wells drilled on the north side of the area, beyond the productive limits, have cored Pliocene sediments showing dips as high as 50 degrees, and equally steep dips were found in the two deep tests, in sediments below the Pliocene sands and conglomerates, which were drilled on the west plunge. These wells suggest that the fold may be asymmetrical or faulted along the north flank.

There is some evidence of cross-faulting in the central part of the area. The evidence is not conclusive, however, due to the lenticular nature of the sediments. The fault shown on the longitudinal section, near the west edge of the area, is based primarily on production data and has not been recognized in the development of West Montebello. The thrust fault shown on the longitudinal section, east of the area, is the one against which the oil in East Montebello has accumulated.

The nature of the folding in the Miocene has not yet been clearly demonstrated. It is suggested by the Miocene development in East Montebello and in West Montebello that a structural saddle, due to an abnormally thick section of Pliocene sediments, may occupy the interval between these two areas, under the Pliocene fold of the Montebello area. The two deep tests drilled in the Montebello area proper, which were not definitely on the flank of either the West or East Montebello areas, encountered 40 degree to 60 degree dips in the Miocene rocks.

PRODUCTIVE HORIZONS AND KIND OF OIL

The producing horizons in the Montebello area are confined to the Repetto formation. The aggregate thickness of these zones at the crest of the field where there were originally no intermediate waters, is about 2,000 feet. They were named in order of discovery, from the shallowest downward.

First Zone

This zone, at the crest of the area, has a thickness of about 900 feet. The only persistent sand member is the so-called "first" main sand. It varies from 100 to 150 feet in thickness, and is in reality a conglomerate overlain by silt and fine sand. Below it are lenticular sands, conglomerates, and silts. The First zone water string is

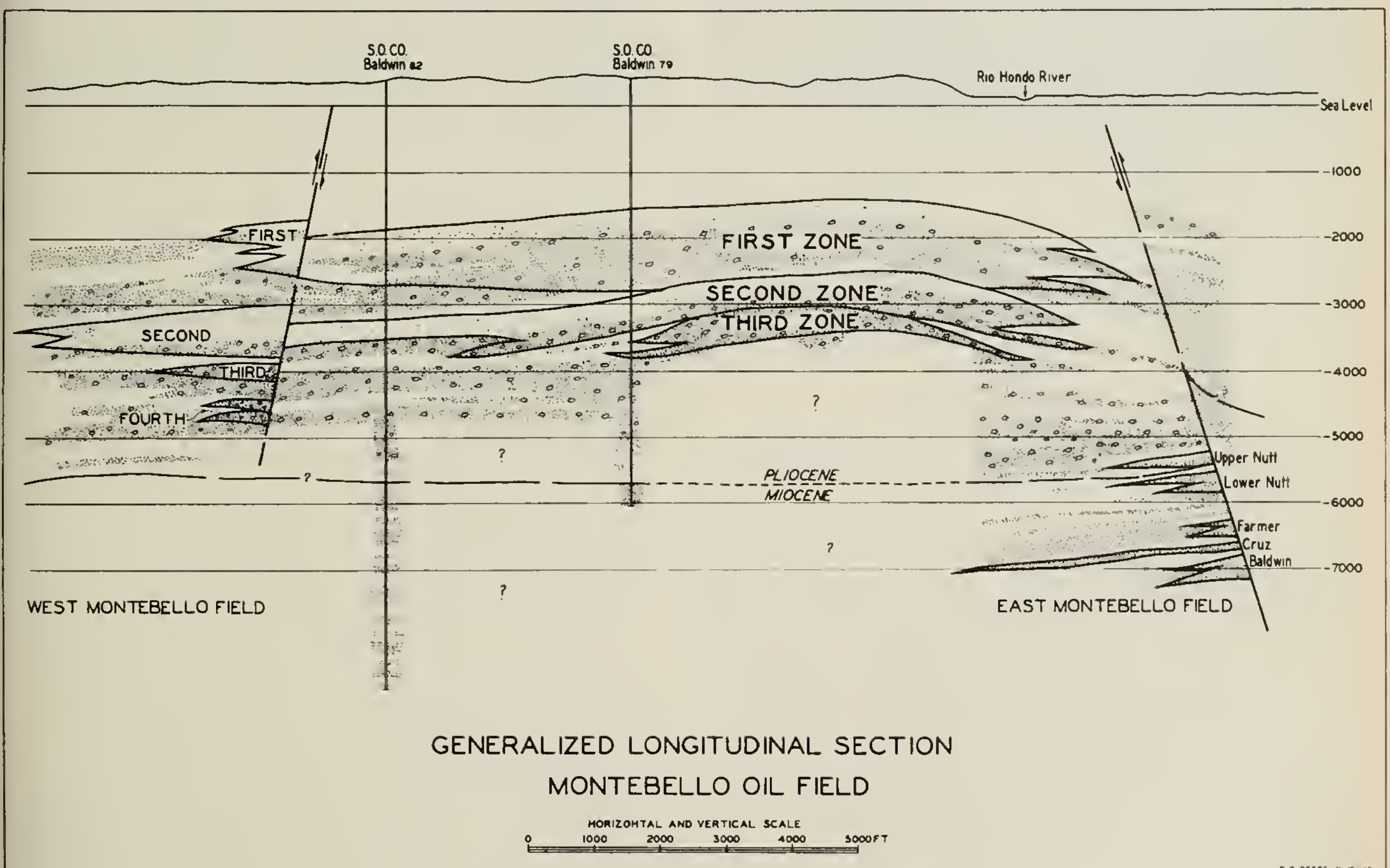


FIG. 141. Montebello oil field: generalized longitudinal section.

commonly cemented at a point about 250 feet above the top of the first main sand in order to include the finer grained sand beds which show oil. Although many of the wells were completed to include the Second zone along with the First zone, the latter is generally considered to be confined to a penetration of about 750 feet below the top of the first main sand at which penetration a fairly persistent silt is found. The wells in this zone produced at initial rates of 400 to 500 barrels daily, and the oil averages about 20 degrees gravity. The accumulation is confined to a structural closure of about 600 feet and covers an area of about 760 acres.

Second Zone

This zone, at the crest of the area, is about 600 feet thick. The silt and coarse sand which make up the upper half of the zone in the eastern part of the area grade westerly into essentially shale. The lower half is coarse sand to conglomerate. The point at which Second zone water strings are commonly cemented is in the relatively persistent shale break at the base of the First zone sands. Down the west plunge of the structure the lower half is not saturated and the production is obtained from thin sand and silt beds in the top part of the zone. Initial yields as high as 7,500 barrels daily were obtained in Second zone wells, and it is estimated that no less than two-thirds of the production from the area has come from this zone. The average gravity of the oil is 25 degrees. The accumulation in this zone is confined to a structural closure of about 1,000 feet, and it is productive over an area of about 980 acres.

Third Zone

Production from this zone is confined to two localities —one at the crest of the area and the other at the west end of the area. The maximum thickness is at the crest, where about 250 feet of coarse sand and conglomerate are saturated. Here the shale bed which separates the Third zone from the Second zone is only 8 to 10 feet thick, and the point at which Third zone water strings were cemented was generally picked by formation tests augmented by electric logs. Although the Third zone was recognized in early development of the area, it was produced along with the Second zone in many wells until 1934, when it was developed as a separate zone on the crest and down the west plunge. The small amount of oil produced in the west end of the area apparently from the equivalent of the Third zone seems to be an accumulation against a fault. At least, it is in a separate pool from the accumulation at the crest of the area, for water occupies the interval between the two localities.

The accumulation at the crest of the area is confined to a structural closure of about 150 feet. Initial productions as high as 1,000 barrels daily have been obtained, and the average gravity of Third zone oil is 27 degrees. The Third zone covers an area of about 150 acres at the crest.

This zone represents the base of the oil measures as developed at the present time in this area. Showings and a small amount of production have been found below the Third zone at the ends of the area, but indications are that any deeper zones, if present, will be of lesser extent than that of the Third zone at the crest of the area.

SANTA FE SPRINGS OIL FIELD

By H. E. Winter *

OUTLINE OF REPORT

HISTORY

The Santa Fe Springs field, located 12 miles southeast of the center of Los Angeles, Los Angeles County, was discovered in 1919 by the Union Oil Company of California. Attention was originally attracted to the area by indefinite but somewhat suggestive topography and by the occurrence of gas in water wells. Prospecting began as early as 1907, when the Union Oil Company drilled No. "Meyer" 1 to a total depth of 1,445 feet and a year later drilled No. "Meyer" 2 to 350 feet. Both holes were abandoned because of mechanical difficulties.

No further drilling was done until February, 1917, when the Union Oil Company spudded No. "Meyer" 3, and after experiencing considerable difficulty in drilling, the well was completed as a producer October 3, 1919, from a depth of 4,595 feet. The well flowed at the rate of 3,000 barrels per day for a few hours before water broke in. The water string was recemented at 4,568 feet, but on recompletion the well made only a small producer, averaging 100 to 150 barrels per day.

Although No. "Meyer" 3 was the discovery well of the field, very little attention was focused on the area until November, 1921, when the Union Oil Company completed No. "Bell" 1, flowing 2,588 barrels per day of 31° gravity oil from a depth of 3,788 feet. This discovery started an intensive drilling campaign, and the production of the field mounted rapidly. By 1923, the daily production had reached a point that threatened to upset the entire price structure of the country. This great flood of oil could not be absorbed on the Pacific Coast, and during the summer of 1923, intercoastal shipments of crude amounted to 4,004,049 barrels in July; 5,285,042 in August; and 5,952,530 barrels in September; or a shipment of two tankers per day.

At this point, it is interesting to quote directly from a report on the Santa Fe Springs field by R. R. Templeton and C. R. McCollom (23), written September, 1923:

"During the past two months Santa Fe Springs has produced more than ten million barrels of oil per month, and the production is now standing at about that figure. As a result, the industry in the Mid-continent is almost paralyzed, the transportation and refining facilities of the Atlantic Coast are taxed to the limit, and the price of gasoline has been universally forced down to a point where only few refiners are able to make a profit.

"This production, which represents about one-sixth of the production of the United States, is the more remarkable when it is considered that this tremendous flood of oil is coming from a field comprising only some 1,500 acres of proved oil land, and that the oil is coming from the heretofore unheard of depth of nearly a mile."

Twice during the life of Santa Fe Springs, this field has produced more oil in one year than any other field in California. The first stage of active development of the field was due to the rapid drilling of the Foix, Bell, and Meyer zones. After reaching the peak production of 80,671,112 barrels in the year 1923 (daily average for August, 1923, was 319,989 barrels), the output of the field declined until 1928, when it made 16,026,960 barrels for the year (daily average June, 1928, was 37,011 barrels). The five years following the peak of drilling in 1923 saw a rather small amount of activity, but in July, 1928, the Wilshire Oil Company discovered a deeper zone in No. "Buckbee" 1. This well was brought in from a total depth of 5,860 feet for 2,000 barrels per day of 35° gravity oil, and initiated a period of deeper drilling in which the Nordstrom, Buckbee, O'Connell, and Clark-Hathaway zones were discovered. A second intensive drilling campaign took place, and production again mounted to a peak of 77,576,147 barrels for the year 1929 (daily average for August, 1929, was 285,095 barrels).

Following this second peak of activity, the field declined rather steadily. However, during the last four years, due to remedial work—much of which consisted of plugging back and perforating portions of higher oil zones—the production has been held fairly steady at about 27,000 barrels per day. The Umpire potential for January, 1940, was 36,064 barrels per day from 658 wells. There are an additional 39 idle wells in the field. The total net production of the field to December 1, 1939, was 458,397,637 barrels.

Considered in the light of total production to date, Santa Fe Springs ranks second in importance in the Los Angeles Basin and third in the State, being surpassed only by Long Beach and Midway-Sunset.

PRODUCTIVE HORIZONS

Following is a short description of the various oil zones. The depths and thicknesses are those pertaining to the top of the structure.

Gas Zone. The gas zone lies at a depth of about 2,030 feet on top of the structure, and although the gas may have been distributed through a considerable interval originally, it is probable that any gas that could have been developed would come from sandy members in the interval between 2,030 and 2,160 feet.

Originally eight wells were drilled for gas and oil. Some of the gas was used for awhile, but it is probable that none of these wells could be considered of commercial importance, and certainly no gas wells could now be drilled that would be of commerical use. Several wells had disastrous blow-outs while drilling through this zone, some of them blowing anywhere from a few days to a month; occasionally large craters and fires resulted. The zone did not last long on a commercial basis because of the rapidly encroaching water, and is not now considered of much importance.

* Division Petroleum Engineer, Union Oil Company of California. Manuscript submitted for publication February 8, 1940.

Foix Zone (Pliocene). The Foix sand is found at a depth of approximately 3,440 feet and is overlain by a shale 135 feet in thickness. Originally, the zone was saturated for 183 feet, but at present only about 60 feet can be considered as capable of clean production on the top of the structure.

At the present time there are six wells, all of which are shut in, which are capable of production and probably could make together an aggregate of about 1,200 barrels per day. This zone is characterized by a high fluid level.

Bell Zone (Pliocene). The Bell sand is found at a depth of 3,670 feet. The sand is overlain by a 50-foot shale. The original wells were able to take the full penetration of 315 feet, but at the present time there are intermediate waters, and in order to get clean production, a well should take from 10 to 100 feet of penetration, depending upon its position on the structure. There are four subzones which can be produced clean by selective perforating, taking in from 10 to 100 feet. The Bell zone had a high fluid level and rather active edgewater drive.

Meyer Zone (Pliocene). The Meyer sand lies at a depth of 4,150 feet, and is overlain by a 165-foot shale. While the zone consists of 735 total feet of sands and streaks of shale, the upper 650 feet of this interval was the maximum amount of penetration that would produce clean.

In the western part of the field, the 165-foot shale has a productive sand stringer near the middle of the shale body. In other parts, this shale is practically solid. At present, there are several intermediate waters and the greatest thickness that can be taken is 365 feet. The top of the Meyer shale is one of the distinctive markers of the field and can be recognized easily while drilling. It also gives a distinctive reaction on the electrical log. For this reason, the top of the Meyer shale has been used in contouring, and it is necessary to add 165 feet to the figures on the attached contour map, in order to find the contour on the top of the oil sand.

The Meyer shale is a competent member. There is no water within the 165-foot interval. It has been possible to get an effective water shut-off in almost every part of the shale. Some of the early wells were shut off in various parts of this shale, and it is impossible to tell the top of the shale from their logs, as in many cases only the point of shut-off is available. However, since 1934, there has been enough redrilling and new drilling for lease requirements to enable a good contour map to be made from electrical logs.

The Meyer zone was by far the most prolific and most extensive zone of the field. Its actual extent was about 1,450 acres. While a few wells produced outside this limit, they were hardly of commercial importance.

Nordstrom Zone (Pliocene). The Nordstrom sand is found from 4,905-5,450 feet and is overlain by 25 feet of shale. At one time approximately a 520-foot interval was productive. However, at the present time there are intermediate waters which limit the possibilities of the productive intervals, ranging from 20 to 100 feet.

This zone is characterized by low head waters of large volume.

Buckbee Zone (Pliocene). The Buckbee sand lies at a depth of 5,515-6,185 feet and is overlain by 60 feet of shale.

The Buckbee zone has an interval of 670 feet, of which 610 feet was at one time productive. The zone is characterized by five producing intervals and four intermediate shales. The top of the Buckbee shale is distinctive and has been used as a marker. It is also a good foraminiferal zone. In drilling, about 15 feet of thin laminated sand and shale was penetrated before entering the solid shale. This made a good marker when coring, before the use of the electrical log.

Sands in this zone are more compact and finer than in the Nordstrom or O'Connell zones. Early wells on the top of the structure had a high gas-oil ratio (the highest gas-oil ratio in the field.)

At the present time, edgewater is encroaching rapidly. In some parts of the field, the first two sand members can be produced, but in many parts of the field, intermediate water occurs between these sands.

The zone is now limited in extent and new production is unlikely. Also, it is probable that results would be poor if wells were plugged back and perforated in this zone.

O'Connell Zone (Pliocene). The O'Connell sand occurs at a depth of 6,220-7,150 feet and is overlain by 35 to 40 feet of shale. All of this 930-foot interval could be produced at one time. The upper 650 feet of the zone is comparatively sandy, while the lower 280 feet is rather shaly.

The third O'Connell shale, from 6,575-6,640 feet, is called the first Clark shale by many operators.

Clark-Hathaway Zone (Miocene). The upper part of this zone was sometimes referred to as the Clark and the lower part as the Hathaway, since the discovery wells of the zones were far enough on the edge of the structure to have water between. Wells higher on structure than the discovery wells could take in both zones, so they are usually grouped together as the Clark-Hathaway.

The top of the zone is at 7,250 feet and is overlain by a 60-foot shale body. The wells originally produced to 8,000 feet, but rapidly encroaching edgewater made it necessary to complete the later wells above 7,950 feet.

Since the zone is in the Miocene, the sands are hard, fine, and rather argillaceous. There are a large number of intermediate shales.

In 1937, the Union Oil Company drilled No. "Bell" 100 as a prospect well on the top of the structure. A depth of 11,314 feet was reached and it was decided to test a few poorly saturated intervals.

Various tests below 9,880 feet were nonproductive. A test of selected intervals between 9,440 and 9,880 feet was completed March 12, 1938 for about 160 barrels of oil and 100 barrels of water daily, with a gravity of 33°. At the present time, the well is being tested from 9,070 to 9,250 feet, where it is making about 10 barrels of oil and 20 barrels of water daily, which cannot be considered of commercial importance.

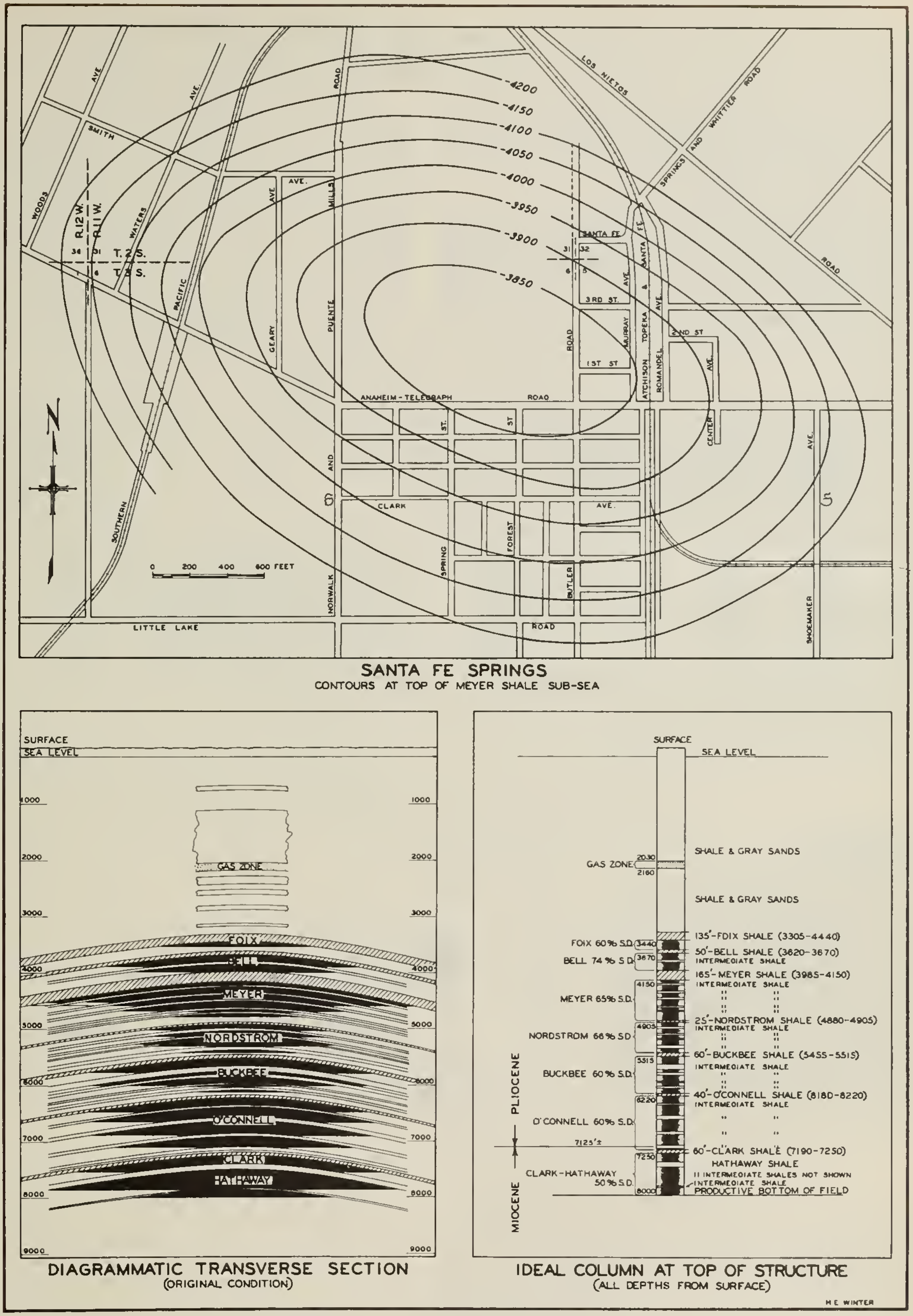


Fig 142. Santa Fe Springs oil field: structure map; diagrammatic transverse section; ideal column at top of structure.

STRATIGRAPHY AND STRUCTURE

Structurally, the field is a relatively flat elongated dome with the axis trending approximately N. 70° W. Originally the field was 2½ miles long on the axis and 1 mile wide at the widest part, and had a proven commercial area of approximately 1,450 acres. However, at present the commercial production is limited to an area of approximately 1,000 acres.

The field is characterized by a shallow gas zone and by eight definite and distinct major oil zones, each of which has several subzones with local names. The interval between zones is relatively uniform over the field, and no faulting has been observed. The Meyer is the most extensive of the upper zones and the Clark-Hathaway the most extensive of the lower. Production comes from the Pliocene, with the exception of the Clark-Hathaway and "deep" zones. The only deep zone well is the Union Oil Company prospect well No. "Bell" 100. The top of the Miocene approximately coincides with the top of the Clark zone at a depth of approximately 7,125 feet on the top of the structure.

In this field, 1,173 wells were drilled, of which 1,040 were completed successively in one or more zones, while 133 were either abandoned as drilling wells or gas wells and blowouts. The activity of the town-lot promoter in the boom development of 1922 accounted for a great many of the above 133 wells. These wells were either located on the edge, or finances were insufficient for their completion. The field is distinctive in that a number of successive completions may be made by one well in different zones. This has added considerably to the production of the field. The oil from the various zones is considered quite desirable from a refinery standpoint especially as it is quite free from sulphur and often commands a premium over the posted price.

SANTA FE SPRINGS OIL FIELD

Zone	Original area of commercial production (acres)	Jan. 1, 1940, approximate area of commercial production (acres)	Number of wells completed in zone	Number of producing wells in zone, Jan. 1, 1940	Barrels production to Dec. 1, 1939	Per cent of field production	Gravity range	Date of discovery	Range of I. P.	Original number of feet of oil sand in zone	Original per cent of sand in producing horizon	Barrels recovery per acres to Dec. 1, 1939 (original area)
Gas	75	0	.8	0	0			1/ 5/22				
Foix	130	30	24	6	2,875,959	0.6	25–28	5/23/22	1,000- 3,000	100	60	22,122
Bell	450	300	201	90	49,399,843	10.8	27–31	10/25/21	2,000- 4,000	229	74	109,777
Meyer	1,450	1,000	685	353	218,014,970	47.5	34–36	10/ 3/19	4,000- 7,500	417	65	150,355
Nordstrom	200	100	66	31	30,387,147	6.6	34–35	9/16/28	3,000- 6,000	382	66	151,935
Buckbee	475	200	175	64	37,053,950	8.1	34–35	7/26/28	2,000- 6,000	410	60	78,008
O'Connell	475	200	191	58	72,204,418	15.8	33–35	2/16/29	4,000-10,000	558	60	152,009
Clark	900	325	264	56	48,461,350	10.6	32–34	5/17/29	1,000- 5,000	375	50	53,770
				658	458,397,637	100.0						316,136 (1,450 acres)

CITATIONS TO SELECTED REFERENCES—Continued

ARTESIA AREA

Oil Weekly 37b.

SANTA FE SPRINGS OIL FIELD

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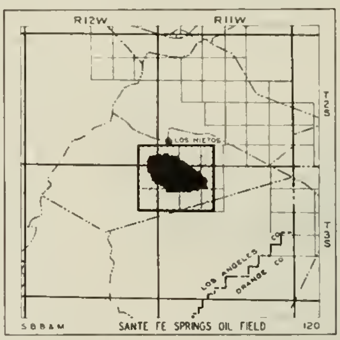


Santa Fe Springs oil field.

WEST COYOTE AREA OF THE COYOTE HILLS OIL FIELD

By Richard G. Reese *

OUTLINE OF REPORT

LOCATION AND HISTORY

The West Coyote area of the Coyote Hills oil field is located at the northwest edge of Orange County, about 18 miles southeast of the City of Los Angeles, 6 miles southeast of the Santa Fe Springs oil field, and 3 miles northwest of the town of Fullerton. It covers the larger part of a topographic feature known as the Coyote Hills, which lies in Secs. 17, 18, 19, and 20, T. 3 S., R. 10 W., S. B.

When the discovery of commercial production was made in this field (April 26, 1909) there were just four other fields producing in the Los Angeles Basin area, namely, Brea-Olinda (1890), Los Angeles City (1892), Whittier (1897), and Salt Lake (1902). The discovery well, Murphy Oil Company No. "Coyote" 3, was drilled because of oil showings observed in a hole being bored in the search for water. It was completed at a depth of 3,756 feet. This discovery led to development which reached a daily production peak of 31,600 barrels during the month of June 1918. Up to the present there have been 216 wells drilled in the development of this field. At the present time 150 of these are still capable of producing, and the current production from the field is about 10,000 barrels daily. The proved limits cover an area of about 1,000 acres, and the total accumulative production to date is about 125 million barrels.

DISTINGUISHING FEATURES

The West Coyote field is of historic interest in the development of the Los Angeles Basin area. It was the first discovery for which surface seepages of oil and gas were not the cause of exploration, and also the first discovery in a more or less isolated hill or group of hills. These facts were recognized, no doubt, at an early date and encouraged exploration which led to the discovery of such fields as East Coyote, Richfield, Dominguez, and Long Beach. They also contributed to the fact that nearly every topographic "high" in the Los Angeles Basin has had at least one hole drilled in it in the search for oil.

The field is also the only one in the Los Angeles area which has been practically controlled by one operator and consequently has not experienced the competitive drilling and close well spacing so common in most of the other Basin fields. Except for a small area at the southwest edge of the field and a small area at the east end of the field, the production and consequent development have been confined to two properties, both of which have been under lease to the Standard Oil Company of California since shortly after the discovery of the field.

* Standard Oil Company of California, Los Angeles. Manuscript submitted for publication November 7, 1941.

STRATIGRAPHY

An aggregate of about 500 feet of sediments is exposed at the surface. It includes the San Pedro (Pleistocene) and the uppermost part of the Pico (Pliocene) formations. The wells penetrate about 7,600 feet of sediments, which comprise the Pico and Repetto (Pliocene) and upper Puente (upper Miocene) formations.

San Pedro Formation

This formation is represented by 50 to 200 feet of more or less indurated sands and gravels containing some poorly preserved fossils. It is overlapped by sandy brown clays and thin sands, weathering to a reddish color, which grade upward into the Recent alluvium. The San Pedro formation rests, with minor angular discordance, on the Pico (uppermost Pliocene) sediments, and reflects the folding and associated cross-faulting of the area.

Pico Formation (Upper Pliocene)

This formation has a thickness of about 2,400 feet at the crest of the fold. It apparently thickens in all directions away from the crest, suggesting continued uplift during its deposition. It is essentially siltstone and shale, but includes some lenticular sandstone beds in the lower part. The top 200 feet is exposed in the canyons at the surface where the anticlinal nature of the structure is mappable.

Repetto Formation (Lower Pliocene)

This formation, which underlies the Pico formation, has been penetrated for a distance of about 3,900 feet at the crest of the fold where the deepest wells have not penetrated the complete Pliocene section. There is some evidence to indicate that at least the lower part of the Repetto formation becomes progressively thinner in an easterly direction. The top 1,000 feet is essentially shale, but includes lenticular sandstone beds. The next 2,900 feet is essentially sandstone, but includes some persistent shale beds which serve as the "cap rocks" for the oil-producing zones of the field. The most prominent sandstone member occurs near the middle of the formation. It is about 700 feet thick, generally coarse grained and poorly sorted, and includes only a few thin shale beds. The individual sandstone beds become increasingly more lenticular in an easterly direction and also at depth.

Puente Formation (Upper Miocene)

This formation has been reached in only one well, located at the east end of the field. Here it was penetrated for a distance of about 1,400 feet. The top 600 feet is dense shale, and the underlying 800 feet is essentially a fine- to coarse-grained, poorly sorted, and highly indurated sandstone.

STRUCTURE

The structure of the field is anticlinal, the crest being in the SE¼SW¼ Sec. 18, T. 3 S., R. 10 W., S. B. The Pliocene axis, eastward from the crest, follows a straight line trending about S. 80° E. and plunging at the average rate of about 75 feet per 1,000 feet, becoming even less steep in an easterly direction. The Pliocene axis, westward from the crest, has an almost due west trend, but is offset to some extent by cross-faulting. The west plunge, which is 170 feet per 1,000 feet, is considerably steeper than the east plunge. The south flank is relatively steep as compared to the north flank and may be faulted beyond the productive limits of the field.

PRODUCTIVE HORIZONS

The producing horizons are all confined to the Repetto formation. They are referred to as the Top, Main, Upper 99, Lower 99, and Emery zones. Although some showings were cored in Miocene beds in the test at the east end of the field, the sandstones in this formation were found to be very "tight," and their value as reservoir rock is still questionable.

The Top zone is confined to a very small area at the crest of the fold. The oil is 18 to 20 degrees gravity, and although the zone may not be completely exhausted, it is of little, if any, economic importance. The top of the zone is found at a depth of about 2,300 feet below sea level at the crest of the field.

The Main, Upper 99, and Lower 99 zones could have been produced, originally, as a unit at the crest of the field. In fact, the Main and Upper 99 zones were formerly referred to as the Main zone, and it was not until edgewaters were identified down dip that the name Upper 99 was given to the lower part of the interval. These three zones occur at below-sea-level depths, on the crest of the structure, of 2,800, 3,300, and 3,600 feet, respectively, and the gravities of the oils are 26 to 30, 28 to 30, and 28 to 30 degrees, respectively. The Main and Upper 99 zones are productive to the outer limits of the field, within a structural closure of 600 to 700 feet. The Lower 99 zone is confined to a much smaller area and to a structural closure of 300 to 400 feet. It extends into the top 75 feet of the 700-foot sand near the middle of the Repetto formation at the crest of the structure. The rest of the 700-foot sand is barren throughout the field.

The Emery zone is the deepest zone producing in the field. The top of the zone is found at a depth of about 4,800 feet below sea level at the crest of the field where it has been penetrated for a distance of about 1,000 feet. The sandstones are generally poorly sorted and are not as good reservoirs as the other producing horizons in the field. The productive area, although it extends slightly farther along the axis, is not as large as that of the Main zone. This is due to the steeper flanks at depth, especially on the south. The zone is confined to a structural closure of 700 to 900 feet and produces 30 to 35 degrees gravity oil.

EAST COYOTE AREA OF THE COYOTE HILLS OIL FIELD

By Paul H. Dudley*

OUTLINE OF REPORT

HISTORY

The East Coyote area of the Coyote Hills field lies approximately 2 miles northeast of the town of Fullerton and 3 miles east-southeast of the West Coyote area of the Coyote Hills field, in Orange County. The producing area is a quarter to three-quarters of a mile in width, and 4 miles in length.

The East Coyote area, originally known as La Habra field, was found during the exploratory drilling which followed discovery of the West Coyote area in 1908. The discovery well was drilled in 1911, southeast of the center of Sec. 13, T. 3 S., R. 10 W., S. B. It was located not on the exposed anticline which is now called Hualde dome, but more than 1½ miles to the northeast in an alluviated area lying east of, and roughly in line with, the axis of the West Coyote area. At the time, an unusual feature of this well, the Amalgamated Oil Company (now Tide Water Associated Oil Company) No. "Anaheim Union Water" 1, was the fact that it was drilled with rotary equipment. Production amounted to 600 barrels per day of 17° gravity oil, and was obtained between 2,830 and 3,340 feet, an interval including part of what is here called the First oil zone. The subsurface anticline eventually outlined in this locality during brisk drilling by more than a dozen companies was called the Anaheim dome. Continued development finally proved the existence of a smaller dome to the east and another dome of moderate size, the Hualde dome, to the southwest of this structure. Intervening areas were proved to be productive.

After the general outline of the field was established and it became known that the producing areas of East and West Coyote were separate and distinct, there was little new drilling for many years. A deep test was made in 1931, when Graham-Loftus Oil Corporation's No. "Graham-Loftus" 1, located on the crest of Anaheim dome, was drilled to 9,284 feet. Although thick sands were encountered intermittently to bottom, no deep production was found and the well was plugged back to produce from an interval that includes the Pliocene-Miocene boundary, the Pliocene portion of the interval falling within what is now called the Third oil zone.

The most important of fairly recent attempts to extend the field was the completion in 1934 of Bartholomae Oil Corporation's No. "Stern" 1. This well was located in the east-central part of Sec. 22, T. 3 S., R. 10 W., S. B., immediately west of Hualde dome, in an area where the First oil zone had already yielded what appeared to be marginal production. Scheduled as a deep test similar to Shell Oil Company's No. "Stern" 1-1 (now operated by Arrowhead Oil Company), which in 1929 had obtained Miocene production half a mile farther to the southwest, Bartholomae Oil Corporation's No. "Stern" 1 encountered better production than anticipated in the First oil zone and eventually established in this area the first important Miocene production. Subsequent drilling in the locality of this well has been extensive, but subsurface structure is still not definitely known. It seems, however, that the area is underlain by either a separate dome or possibly the faulted extension of the Hualde dome.

Exploration at the extreme eastern end of the area received considerable impetus in 1936 when DeAugustine, Abrams, and Daly brought in their No. "Barnett" 1 for 350 barrels per day of 22.8° gravity oil from the First oil zone. However, due principally to the limited accumulation of oil in this area, which may be underlain by a small local dome, the resulting drilling campaign turned out to be generally unprofitable.

Fairly recent wells such as Sonwell Oil Company's No. "Coyote" 1, drilled in 1939, and Master Petroleum Corporation's No. "Wright" 1, deepened in 1940, have extended former margins of production on the north and south flanks of the central portion of the area.

DISTINGUISHING FEATURES

The East Coyote area possesses several features that serve to distinguish and classify it as to type.

One of these is the fact that it is an alignment of several subsurface domes. Although the domes are not large, there are at least five and possibly seven of them. They represent, consequently, more complex folding than occurs in most fields of the Los Angeles Basin, which consist usually of a single or at the maximum a double dome.

The arrangement of these domes en echelon along a structural axis having a general easterly trend at variance to regional structure furthermore is a feature that is characteristic of the fields of the Coyote Hills uplift and distinguishes these fields from those of the northwest-trending Whittier fault zone and the producing anticlines of the prominent Newport-Inglewood uplift which, farther to the southwest, trends northwesterly across the Los Angeles Basin. The explanation of the abnormal alignment of the axis of the East Coyote area and the unusual arrangement of its various domes is purely a matter for speculation. It is possible that the axis may mark the trend of a large en echelon anticline resulting from rotational stresses accompanying lateral movement along the Whittier fault and that the various domes along the anticline may be attendant minor replicas, possibly dislocated by cross-faulting. Or, this localized easterly trend may be an isolated expression of the structural dynamics which produced the Transverse Ranges of southern California.

* Richfield Oil Corporation. Manuscript submitted for publication February 3, 1941.

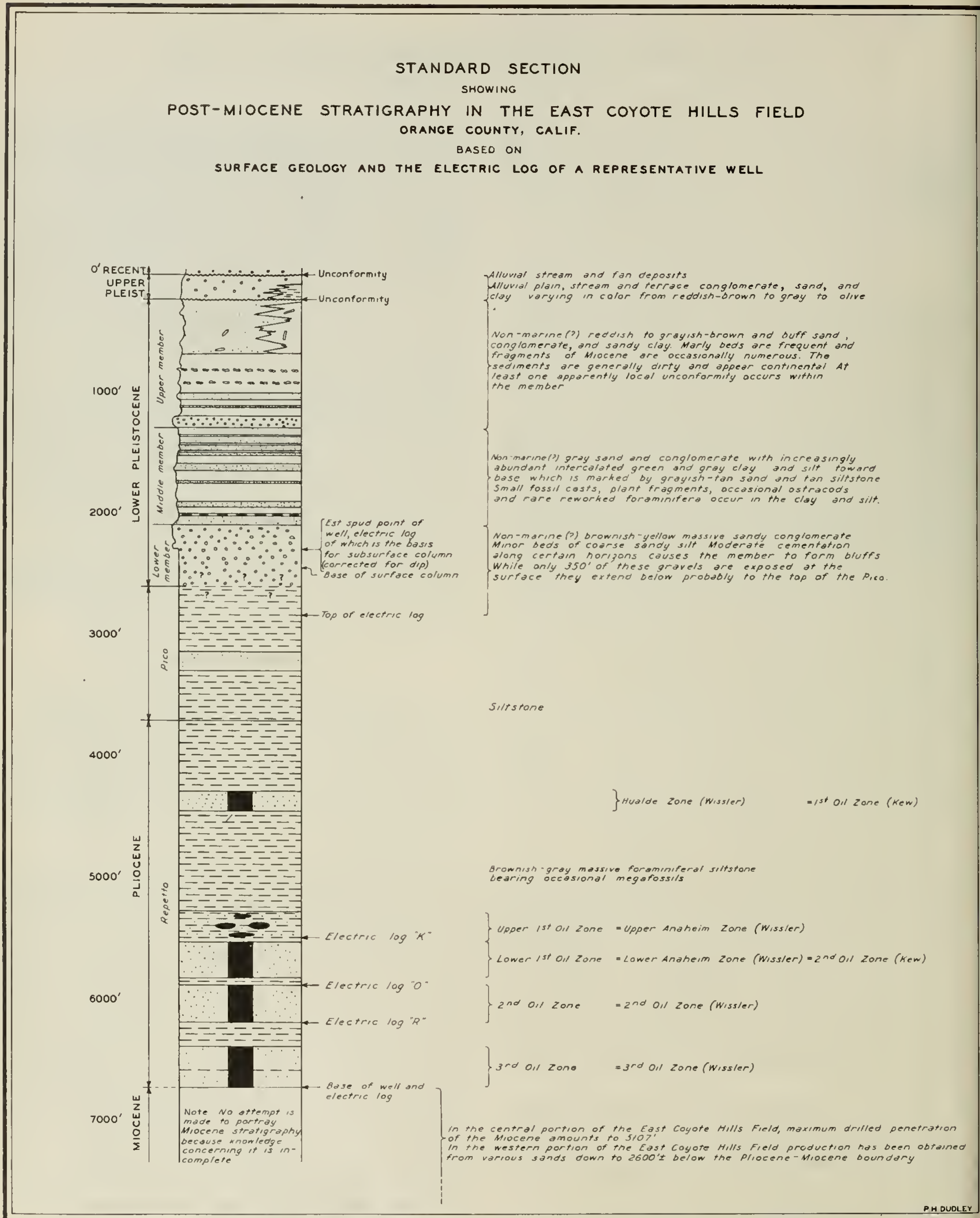


Fig. 143. East Coyote (East Coyote Hills) area of the Coyote Hills oil field: standard stratigraphic section.

Another feature that appears to broadly distinguish the East Coyote area as well as certain other fields in the northeastern part of the Los Angeles Basin, from many of those along the Newport-Inglewood uplift, is the relative thickness of the lithologic units comprising the stratigraphic column. In East Coyote, for instance, the sand and silt (or shale) members are often massive, the latter being as much as 1,000 feet in thickness. As a result, the assemblage is rather different from the alternating thin beds of sand and silt that so frequently characterize fields in the southwestern part of the basin.

STRATIGRAPHY

Discussion of the stratigraphy of the East Coyote area is, for reasons later given, confined to post-Miocene sediments. These are best portrayed by a composite of the Quaternary sediments exposed on the south flank of the Hualde dome, in the southern half of Sec. 23, T. 3 S., R. 10 W., S. B., and the subsurface Pliocene sediments encountered in neighboring wells. Surface lithologic data have been determined by field investigation and subsurface data have been obtained from both cores and electric logs. Geologic time divisions are based on microfaunal determinations by M. L. Natland and Stanley G. Wissler.

DESCRIPTION OF STRATIGRAPHIC SECTION

Recent 50′±		Alluvium.
		(Unconformity)
Upper Pleistocene 200′+		Alluvial plain, stream and terrace conglomerate, sand and clay, varying in color from reddish-brown to gray to olive.
		(Unconformity)
Lower Pleistocene 2350′+	1050′+	Non-marine (?) reddish to grayish-brown and buff sand, conglomerate, and sandy clay. Marly beds are frequent. Sediments are dirty and appear continental.
	800′±	Non-marine (?) gray sand and conglomerate with increasingly abundant intercalated green and gray clay and silt toward the base, which is marked by grayish-tan sand and tan siltstone. Small fossil casts, plant fragments, occasional ostracods and reworked Foraminifera occur in the clay and silt.
	500′±	Non-marine (?) brownish-yellow massive sandy conglomerate with minor beds of coarse sandy silt.
Pliocene 4100′±	Pico 1100′±	Gray massive foraminiferal siltstone with a sand member 150± in thickness 525± below the top. Scattered megafossils occur throughout.
	Repetto 3000′±	Greenish-gray, gray, grayish-brown massive foraminiferal siltstone with a 150′ massive, locally petroliferous sand (Hualde zone) 600′ below its top and several generally massive oil sands (First, Second and Third oil zones) in its basal portion. Mega-fossils are scattered throughout.

The lower Pleistocene sediments described in the foregoing column elsewhere have been named La Habra conglomerate. The series is strongly folded, the dip of the strata on the south flank of the Hualde dome ranging as high as 57 degrees. Evidence obtained outside of the East Coyote area indicates that these sediments overlie the Pliocene conformably and, in part, are marine (Eckis, R. 34, p. 217).

Pliocene sediments are not exposed in the East Coyote area, but near the crest of the structure they are known to be only a short distance below the surface.

Relatively few wells have been drilled into the Miocene (Puente) but, in the deepest well of the field, nearly 5,100 feet of these sediments have been penetrated. Information concerning the Miocene, however, is very incomplete. This is due principally to the limited number of cores taken, the scarcity of diagnostic fossils in important parts of the section, the difficulty of correlating electric logs in this area, and the few dips recorded in penetrated sediments. In view of these handicaps, it seems premature at present to discuss the Miocene stratigraphy of this field.

STRUCTURE

The structure of the East Coyote area is best portrayed by subsurface contours on the top of what is here named the lower First oil zone. This zone, occurring in the Repetto formation, is the most important one of the field and was first contoured in 1926 by W. S. W. Kew, who called it the "Second" oil zone (English, W. A. 26, pl. XIII). At that time, it was recognized partly from the lithology of cores, but frequently on the basis of drillers' logs. The zone is fairly well defined, however, and control was based on so many wells that the resulting structural interpretation is still more accurate than one based solely on the scattered microfaunal determinations or the relatively few electric logs existing today. Kew's original contours have been adjusted and extended wherever possible by correlation of all available logs. The original name for this zone has been abandoned, however, and the total zone, of which it is the lower half, is designated the "First oil zone." This revision is prompted by the fact that the First oil zone, as presently defined, is the first sand body that is productive throughout the entire area, and the definition fits terminology that has arisen recently in the west end of the area.

With the exception of contours southwest of Hualde dome, the present portrayal of subsurface structure of the area differs from the original only in relatively minor details. Trend and position of the axis are essentially the same. Proceeding from east to west, structural units into which the area can be divided, in spite of almost continuous intervening production, are as follows: (1) a dome or rising nose east of Anaheim dome; (2) the double-crested Anaheim dome; (3) Hualde dome, and (4) the questionable dome to the west, in Sec. 22, T. 3 S., R. 10 W., S. B., in which Miocene production was discovered by Bartholomae Oil Corporation's well No. "Stern" 1.

Field mapping shows that well-defined anticlinal axes in East Coyote are exposed in two localities, namely at the extreme western end of the area, and in Hualde dome. The intervening alluvial cover makes it difficult to prove that these segments are part of the same axis but their general alignment suggests this interpretation. The first passes approximately through the abandoned location of Union Oil Company's No. "Fullerton Heights" 1 and trends westerly. The second, in Hualde

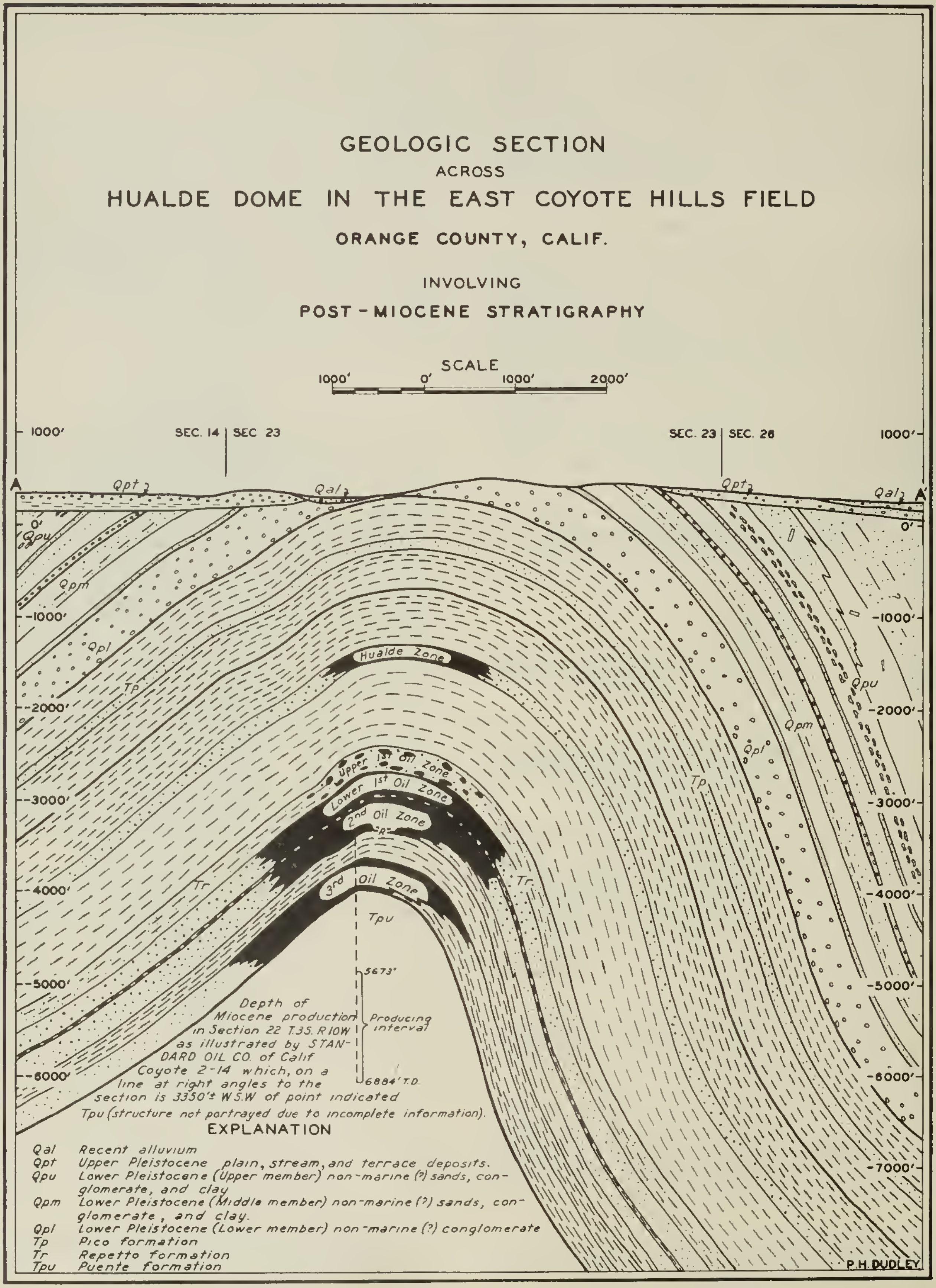


FIG. 144. East Coyote (East Coyote Hills) area of the Coyote Hills oil field: geologic section across Hualde dome.

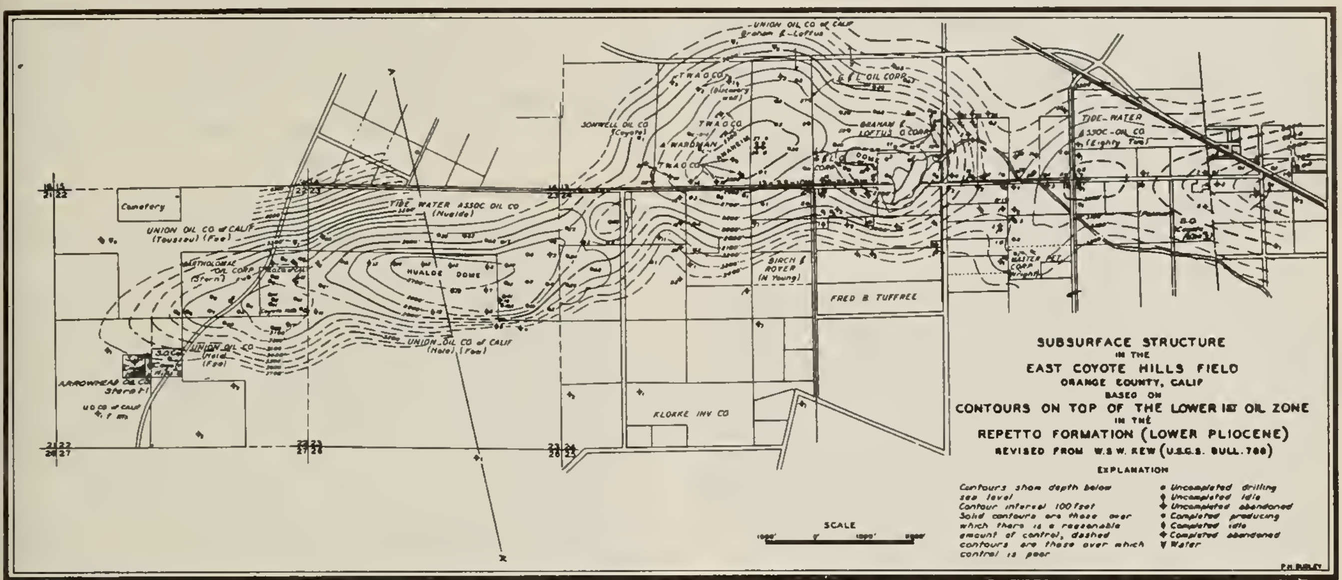


FIG. 145. East Coyote (East Coyote Hills) area of the Coyote Hills oil field: subsurface structure.

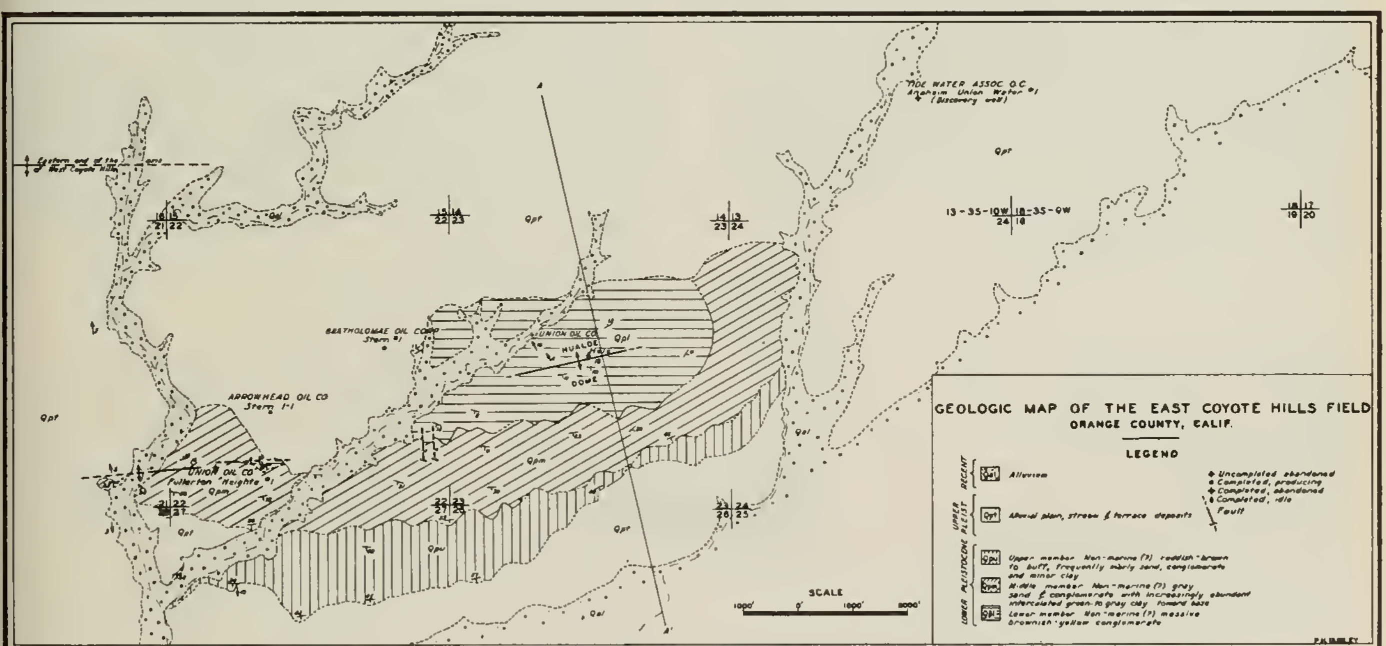


FIG. 146. East Coyote (East Coyote Hills) area of the Coyote Hills oil field: geologic map.

dome, runs just south of the same company's No "Hole" 18 and appears to have a trend of about S. 75° W. Structural closure on the east end of this latter axial segment is unquestionable.

These axial segments are located somewhat south of the probable position of the subsurface axis at the top of the lower First oil zone. This suggests, as illustrated in a section through Hualde dome, that folding locally may be asymmetric. Horizontal migration of the axis at depth must be regarded as tentative, however, because the location of the subsurface axis is not above question, the reason being that in Hualde dome subsurface contours are based on drillers' logs and, in the possible dome to the west, subsurface contours depend on admittedly incomplete structural control.

A further structural problem of interest is the question of whether there is faulting within and adjacent to East Coyote. The possible cross-faulting already mentioned may be an underestimated feature of the area. There is also some reason for suspecting the presence of one or more important faults outside of the margin of the area. The surface geology offers little positive evidence on these questions, however, and their final answer appears to lie in the interpretation of future subsurface information.

PRODUCTIVE HORIZONS

Oil zones in East Coyote are distributed through an interval which includes the basal 2,400± feet of Pliocene and 2,600± feet of Miocene.

The Hualde zone is the highest of the various Pliocene oil zones and is productive only in the eastern part of the Hualde dome. The zone is about 150 feet thick and its top occurs roughly 600 feet below the top of the Repetto Oil ranges between 17° and 20° Baume gravity.

The top of the First oil zone is 800 feet stratigraphically below the Hualde zone. To date it has been the most productive and it is the best known oil zone in the East Coyote Hills. On the basis of lithology it can be divided into (1) an upper First oil zone, comprised of alternating, usually thin beds of sand and siltstone totalling 250± feet in thickness; and (2) a lower First oil zone, largely sand with minor amounts of siltstone, totalling 300± feet in thickness. Some wells completed in the First oil zone have produced 500 to 2,000 barrels per day (Hoots and Herold 35, pp. 207-209). The rate of decline generally has been rather rapid. Top, intermediate, and bottom water are all present. The oil varies between 16.2° and 25° gravity and analyses have shown that it is a waxy type, being high in asphalt and light ends (English, W. A. 26, p. 106).

A small amount of production from sands midway between the Hualde and First oil zones has been established recently in the eastern end of the area. Gravity of the oil ranges from 17° to 23°.

The Second oil zone is approximately 300 feet in thickness. Its top occurs 60 feet below the base of the First oil zone and 850 feet above the base of the Pliocene. The Second oil zone is characterized by an appreciable amount of lensing. It yields more prolific production in the west end of the area where some wells have produced initially more than 650 barrels per day. Gravity of the oil ranges between 17° and 26.9°.

The Third oil zone is often 350 feet thick. However, in wells of the south side of the area, this zone is usually thinner or absent, suggesting pronounced lensing, or lateral change from sand to shale. Stratigraphically the zone extends from approximately 200 feet below the base of the Second oil zone to the Miocene. Production from the Third oil zone has been more important in the west end of the East Coyote area where, on completion, some wells have yielded nearly 600 barrels per day. Gravity of the oil varies from 18° to 26.7°.

Since present knowledge of Miocene stratigraphy is incomplete, no attempt is made to differentiate or name production below the Third oil zone. Production from deeper sands is obtained principally in the western end of the area, where wells have produced initially as much as 750 barrels per day. The gravity of the oil varies from 18° to 26°

CITATIONS TO SELECTED REFERENCES—Continued

COYOTE HILLS OIL FIELD

Arnold, R. 15; Emmons, W. H. 21; Huguenin, E. 26; Kirwan, M. J. 18; 18a; Masser, H. L. 22; 23; Miller, H. C. 29; Prutzman, P. W. 13; Soper, E. K. 32a; Thoms, C. C. 24; Vander Leck, L. 21.

Anaheim Dome

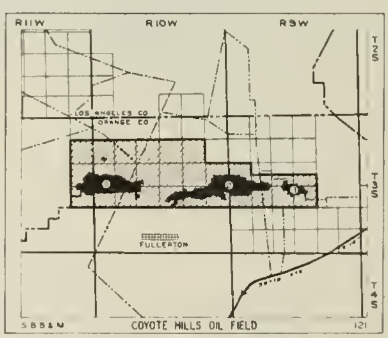
English, W. A. 26; Taff, J. A. 34.

Anaheim-Hualde (East Coyote) Area

Taff, J. A. 34.

East Coyote (East Coyote Hills) Area

English, W. A. 26; Hoots and Herold 35; McLaughlin and Waring 14, pp. 361-362; Moran, R. B. 17; Stockman, L. P. 41c; Taff, J. A. 34; Vallat, H. E. 41a.



Coyote Hills oil field. Areas: (1) West Coyote; (2) East Coyote; (3) Yorba Linda.

Hualde Dome

English, W. A. 26, p. 84; Taff, J. A. 34.

La Habra (East Coyote) Area

McLaughlin and Waring 14; Soper, E. K. 32a; Stockman, L. P. 40, no. 18, p. 74; Watts, W. L. 00.

West Coyote (West Coyote Hills) Area

Arnold, Darnell, et al. 20; English, W. A. 26; Hoots and Herold 35; Kirwan, M. J. 18; McLaughlin and Waring 14, pp. 362-363; Moran, R. B. 17; Taff, J. A. 34.

Yorba Linda (Yorba) Area

Hoots, H. W. 38, p. 708; Huguenin, E. 26, rept. 24, no. 3, p. 18; 39.

YORBA LINDA AREA OF THE COYOTE HILLS OIL FIELD

By Frank S. Parker *

OUTLINE OF REPORT

HISTORY

The Yorba Linda area of the Coyote Hills field includes an area of about 300 acres in Secs. 15, 16, 21, and 22 of T. 3 S., R. 9 W., S. B., about a mile northwest of the town of Yorba Linda, in Orange County.

The first production from this area was obtained by the S. V. Smith (then L. S. Simmel) well No. "Todd" 1 near the northwest corner of Sec. 22. This well was brought in on the pump for 150 barrels of 14° gravity oil, from sands in the interval 1,643 to 1,733. An earlier well, the Mid Cities Oil Company (then Southwestern Oil Company). "Day," half a mile to the southwest, obtained good showings from 1,866 to 2,259 feet, but was not commercially productive. The "Todd" was taken over by the International Petroleum Corporation, and was deepened to 2,722 feet without additional showings. It was plugged back to the zone tested, and produced from that sand. The decline was rapid, and 30 days after completion the well was producing only 20 barrels per day. It was later acquired by S. V. Smith.

Probably because of the low gravity of the oil obtained, little interest was shown in the area until the completion of the Shell Oil Company well "Olinda Land Company" E, drilled as an exploratory core hole. This well was completed with 2-inch casing, flowing through 1-inch tubing from the zone 1,660 to 2,090 at a rate of 250 barrels of 18° gravity oil, in December 1937. It quickly sanded up, and was abandoned in January 1938. A test of the zone by "Olinda Land Company" F, in December 1937, showed a production rate of 1,200 barrels of 19° gravity oil per day. The Shell Oil Company wells were not produced except for these tests.

The success of the two Shell Oil Company wells led to increased activity in the subdivided area of Secs. 21 and 22, and in the following year 20 wells were drilled, proving an additional area of 120 acres productive, and yielding a peak production of about 700 barrels per day in July 1938. Wells in the portion of the area in Secs. 21 and 22, however, obtained production principally from the Todd sand (also called the "Smith" sand), and the greatest part of the oil did not exceed 14° in gravity. The Todd sand is unconsolidated, and many of the wells had constant sand trouble. This resulted in much shut-down time, and in June 1940 there were only 14 wells operating part time, and four idle wells, in the field.

Interest was renewed somewhat by the completion in February 1940, by George Morgan and others, of the well No. "Fricke" 1 for 90 barrels per day of 15.8° gravity oil from a sand possibly the correlative of that found in Sloan Oil Company "Yorba" (then Burmah Oil Company well No. "Sloan" 1), the Krieger (then Hancock Oil Company, and later Landon) well No. "Day" 1, and the Beth Petroleum well No. "Pickering" 1; none of these wells, however, equalled the Morgan well No. "Fricke" 1 in production. The Silver Star Oil Company well No. "Scott" 1 apparently is more akin to the "Yorba," "Day," and "Pickering" wells than to the "Fricke" and Fairfield "Tuffree" wells. These two groups of wells may be separated from each other and from the Shell wells by faults.

STRATIGRAPHY

The surface rocks of the area are late Pleistocene clayey gravels underlain by some 200 to 500 feet of more steeply dipping beds of similar material, earlier Pleistocene in age. This in turn is underlain unconformably by faulted and more steeply dipping sands, conglomerates, and siltstones of Pico age, 1,200 to 1,500 feet in drilled thickness. Beneath the Pico lies some 1,000 feet of Repetto sands, coarse sands, conglomerates, siltstones, and shales. Both oil sands are found in the upper part of the Repetto, but the E sand is the younger and is not present in the area of Todd sand production. Miocene beds were penetrated by both "Day" wells, the Krieger "Day" being definitely in Miocene at 3,500 with the top of the Miocene probably at 3,200, according to data from Shell Oil Company paleontologists. No significant oil showings were noted in the Miocene beds. The Pliocene strata are very lenticular in character, and in short distances thick conglomerates grade into sands or siltstones, or split into thin beds.

Microfauna are sparse, many of the wells were incompletely cored, and few electric logs were available for study; so that correlations and interpretation of structure must be regarded as tentative.

STRUCTURE

Regionally the area is monoclinal with the dip southwest away from the Whittier fault zone, which lies about a mile to the northeast. From the Whittier zone a number of faults branch westward, and it is one of these, together with minor faults and stratigraphic variation, that govern the accumulation of oil in this area. The fault shown on the map between Shell Oil Company E and the Union Oil Company dry hole is known from surface field work. The others are inferred from the differences in gravity of oil in the various groups of wells, and from the difference in age of the producing horizons between the wells to the southeast and the Shell Oil Company wells, as determined by the Shell Oil Company paleontologists. The location and attitude of these faults are uncertain. They may cut only Repetto and older beds, as there is some evidence that the Pico beds extend across them unbroken. Apparently some faulting and tilting occurred in this area after the Repetto deposition. Then the area was planed down, the E sand eroded from the upthrown blocks, and the Pico beds deposited across the beveled edges of Repetto beds.

Even though it is implied in the context, the writer wishes to stress that the conclusions of this paper as to geology are interpretive rather than factual.

* Geologist, Los Angeles, California. Manuscript submitted for publication November 29, 1940.

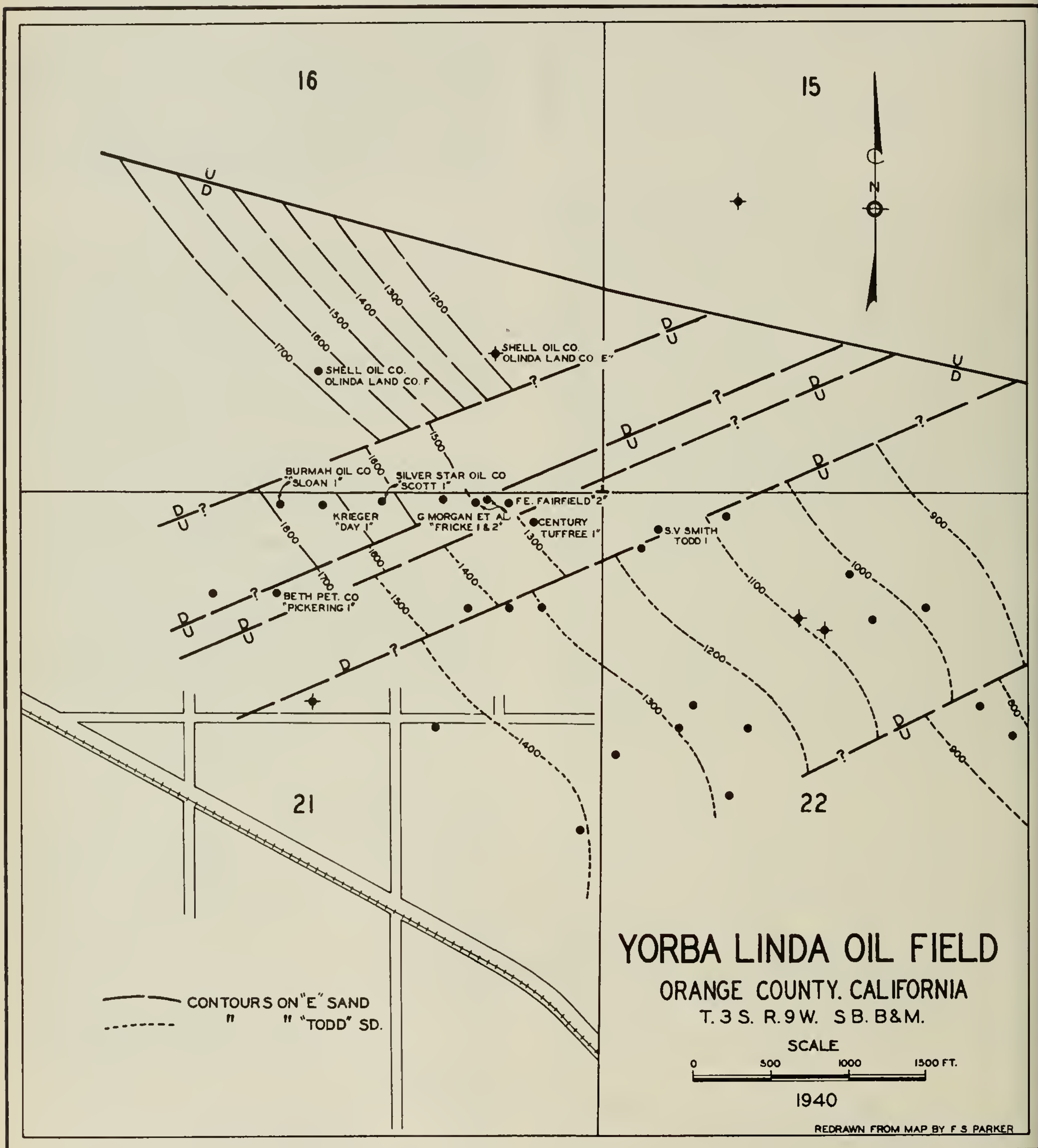


FIG. 147. Yorba Linda (Yorba Linda oil field) area of the Coyote Hills oil field: structure map.

RICHFIELD AREA OF THE RICHFIELD OIL FIELD

By Chester M. Gardiner *

OUTLINE OF REPORT

HISTORY

The Richfield area of the Richfield oil field is located 6½ miles east of Fullerton in Orange County, in a series of low-lying hills 300 feet or less in elevation. Showings of gas in a water well drilled on the Coyle property in this low-lying topographic feature encouraged exploration which resulted in the discovery of a very prolific oil field.

The Richfield area was discovered March 11, 1919, by the Union Oil Company well No. "Chapman" 1, which was completed at a depth of 3,025 feet. The initial production was approximately 1,750 barrels per day of 22 degrees Baume gravity oil, cutting less than 1.5 percent water, from a zone designated as the Chapman zone. It was not until June 22, 1920, that the Standard Oil Company completed well No. "Kraemer" 2-6, at a depth of 4,130 feet, which proved the existence of a lower and more prolific zone than the overlying Chapman zone. This well, after 22 years, still has a potential production of 185 barrels per day. The author has made estimates of reserves throughout California, Montana, Wyoming, Texas, Oklahoma, and New Mexico for some 20 years; but in none of these states has he seen more sustained production than that on the westward plunge of the main Richfield anticline. Any number of wells in this area have produced to date from 900,000 to 2,000,000 barrels of oil and are still producing at a rate of from 50 to 300 barrels of oil per day. This is probably due to the fact that, as shown in recently drilled wells, sands have a porosity of 20 to 35 percent and permeabilities of 100 to 1,300 millidarcys. When coupled with the thickness of the reservoir beds, the low middle gravities of the oils produced, and the low percentage of occluded gases within the oil itself, these factors are sufficient to cause such sustained production.

The Richfield area was rather rapidly developed considering the period which came right after World War I, and at the present time there are some 1,300 acres of proven producing oil land, including approximately 300 wells. These wells are all on the pump and have produced to date approximately 95,000,000 barrels of oil. The gas produced contains approximately 1.4 gallons of casinghead gasoline per 1,000 cubic feet, and approximately 1,000 cubic feet per barrel of oil have been produced to date.

* Petroleum Geologist and Valuation Engineer, Los Angeles, California. Manuscript submitted for publication March 24, 1942.
The author wishes to acknowledge the kindness of Mr. V. H. Wilhelm of the Texas Company and Mr. Eggleston and Mr. Wissler of the Union Oil Company, who allowed him to use pertinent data regarding general analysis and also the complete section as exposed by the drilling of Union Oil Company's well No. "Chapman Lease" 29.

DISTINGUISHING FEATURES

The outstanding features of this area as compared to the other fields in the Los Angeles Basin are: (1) the complexity of the structure; (2) the sulphur content; (3) the fact that there are five different traps containing commercial accumulation; (4) the fact that this field is one of the few in the Los Angeles Basin which has approximately an east-west structural trend; (5) the definite fact that there is no Repetto section; (6) the extreme sustained production from the west plunge of the major axis; (7) the presence of the most complete Tertiary section in the Los Angeles Basin.

The above items will be taken up subsequently. This field is well located as regards market, and at the present time there are four major-company pipe lines extending from it to refining centers located at or near the coast. With reference to cracking of high-octane gasoline and the residual specification fuel oil, the crude produced is a premium oil.

STRATIGRAPHY

The stratigraphy of the Richfield oil field is shown in the graphic log accompanying this report. Briefly, there are some 400 to 500 feet of San Pedro sands and gravels located at surface. The Pico-Pliocene section extends from 400 feet to approximately 2,500 feet, and is composed of gravels and conglomerates, blue clays, and soft blue shales. There is definitely no Repetto section existent here, and there was apparently little dynamic evolution prior to the laying down of the Pliocene in contact with the upper Puente or Miocene section. The angle of unconformity rarely exceeds 7 degrees. The top of the Chapman producing zone underlies the Pico-Puente contact about 400 feet. As shown on the graphic log, the Chapman zone is comprised of two major producing sands separated by 60 feet of shale. There is approximately 230 feet of platy shale, locally designated as the Kraemer shale, separating the base of the Chapman producing horizon from the top of the Kraemer producing horizon.

The Kraemer zone varies widely as regards porosities and permeabilities, but in general has a thickness of about 750 feet. The upper half of the Kraemer zone is by far the most prolific. However, recently drilled wells show porosities and permeabilities from the lower half of this zone, which are comparable to those of the upper half, but almost without exception the sands are wet on the north flank. The top of the middle Puente sandstone series seems to have porosity on the south flank of the major axis. This fact was definitely shown in the Chicksan Oil Company well No. 3, drilled to a depth of 5,050 feet some years ago. Unfortunately, the upper middle Puente sandstone was not tested because of the loss of the hole through mechanical difficulties.

In the author's opinion, there are definite future possibilities with respect to this horizon underlying the Kraemer zone on the south flank. As can be seen from the graphic log, the middle Puente sandstone series extends to a depth of approximately 6,300 feet. Below this depth there is an almost continuous column of middle Puente shale down to a depth of 6,860 feet. The base of this shale body represents, roughly, a contact of the middle and lower Puente. Union Oil Company's well No. "Chapman" 29 found some 400 feet of more or less porous sands underlying the middle Puente shale. These sands had very interesting showings. The cores and electric log led the author to believe that this sand could very well be productive if found on structure.

There is a hade to the south of the long axial plane on the westward plunge of the main Richfield anticline. This hade of asymmetry is sufficient to place the axis of the Kraemer zone some 400 feet south of the axis of the Chapman zone in this area. If this asymmetry and hade to the south continue with depth, it is quite possible that deep production might be obtained at the middle-lower Puente contact, if drilled on the south flank of the present producing structure. Underlying this 400 feet of porous sands is 700 feet of lower Puente hard, indurated, homogeneous, dark-brown shale. In general, this shale continues down to the altered broken volcanic andesites, which act as a very good marker bed for the contact between the lower Puente (Miocene) and Topanga (Miocene). These volcanics extend downward for about 250 feet. The Topanga formation is comprised of alternating sands and shales, gray sands, and sands which gave light amber cuts. However, in well No. "Chapman" 29 there was no separation between the gray sands and the sands which gave the light amber cuts, indicating an edge condition. These alternating sands and shales continued down to a depth of approximately 9,125 feet, where heavy, dark-brown, indurated shales without definite bedding planes were encountered. These shales were tentatively classified as Vaqueros (lowermost Miocene), and were interspersed with definite terrestrial red beds. The horizon was tentatively classified as Vaqueros-Sespe undifferentiated. This classification is not accepted by the author, for it assumes that lower Miocene is intermingled indiscriminately with Oligocene. The red beds found were land-laid deposits, and either they must have been lower Miocene, or the heavy shales Oligocene.

STRUCTURE

On the map accompanying this brief report an attempt has been made to show the general structure of the Richfield area by contouring the top of the uppermost producing horizon, the Chapman zone. The map is based on sub-sea-level datum. The geologic column is based on surface. It must be stated that the contours as shown for the top of the Chapman producing zone do not, within rather wide limits, show the contour of the structure as regards the lower or Kraemer zone. It is quite definite that the West and East Coyote areas of the Coyote Hills oil field and the Richfield and Kraemer areas of the Richfield oil field underwent structural deformation which provided traps, long before other Los Angeles Basin oil fields. As can be seen from the stratigraphic column, there is no Repetto section east of the West Coyote area of the Coyote Hills oil field. It is quite evident that the shore line of the Repetto sea fell west and south of the above-mentioned areas. The

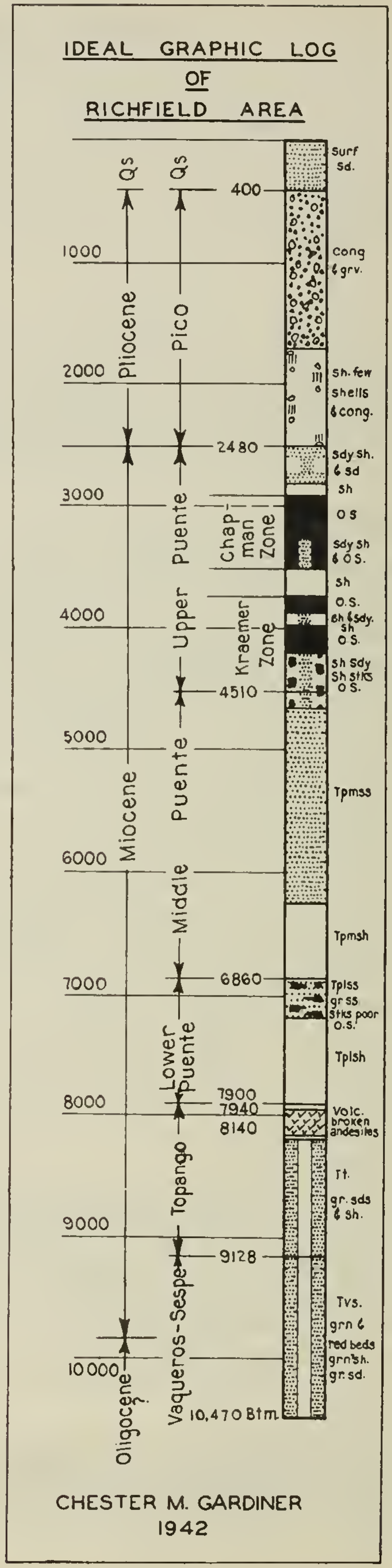


FIG. 148. Richfield area of the Richfield oil field: ideal graphic log.

Texas Company is now exploring the edge of the Repetto sea south and west of these areas. It is also evident that the balance of the Los Angeles Basin oil fields follow a definite northwest trend, based on subsequent deformation.

The structure of the Richfield area is complicated, for within this area are five traps that hold commercial accumulations, and these are without definite separation of productive limits. The main axis of accumulation has a slight northeast trend. All production is obtained from the uppermost Miocene, locally designated the upper Puente. The first reservoir bed of accumulation is located some 400 feet below the Pico (Pliocene)-upper Puente (Miocene) contact. The base of the Kraemer zone acts as a fair marker for the top of the middle Puente sandstone series. Lenticularity of the sands is a typical characteristic of the upper Puente formation. In the Richfield area, lenticularity has been given credit for the differences in the productivity of the two separate zones. In the writer's opinion, however, this is definitely not the case. The difference in productivity is caused by gradations from sand to shale and vice versa within the zone itself, without any apparent changes in thickness of the zone. It is also common in the upper Puente to find that there have been slight infiltrations of silica-bearing waters, which caused a change in porosities and permeabilities without any relationship to the thickness of the zone itself. This feature is definitely without regard to position on structure, and without any definite trend. There are many small localized faults that have very little measurable vertical or horizontal displacement, but which have caused sufficient brecciation and impaction to explain the large variations in present productive potentials existent between offset wells.

The main producing structure in the Richfield area is that which measures from the middle of the central sector throughout the entire westward plunge of the main axis. There is a small producing area to the east on the main axis, that had low initial production, and has extremely low present production; that contains large quantities of infiltrating waters, almost without exception from the north. It is logical to expect bigger wells on the south flank of this area, due to the fact that it is on the basinward side, which apparently contains the chief source beds. As can be seen from the accompanying map, there is a separate closed structure existent in the southeast portion of this area, which has been locally classified as the Richfield Consolidated anticline. This small anticline is about 100 feet higher structurally than the main Richfield anticline. There is also a saddle on the main anticline between the major portion of the area and its northeast extension. However, small wells have been producing from this saddle for many years.

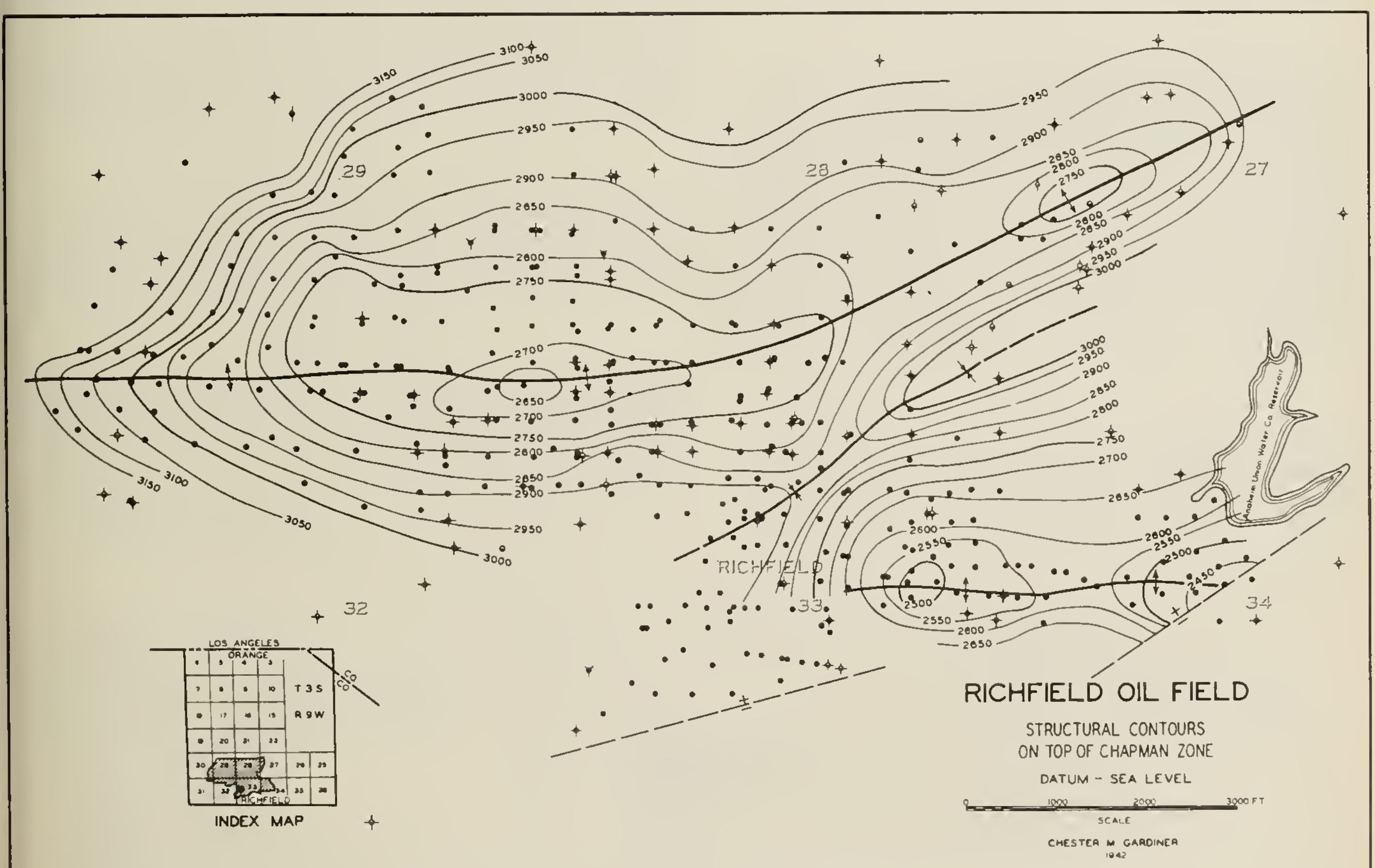


FIG. 149. Richfield area of the Richfield oil field: structure map; index map.

The Richfield Consolidated anticline is separated from the major axis by a zone of shear, in conjunction with a short, sharp syncline. The productive limits of the Richfield Consolidated anticline are cut off from a structural saddle after heading east, by a zone of shear having a northeast trend. There is another zone of shear coming out en echelon from that short, sharp saddle, existent between the major fold of the Richfield Consolidated anticline and the plunging nose buttressed against the eastern shear zone. This forms a trap, or properly a buttress accumulation against a zone of shear, from the zone of shear westward. This accumulation produced oil of lower gravity and higher sulphur content than those traps existent to the north.

KIND OF OIL AND GAS

The gravity of the oil produced in the Richfield area varies from approximately 18 degrees A.P.I from the flank wells of the Chapman zone to approximately 25 degrees A.P.I. from the central wells of the Kraemer zone, at the present writing. The gravity of the oil has dropped 1 or 2 degrees since the area was discovered. This of course is due to the fact that occluded gases have been dissipated, to a large extent. An average gravity oil for the entire Richfield area would approximate 21.5 degrees A.P.I. This average gravity oil would show a gasoline content at 60 degrees of about 7 percent, the gas tops at 52 degrees would be about 9 percent, middlings would run about 22 percent. The balance of the oil is of necessity blended with residual fuels from Santa Fe Springs, Signal Hill and other fields, to effect a reduction of the sulphur content in order to make marine specification fuel oil. A fair average of the sulphur content for the Richfield area oil would not exceed 1.6 percent. However, flank wells have been known to produce as high as 2.75 percent sulphur. At the present time the oil produced in Richfield comes within the premium crude demanded for the war effort.

KRAEMER AREA OF THE RICHFIELD OIL FIELD

By Richard G. Reese *

OUTLINE OF REPORT

HISTORY

The Kraemer area of the Richfield oil field is located in the N½ Sec. 36, T. 3 S., R. 9 W., S. B., Orange County, on the north bank of the Santa Ana River. This area is also known as the Santa Ana Canyon field.

Oil was discovered here September 16, 1918, by the Standard Oil Company No. "Kraemer One" 1 well, pumping 144 barrels of 15.3° gravity oil, together with 176 barrels of water from a depth of 2,762 feet. Of the 25 wells drilled subsequent to this discovery, 17 were completed prior to 1923. Development since that time failed to extend the productive limits as defined by this first group of wells, and from them have come the 1,400,000 barrels of oil which the area had produced to June 1, 1939.

The wells, which produced from a minimum of 5,000 barrels to a maximum of 440,000 barrels total accumulative each, cover an area of approximately 120 acres. Ten have not yet been abandoned and are still capable of producing some oil.

DISTINGUISHING FEATURES

The interesting features of this area are: (1) that it is the productive area farthest east in the Los Angeles Basin; and (2) that the anticlinal nature of the structure is conveniently exposed at the surface.

STRATIGRAPHY

The section penetrated by wells in this area is of Miocene age, equivalent to the upper Puente shale and middle Puente sandstone. The upper 1,000 to 1,600 feet of formation is medium- to fine-grained sand and interbedded silty, brown shales, believed to be a sandy phase of the upper Puente shale. The next 1,000 feet is essentially brown shale that becomes thinly laminated in the lower 200 to 400 feet. Some 3-inch to 2-foot lenticular sand beds are present in this interval. This is the characteristic shale member of the upper Puente shale. It grades into a medium- to coarse-grained sand which is believed equivalent to the middle Puente sandstone. This member has been entered for a distance of 2,100 feet, and at this depth is practically solid sand.

STRUCTURE

The surface structure is quite clearly a west-plunging asymmetrical anticline, the north flank of which has an average dip of 25°, while the south flank attains dips as high as 75°. The axis trends about N. 70° E. Because of the early development in the area, without benefit of the use of core barrel or knowledge of deviation of the holes, the subsurface conditions are not definitely known. It is quite apparent, however, that the structure persists at depth and that the axis at the producing zone approximately parallels the surface axis, but on a line about 500 feet to the north. The dip of the axial plane is believed to be 75° N.

PRODUCTIVE HORIZON

The production in this area is derived from the lower 700 feet of the upper Puente shale, together with the top 200 feet of the middle Puente sandstone. The largest part of the oil is believed to have been derived from the middle Puente sandstone, but it is quite obvious that a few of the shallower wells produced from thin sands in the overlying shale. The water strings were cemented over the first substantial showings, and consequently vary greatly in interval above the middle Puente sandstone, which is the only distinguishable datum shown on the old logs.

KIND OF OIL

The gravity of the oil varies from 19° to 22°. As compared to the average crude produced in the Los Angeles Basin, it is of high sulphur content, and contains a higher percentage of gasoline for a given gravity.

* Standard Oil Company of California. Manuscript submitted for publication August 3, 1939.

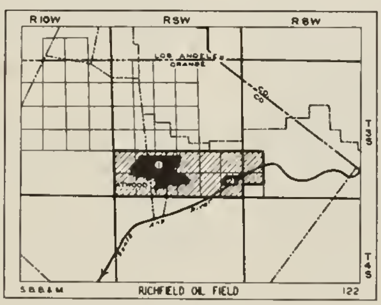
CITATIONS TO SELECTED REFERENCES—Continued

RICHFIELD OIL FIELD
Arnold and Loel 22; Hight, W. 33; Hoots and Herold 35; Huguenin, E. 26; Kirwan, M. J. 18a; Masser, H. L. 22; 23; McCollough, E. H. 34; Soyster, M. H. 22; Stockman, L. P. 351; Taff, J. A. 34; Thoms, C. C. 24; Vander Leck, L. 21; Watts, W. L. 00.

Central Richfield Area
Musser, E. H. 26.

Chapman Anticline
Musser, E. H. 26.

East Richfield (Kraemer) Area
Musser, E. H. 26.



Richfield oil field. Areas: (1) Richfield; (2) Kraemer.

Kraemer Area
Jensen, J. 27a.

Richfield Area
English, W. A. 26; Taff, J. A. 34.

Santa Ana Canyon (Kraemer) Area
English, W. A. 26; Taff, J. A. 34.

West Richfield
Musser, E. H. 26.

BUENA PARK FIELD
Stockman, L. P. 42.

CHINO AREA

By MAX L. KRUEGER*

OUTLINE OF REPORT

HISTORY

A small amount of oil, as yet hardly commercial, has been developed in the area on the southwest side of the Chino fault, adjacent to the eastern border of the Puente Hills, in San Bernardino County.

The first drilling in this locality took place in 1912 when the Clampett brothers drilled a dry hole, to a depth of about 3,000 feet, near the northeast corner of Sec. 11, T. 3 S., R. 8 W., S. B. This well was drilled on the southwest side of the Chino fault. The Chino-Corona Oil Company well No. 1 was drilled (1920-23) near the center of Sec. 1, T. 3 S., R. 8 W., S. B., to a total depth of 4,850 feet. This well was drilled on the northeast side of the Chino fault, and encountered important showings of heavy oil.

The first oil produced on a near-commercial basis came from between 3,740 and 3,763 feet in the Mahala Oil Company well No. 1, drilled (1920-21) in the SE¼ Sec. 13, T. 3 S., R. 8 W., S. B. The well was located far down structure on the southwest side of the Chino fault, but produced initially at a reported rate of about 50 barrels per day. This well was produced intermittently for years, and it finally settled down to a 5- to 10-barrel per day producer of 23° gravity oil; it is at present rated as a small producer. Subsequently No. 2 was drilled about 3,600 feet north of No. 1, and although important showings were obtained, the well never produced commercially; it was lost through mechanical difficulties.

The Western Gulf Oil Company drilled (1930-31) its well No. ''Abacherli'' 1 near the center of Sec. 12, T. 3 S., R. 8 W., S. B., to a total depth of 3,267 feet. When plugged back to 2,640 feet with casing at 2,000 feet, the well was completed initially as a 100-barrel per day producer of 23° gravity oil. Production dropped off to about 30 barrels per day in three months, and now, after intermittent production tests and some shut-in periods, it is producing 15 barrels per day. No. ''Abacherli'' 2 was completed in 1936, by the Chino Petroleum Company, for 5 barrels per day, and No. ''Abacherli'' 3 (Selegna Drilling Company) was completed as a dry hole in early 1938. Hillman and Long, Inc., drilled No. ''Pellisier'' 1 in the northwestern end of the area in 1935 (near the E¼ corner of the NW¼ Sec. 2, T. 3 S., R. 8 W., S. B.) to a total depth of 2,412 feet without encountering commercial production; some minor showings of oil were found.

* Geologist, Union Oil Company of California. Manuscript submitted for publication May 31, 1938.

STRATIGRAPHY

Sediments at the surface are correlated, on lithologic criteria and stratigraphic position, with the Sycamore Canyon formation of upper Miocene age, as it is exposed in the western end of the Puente Hills. A few small inliers of platy, siliceous, and finely laminated shale are exposed along the southwest side of the Chino fault; these siliceous shale inliers are the probable equivalent of the upper Puente shale, also upper Miocene in age.

Most of the wells drilled in the area (on the southwestern side of the fault) surface in the Sycamore Canyon formation, drill through the upper Puente shale interval, and encounter the oil in the top of the middle Puente sandstone. The names of the lithologic members shown in the accompanying type log and cross section are for local usage only. Variegated sediments encountered below 2,600 feet in No. ''Abacherli'' 1, and below 3,000 feet in No. ''Abacherli'' 3, suggest the possible presence of Sespe beds immediately below a rather thin interval of middle Puente.

STRUCTURE

The structure consists of asymmetrical en echelon folding on the west side of the northwest-trending Chino fault; this fault is of major significance. Its upthrow side is to the southwest. The area is bounded on the southwest by the prominent Ridge syncline and on the south by the still more prominent Arena Blanca syncline. It is thus completely closed off on three sides by synclines, and on the northeast by the Chino fault. The reverse, or northeast flanks of the en echelon folded pattern on the southwest side of the Chino fault are steep, smashed, overturned, faulted, and intricately folded, and are of limited horizontal extent. These narrow reverse flanks probably represent drag against the Chino fault.

KIND OF OIL

At present only the No. ''Abacherli'' 1 and 2 wells are producing; an aggregate of 18 barrels per day is pumped from the top of the middle Puente oil sand from 2,100-2,200 feet in these two wells. The oil is 23° gravity, and contains about 20 percent gasoline with an octane number in excess of 71.

CONCLUSION

The southwestern side of the Chino fault seems to have been adequately tested to date, resulting in the production of small amounts of medium gravity oil. A general lack of pressure on the oil sands seems to account for the smallness of the wells. Only one other test has been made of the northeastern side of the fault; this was by the Chino-Corona well, which seems to have been unfavorably located as to structure.

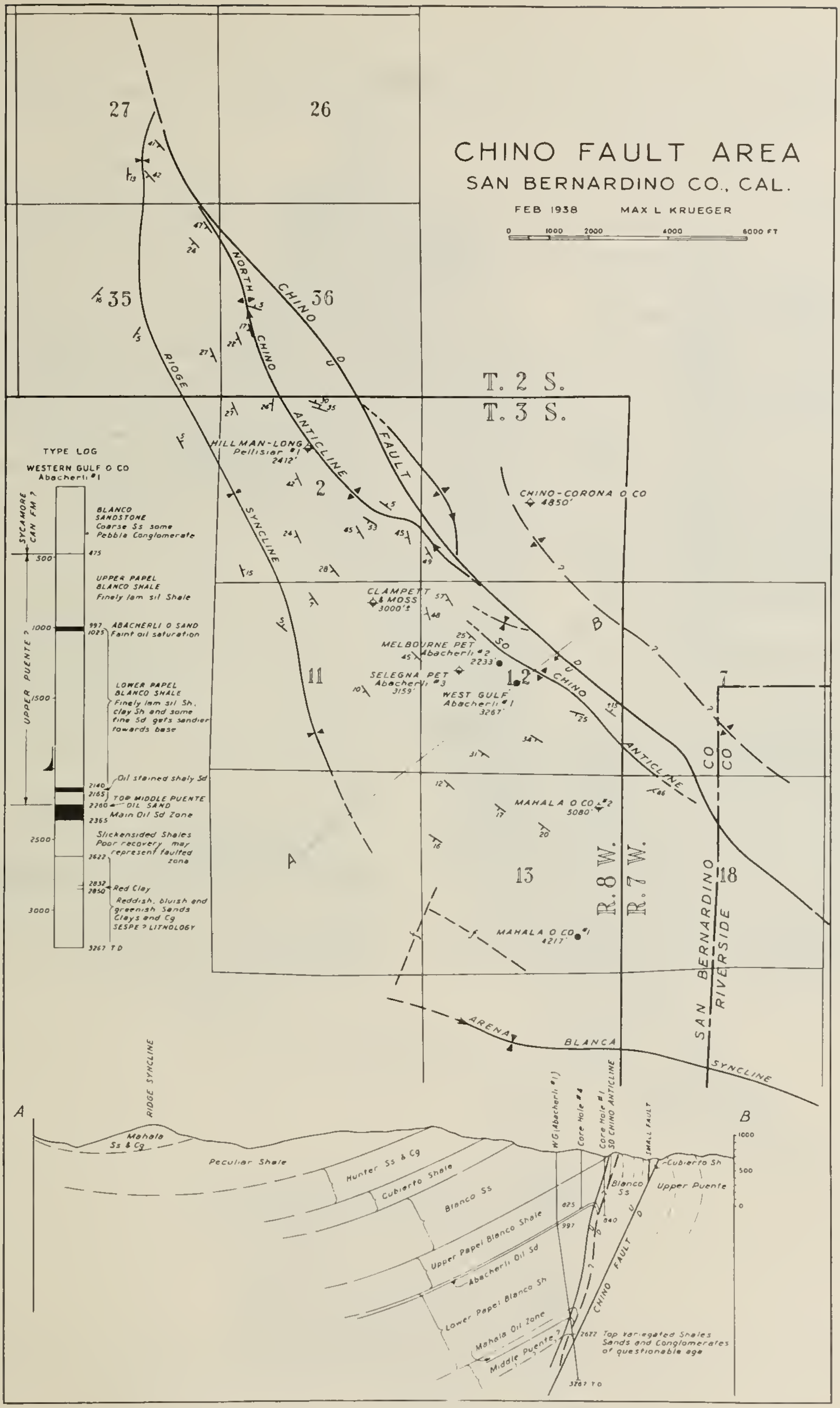


Fig. 150. Chino fault area: structure map; type log; cross-section.

CRETACEOUS FORMATIONS OF THE NORTHERN SANTA ANA MOUNTAINS*

By W. P. POPENOE **

OUTLINE OF REPORT

LOCATION OF THE AREA

The Santa Ana Mountains extend in a southeasterly direction from the canyon of Santa Ana River, about 40 miles southeast of Los Angeles, into southwestern Riverside and northern San Diego counties. The Riverside County-Orange County boundary line follows the crest of the range. The Cretaceous formations described in this report occupy a roughly triangular area of about 35 square miles on the southwest slope of the mountains, between Santa Ana and Trabuco Canyons, in Orange County. The towns of Anaheim, Orange, and Santa Ana lie a short distance to the west. The town of Corona, in Riverside County, lies about 10 miles to the east of the northern end of the Cretaceous exposure.

* The field work leading to the conclusions summarized here was begun in 1931, but was principally done in the summers of 1934 and 1935. Laboratory investigations of the fauna and completion of the more comprehensive report were not finished until some time later.

I wish to thank the following colleagues for assistance given me at various stages in my study of the Cretaceous of the Santa Ana Mountains region: J. P. Buwalda, Chester Stock, Ian Campbell, and Robert M. Kleinpell, of the California Institute of Technology, for advice and criticism offered in the course of the work; G. H. Anderson of the Texas Power and Light Company for assistance and advice in the field; B. N. Moore of the Sinclair Petroleum Company for release to my use of his Cretaceous fossil collections from the Santa Ana Mountains; L. W. Stephenson, J. B. Reeside, Jr., W. P. Woodring, and Ralph Stewart, of the United States Geological Survey; and F. M. Anderson of the California Academy of Sciences for aid in the study of the fauna; and David P. Willoughby of the California Institute of Technology for assistance in preparation of the illustrations.

I wish also to thank J. P. D. Hull, Business Manager of the Bulletin of the American Association of Petroleum Geologists for release of prior publication rights to this article and its illustrations.

** Curator, Invertebrate Paleontology. Department of Geological Sciences, California Institute of Technology, Pasadena. Manuscript submitted for publication August 28, 1941.

STRATIGRAPHY

The Cretaceous strata of the Santa Ana Mountains are divided on a lithologic basis into five units, grouped into three formations. Each of the two upper formations consists of two members. Except for local areas where parts of the section have been cut out by faulting or overlap, these units may be recognized from end to end of the area of outcrop. The general lithologic characters of these members, their average thicknesses, and their relationships to one another are summarized in the columnar section and its explanatory notes accompanying the geologic map.

Two apparent discrepancies between the legends of the structure sections and the map require explanation. North of Silverado Canyon, the Pleasants member of the Williams formation outcrops in discontinuous, small patches, and in many places has been cut from the section by faulting and overlap. Therefore, in this region the Schulz and Pleasants members have not been differentiated on the map.

In the region between Silverado and Baker Canyons, a thick conglomerate and sandstone lens, developed apparently in the basal Holz shale, merges northward with the Baker Canyon member, and has been mapped with this member and indicated by the same symbol. In the structure section B-B′, this lens is included with the Holz shale, as at this point the lens is included above and below by the shales.

The Cretaceous series of the Santa Ana Mountains overlies the basement complex of Triassic meta-sediments and Jurassic intrusives with a profound angular and erosional unconformity. In a number of places in which the basal Cretaceous overlies Triassic slates, the differences of dip or strike across the contact approach 90 degrees. At other places, the basal Cretaceous contact truncates the contact plane between the Triassic sediments and the intrusive rocks.

CITATIONS TO SELECTED REFERENCES—Continued

BURRELL POINT REGION
McLaughlin and Waring, 14, p. 364; Watts, W. L. 00.

Olive Region
Watts, W. L. 00.

CHINO AREA
Eldridge and Arnold 07; Goodyear, W. A. 88, pp. 91-93; McLaughlin and Waring 14; Vander Leck, L. 21, pp. 142, 158-159; Watts, W. L. 00.

SANTA ANA MOUNTAINS, NORTHERN
Anderson, F. M. 02; Cooper, J. G. 94a, pp. 34, 35, et seq.; Dickerson, R. E. 14b, pp. 262-263; English, W. A. 26, pp. 17-19; Fairbanks, H. W. 93a, pp. 115-118; Goodyear, W. A. 88a, pp. 337-338; McLaughlin and Waring 14, p. 364; Moore, B. N. 30; Packard, E. L. 16, pp. 137-159; 22; Popenoe, W. P. 37; 41; 42; Smith, J. P. 00, p. 210; Sutherland, J. C. 35, p. 58; Vander Leck, L. 21, pp. 142-144.

SAN JOAQUIN HILLS
Bode, F. D. 40; Bruff, S. C. 40.

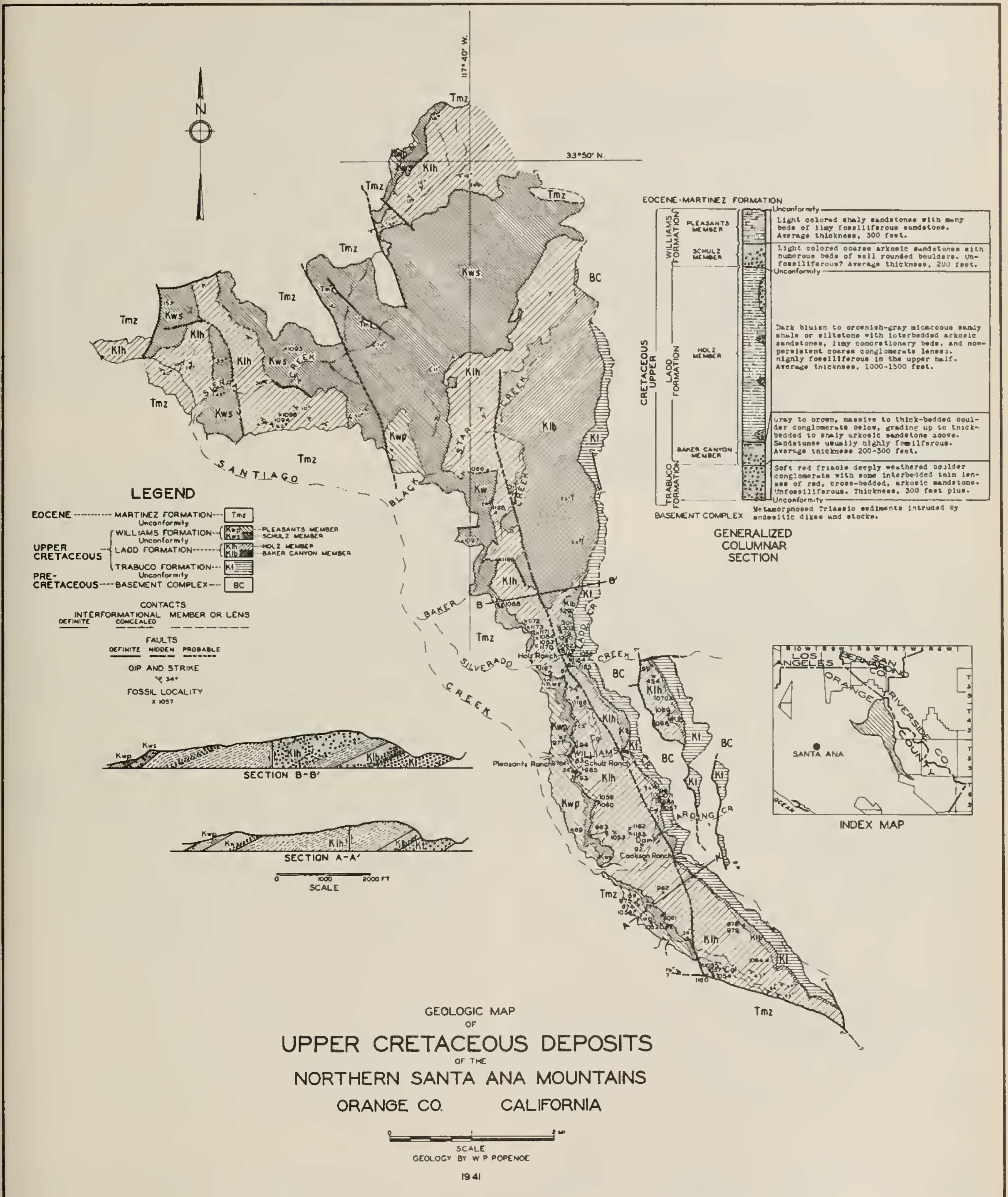


FIG. 151. Northern Santa Ana Mountains: geologic map of Upper Cretaceous deposits.

The contact separating the Ladd and Williams formations appears to be slightly unconformable. There is no very marked difference in dip and strike noticeable across the contact, but the gradual thinning out to the north and disappearance of a sandy bed at the top of the Holz shale are believed to be due to overlap of the younger formation upon the older, rather than to lensing. With this probable exception, the formational and member contacts within the Cretaceous series are conformable and gradational.

The Cretaceous is overlain unconformably by light-colored sandstones, conglomerates, clays, and coal-bearing beds of "Martinez" Paleocene age. There is little angular discordance between the Cretaceous and Tertiary here, but the unconformity is strikingly shown by the irregular overlap of the Martinez over the Cretaceous all along the contact. In most places south of Black Star Canyon, the Paleocene beds directly overlie various levels of the Pleasants member, and rest upon the Schulz member. On the north side of Sierra Canyon, the Paleocene beds overlap both the Pleasants member and the Schulz member, and overlie the upper Holz shale. On the east side of the Santa Ana Mountains, opposite the town of Corona, Martinez beds are found overlying lower Holz shale beds, only two or three hundred feet above the top of the Baker Canyon sandstones.[1]

STRUCTURE

South of Black Star Canyon, the Cretaceous beds show a regular homoclinal dip to the west and southwest. From Black Star Canyon south to Silverado Canyon, the strike of the beds is nearly due north, and the dips range from 20 to 40 degrees west. South of Silverado Canyon, the general strike trends in a more nearly northwesterly direction, being almost due northwest at Harding Canyon. Near the southern tip of the Cretaceous outcrop, the strike is nearly N. 75° W. South of Silverado Canyon, the dip of the beds usually does not exceed 35 degrees, and averages about 25 degrees. Near the southern end of the outcrop, steeper dips are found, epecially near the Cretaceous-Tertiary contact, which is here a fault contact. Dips from 60 to 70 degrees southwest are found here in places, and in one locality near the fault contact, the beds have been overturned.

The structure of the Cretaceous north of Black Star Canyon is considerably more complex than in the region to the south, and because of poorer exposures, massive character of much of the exposed rock, and absence of good horizon markers, it is much more difficult to work out. The Cretaceous beds here appear to be folded into a broad open syncline, the faulted axis of which trends somewhat west of north from the mouth of Black Star Canyon. The west limb of the syncline is modified by two or three small folds, and is broken by several high-angle faults trending in the same direction as the axis of the syncline, and usually, though not always, with downthrow to the west.

The principal faults affecting the Cretaceous beds appear to be referable to two systems. First, the group of high-angle, northwestward-trending faults mentioned above. The majority of them are found only north of Black Star Canyon, but one persistent fault of this system has been traced southward from Black Star Canyon to about a mile and a half south of Harding Canyon, where it passes into the Tertiary beds. The displacement of this fault is at least 200 feet, and may be considerably more. The second system of faults includes two nearly parallel low-angle normal faults with downthrow to the east, traceable from Silverado Canyon south beyond Harding Canyon. These faults have dropped down a considerable thickness of the lower members of the Cretaceous against the basement, duplicating the succession. The amount of displacement is not precisely known, but along the westernmost fault it probably exceeds 2,000 feet. An important fault, not referable to either of the above-described systems, determines the upper contact of the Cretaceous along approximately the southernmost 2 miles of outcrop. This high-angle fault trends approximately N. 60° W., the downthrow being to the southwest. It has faulted the Eocene beds on the southwest against the Cretaceous, cutting out at least 700 feet of the top of the Cretaceous section.

FAUNA

The Trabuco formation at the base of the section is unfossiliferous. The remainder of the section above, with the probable exception of the Schulz member, is fossiliferous, and in some places very richly so. The known fauna includes approximately 100 specifically identified forms, and perhaps 50 more species that are new. The fauna as a whole may be divided into two large distinct groups. The older group, found in the Baker Canyon member and the lower 200 feet of the Holz shale, is characterized by numbers of *Glycymeris pacificus*, *Actaconella oviformis*, *Trigonarca californica*, *Cucullaea gravida*, several species of *Schlocnbachia*-like ammonites, and many other forms. The younger faunal group ranges through the upper 600 to 700 feet of the Holz shale and the Pleasants sandstone. This group is particularly characterized by the presence of abundant *Glycymeris veatchii* and its variants, *Turritella chicoensis* and its variants, *Acila demessa*, *Crassatella lomana*, *Trigonocallista bowersiana*, *Flaventia lens*, *Cucullaea youngi*, and in the uppermost beds, *Metaplacenticeras pacificum*. The faunas indicate that the Baker Canyon member and lower Holz shale are approximate correlatives of the basal Cretaceous of the Redding region, Shasta County, and of the Hornbrook-Henley region in Siskiyou County, and of a not yet delimited part of the thick Cretaceous section exposed on the western borders of the Sacramento and San Joaquin Valleys. The younger fauna is closely related to the younger faunas of the Redding region and the faunas derived from the classic localities of Tuscan Springs, Penz Ranch, Chico and Butte Creeks in Butte County, and is certainly very close to the dominant faunal groups found in the Cretaceous of the Simi Hills and Santa Monica Mountains near Los Angeles.

The precise age of the Trabuco formation is not known. Structurally, the formation is very closely related to the overlying Baker Canyon member, and for this reason it is believed to be of late Lower Cretaceous or early Upper Cretaceous age.

[1] Personal communication from Alex Clark.

SOUTHWESTERN SAN DIEGO COUNTY

By Leo George Hertlein * and U. S. Grant, IV **

OUTLINE OF REPORT

AREA DISCUSSED

The most significant features of the geology of southwestern San Diego County, together with data on wells drilled in this region, have been summarized in a paper (Hertlein and Grant 39) published in a recent number of the California Journal of Mines and Geology. The present paper consists of a brief summary of the essential facts pertaining to the stratigraphic geology of the region in general and of the Soledad Mountain anticline in particular.

STRATIGRAPHY

The accompanying stratigraphic column shows the relatively thin cover of Tertiary sedimentary rocks that overlies Cretaceous and earlier metamorphic and igneous rocks. Marine Oligocene and Miocene sediments are entirely absent. The slight angular unconformity between the Eocene and Pliocene, and the flat attitude of all the Cenozoic beds, testify to the lack of pronounced orogenic activity in this region after Mesozoic time. The Eocene is not known to be over 1,600 feet thick, and more than half of this thickness consists of upper Eocene Poway conglomerate. The Pliocene has a maximum thickness of about 1,300 feet, and the marine Pleistocene does not exceed 100 feet in thickness.

Areally, the Eocene and Pliocene beds occupy most of the region along the coast that is not concealed by Quaternary terrace deposits and alluvium. Upper Cretaceous sedimentary rocks are exposed in places, but only about 500 feet in stratigraphic thickness could be measured on the surface. The Borderland Exploration Company well, however, located in Sec. 30, T. 16 S., R. 3 W., S. B., drilled through 2,110 feet of Cretaceous (1,211 feet of "Chico" and 899 feet of red beds), apparently beneath Quaternary alluvium, and reached the pre-Cretaceous metamorphic-igneous basement at a depth of 3,735 feet. The San Diego Gas and Petroleum Corporation well No. "Holderness" 1 (Sec. 32, T. 18 S., R. 2 W., S. B.) drilled through 1,360 feet of "Chico" formation and 269 feet of Trabuco formation, or a total of 1,629 feet of Upper Cretaceous lying between the Delmar sand (upper Eocene) above and the Black Mountain formation (basement) below. Because of the lack of knowledge regarding the true dip of the beds penetrated in the wells, the true thickness of the Cretaceous sediments is unknown.

Lithologically the Cretaceous beds are characterized by tan and gray marine concretionary sandstones and occasional dark-gray carbonaceous shales. The Eocene consists of sandstones, somewhat carbonaceous toward the base, overlain by marine silty and limy shales, and, at the top, massive conglomeratic sandstone with rare marine silty lenses. The Pliocene consists of predominantly gray and tan marine sandstone with rare pebble beds and, in the southern part of the area, occasional layers of bentonite. This bentonite may have been formed as a result of the volcanic activity, the evidence of which is so prominent 30 or more miles south of the United States-Mexico boundary. Micaceous sandstone is present locally in the upper part of the Pliocene. The marine Pleistocene is mostly soft sandstone with some gravel beds. Diagnostic marine invertebrate fossils have been found at several localities in these sedimentary rocks.

Reviewing the stratigraphic column as previously published (Hertlein and Grant 39, figure 4, page 63), the following beds are found in sequence from top to bottom:

	Thickness in feet
RECENT	
Alluvium	0–300
PLEISTOCENE	
Bay Point formation	1– 30
PLIOCENE	
Sweitzer formation	5– 30
San Diego formation (middle Pliocene)	1250
EOCENE	
Poway conglomerate	875
Rose Canyon shale	300
Torrey shale	25–200
Delmar sand	200
UPPER CRETACEOUS	
(Exposed at Point Loma and La Jolla)	500+
TRIASSIC OR JURASSIC	
Black Mountain volcanics	2000+

The Eocene shown on the accompanying map is largely Rose Canyon shale. The Pliocene is the San Diego formation. Although only 500 feet of Cretaceous sediments are exposed, a much greater thickness is probably present on the axis of the Soledad Mountain anticline.

STRUCTURE

Structurally the area is relatively simple, with the exception of the details of the Point Loma and Soledad Mountain masses. The Pliocene dips gently (1 to 11 degrees) south and southwest, but it is nearly horizontal at Otay Mesa and environs. The Eocene is nearly horizontal, or has gentle regional dips eastward except at Point Loma and Soledad Mountain. Point Loma has been broken by faults which produce diverse dips, but a general eastward dip predominates.

Soledad Mountain is complicated by a pronounced anticline and minor faults, as shown on the accompanying map. The northeast limb of the structure dips steeply, becoming steeper southeastward from near the

* Assistant Curator, Department of Paleontology, California Academy of Sciences.
** Professor, Department of Geology, University of California at Los Angeles. Manuscript submitted for publication July 15, 1941.

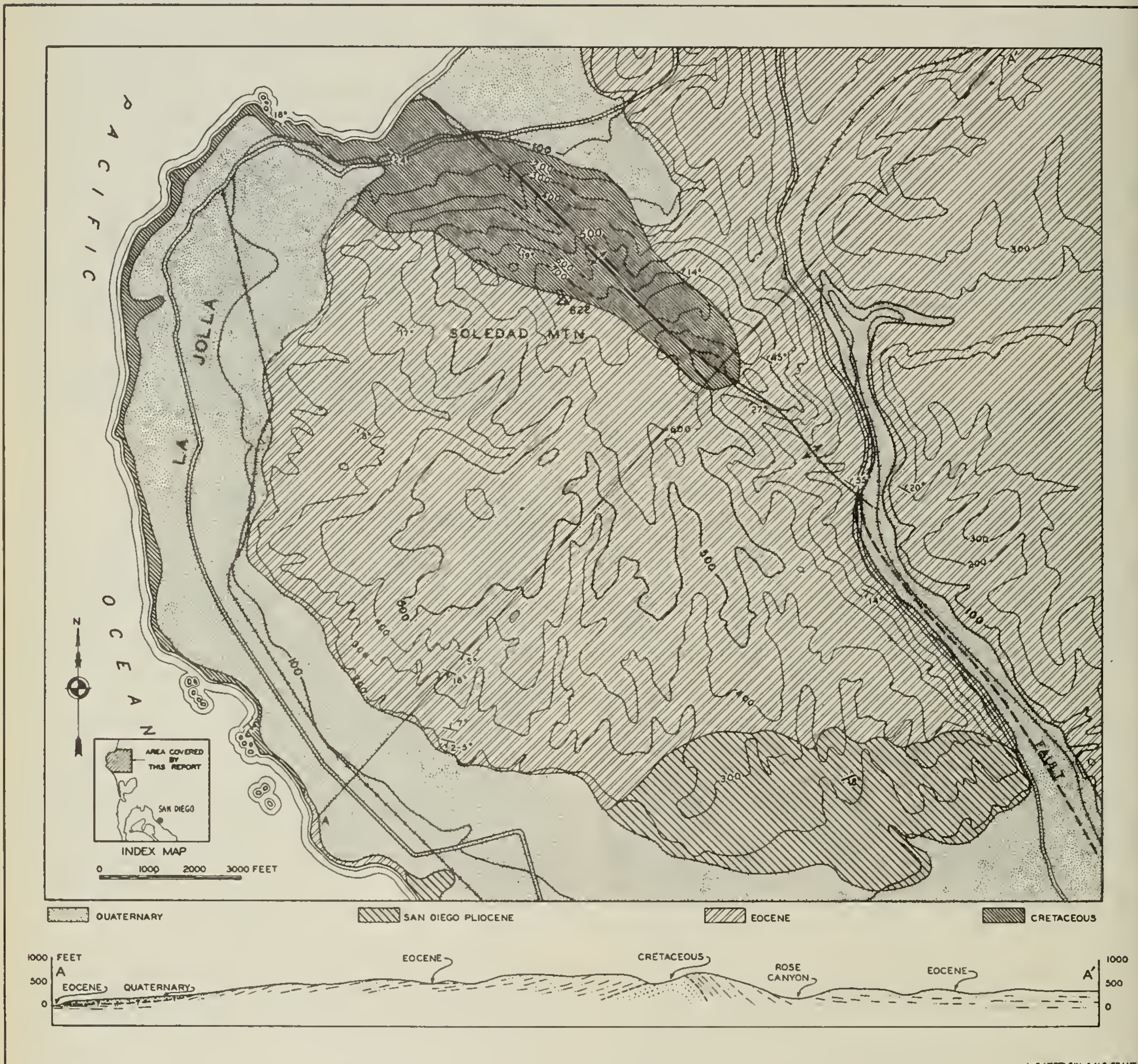


FIG. 152. Southwestern San Diego County: geologic map; cross-section.

summit of Soledad Mountain to Rose Canyon, where it abruptly passes into the Rose Canyon fault. This anticline appears to transect Rose Canyon diagonally and pass into the Kearney Mesa as a relatively gentle fold, but field relations suggest that the force producing the fold was largely dissipated along the Rose Canyon fault. This fault appears to terminate at the axis of Soledad Mountain anticline on the west side of Rose Canyon about 1¼ miles north of the canyon mouth. The fault extends southward along the east side of Mission Bay at least as far as the mouth of Mission Valley, where evidence of its presence is hidden by Recent alluvium. A fault probably parallels the west side of Point Loma, and another one, at right angles, may exist near the north end of Point Loma. This latter hypothetical fault may pass up Mission Valley. The time of folding in the Soledad Mountain anticline was apparently post-middle Pliocene.

PALEONTOLOGY

Fossil marine invertebrates occur at a number of localities in the San Diego region. Cretaceous mollusks are found on Point Loma and at La Jolla, and Eocene fossils are present at certain localities in the canyons cut into the mesas north of the San Diego River. Middle Pliocene fossils occur abundantly at Pacific Beach, on the south slope of Soledad Mountain, and at several localities in the mesas within the City of San Diego and south to the Mexican boundary. The Pliocene fossils of the San Diego region are indicative of shallow-water conditions. On the other hand, the Pliocene sediments of the Los Angeles Basin, for the most part, were deposited in comparatively deep water. As a result, Foraminifera of the San Diego region resemble more closely the Pleistocene forms of the Los Angeles Basin than the Pliocene forms of that region. Typical Pliocene mollusks, such as *Arca (Anadara) trilineata*, *Pecten (Patinopecten) healeyi*, and *Ostrea vespertina*, definitely prove the Pliocene age of the San Diego formation. Numerous Pleistocene marine mollusks occur at low elevations bordering the coast at San Diego. These indicate a late Pleistocene age for the low terraces upon which they are found.

EXPLORATION FOR OIL AND GAS

Petroleum in commercially important quantities has not been discovered in the San Diego area, although about 50 wells have been drilled there in the search for oil (Hertlein and Grant 39, pages 74-76). None of these wells, however, were drilled on the Soledad Mountain anticline.

The San Diego basin is unlike the Los Angeles and Ventura basins, where thick Tertiary sediments have been folded into series of anticlines, many of which are known to be petroliferous. Orogenically the San Diego basin has been relatively stable since Eocene time.

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IMPERIAL VALLEY

American Association of Petroleum Geologists 41; Augur, I. V. 20; Henderson, W. H. 21; Kew, W. S. W. 20; King, V. L. 23; Levorsen, A. I. 41; McLaughlin and Waring 14; Merrill, F. J. H. 14; 16a; Skeats, E. M. 23; Tucker, W. B. 21; U. S. Geological Survey 20a; Vander Leck, L. 21.

Carrizo (Carriso) Creek

Kew, W. S. W. 14; McLaughlin and Waring 14, p. 459; Vander Leck, L. 21, pp. 148-152, pl. 6; Vaughan, T. W. 17.

Coyote Mountain

Hanna, G. D. 26a; Vander Leck, L. 21, pp. 148-152, pl. 6.

El Centro Area

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Fish Creek Mountain Area

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Indio Hills

Buwalda, J. P. 30.

Niland Region

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Salton Sea Region

Brown, J. S. 23; Buwalda and Stanton 30; Kelley and Soske 36; Mendenhall, W. C. 09; Orcutt, C. R. 90; Sykes, G. 37; U. S. Geological Survey 34; Woodring, W. P. 31.

MOJAVE DESERT AND BASIN-RANGES PROVINCES

Mojave Desert

Buwalda, J. P. 14; Gardner, D. L. 40; Hulin, C. D. 35; McLaughlin and Waring 14; Merriam, J. C. 15; 19; Pack, R. W. 12; Vander Leck, L. 21, pp. 156-158.

Antelope Valley

California Oil World 37; Simpson, E. C. 34.

Ivanpah Region

Hewett, D. F. 39.

Inyo Mountains

Anderson, G. H. 35; 37.

Death Valley Region

Noble, L. F. 34.

El Paso Range

Baker, C. L. 12.

Chapter IX

Ventura Basin and Transverse Ranges

CONTENTS OF CHAPTER IX

CITATIONS TO SELECTED REFERENCES—Continued

VENTURA BASIN AND TRANSVERSE RANGES

Arnold and Kemnitzer 31; Eaton, J. E. 26a; 35a; Eldridge, G. H. 01; Henry and Davis 29; Hoots and Herold 35; Jahns, R. H. 39; 40; Kew, W. S. W. 40; Menken, F. A. 40a; Petroleum World 37a; Pressler, E. D. 29; Stockman, L. P. 30b; 35i; U. S. Geological Survey 34; Westsmith, J. N. 29.

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GAVIOTA-CONCEPCION AREA

By WILLIAM W. PORTER II *

OUTLINE OF REPORT

HISTORY

The Gaviota-Concepcion area is in Santa Barbara County, about 40 miles west of the town of Santa Barbara, on the coast. It was prospected in considerable detail shortly after the discovery of the Elwood field. The existence of an anticline, readily apparent from surface geology, is generally known. Six wells have been drilled to date (April, 1941), and some of them have had gas and oil showings of possible commercial significance; but all have been abandoned.

The first well on the structure was drilled in 1929 by the Western Gulf Oil Company. Casing was set at the top of the Vaqueros sand at 3,088 feet. While the cement was being drilled out, the well blew in, producing an amount of gas estimated at 25 million cubic feet per day. The well was deepened to a total depth of 3,596 feet, but, although another string of casing was set at 3,152 feet, it failed to produce commercial quantities of oil.

The Western Gulf well No. 2 reached the top of the Vaqueros at about 3,094 feet. Casing was cemented at 3,096 feet, and, after being drilled out, the well produced an estimated six million cubic feet per day of dry gas. The total depth of the well was 3,200 feet, but even after cementing a liner through perforations, no commercial quantity of oil was found.

A third well was drilled in the area by Monterey Exploration Company in 1933, but a fault with displacement of more than 200 feet was crossed, and the results were therefore inconclusive. It is reported that the Vaqueros looked wet.

In 1937 a well was drilled by the Gaviota Oil Company to a depth of 3,206 feet. The top of the Vaqueros was encountered at 3,126 feet. Casing was cemented at 3,185 feet. With the permission of all interested parties, a 10-day test was made, during all of which time the well produced a measured amount of 8 to 10 million cubic feet of gas per day. Operations were then suspended, during the drilling of a well on a nearby lease held by the Wilshire Oil Company. Later, gas was supplied by the Gaviota well to Wilshire for drilling, but finally water drowned the gas, and the Gaviota well was abandoned, in 1938. The Wilshire well was drilled to a depth of 4,658 feet. It is reported that the presence of oil and gas is known from a depth below 4,000 feet, from formation-tester results. Though several tests were made and a liner cemented, the well was abandoned. Oil sand was cored in the Gaviota well at about 3,191 to 3,206 feet. This oil sand appeared to be well saturated and gave strong black cuts with carbon tetrachloride. A small amount of the oil recovered during the gas test was about 40 degrees A. P. I. The sand was tested for several weeks, but failed to produce oil.

In 1940 Republic Petroleum drilled a well about a mile and a half east of the Gulf wells, to a depth of 3,630 feet. No casing was set below the surface string, and the well was abandoned.

On February 8, 1929, Standard Oil Company commenced its well No. "Gerber" 1 at Point Conception. This well was abandoned at a depth of 6,820 feet on February 1, 1931. It is on a different structure than the wells above discussed. About a mile landward from Point Conception is the axis of a fairly large syncline in which occur beds often called Santa Margarita. Seaward to the southwest from the synclinal axis the Monterey comes to the surface, and its harder beds account for the two-pronged Point Conception. The well was drilled apparently because it was thought that the northeastward- or landward-dipping beds dipping into the syncline were a reversal, and that in the ocean seaward- or southward-dipping beds existed that would form an anticline.

STRATIGRAPHY

Santa Margarita

Surface strata in the prospected area consist of splintery to platy, slightly sandy shales which have been called Santa Margarita. About 600 to 800 feet of Santa Margarita occurs near the surface of the anticline. A basal tar sand has been noted in wells and in outcrop.

Monterey

Below the Santa Margarita occurs approximately 1,200 feet of shale generally called Monterey. It is a light-weight, cream to grayish white, punky, platy, diatomaceous shale. It contains zones of "paper shale"—dark, bituminous highly foraminiferal (*Valvulineria californica*) bands. Its platy flagstone character is outstanding. The flinty, cherty, siliceous character increases toward the west by slow lateral change.

Rincon Shale

This formation, formerly called "Temblor," is now generally referred to as the Rincon shale. It is a uniform gray clay shale underlying the Monterey. Bedding is obscure, if present at all. Several feet of bentonite occur near the base in the Gaviota-Concepcion area. Nodules of limestone are characteristic but not abundant. A fossil zone, valuable for correlation purposes, occurs approximately 300 feet above the base in the Gaviota-Concepcion area, and is known as the *Siphogenerina* zone. The formation is approximately 1,125 feet thick in the Gaviota-Concepcion area.

* Consulting Geologist, Los Angeles, California. Manuscript submitted for publication October 1939; revised April 1941.

Vaqueros

The Vaqueros sandstone underlies the Rincon shale and is a source of oil in the Elwood and Capitan fields. It consists of medium-grained to coarse, pebbly, angular, quartzitic sandstone in which occur a number of well-cemented, hard, calcareous reefs. These well-cemented calcareous reefs are apparently sufficiently impermeable to segregate gas, oil, and water zones in the ground.

Sespe

The Sespe formation in the neighborhood of Santa Barbara is a continental deposit of red conglomerate, sandstone, and shale some 5,000 feet thick. The formation thins to the west, being only a few hundred feet thick near Point Conception. Several beds of the Sespe formation north of the Gaviota-Concepcion area contain marine fossils. From this area westward to near Refugio Creek occurs a transition from continental deposits to marine deposits. As far east as the Gaviota-Concepcion area, the Sespe beds seem to be primarily marine oyster-bearing sandstones interbedded with gray, red, and green shale. These beds have been classified (Schenck and Kleinpell 36, p. 220) as the Refugian stage of the Oligocene, the type locality being between the Gaviota-Concepcion area and Gaviota Pass at the Sespe outcrops, less than a mile north of the coast line. The Sespe formation contains oil in the Elwood and Capitan fields, and Sespe oil sand is reported to have been discovered in non-commercial quantities in the Wilshire Oil Company well No. "Hollister" 1.

STRUCTURE

The regional structure of the area consists of a steeply south-dipping monocline of the south flank of the Santa Ynez Mountains. A local minor modification of this general structure has produced a small syncline and anticline near Drake Station on the Southern Pacific Railroad. Though geologically minor, this folding is on a sufficient scale to be an oil field, as far as size is concerned.

A few faults are known to exist in the area, and others are suspected, but the specific influence of these faults upon oil and gas accumulation is not clearly understood. The presence of gas and some oil is evidence of the existence of structural closure of some type, regardless of the uncertainty as to the exact effects of these structural features.

KIND OF GAS

The following is a summary of analyses made by Shafer Laboratory of gas samples from Gaviota Oil Company well No. "Hollister" 1.

Fraction	Sample No. 1 September 26, 1937		Sample No. 2 September 26, 1937		Sample No. 3 October 12, 1937	
	Analysis per cent by volume	Gasoline content gal. per MCF	Analysis per cent by volume	Gasoline content gal. per MCF	Analysis per cent by volume	Gasoline content gal. per MCF
Air	-------	-------	-------	-------	-------	-------
Carbon dioxide	0.10	-------	0.10	-------	0.10	-------
Methane	92.80	-------	92.37	-------	93.43	-------
Ethane	3.75	-------	3.73	-------	3.13	-------
Propane	1.66	-------	1.91	-------	1.65	-------
Isobutane	0.28	0.09	0.28	0.12	0.19	0.06
n-Butane	0.55	0.17	0.62	0.20	0.64	0.20
Pentanes-plus	0.86	0.35	0.89	0.36	0.86	0.35
Totals	100.00	0.61	100.00	0.68	100.00	0.61

Calculated specific gravity:
No. 1 0.621
No. 2 0.627
No. 3 0.618

Pentanes-plus residue calculated as n-Hexane.

CITATIONS TO SELECTED REFERENCES—Continued

SANTA YNEZ RANGE
Woodring, W. P. 31a.

GAVIOTA-CONCEPCION AREA
Stockman, L. P. 40, no. 12, p. 63.

CAPITAN OIL FIELD

By George R. Kribbs *

OUTLINE OF REPORT

HISTORY

The Capitan oil field is located on the ocean shore 24 miles west of Santa Barbara, Santa Barbara County, on Highway 101. It lies chiefly in the S½ Sec. 32, T. 5 N., R. 30 W., S. B. Productive acreage on the uplands is under lease to the General Petroleum Corporation and Shell Oil Company; the Oakburn Drilling Company has developed two small producers on tideland permits.

The finding of an oil-producing horizon in the Vaqueros formation at Elwood in 1928 encouraged exploration in the Capitan area, where discovery was made by the General Petroleum Corporation well No. "Erburu" 1, completed in August, 1929, at a depth of 1,446 feet in the Vaqueros formation. The succeeding development of the field was slow. Eight producing wells and two dry holes were drilled in the Vaqueros. In the Spring of 1930, General Petroleum's No. "Erburu" 8 was drilled to a depth of 4,071 feet in the Eocene, and then was plugged back and completed in the Sespe at a depth of 2,430 feet. Two other wells were drilled into the Sespe before operations were suspended in 1930. In 1934, after the installation of a marine loading line, both the Sespe and Vaqueros horizons were developed. Development was completed in 1937—all but a few available locations had been drilled, and the limits of the field on all sides determined—and the field is now produced under curtailment.

* Geologist, Bankline Oil Company. Manuscript submitted for publication January 27, 1938.

SIGNIFICANCE

The Capitan field is one of the minor fields of California. Productive acreage is a little less than 300. Total production to January 1, 1938 (November and December 1937, estimated), has been: Vaqueros 1,033,000 barrels of oil; Sespe 1,278,000 barrels of oil. Daily production at the present time is approximately 3,100 barrels, from all horizons.

DISTINGUISHING FEATURES

The Capitan field's outstanding contribution to the oil industry has been the discovery of producing horizons in the Sespe formation of Santa Barbara County.

Unique structural features, entirely contrary to the east-west regional structure, distinguish Capitan from other fields of its province.

STRATIGRAPHY

Erosion of an upthrown fault block has brought to the surface Temblor clay shales. Monterey chert and shale occur in the syncline west of the Capitan field, and Monterey and Santa Margarita silts and diatomite occur in the syncline to the east. Subsurface formations encountered in the field are Vaqueros sandstones (Miocene), Sespe freshwater and continental silts and sands (lower Miocene, Oligocene, and upper Eocene), and the Tejon sands and shales (Eocene).

The first productive zone in the Capitan field occurs near the top of the Vaqueros sandstone. It ranges in thickness from a few feet to 300 feet, depending on location on structure. Wells producing from this zone yield from 100 to 600 barrels of 20° A.P.I. gravity oil and practically no gas; production is relatively steady, and shows a relatively slow rate of decline. Wells completed for 175 barrels in 1930 are now producing approximately 125 barrels.

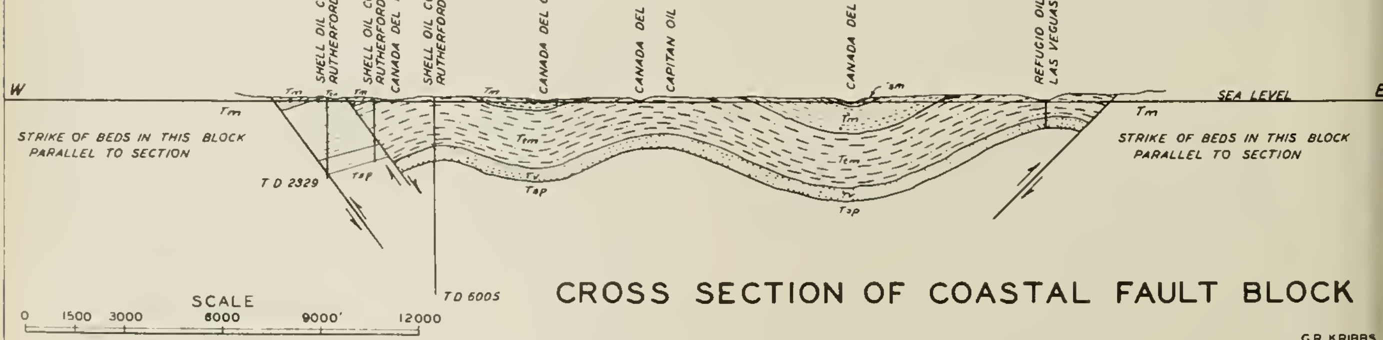


Fig. 153. Capitan oil field: cross-section of coastal fault block.

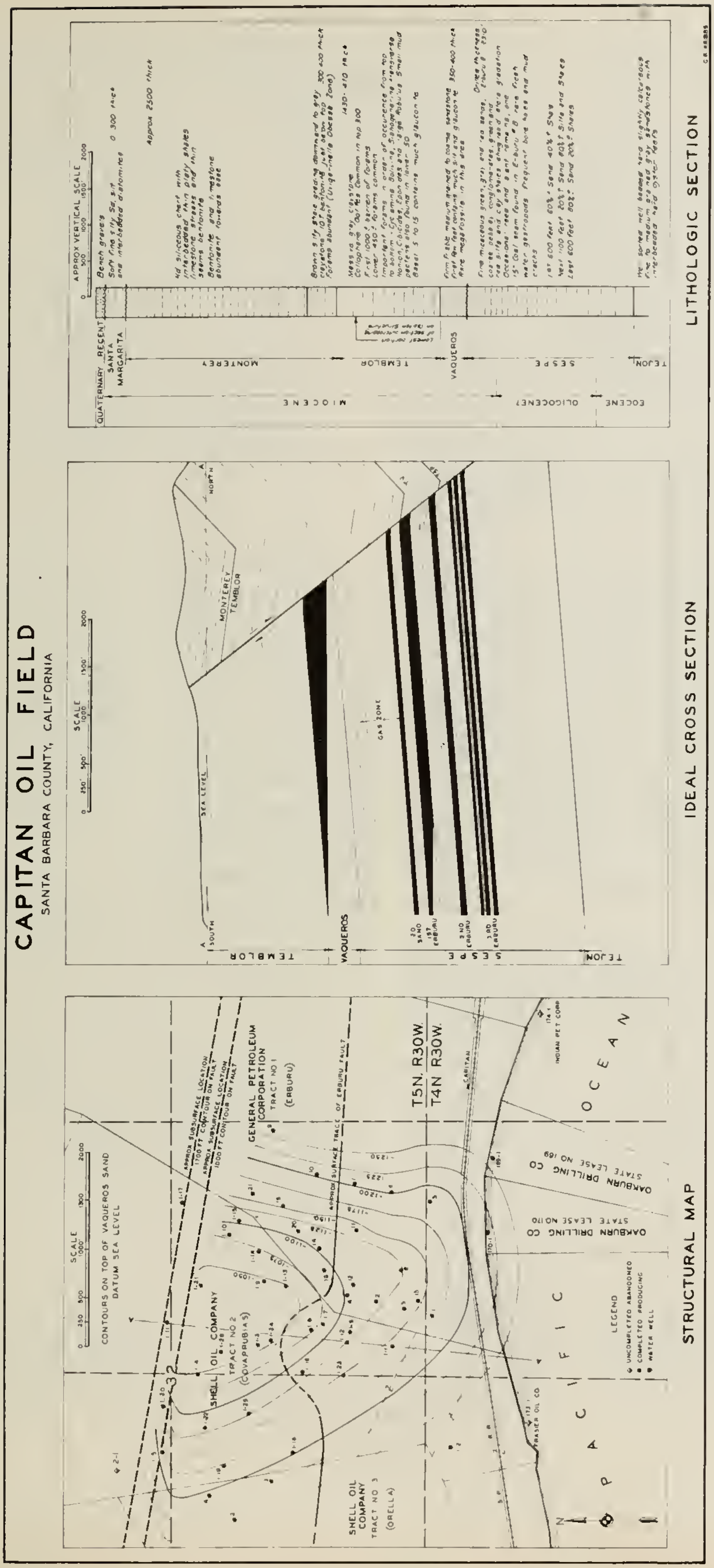


FIG. 154. Capitan oil field: structure map; ideal cross-section; lithologic section.

The Vaqueros horizon has never been heavily produced because of the small demand for oil with a gasoline content as low as 10 percent. Edgewater was originally found just outside the 1,225-foot contour, and, because of the lack of extensive drainage, it has moved up to the 1,200-foot contour, but only in the vicinity of General Petroleum's Erburu No. 1 and No. 5 wells. The water in the Vaqueros is of low salt content—less than 70 grains per gallon—but is heavily impregnated with hydrogen sulphide gas.

The second zone occurs in the upper portion of the Sespe formation. Two gas blowouts and the resulting fires established the fact that gas in some quantity occurred in the first 600 feet of the Sespe. The Shell Oil Company cored and formation-tested this zone, and established the existence of an accumulation of gas from the top of the Sespe down to what is locally known as the 20-foot sand, which occurs just above the shale over the first Erburu oil zone. This gas zone is, therefore, roughly 500 feet thick. Volume was determined to be approximately 7 million cubic feet, and shut-in pressure 650 pounds. No wells have been drilled to produce this zone.

At a point 660 feet below the top of the Sespe, a zone of sand and shale 125 feet thick is encountered, which carries a light oil of 41° A.P.I. gravity. This zone is known as the first Erburu oil zone. Wells producing from it yield from 125 to 1,000 barrels initial production. One thousand feet below the top of the Sespe is a similar zone known as the second Erburu, only 75 feet in thickness; wells producing from it yield from 100 to 600 barrels initial production of 44° A.P.I. gravity oil.

A third zone was opened in the General Petroleum well No. "Erburu" 9 approximately 150 feet below the second Erburu zone. Apparently, however, this third zone did not contribute much to the production of the well. One or two other wells prospected this zone and produced it along with the second Erburu, with questionable success.

The Sespe zones have been prospected and produced to a greater extent than the Vaqueros because of the higher gravity of their oils. Wells decline rapidly from high flush initials to 100 or 200 barrels, a production which to date has held fairly steady. The production record of the older wells in the Sespe, however, indicates the probability of relatively short life. The sands and shales in the zones are lenticular, as would be expected of continental deposits. While some wells have obtained large sand bodies in either or both of the two Erburu zones, adjacent wells have found these bodies to be greatly diminished in thickness, and, in a few cases, to have practically disappeared. This condition has contributed to erratic initial productions from individual wells. Water, although beginning to show in the edge wells, has not yet become a serious factor. The water associated with the Sespe is brackish at the top, and becomes more salty with depth. The salt content varies from 150 to 700 grains per gallon.

The drilling practice common to all the latter wells developing the Sespe horizons is the following:

(1) a primary water string, 9-inch casing, is set in the Erburu shale over the first Erburu zone;

(2) a string of 6⅝-inch casing is landed at the base of the second Erburu, with perforations opposite this sand; a combination cement job is then made at the top of the zone;

(3) after the second Erburu has been given a production test to establish the effectiveness of the cement job, the 6⅝-inch casing is gun-perforated opposite the first Erburu, and the two zones are produced together.

STRUCTURE

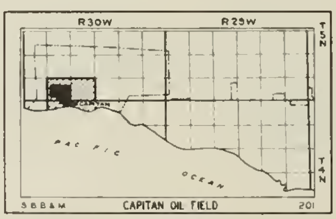
The Capitan structure consists of a north-trending anticlinal nose terminated on the north by a prominent east-west normal fault that furnishes the north closure.

The Santa Ynez Mountains, which form the highlands just back of the coast, are anticlinal; the beds are overturned in many places, and show evidence of great diastrophism. The flanks of the structure are broken by numerous east-west faults, and many minor east-west folds are present. The well-developed Goleta anticline and an accompanying syncline traverse the foothill region from east to west for a distance of approximately 20 miles, starting in the foothills back of the Elwood field, and extending west to Tajignas Canyon some 6 miles west of Capitan.

The anticline on which Capitan is located is the central structure of three north-trending noses. They are separated by two well-developed synclines, and all lie in a fault block 2½ miles long in front, or south, of the east-west terminating normal fault. It would appear that this block has been forced up between two thrust faults, one trending northwest, located at the mouth of Refugio Canyon a mile west of Capitan, the other trending northeast, located at the mouth of Yeguas Canyon, 1½ miles east of Capitan. Both thrust faults can be traced inland and are probably terminated by the normal fault north of the field.

CITATIONS TO SELECTED REFERENCES—Continued

CAPITAN OIL FIELD
Arnold and Kemnitzer 31; Dolman, S. G. 30; 38a; Sanders, T. P. 37c; Taff, J. A. 34.
El Capitan Oil Field (Capitan Oil Field)
Taff, J. A. 34.



Capitan oil field.

Erburu Oil Field (Capitan Oil Field)
Arnold and Kemnitzer 31.
Orella Oil Field (Capitan Oil Field)
Arnold and Kemnitzer 31.

GOLETA OIL FIELD

By Frederick P. Vickery *

OUTLINE OF REPORT

HISTORY

The Goleta field of Santa Barbara County is noted in the annals of the California petroleum industry for its brief period of production and the fine quality of its oil. The discovery of oil on February 25, 1927, on the Tecolote Ranch, 5 miles west of Goleta, extended the productive area of the Ventura Basin 18 miles west of the previous westerly production at Summerland. Considering the production of Sespe oil alone, the extension was 52 miles west of South Mountain, Ventura County, the previous Sespe outpost.

The Goleta field is situated 12 miles west of the city of Santa Barbara and 2 miles north of the shore of Santa Barbara Channel. It is located in the old Spanish land grant, Dos Pueblos. If the ranch had been subdivided into townships, the productive area would lie in T. 4 N., R. 29 W., S. B., Santa Barbara County, and the discovery well in the SW¼ NW¼ Sec. 3.

Early in the spring of 1921 Mr. E. J. Miley made arrangements with Mr. H. R. Johnson, consulting geologist of Los Angeles, and his assistant, the author, for a geologic investigation of the coast west of Santa Barbara. The first intimation that an anticlinal structure existed resulted from a casual examination of the Goleta topographic map. Within a few days the physiographic evidence was confirmed by the discovery of the anticline. The exploration of the region was conducted during the spring of 1921.

Discovery of oil was made in Miley Oil Company well No. "Goleta" 1. At a depth of 613 feet a yellowish-green paraffine oil was discovered. As this well was planned as a deep exploratory test, the oil was cased off. Another oil horizon was found at 1,527 feet. This horizon was also cased off. Diamond drilling equipment was used, and the well was cored throughout. The object of this well was to determine whether or not the oil horizon at the top of the upper shale of the Topatopa formation, known to be petroliferous in Oil and Toro Canyons, would be productive on the Goleta anticline. After passing through the basal Sespe, it was found that the sands and shales of the Topatopa formation were so highly cemented that the cores had to be broken up with a sledge hammer. A few traces of oil were reported. The well was drilled to a depth of 5,664 feet.

* Sacramento Junior College, Sacramento, California. Manuscript submitted for publication June 15, 1941.

The first production of oil was obtained from No. "Goleta" 2, which reached a maximum of 450 barrels from the second horizon. No. "Goleta" 3 was drilled to test the second horizon. No. "Goleta" 5, the most southerly well, proved that a fault with a downthrow of 400 feet on the south wall lay between that well and the main field. This fault was known on the west side of Tecolote Canyon, but could not be traced on the surface across the valley. The Santa Barbara Oil Company's No. "Hollister" 2 attained a maximum of 1,040 barrels a day. All the wells on the summit of the dome were productive, except the exploratory well.

The southern flank of the structure was tested by the Santa Barbara Oil Company's No. "Hollister" 7 and their No. "Elwood" 1 on the Doty property. The eastern end of the structure was tested by Berry Oil Company's No. "Cavalletto" 1 and by Barnhart No. "Pomatto" 1. The California Eastern Oil Company reached the upper zone in its No. "Doty" 1. The western pitch of the structure was tested in Miley's No. "Dreyfus" 1. None of these wells was successful.

The close of the field's history was heralded by the appearance of water in a number of wells. Further drilling on the dome was stopped. By February, 1928, the Miley wells were abandoned, 13 months after the discovery of oil. The short life of the field may have been due to the breaking in of water along a fault line, or it may have been due to the limited quantity of high-gravity oil in the anticline.

STRATIGRAPHY

The strata that are exposed on the summit of the dome are middle Sespe in age. Beneath the Sespe is the Topatopa of Eocene age, and above the Sespe on the southern flank of the structure are Miocene strata. No other formations, except Pleistocene gravels and alluvium, are found in the area.

On the northern flank of the Santa Ynez Mountains the Eocene rests unconformably on the Cretaceous. The Martinez formation has not been found in these mountains. It is probable but not proven that the Cretaceous underlies the Goleta anticline. The Eocene, called the Topatopa farther east in the Ventura Basin, is exposed along the southern flank of the Santa Ynez Mountains. The Eocene can be divided into three lithologic units: (1) a heavily bedded indurated sandstone which includes an important shale member at the base; (2) a shale series with subordinate sandstone beds in the middle; and (3) an upper sandstone series with subordinate shale. The lowest unit is not considered as part of the Goleta problem because it is below the depth of economical drilling.

The middle member of the Eocene is a black shale that weathers a gray-green color. This shale weathers so readily that landslides are common, streams cut subsequent courses by headwater erosion, and, where such streams head together, low gaps are formed. The black color of the shale, its stratigraphic position as the only shale below the Sespe, and oil seeps in Romero, Oil, and Toro Canyons, led to the belief that this member is the source of oil in the Sespe formation. It has a thickness of slightly more than 2,500 feet.

The upper member of the Eocene is composed of heavily bedded and highly indurated sandstones which are interbedded with subordinate clay shales and less-cemented sandstones. The highly indurated sandstones make prominent outcrops along the southern flank of the Santa Ynez Mountains. A *Venericardia planicosta* var. *horni* was found about 400 feet below the top of the upper member. Near the top of the member is a prominent but lenticular oyster bed. Above the oyster bed and below the true Sespe red beds are some moderately cemented greenish-gray sandstones which are interbedded with occasional red beds. This is evidently a transition zone, formed as the expanding Sespe alluvial plains were driving back the Eocene gulf.

The Sespe formation, whose widely spread red beds are so prominent east of Ventura, extends westward along the Santa Ynez Mountains. The thicknesses found on the Tecolote Ranch, 2,200 feet on the homocline north of the field, are much less than those reported from the Ventura region and even than those on the San Marcos grade. To the west the red beds gradually disappear, being reduced to a few feet in Gaviota Pass. It is now known that the red beds are replaced by marine strata of Refugian age. The formation is composed of conglomerates, sandstone, and shale. While the color is prevailingly red, some of the sandstones are buff and some of the shales are green. The base of the formation is a lenticular conglomerate that has a thickness of 150 feet on the San Marcos grade, 50 feet at the head of Las Varas Canyon, and is very limited in Tecolote Canyon. The formation is composed of alternating sandstones and shales. The shales are prominent in the middle of the formation. The formation is interpreted as a terrestrial basin-fill deposit which gradually drove the sea westward in the Ventura Basin.

Miocene strata are exposed along the southern flank of the Goleta anticline. These strata include the Vaqueros sandstone, the Rincon shales, and the lower part of the Modelo shale. Resting on the Sespe formation with general conformity, but with local unconformity in Las Varas Canyon, is a prominent buff sandstone which is more resistant to weathering than are the associated beds, and so forms rounded peaks on the ridges and shoulders projecting into the valleys. It attains a thickness of 450 feet, but thins to the southeast. This is called the Vaqueros sandstone, and is assigned to the early part of the Vaqueros epoch. Above the Vaqueros sandstone is the Rincon formation of upper Vaqueros age. This formation is a clay shale, gray on fresh exposure, weathering to a buff color, and forming a black soil. These clay shales are separated from the overlying Modelo formation by calcareous beds. The Modelo formation is composed of thinly laminated diatomaceous shales, sometimes white and powdery, sometimes opaline and brittle. This formation is prominent along the southern front of the hills. Although upper Pliocene is known in the Goleta district, none has been found near the field. Pleistocene terrace gravels occur in patches on the old land surface that is preserved on the ridge tops. Recent alluvium floods the floors of the valleys, probably as a consequence of the raising of sea level when the glacial waters were released from the continental glaciers.

The possibility of finding oil in the Goleta anticline was supported by the frequent occurrence of oil in the Sespe formation in the eastern part of the Ventura Basin, by oil seeps from the upper shale in the Topatopa formation in Oil and Toro canyons northeast of Montecito, and by an oil sand, 400 feet thick, reported in the Mission tunnel which was drilled through the Santa Ynez Range to obtain water for Santa Barbara. A seepage of oil at the time of the Santa Barbara earthquake, June 29, 1925, on the part of the Hollister Ranch that lies north of the axis of the Goleta anticline was not recognized as an evidence of oil until after the discovery of oil in No. "Goleta" 1.

STRUCTURE

The Goleta anticline traverses low hills which border the southern flank of the Santa Ynez Mountains between Goleta and Naples. To the east the summits of the hills descend eastward and disappear beneath the alluvium on which the town of Goleta is built. To the west they are reduced to a narrow coastal belt beyond Naples. A physiographic examination of these hills shows that their summit uplands form a part of an old land surface which evidently before its uplift and anticlinal warping was a coastal plain that separated the base of the Santa Ynez Mountains from the Santa Barbara Channel. The plain was uplifted and anticlinally warped in two stages. This ancient terrace is bordered on its southern flank by a scarp which, despite its petty faults, appears to be due to erosion at the time the present coastal plain was

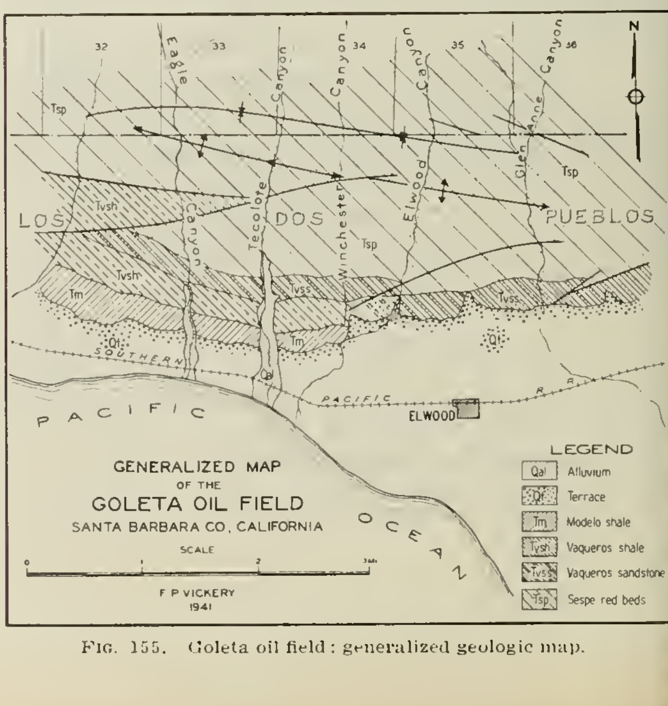


FIG. 155. Goleta oil field: generalized geologic map.

formed. The drainage of the Santa Ynez Mountains is carried from north to south across this belt by a series of incised extended consequent stream segments. During the uplifts and anticlinal warpings these streams maintained their courses. After the first uplift, which was not great, broad valleys were formed. During and after the second uplift the streams incised their courses and broadened their valleys. The flat floors of the valleys are probably due to alluviation that was a result of the rise in sea-level which resulted from the melting of the glaciers. On the sides of these valleys scant terraces indicate the position of the early shallow valleys, and the warping of these terraces into an anticlinal arch shows the position of the anticline and proves that the anticline received additional folding at this time. The anticlinal high and the structure are separated from the homocline to the north by a faulted syncline.

The structure of the coastal belt from Santa Barbara to Point Conception, a distance of 40 miles, is broadly speaking a homocline which strikes nearly east and dips from the crest of the range south beneath the Santa Barbara Channel. However, this general structure is modified by faults and folds. The trends of the folds and the more important faults are generally at slight angles to the strike of the homocline.

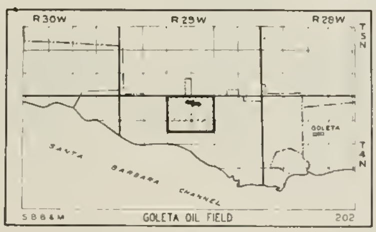
The axis of the Goleta anticline trends N. 82° W. The axis is exposed between Eagle and Carneros Creeks, a distance of 5 miles. To the east the local elevation of the hardpan beneath the alluvium as shown in water well logs suggests an easterly extension of the structure as far as Goleta. Traces of the anticline can be found as far as Dos Pueblos Canyon. The probable length of the structure is about 10 miles. The southern flank of the structure dips southward to the Elwood fault, and the northern flank to the faulted Hollister syncline. The southern flank has a width of 2¼ miles while the northern flank has a width of but half a mile. While the dips for some distance on either side of the axis are gentle, within half a mile they attain 25°, giving the structure a closure of about 300 feet. The summit of the dome is in the ridge between Winchester and Tecolote Canyons. The pitch to the east is long, and is slightly disturbed by minor faulting. The pitch to the west becomes obscure beyond Eagle Canyon.

A wedge-shaped graben trends east-northeast from the vicinity of Dos Pueblos ranch house near Naples to the summit of the dome. Vaqueros is downfaulted into the Sespe. On the southeastern flank of the structure is a minor fault in the Miocene strata, named the Glen Anne by Mason L. Hill (32).

KIND OF OIL

The oil produced on the Goleta anticline was a paraffine base oil. That produced from the upper horizon had a gravity of 44 degrees Baume, a gasoline content of 70.8 percent, and a kerosene content of 2.5 percent, while the lower horizon varied from 40 to 40.2 degrees Baume with 60 percent gasoline and 16.5 percent of kerosene. There was a trace of sulphur.

CITATIONS TO SELECTED REFERENCES—Continued



Goleta oil field.

EDWARDS ANTICLINE
Sherman, R. W. 27.

GOLETA OIL FIELD
Dolman, S. G. 30; Jensen, J. 27; McCabe, R. E. 25; Mining and Scientific Press 31; Sherman, R. W. 27; Taff, J. A. 34; Vickery, F. P. 27a; Vickery and Garrison 27; Wagy, E. W. 27.

ELWOOD OIL FIELD

By MASON L. HILL *

OUTLINE OF REPORT

HISTORY

The Elwood field, 10 miles west of Santa Barbara, Santa Barbara County, was discovered by drilling a structure that was revealed through surface geologic mapping. On July 26, 1928, Barnsdall and Rio Grande's No. "Luton-Bell" 1 was completed at 3,208 feet, in the upper 34 feet of "Vaqueros" (lower Miocene) sand for a daily flow of 1,755 barrels of clean oil of 37.8 degrees A.P.I. gravity, and an estimated 750,000 cubic feet of gas containing approximately 1.6 gallons of gasoline per 1,000 cubic feet.

Exploration progressed rapidly, the large leases permitting orderly and systematic development. Peak production was obtained during 1930, when the field accounted for 6 percent of all California production for the year. To January, 1938, the production from 94 wells had been 62,133,532 barrels of oil; and 10 nonproducing wells, along with edge producers, had apparently served to delimit the area and to indicate the possible zones of production. Early completions commonly flowed about 2,500 barrels of clean oil daily, but rapid water encroachment and decrease of pressure necessitated the early use of gas lift and pumping. Since May, 1930, the month of peak production when 33 wells produced an average of 1,480 barrels of oil daily, the field has declined until the daily production from 69 wells in January, 1938, averaged 115 barrels of oil and 230 barrels of water per well.

The Elwood field is generally considered to be adequately explored and its production has now declined to the settled stage.

SIGNIFICANCE

The Elwood field was a remarkable geologic discovery because prior to this time the "Vaqueros" sand had not produced commercial quantities of oil. Theoretically unfavorable also was the fact that the "Vaqueros" at Elwood is directly underlain by some 5,000 feet of nonmarine Sespe and inorganic Eocene sandstone, and directly overlain by more than 1,000 feet of "Temblor" claystone, all apparently too lean in organic matter to constitute adequate source for petroleum. This unprecedented discovery gave geologists a new objective and thus stimulated exploration not only in this immediate region but in other regions where lower Miocene sand was known.

The Elwood field is significant structurally in that the sharply folded surface structure is underlain by a relatively broad anticline.

STRATIGRAPHY

The geologic formations, known from exposures in the adjoining region, comprise a few feet of marine terrace deposits; a few hundred feet of Santa Barbara (upper Pliocene?) sand which is delineated above and below by sharp angular unconformities; a few hundred feet of "Santa Margarita" (upper Miocene) argillaceous siltstone; about 1,500 feet of "Monterey" (middle Miocene) organic shale; 1,500 to 1,800 feet of "Temblor" (lower Miocene) claystone; 275 to 400 feet of "Vaqueros" (lower Miocene) sand; roughly 3,000 feet of Sespe (Oligocene+ ?) nonmarine sandstone and maroon siltstone; and about 10,000 feet of Eocene sandstone and shale formations.

All wells in the field began drilling in the upper portion of the "Monterey" formation (terrace deposits excepted) and, although most wells bottomed in the "Vaqueros" or Sespe, one well has penetrated approximately 1,700 feet of Eocene strata. Numerous lithologic and faunal marker horizons above the "Vaqueros" oil sand have facilitated exploitation.

STRUCTURE

The Elwood coastal area lying between the Santa Ynez Mountains and the Pacific Ocean is a marine terraced and foothill belt which is characterized by southward dipping strata. This homocline is broken by numerous faults and is interrupted by several comparatively small east-trending anticlinal folds.

Elwood anticline is one of the largest of these folds. Its surface structure, as exposed in the incompetent "Monterey" shale, is faulted and sharply crenulated with its axial part composed of several subsidiary folds having 50-degree dipping limbs. The subsurface structure, however, is that of a comparatively gentle anticline with eastward and westward closure of several hundred feet. Only one fault is shown on the accompanying structural contour map but there are probably several other lesser faults which effect anomalies of production.

PRODUCTIVE HORIZONS

All production prior to 1931 was from the "Vaqueros" formation. In August, 1931, the "Temblor" zone was discovered upon completion of No. "Luton-Bell" 18 at a depth of 3,000 feet; with 1,522 feet of "Temblor" fractured shale open, this well produced 147 barrels daily of 23 degrees A.P.I. oil with 30 barrels of salt water and some 800,000 cubic feet of gas.

The next new zone (Bell 14 zone) discovery was made in October, 1931, when No. "Luton-Bell" 14 was deepened to 4,385 feet, and from 60 feet of Sespe sand

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* Richfield Oil Corporation. Manuscript submitted for publication November 1, 1938.

The writer is indebted to Messrs. A. G. Fisk, G. R. Kribbs, John O'Keeffe, and H. W. Hoots for assistance in the preparation of this report.

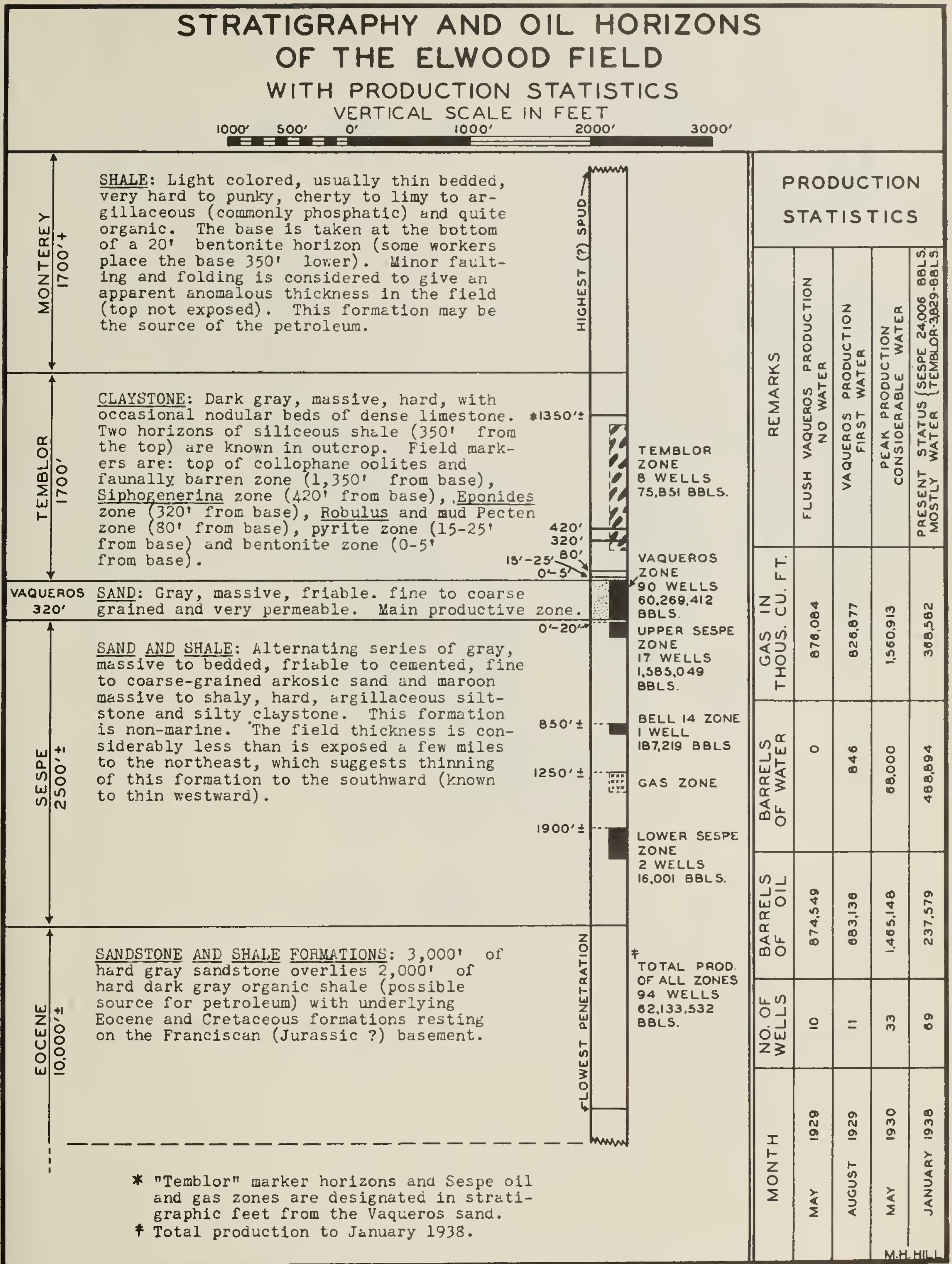


FIG. 156. Elwood oil field: stratigraphy and oil horizons.

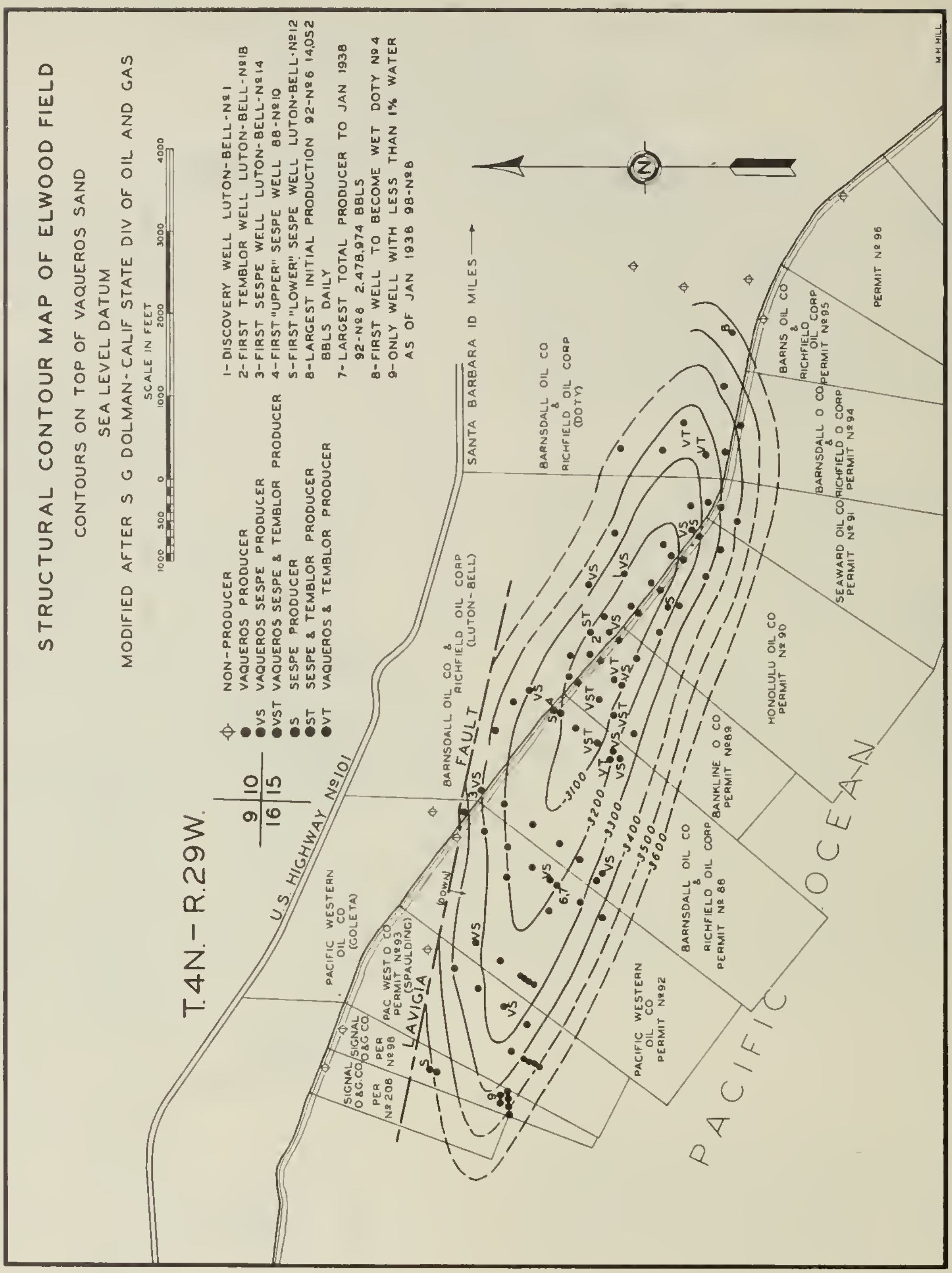


Fig. 157. Elwood oil field: structure map.

flowed initially at a rate of 2,389 barrels of oil (42 degrees A.P.I. gravity) and 2,000,000 cubic feet of gas per day. This zone is about 850 feet below the top of the Sespe.

In May, 1935, the "upper" Sespe zone was discovered with the completion of State Lease 88 No. 10 well, from an interval between 3,530 and 3,616 feet, flowing initially at a rate of 1,059 barrels of 36.4 degrees A.P.I. oil and 546,000 cubic feet of gas daily.

The "lower" Sespe zone, lying some 1,900 feet below the top of the Sespe, was discovered in June, 1936, by No. "Luton-Bell" 12. This well was completed on gas lift for a daily production of 68 barrels of 33.5 degrees A.P.I. oil, 17 barrels of salt water, and 602,000 net cubic feet of gas from an interval between depths of 5,980 and 6,271 feet. While drilling this well, which explored the entire Sespe formation and the upper part of the Eocene, a stratigraphically higher gas zone was discovered at 5,392 to 5,405 feet, which yielded 2,315,000 cubic feet per day.

The Sespe and "Temblor" zones have produced only minor quantities of oil. The No. "Luton-Bell" 14 completion justly stimulated Sespe exploration, but this prolific high-gravity zone has not proved productive elsewhere in the field. The "lower" Sespe zone has contributed only a few barrels of oil. The "Temblor" zone is best near the center of the field but is erratic in its performance and at best can not be expected to produce more than a few thousand barrels of oil per well.

KIND OF OIL AND GAS

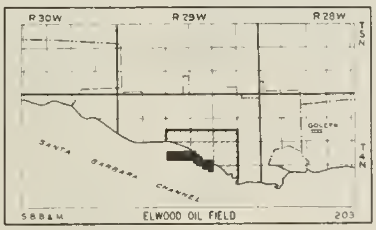
The gravities of the oils from the Sespe and "Vaqueros" vary from 32 degrees to 38 degrees A.P.I. except for the oil from the Bell 14 zone, which is 42 degrees. The gravity of the "Temblor" oil ranges from 14 degrees to 31 degrees A.P.I. but is commonly about 26 degrees in the central part of the field.

Gasoline content per thousand cubic feet of gas commonly ranges from 1.5 to 3 gallons (12 have been obtained) from the Vaqueros sand; 1 to 1.5 gallons from the "upper" Sespe zone; approximately 1 gallon from the Bell 14 zone; and 0.75 gallon from the "lower" Sespe zone and the gas zone.

The salinity of the waters in grains per gallon is approximately as follows: "Vaqueros" 1,000 to 1,400; Sespe 900 to 1,100; and "Temblor" 1,850 to 2,050. Water encroachment was rapid and irregular, the wells on the east plunge and north flank being the first to become wet. By 1932 it was necessary to plug all but the upper 35 to 50 feet of the 320-foot Vaqueros zone. This repairing operation was temporarily effective but in about nine months water encroachment again became noticeable.

Casing pressures in the field were originally 1,000 to 1,200 pounds per square inch but at the present time most wells are pumping with the casing open. Gas lift was first used early in 1930 and pumping began to be generally employed early in 1933.

CITATIONS TO SELECTED REFERENCES—Continued



Elwood oil field.

ELWOOD OIL FIELD

Broomfield, R. A. Jr. 35; California Oil World 31; Dolman, S. G. 30; 31; Hight, W. 33; Hoots and Herold 35; McCabe, R. E. 25; Mercer, A. F. 30; Mills, B. 29a; Petroleum Times 30a; Petroleum World 31; 35; 36a; Sherman, R. W. 28; Smith, W. 30; Stockman, L. P. 35i; 36; 36d; 36e; Taff, J. A. 34; Van Tuyl and Parker 41.

COAL OIL POINT

Petroleum World 36a; 36e; Stockman, L. P. 40, no. 19, pp. 205-206.

LA GOLETA GAS FIELD

By R. O. Swayze *

OUTLINE OF REPORT

HISTORY

La Goleta gas field is located on the coast of the Pacific Ocean at the mouth of Goleta Slough, Santa Barbara County, about 4 miles east of the Elwood oil field, and is one of several structures lying within the belt of folding which extends along the sea coast from Carpinteria to Point Conception parallel with the south flank of the Santa Ynez Range.

The existence of gas seeps along the east bank of Goleta Slough where it is crossed by the axis of La Goleta structure has been known for many years. The field, however, was discovered August 5, 1929, when General Petroleum Corporation of California No. "More" 1 blew out at a depth of 4,533 feet, and flowed gas at a rate estimated at 60 million cubic feet per day. This well, which penetrated the Vaqueros sandstone, was subsequently redrilled and completed for 58 million cubic feet per day. Five wells have been completed in the main part of the field, and one has been completed about a mile to the southwest of the westerly plunge of the anticline where structural conditions are not well understood. Dry holes have been drilled on the north and south flanks of the structure.

The proved productive area of La Goleta field is about 250 acres; however, the limit of production on the ends has not been defined. To the end of 1937 the field had produced 14,000 million cubic feet of gas.

STRATIGRAPHY

The formation exposed at the surface is diatomaceous Monterey shale of Miocene age. Wells reach the base of this formation at about 2,300 feet, and enter the clay shales of the Temblor which are approximately 1,800 feet in thickness. These overlie the Vaqueros sandstone (lower Miocene) which is 350 feet thick and is the gas-producing horizon of the field. The Sespe formation is encountered at about 4,500 feet, and has been completely penetrated by one well, in which it had a thickness of 2,380 feet. It consists of reddish clays and silts and greenish to gray clay shales and sands, for the most part, if not wholly, of non-marine origin. The oldest formation reached by any well drilled in the field is the Tejon sandstone.

A tar seep exists on the beach on the southeastern flank of La Goleta structure where faulting is in evidence in the surface rocks. The Monterey shales exposed along the axis and on the south flank of the fold are coated with tar on their fractured surfaces. No showings of oil have been noted in the Vaqueros in any well so far drilled in the field. The upper part of the Sespe, in the one well drilled through this formation, contained numerous sands showing some oil saturation. However, production tests made on the best of these showings failed to develop commercial production.

STRUCTURE

La Goleta structure is an asymmetric anticlinal dome complicated by overthrust faulting along the crest. A fault with a displacement of about 1,000 feet, downthrown on the north, parallels the axis on the north flank, and probably limits the production on that side.

PRODUCTIVE HORIZONS

The Vaqueros, a medium-grained, fairly well indurated gray sandstone with about 15 percent porosity, is the reservoir rock; on top of the structure it is filled with gas throughout its entire thickness. Several wells have had strong gas showings, and one well is producing gas from the fractured shales of the Temblor. Although no water is known to exist above the Vaqueros, wells are finished with a primary water string at the top of this horizon. Some wells are completed with perforated liner; others are produced barefoot through tubing landed inside the water string. Initial production of wells in good mechanical condition and with the entire thickness of Vaqueros open to production ranges from 35 million cubic feet to 60 million cubic feet per day. Initial reservoir pressure was 1,800 pounds per square inch. Pressure does not decline rapidly, and it is believed that, because of the very slow rate of gas withdrawal, the reservoir pressure is held up by the encroachment of edgewater on the flanks of the fold. The gasoline content of the gas is about 0.30 gallons per thousand cubic feet. A small amount of condensate of about 60 degree gravity is produced with the gas.

* General Petroleum Corporation of California. Manuscript submitted for publication June 22, 1938.

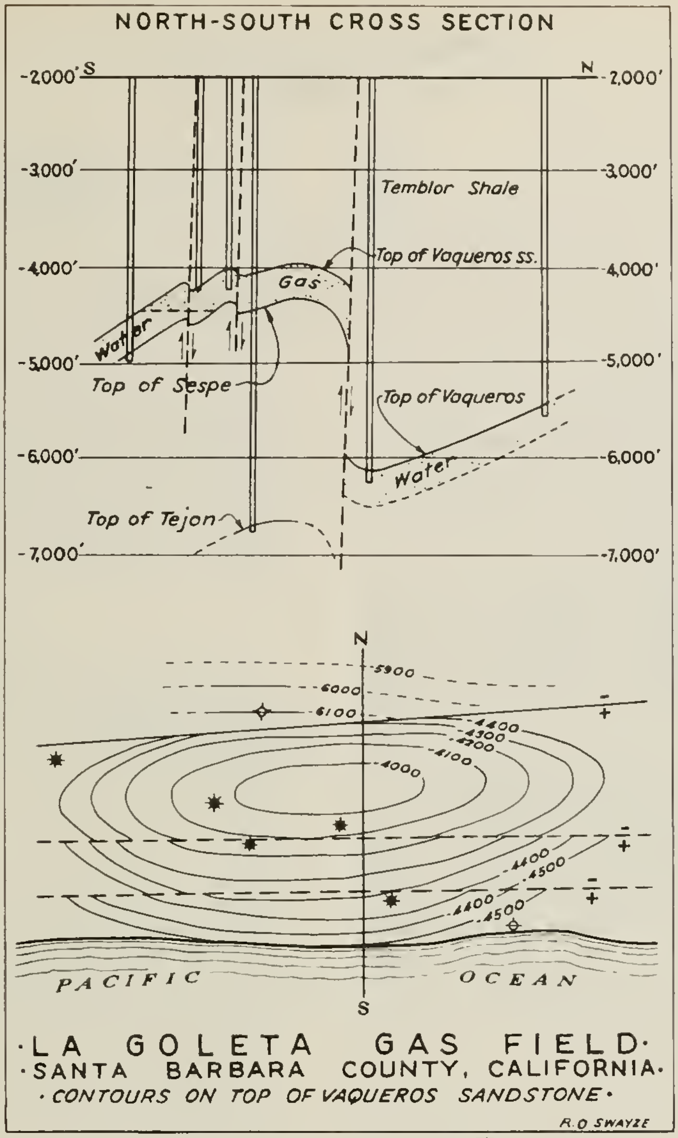
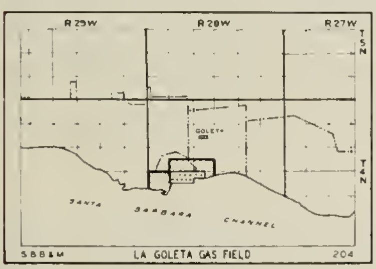


Fig. 158. La Goleta gas field: cross-section; structure map.

CITATIONS TO SELECTED REFERENCES—Continued



La Goleta gas field.

LA GOLETA GAS FIELD

Dolman, S. G. 30; Hanks, H. G. 86; Oil and Gas Journal 41f; Rousselot, N. A. 35; Stockman, L. P. 39f.

More (Moore) Ranch Gas Field (La Goleta Gas Field)

Dolman, S. G. 30; Rousselot, N. A. 35.

MESA OIL FIELD

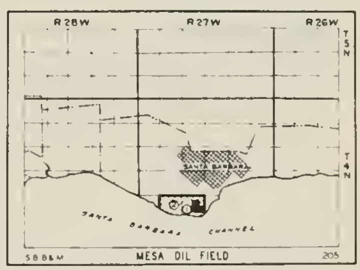
Chase, J. L. 29; Dolman, S. G. 30; 38; Powell, E. B. 34; Stockman, L. P. 35i.

Palisades Area

Stockman, L. P. 35; 35g.

Santa Barbara Mesa Oil Field (Mesa Oil Field)

Chase, J. L. 29; Powell, E. B. 34; Stockman, L. P. 35i.



Mesa oil field. Areas (1) La Mesa; (2) Palisades.

SUMMERLAND OIL FIELD

By EMIL KLUTH *

OUTLINE OF REPORT

HISTORY

The earliest production from the Summerland oil field was made prior to 1907 from shallow wells (Arnold, R. 07b). After that period of development, very little was done until 1927, when the late George F. Becker of Summerland, started a deep hole on the southeast corner of the main highway and Temple Street in the town of Summerland, Santa Barbara County.

Ralph Arnold had reported in 1907 that the old Summerland wells were producing only from a zone above the Vaqueros, and that if structural conditions were right there would be an opportunity for deeper production in the Vaqueros and Sespe formations. With the discovery of Vaqueros production in the Elwood field, activity increased at Summerland.

George F. Getty, Inc., agreed to develop all of the lands held by Mr. Becker in the Summerland district, and to deepen the Temple Street well below 3,100 feet. At that time it was believed that the well had not penetrated either the Vaqueros or Sespe formation. After the deepening had been started, however, a core was discovered, evidently taken when the well was first started, which indicated that at 400 feet the Sespe had already been penetrated. However, the company decided to continue the drilling in accordance with the contract, and the well was not abandoned until a depth of 5,041 feet had been reached.

In the meantime, the Lincoln Drilling Company started a well about a quarter of a mile west of the western boundary of the town of Summerland, on the beach. This well reached the top of the Vaqueros sand at 1,025 feet, and finished at 1,417 feet. After being plugged back to 1,345 feet, it was completed for about 300 barrels of 16 degrees gravity oil.

* Vice President, George F. Getty, Inc. Manuscript submitted for publication May 6, 1938.

STRATIGRAPHY

Numerous surface outcrops occur about a mile southeast of the town of Summerland, as well as west of the town, and in the hills north of the town. The surface stratigraphy and structure are discussed by Arnold (07b). The old shallow oil sand near the beach at the west end of the town is found a few feet below the beach sand, and becomes deeper toward the ocean. This sand may possibly represent the basal part of the Pliocene. In drilling the deep wells during 1929, shales evidently belonging to the lower portion of the Miocene were encountered below the shallow sand. After penetrating about 1,000 feet of shale, the Vaqueros sand was reached. Evidently some 500 feet of Vaqueros sand was penetrated before the Sespe was reached. The well taken over from Mr. Becker by the Getty Company must have penetrated some 4,700 feet of the Sespe formation.

STRUCTURE

A sufficient number of wells have been drilled in the Summerland area so that the structure, especially on top of the Sespe horizon, can be well defined at least south of the State highway. The strike of the formation is practically east; the dip is southwest near the west end of the field, and southeast near the east end of the field, with an oceanward dip of 45 degrees.

PRODUCTIVE HORIZONS

The old productive horizon is probably a basal part of the Pliocene that lies unconformably against the Miocene shales. The productive sand of the Vaqueros is more porous at the west end of the field than at the center of the town; wells drilled south of the railroad depot and on the Seaside pier showed that the Vaqueros consists mostly of gray sand of very poor porosity, and evidently does not carry water at these points. The only water in the Vaqueros appears in the west end of the field, where the wells are too far down structure. No oil showings were found in the Sespe formation.

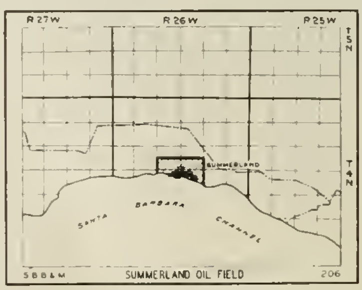
KIND OF OIL AND GAS

Gravity of the oil of the Vaqueros sand production is about 16 degrees. There is very little gas present.

CITATIONS TO SELECTED REFERENCES—Continued

SUMMERLAND OIL FIELD

Arnold, R. 07b; 15; Blackwelder, Thelen, and Folsom 17; Burkhart, H. W. 10; Colloni, R. E. 18; Crawford, J. J. 96; Dolman, S. G. 30; Eldridge, G. H. 03; Emmons, W. H. 21; Jones, E. C. 97; Kew, W. S. W. 32; McLaughlin and Waring 14; Mining and Scientific Press 97; 10; Moran, R. B. 17; Prutzman, P. W. 04; 13; Taff, J. A. 34; Vander Leck, L. 21, p. 109; Watts, W. L. 00; Wheelan, F. H. 90; Young, W. G. 01.



Summerland oil field.

RINCON OIL FIELD

By R. E. Stewart *

OUTLINE OF REPORT

HISTORY

"In the district lying west from the Ventura River to the Santa Barbara County line, there is only one possible area of development * * *, namely an extension of this (Ventura Avenue) field along the axis of the fold (Ventura Avenue anticline), westward from the Taylor wells of the Shell Company. It is most probable, however, that this extension can not be carried much more than a mile west of the river. The extreme westward end of the Ventura Avenue anticline has been tested in two wells by the General Petroleum Corporation and found unproductive * * *. (Their) Hobson No. 1 was located on Padre Juan Canyon and Hobson No. 2 on Madranio Canyon." (Vander Leck, L., 21, p. 117.)

This statement reflects a belief which was quite prevalent throughout the petroleum industry, not only in 1921 when it was published, but subsequently until the discovery of the Rincon field in 1928. Even up to 1937 or later it was quite generally believed that the Rincon field, although capable of some production, was too much complicated by faulting and other structural and lithologic handicaps to permit profitable development.

Since 1921, however, more than 6 of the 9 miles lying to the west along the structural trend between Ventura River and Punta Gorda have been proved commercially productive. Approximately 2 of these 6 miles are included in the westward extension of the Ventura Avenue field; the remaining 4 comprise the Rincon, Padre Canyon, and San Miguelito areas of the Rincon oil field. It is not at all beyond the realm of possibility that the present productive areas will be extended until, either by their union or en echelon overlap, it will be made impossible to draw more than one or two, if any at all, north-south sections across this area without intersecting one or more oil fields.

In 1923 and 1924 the Associated Oil Company drilled their well No. "Taylor" 1-A in Canada del Diablo near the eastern end of what is now the San Miguelito area. It was carried to 5,215 feet with only a few slight shows of oil and gas, and was abandoned after a bailing test showed no oil or gas entering the hole. It now appears that another 500 feet more or less would have put it in highly productive oil sands.

In August 1925 the Chanslor-Canfield Midway Oil Company spudded well No. "Hobson" A-1 in Padre Juan Canyon about 200 feet from General Petroleum's old "Hobson" 1 well, and abandoned it in May 1928 at a depth of 7,002 feet. The old "Hobson" 1 well was drilled to 3,202 feet with cable tools. "Hobson" A-1 encountered oil sand and had good shows of oil and gas on the ditch, but failed to develop commercial production. Available records give it the appearance of an edge well which, except for a considerable north drift, would have been out of the area of accumulation altogether.

The next test drilled in this general area was Chanslor-Canfield Midway Oil Company's well No. "Hobson" B-1, spudded January 14, 1927, and completed on production May 30, 1928, in the hills between Javon and Madranio canyons. However, another well, Pan American Petroleum Company's No. "State" 1, located on the coast about a mile to the west, was the first actually to produce oil from the Rincon field when, on November 2 and 3, 1927, it flowed to the sump for a few hours at an estimated rate of 1,500 barrels per day, and then died. It was recompleted January 22, 1928, but did not hold up as a commercial producer; so credit for the discovery of the Rincon area finally went to Pan American's No. "Fee" 3, which was completed December 24, 1927.

Chanslor-Canfield Midway Oil Company's No. "Hobson" A-2 on top of the oceanward end of the ridge between Faria Canyon [1] and Canada Linea del Rancho [1] near the western end of the Ventura Avenue anticline is the next test entitled to the status of a discovery well. Spudded August 16, 1929, it passed the then world's record depth of 9,702 feet on May 8, 1931, and on May 16, 1931, was the first well to reach the 10,000-foot mark, and was bottomed at 10,030 feet. After being plugged back to 7,825 feet, it was completed on production September 14, 1931, and has since produced over 270,000 net barrels of oil.

On November 22, 1931, Continental Oil Company's well No. "Grubb" 1 was completed at a depth of 6,750 feet for an initial production of 616 barrels per day, and has since been credited with the discovery of the San Miguelito area. It was later deepened and on August 11, 1932, recompleted at a depth of 7,152 feet for a 24-hour initial production of 2,449 net barrels of 30.0 degrees gravity oil, 3 percent cut, 1,360 pounds tubing pressure, 500 pounds casing pressure, 44/64-inch bean. The potential established the following day was 2,558 barrels net oil, 30.3 degrees gravity, 2.8 percent cut, 360 pounds tubing pressure, 1,160 pounds casing pressure, 44/64-inch bean, 1,511 M.c.f. gas.

Continental's "Hobson" 1 in Padre Juan Canyon was completed for an initial production of 570 barrels per day gross, 29.5 degrees gravity, 7.7 percent cut, 40/64-inch bean, 100 to 370 pounds tubing pressure, 400 to 815 pounds casing pressure, on March 22, 1936. The following day it established a potential of 649 gross barrels. This well deserves credit for the discovery of the Padre Canyon area if the production in Padre Juan Canyon proves to be separate and distinct from that of the Rincon area and that of Chanslor-Canfield Midway's Oak Grove and eastern Hobson "A" leases.

Fourteen years after the first discovery of commercial production in this field, the status of one discovery and three other possible discovery wells is still not definitely established. These four take precedence in the following order: Pan American's (now Richfield's) well No. "Fee" 3; Chanslor-Canfield Midway's well No. "Hobson" A-2; Continental's well No. "Grubb" 1; and Continental's No. "Hobson" 1. Their status as discovery wells depends upon what future development shows to be the structural relationships between the various producing areas of the Rincon field.

* Geologist, Chanslor-Canfield Midway Oil Company. Manuscript submitted for publication April 2, 1942.

[1] For convenience of reference three heretofore unnamed canyons located between Padre Juan Canyon and Canada del Diablo are here given the following names as shown on the accompanying map: Faria Canyon, Canada Linea del Rancho (ranch-line canyon), and Canada del Anfiteatro (amphitheater canyon). These names have come into common usage among local operators.

STRATIGRAPHY

Probably the thickest marine Pleistocene-Pliocene section in the world occurs in the vicinity of Ventura, its total thickness being between 18,000 and 19,000 feet. The local geologic column down to the Sespe, which is the oldest formation exposed in the vicinity of the oil-producing areas under consideration, may be divided as follows:

Quaternary
- Undifferentiated. 500 feet. Marine and fluviatile fans and terraces; bedded Pleistocene sandstone.
- Las Posas. 2,500 feet. Soft argillaceous shales, sandstones, and conglomerates; commonly buff in color; cross-bedding not uncommon; fossiliferous in many places; characterized by estuarine and brackish-water Foraminifera together with many reworked Pliocene and Miocene forms. An estuarine or brackish marine-water phase of the Saugus.

Pliocene
- Upper Pliocene: Mud-pit shale.[2] 1900 feet. In some places it appears to be considerably thicker. Predominantly blue-gray claystone, occasional thin beds of fine-grained buff-colored sandstone; two or three thin layers of white volcanic ash; fossiliferous in places, especially near the base: Foraminifera common to abundant throughout most of its thickness, several of the species being characteristic of the Bath House Beach beds at Santa Barbara. Locally called "Mud-pit shale" because of its excellent exposure in relatively recent cuts in the hillside about a mile south of the Ventura Avenue field on the east side of Ventura River valley. These cuts were made to obtain material for making rotary mud and bricks.
- Middle Pliocene: Santa Paula (or Pico)
  - Upper Santa Paula. 8,000 feet. Thin to massive bedded buff sandstone, conglomerate, claystone, and shale: small-scale cross-bedding and lenticularity common; pebbles of Miocene and other older formations common at certain horizons; molluscan fossils rare to common throughout a considerable portion of these beds, but only a few species represented; Foraminifera common to abundant in most of the claystone and shale beds. The division between upper and lower Santa Paula is based upon certain foraminiferal relationships, notable species being *Bulimina pagoda* Cushman, var. *hebespinata* R. E. and K. C. Stewart, and *Cyclammina constrictimargo* R. E. and K. C. Stewart. This division point is locally called the "Gosnell horizon."
  - Lower Santa Paula. 2,000 feet. Lithologically very similar to the upper Santa Paula, although the writer has not noted the presence of Miocene and older pebbles nor of as much cross-bedding and lenticularity, and molluscan fossils are very rare. In the Rincon area where a section has just been cored through these beds, conglomerates are absent.
- Lower Pliocene: Repetto. 3,500 feet. The Repetto beds exposed at the surface on the south flank of Sulphur Mountain are lithologically very similar to the upper Santa Paula, including the conglomerate and even boulder beds. Ripple marks, or more probably current marks, have been noted in a couple of places. In the Rincon area a section through the upper 2,000 feet of the Repetto has just been cored without encountering any of this very coarse material. Small-scale cross-bedding and lenticularity are present but uncommon in the cores, and molluscan fossils and Miocene and older pebbles appear to be absent. The Repetto is identified largely on the basis of Foraminifera, diagnostic species including *Nonion umbilicatula* (Montagu), *Plectofrondicularia californica* Cushman and Stewart, *Bulimina rostrata* H. B. Brady, *Virgulina nodosa* R. E. and K. C. Stewart, *Nodosaria parexilis* Cushman and K. C. Stewart, *Nodogenerina lepidula* (Schwager), *Cassidulina cushmani* R. E. and K. C. Stewart, *Sigmoilina tenuis* (Cjzek).

Miocene
- Santa Margarita. 2,100 feet. Massive silty shales, with occasional sandstone members; commonly chocolate-brown in color; considerable gypsum and sulphur; Foraminifera and molluscan fossils sparsely represented; formation locally folded, distorted, and badly fractured; lower 400 feet fine-grained sandstone interbedded with platy brown shales.
- Modelo. 2,000 feet. Hard, siliceous, cherty, thinly laminated diatomaceous shales with a few 1- to 2-foot beds of sandstone; argillaceous sandstone and clay-shale occur near base; buff to dark gray in color; often contorted; cracks and crevices commonly filled with gypsum and sulphur; Foraminifera abundant; fish scales and small pectens common.
- Rincon (Temblor). 2,200 feet. Brittle, thinly laminated, gray and black clay-shales with large yellow dolomitic and cherty concretions.
- Vaqueros. 300 feet. Fine-grained buff to gray sandstone and shaly sandstone; thin oyster bed 50 feet above base.

[2] This is the upper Pico of Lon D. Cartwright, Jr. (28).

Below the Vaqueros is about 4,000 feet of Oligocene (?) Sespe which lies 17,000 to 20,000 feet or more below sea level in all of the fields from the Rincon to and including Ventura Avenue. The Eocene Coldwater, Cozy Dell, and Matilija formations and the Cretaceous Chico formation probably underlie the Sespe in the order named, but none of them can be expected to serve as source beds for any appreciable amount of oil. Oil might, however, get to the Sespe by downward migration from the organic shales of the Miocene which are believed to be the source of the oil now being produced from the overlying Pliocene.

The production of the Rincon, Padre Canyon, and San Miguelito areas comes from the Pliocene as does that of the Ventura Avenue field to the east.

Practically all of the Rincon area production to date has come from the lower 1,400 feet of the upper Santa Paula. This has been divided into three zones: the Top, approximately 50 feet thick; the Intermediate, 100 to 400 feet thick; and the Miley, about 800 feet in thickness. The top zone is overlain by the Top shale, which ranges from 6 to about 20 feet in thickness, and is underlain by a similar shale in some cases, and by no shale at all in others. The Intermediate and Miley zones are separated by the Miley shale, which ranges from about 50 feet in thickness at the western end of the field to about 150 feet in the eastern end. Aside from these two shales, the division between producing sands is usually marked by intermediate waters, although shaly zones occur throughout most of the Miley zone. The scarcity of shale throughout the Top and Intermediate zones has made their development and handling very difficult, and to complicate things still further, faulting, and perhaps to some extent lithologic gradation, have made oil accumulation so erratic throughout the Miley as well as the Top and Intermediate zones that it has been practically impossible to tell in advance what to expect from any new well. It has become common practice during recent years to core approximately the last 1,000 feet of each new well and to study the cores together with electric logs in detail before deciding definitely on a completion program. The Rincon area has consistently lived up to the reputation of being one in which "every well is a wildcat."

The deep zone tested in Richfield's No. "Miley-Hobson" 1 and Chanslor-Canfield Midway's No. "Hobson" C-9 wells occurs near the base of the lower Santa Paula. All of the other deep sands of the Rincon area are in the lower Pliocene Repetto, extending from the top of this formation down to within 1,000 to 1,500 feet of the base of the Pliocene. Drilling is now under way with the objective of prospecting the remainder of the Pliocene and the underlying upper Miocene Santa Margarita.

The lowest producing sands of the Padre Canyon area correlate very closely with the base of the Miley zone in the Rincon area, and the uppermost Padre Canyon production comes from sands about 700 feet higher in the section than those of the Top zone of the Rincon. No prospecting has been done in the Padre Canyon area below the present producing zones.

The producing sands of the San Miguelito area correlate closely with the upper 1,900 feet of the deep sands of the Rincon area. The equivalents of the Rincon Top, Intermediate, and Miley zones are barren in the San Miguelito area. Prospecting has not been carried below the present producing zones.

The Top, Intermediate, and Miley zones of the Rincon area considered together appear to be the approximate stratigraphic equivalent of the upper and lower light-oil zones of the Ventura Avenue field (Hertel, F. W. 29, pp. 729-732). The deep sands encountered between 7,450 and 10,500 feet in the Rincon area extend downward from what now appears to be the approximate stratigraphic equivalent of the middle of the old Lloyd zone of the Ventura Avenue field to that of the Gosnell 35 zone in which the deepest Ventura Avenue wells are now bottomed.

STRUCTURE

Structurally, the Rincon-Padre-Canyon-San Miguelito area is divided into three main fault blocks by the Red Mountain and Padre faults.

The Red Mountain fault, between the northern and central blocks, is upthrown 20,000 feet or more on the north and has a north hade of about 25 degrees. The Padre fault, between the central and southern blocks, is upthrown on the south and hades southward at about the same angle. An interval of more than 4,000 feet occurred in one well between the "Gosnell horizon" above the Padre fault and its recurrence below the fault, but it is believed that this was not entirely the result of vertical displacement along the fault.

The central block, being on the downthrow side of both of these faults, is a graben whose width increases with depth.

Considerable minor faulting occurs in all three of the blocks.

The production of the Rincon and Padre Canyon areas is obtained respectively from Rincon and North anticlines in the central fault block. Both are faulted anticlines. Chanslor-Canfield Midway's Oak Grove and eastern Hobson "A" Lease wells, although located in the southern block at the surface, passed through the Padre fault before encountering production.

The exact structural condition which is responsible for the separation between the oil accumulation in Rincon anticline and that in North anticline has not yet been definitely determined, but it appears to be the result of faulting which, near the surface at least, is associated with, perhaps responsible for, the folding of North syncline.

The production of the San Miguelito area is from the Ventura Avenue anticline in the southern fault block. This anticline, as it continues westward, has its north flank cut away by the Padre fault between Canada Linea del Rancho and Faria Canyon. Still farther to the west it pinches out altogether along the Padre fault between Padre Juan and Javon canyons.

No production has yet been encountered by wells drilled in the northern fault block.

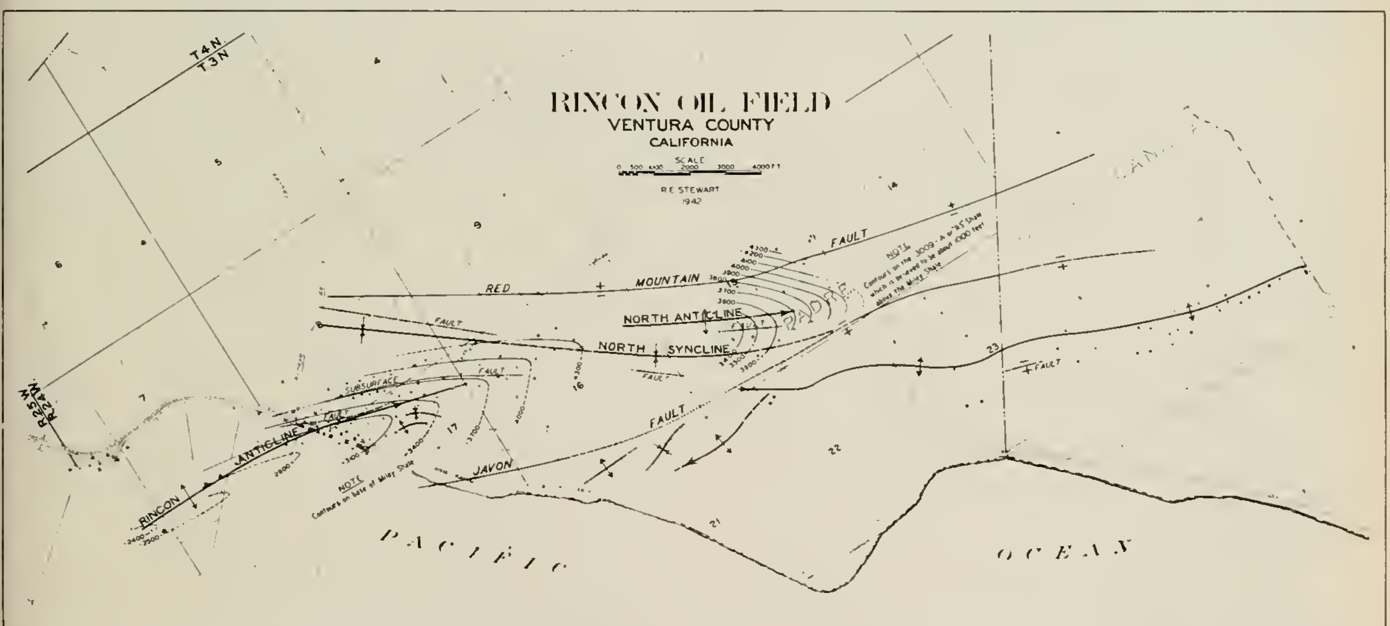


FIG. 159. Rincon oil field: structure map. (Javon fault is also known as Padre fault.)

CITATIONS TO SELECTED REFERENCES—Continued

CARPINTERIA REGION

Burkhart, H. W. 10; Chaney and Mason 33; Eldridge, G. H. 01, pp. 444-445; Hanks, H. G. 84; Mining and Scientific Press 81.

RINCON OIL FIELD

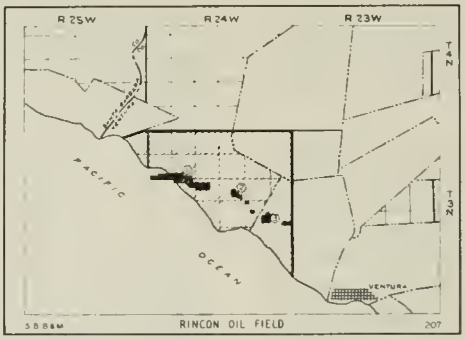
Cadle, A. 28; Cooper and Sturdevant 40; Fox, L. S. 30; Head, E. R. 28; Kew, W. S. W. 32; Kotick, O. F. 28; McCollough, E. H. 34; Stockman, L. P. 30a; 41l; Thoms, C. C. 26b; 39; U. S. Geological Survey 34; Wagy, E. W. 27; Westsmith, J. N. 31.

Javon Area

Stockman, L. P. 36c; 36g.

Javon Canyon Area

Petroleum World 36a.



Rincon oil field. Areas: (1) Rincon; (2) Padre Canyon; (3) San Miguelito.

Padre Canyon (Padre Juan Canyon) Area

Edwards, M. G. 37; Petroleum World 37f; Porter, W. W. II 39b; Stockman, L. P. 36c.

Rincon Area

Stockman, L. P. 35i.

San Miguelito (San Miguelitos) Area

Sanders, T. P. 41b; Stockman, L. P. 32; 33; 35i; Taff, J. A. 34; Wilhelm, V. H. 32; 38.

Seacliff Area (Rincon Area)

Wagy, E. W. 27.

VENTURA AVENUE OIL FIELD

By C. C. THOMS* and WM. C. BAILEY**

OUTLINE OF REPORT

HISTORY

The Ventura oil field is located on the Ventura anticline, about $2\frac{1}{2}$ miles north of the City of Ventura. The proved acreage as estimated by the Division of Oil and Gas January 1, 1941, was about 2,000 acres. The area of the field when fully developed will probably not exceed 2,600 acres. The field is easily accessible from a State highway, which almost bisects the field from north to south.

The surface topography ranges from a flat area along the Ventura River to a rugged terrain to both the east and west. Three large gas lines transport the natural gas to the Los Angeles Basin area, while most of the oil is loaded on tankers through under-sea pipe and flexible hose lines from storage tanks located near the shore line. The balance of the oil, produced by several small companies, is transported by truck.

Shell Oil Company has laid a 10-inch oil line from the field to its Wilmington refinery and, by mid-October 1941, its oil will all be transported by pipe line. This line may later be used to transport practically the entire output of the field. Shell Oil Company conveys its casinghead gasoline through a 4-inch pipe line to Wilmington. This line also carries gasoline for several other companies. The remaining casinghead gasoline is transported by truck.

The first commercial development in the field was in 1903, when seven shallow gas wells were drilled and the gas utilized by the Ventura County Power Company (later absorbed by Southern California Edison Company). Since that time, no further attempt has been made to develop purely gas wells, and the large quantities of gas produced have been merely incidental to oil development. No further drilling was undertaken until 1915. The discovery well, No. "Lloyd" 1, Sec. 28, T. 3 N., R. 23 W., S. B., was drilled and completed by State Consolidated Oil Company at a depth of 2,555 feet in May 1916, for a small amount of 50 degrees gravity oil along with a considerable quantity of flowing salt water and gas. Between 1915 and 1920, the drilling was done almost entirely with cable tools, and it was believed that on account of the high gas pressures and strong flowing salt water, rotary equipment was not suitable for the area.

In 1930 Associated Oil Company took over certain leases and installed rotary equipment in its first well. From this time on, rotary equipment rapidly displaced cable tools in all new work. The use of rotary equipment and heavy mineral muds have allowed the field to be developed against high gas pressures and heavy flowing waters with a minimum number of blowouts and lost holes.

The development of the field has been conducted mainly by four large companies and consequently no intense, congested, high-speed drilling campaigns have occurred. As would be expected, the development at first was confined to areas near the axis and has gradually extended, until now the developed field is about 5 miles long, and is 1 mile wide at the widest point. On June 30, 1941, there were 449 potential producing wells, the deepest of which was 11,157 feet.

The field as a whole has no uniform system of zonal development, mainly because zones, as developed, are not continuous over the field, and are not separated by intermediate waters or thick continuous bodies of shale. For this reason, the oil-producing zones are more or less limited and defined by the productive possibilities of the various horizons, rather than by stratigraphic controls. The areal limits of such zones were determined largely by edgewater. These zones vary in original rock pressure, saturation, porosity, and permeability, which to a considerable extent govern their development. As was to be expected, in a group of wells producing from a certain zone, those located near the crest of the structure produced nearly all gas, and those located lower structurally produced nearly all oil.

STRUCTURE

Structurally the field is a warped, slightly asymmetrical, faulted anticline, the overturn being to the north in the east end of the field, and to the south in the western portion. This anticline is traceable on the surface for about 17 miles. The center and origin of development are near the apex of the structure, near the point where the Ventura River crosses the axis. The producing horizons are intersected by several important faults. Three of these are quite flat, and a fourth very steep. Two Taylor faults in the western portion of the field have a northwesterly dip and converge from west to east. Near the western portion of the field these faults are about 1,700 feet apart, but they converge until, near the Shell Company Edison lease, they are not more than 500 feet apart. In the eastern portion of the field, the Barnard fault is traceable from the easterly limit of the field to about the east line of the Shell Oil Company Taylor lease.

It is reasonably certain that the original folding and faulting began in Pleistocene time and were concurrent (Reed and Hollister 36). Subsequent movements continued on a lessening scale almost up to the present time. This seems to be evidenced by the fact that at least one of the larger faults has a tendency to change in dip and direction on opposite flanks of the structure. The larger faults are not, therefore, at steep angles with the beds.

Both the Taylor faults and the Barnard fault are pressure or thrust faults. The movement in the Taylor faults is from northwest to southeast, while the Barnard fault movement is probably from southeast to the northwest. The maximum movement along any of these fault

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** Petroleum Engineer, Division of Oil and Gas, District No. 2, Santa Paula. Manuscript submitted for publication September 29, 1941.

planes is probably about 2,800 feet and the maximum vertical displacement is as much as 1,200 feet. The three main faults seem to fade out near the highest point of the structure and probably in that area caused a crushing of the beds, which allowed the escape of gas to the surface. This escaping gas was the reason for the original drilling which resulted in the discovery of the field.

A fourth, very steep fault, or series of small slips, cuts across the north-central edge of the field. This is also a thrust fault, and has a vertical displacement of about 200 feet, the south being the upthrow side. There are also several minor faults, both across and more or less parallel with the axis. The producing formations are lower Pliocene in age, beginning with the middle Pico and extending well down into the Repetto. Approximately the lower 3,500 to 4,000 feet of the stratigraphically deepest well are in the Repetto. This includes as much as 1,200 feet of beds repeated by faulting. The depth to the top of the Miocene is unknown, but is estimated to be as much as 1,000 feet below the bottom of the deepest well.

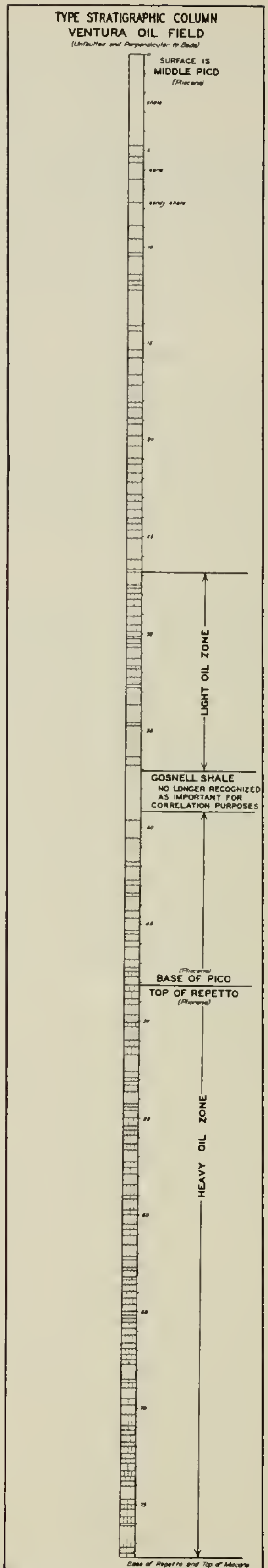


FIG. 160. Ventura Avenue oil field: type stratigraphic column.

OIL AND GAS ACCUMULATION

The source beds of the oil and gas of the Ventura Avenue field are quite certainly of Miocene age. Accumulation has been caused by water and gas drive which forced the gas and oil up the flanks of the structure and along fault and fracture lines. These faults have very definitely affected the accumulation of oil and gas, and especially in the western portion of the field have largely determined the zones opened to production in the various wells.

The original extremely high pressures in the oil zone caused the escape of large quantities of gas through the faulted area in the central part of the field. This gas was in part condensed and caught in favorable traps above. Portions of the uncondensed gas were also trapped in favorable locations between 2,000 feet and the surface, forming the shallowest productive gas zone. The main zone of high-gravity oil (about 50 degrees A.P.I.) was found as shallow as about 2,000 feet, and through a vertical interval of about 1,000 feet.

The interval below about 3,000 feet sub-sea at the apex of the structure, holds the important oil reservoirs of the field, and is the so-called heavy-oil zone. It contains oil ranging from 27 to 39 degrees gravity, and averaging perhaps 30 or 31 degrees. The stratigraphically deepest well has a perpendicular penetration of about 5,800 feet in this heavy oil zone.

WATER CONDITIONS

An important consideration in oil field development is the presence of water. In the Ventura Avenue field, conditions are as follows:

1. Salt water is found almost at the surface, and in the light oil zone there is flowing (2,500-barrel) salt water.
2. An intermediate water, extending over almost the entire developed area, is found some 400 to 600 feet below the top of the heavy-oil zone.
3. At least four, and probably more, edgewaters are present, which finger in between clean oil zones in the upper 2,500 feet of the heavy-oil zone.
4. Still deeper edgewaters appear, whose limits are not yet certainly determined. A flowing water, however, is known to exist very near the bottom of the stratigraphically deepest well drilled. This well is located near the crest and not more than 1,500 feet from the axis.

PRODUCTION

Since this field has not been subjected to any intensive drilling campaigns, the production of oil and gas has been maintained at a conservative amount, the maximum being in 1929, when almost 21,000,000 barrels of oil were produced. Effective voluntary curtailment has since 1932 kept the production below 13,000,000 barrels annually.

The oil of the Ventura Avenue field ranges from about 50 to 29 degrees gravity. The average gas-oil ratio for the years 1924 to 1926 was a little more than 2,300 cubic feet per barrel, and had increased to 2,600 cubic feet per barrel in 1940. This ratio in general is much higher in wells near the apex of the structure than in wells on the flank.

Gas waste in the field was quite high until December 1929, ranging from 30 to 60 percent, depending on the demand for gas. In 1929, however, the State Oil and Gas Supervisor issued an order to control this waste; an appeal from this order was taken to the District Oil and Gas Commission, and the Commissioners issued an order, effective December 1, 1929, requiring that the waste be reduced to not more than 10 percent of the production. This order required the closing-in at that time of 64 high gas-oil ratio wells. Since that time, the operating companies have faithfully complied with the order, with the exception of portions of the years 1931 and 1933. In April 1931 the average daily waste rose to 58,000,000 cubic feet, or nearly five times the allowable; and in February 1932, the waste was nearly 49,000,000 cubic feet, or three times the allowable. During the past 5 or 6 years the gas waste has been kept very low, and in 1940 it was only a little more than 1 percent.

The total production of the Ventura Avenue field has been about 231,500,000 barrels of oil, of which more than 231,000,000 barrels have been produced since 1921. In the 6-month period January 1, to June 30, 1941, the production was 6,148,192 barrels of oil, 1,311,079 barrels of water, and 16,056,291 thousand cubic feet of gas. This shows a cut of 17.6 percent water, and a gas-oil ratio of about 2,600 cubic feet per barrel of oil.

Considering the age and type field, these figures indicate very satisfactory producing conditions.

CITATIONS TO SELECTED REFERENCES—Continued

VENTURA AVENUE (VENTURA) OIL FIELD

Augur, I. V. 18; Brown, C. C. 26; Cartwright, L. D. Jr. 27; 28; Copp, W. W. 25; Craddock, W. N. 24; Eaton, J. E. 26d; 26e; Godde, H. A. 24; 25; Hertel, F. W. 27; 29; Hight, W. 33; Hoots, H. W. 39; Hoots and Herold 35; Huguenin, E. 24; Jensen, J. 27a; Jensen and Hertel 31; Kew, W. S. W. 32; Kirwan, M. J. 18; Lahee, F. H. 34a; Lloyd, R. B. 26; Lyons, J. B. 40; Masser, H. L. 22; McCollough, E. H. 34; Miller, H. C. 29; Mills, B. 31b; Moran, R. B. 17; Petroleum World 26; 35; 37; Prutzman, P. W. 10; Sanders, T. P. 37; Sawdon, W. A. 37; Stockman, L. P. 33; 35i; 41l; Swigart, T. E. 28; Taff, J. A. 34; Thoms, C. C. 20; 26; 26a; 26b; 29; 39; U. S. Geological Survey 34; Uren, L. C. 37; Vander Leck, L. 20; 21; Van Tuyl and Parker 41; Wagy, E. W. 27; Wilhelm, V. H. 38; 39a.

Canada De Aliso

Adams, B. C. 39; 39a.

Fresno Canyon Area

Godde, H. A. 24.

Tip Top (Fresno Canyon) Area

Wilhelm, V. H. 34.

OJAI OIL FIELD

Arnold, R. 15; Augur, I. V. 18; Kirwan, M. J. 18; Michelin, J. 28; Mining and Scientific Press 72; 81; Moran, R. B. 17; Prutzman, P. W. 13; Silliman, B. Jr. 65a; Thoms, C. C. 26b; 39; Vander Leck, L. 21, p. 113.

Astarte Wells

Prutzman, P. W. 13, p. 74; Watts, W. L. 00.

Bard Wells

Prutzman, P. W. 13, p. 75; Watts, W. L. 00.

Lion Canyon Area (Lyon Canyon Wells)

McLaughlin and Waring 14; Prutzman, P. W. 13.

Nordhoff (Pirie) Area

Watts, W. L. 00.

Ojai Area

Godde, H. A. 24.

Peri Wells

Watts, W. L. 00.

Piria (Pirie) Area

Arnold, R. 31.

Pirie (Pirie Ranch) Wells

Eldridge and Arnold 07; McLaughlin and Waring 14; Vander Leck, L. 21.

See-Saw (Sisar) Area

Prutzman, P. W. 13.

Silverthread Area

Edwards, M. G. 37; Eldridge and Arnold 07; McLaughlin and Waring 14; Prutzman, P. W. 13; Watts, W. L. 00.

Sisar (Sisar Creek) Area

Eldridge and Arnold 07; Godde, H. A. 24; McLaughlin and Waring 14; Vander Leck, L. 21.

Sisar Wells

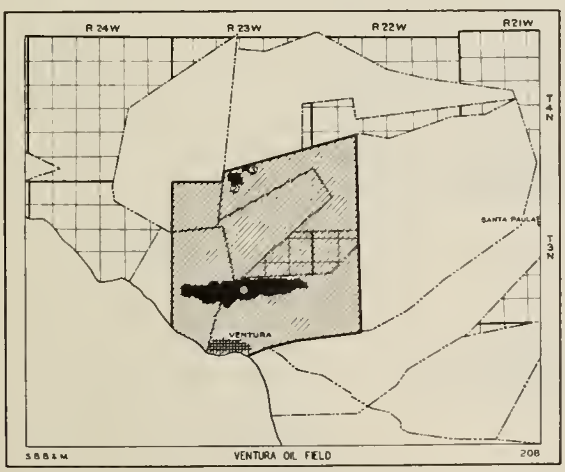
Prutzman, P. W. 13.

Sobra Vista Wells

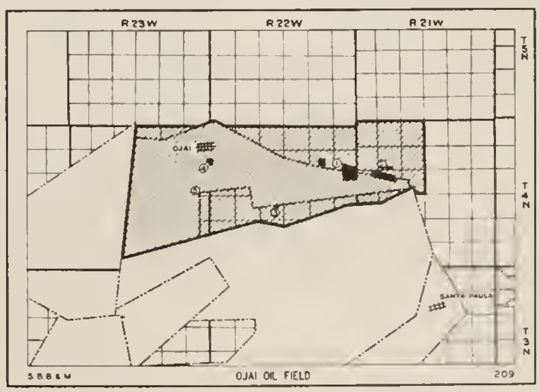
Eldridge and Arnold 07.

Sulphur Mountain Area

Hanks, H. G. 84; Michelin, J. 28; Mining and Scientific Press 81; Prutzman, P. W. 13.



Ventura (Ventura Avenue) oil field. Areas: (1) Ventura; (2) Tip Top; (3) Black Mountain.



Ojai oil field. Areas: (1) Ojai; (2) Sisar-Silverthread; (3) Sulphur Mountain; (4) Pirie; (5) Lion Canyon.

SANTA PAULA OIL FIELD

BY LOUIS N. WATERFALL*

OUTLINE OF REPORT

HISTORY

Santa Paula field is the name applied to a group of small producing areas extending along the south side of Sulphur Mountain, about 5 miles northwest of the town of Santa Paula, Ventura County. The individual areas are Aliso Canyon, Wheeler Canyon, Salt Marsh Canyon, Adams Canyon, and Santa Paula Canyon.

Because of the numerous active oil seeps and the outcrops of oil-impregnated sands along the south side of Sulphur Mountain, the area now known as the Santa Paula field was one of the earliest to attract the attention of oil prospectors. The first development of any consequence, however, was the drilling of a tunnel 80 feet in length into the south slope of Sulphur Mountain, so inclined as to permit the oil to flow by gravity into tanks at the mouth of the tunnel. The tunnel, completed by Leland Stanford in 1866, was the forerunner of about 45 such attempts to produce oil in this manner, the tunnels ranging in length up to 1,600 feet. Production of as much as 60 barrels per day is reported from some of these tunnels.

The record concerning the earliest wells in this area is not clear, but it is probable that several spring-pole holes were drilled during the time of the tunnel development. The area was actively exploited between 1884 and 1900 by Hardison and Stewart, the predecessors of the Union Oil Company of California, and a few wells have been drilled since the latter date. According to rather incomplete records, about 110 wells have been drilled in the Santa Paula field, and they have produced about 1,200,000 barrels of 24 to 28 degrees gravity oil. The average depth of the wells is probably less than 2,000 feet, although one well was drilled in the Wheeler Canyon area, about 1925, to a depth of 4,564 feet.

* Assistant Chief Geologist, Union Oil Company of California. Manuscript submitted for publication November 2, 1939.

STRUCTURE

The structure of the area northwest of the town of Santa Paula is a south-dipping homocline with dips ranging from 45 to 60 degrees. Immediately south of Sulphur Mountain, near the contact between the Pliocene and Miocene, the beds become steeper and are in places overturned. The south side of Sulphur Mountain forms the south limb of an overturned anticline. In the eastern part of the area, the south flank of this anticline is cut by a thrust fault.

Since all the development took place prior to the use of the core barrel, the only formational records are those obtainable from drillers' logs. It is therefore impossible to correlate the various sand bodies which occur in adjacent wells. Accordingly, one can not ascertain any structural reason for the accumulation. The most plausible explanation is that the oil has been trapped in the steeply dipping beds by a sealing action at the outcrop, owing to evaporation of the lighter constituents.

PRODUCTIVE HORIZONS

The producing horizons of the Santa Paula field are the sandstones near the base of the Repetto (lower Pliocene) and the fractured shales at the top of the Modelo (upper Miocene).

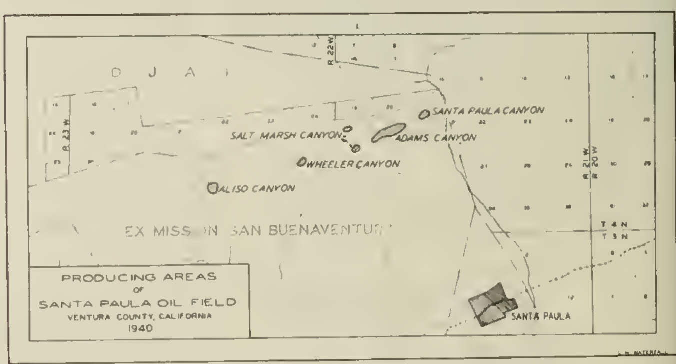


FIG. 161. Santa Paula oil field: map of producing areas.

CITATIONS TO SELECTED REFERENCES—Continued

SANTA PAULA OIL FIELD
Augur, I. V. 18; Burkhart, H. W. 10; Eldridge and Arnold 07; Godde, H. A. 24; Kirwan, M. J. 18; Mining and Scientific Press 81; 83a; 84; Moran, R. B. 17; Taff, J. A. 34, pp. 192, 193; Thoms, C. C. 26b; Vander Leck, L. 21.

Adams Canyon Area
Bowers, S. 88; 90; Goodyear, W. A. 88; Watts, W. L. 00.

Aliso Canyon Area
Bowers, S. 88.

Burrows (Burros) (Wheeler Canyon) Area
Prutzman, P. W. 13, p. 50.

Empire Wells
Prutzman, P. W. 13, p. 88.

Ex-Mission Wells
Prutzman, P. W. 13; Watts, W. L. 00.

Loma Wells
Prutzman, P. W. 13, p. 88.

O'Hara Wells
Prutzman, P. W. 13; Watts, W. L. 00.

Olmstead (Aliso Canyon) Area
Prutzman, P. W. 13, p. 50.

Paula Wells
Prutzman, P. W. 13.

Saltmarsh Canyon Area
Bowers, S. 88; 90; Goodyear, W. A. 88; Watts, W. L. 00.

Santa Paula (Santa Paula Canyon) Area
Goodyear, W. A. 88.

Slocum Area
Prutzman, P. W. 13.

Tar Flat (Tar Creek Canyon) Area
Bowers, S. 90; Prutzman, P. W. 13.

Timber Canyon Area
Kirwan, M. J. 18; Taff, J. A. 34.

Wheeler Canyon Area
Bowers, S. 88; Goodyear, W. A. 88; Watts, W. L. 00.

SULPHUR MOUNTAIN FAULT FIELDS
Taff, J. A. 34.

SESPE OIL FIELD

By Thomas Clements *

OUTLINE OF REPORT

HISTORY

The Sespe oil field in Ventura County comprises several small producing districts in the Sespe Creek drainage area north of Santa Clara Valley. The principal ones occur in Secs. 28, 29, 32, and 33, T. 5 N., R. 19 W., S. B., and in Sec. 1, T. 4 N., R. 20 W., S. B., and Sec. 6, T. 4 N., R. 19 W., S. B. The first, sometimes known as the Topatopa Anticline area, includes also the Tar Creek and Fourforks fields. The second is known as the Sespe Forks area, and includes the Foot-of-the-Hill field and the Little Sespe Creep field. Other scattered wells occur in the intervening area between the two main localities, and also to the north along Sespe Creek: at Devils Gate, and above the junction of Tar and Sespe Creeks in Secs. 23 and 26, T. 5 N., R. 20 W., S. B. As a rule, in reporting production statistics, no breakdown into separate small fields is attempted, the whole being listed simply as the Sespe field.

Although classed as a minor field, the Sespe area is one of the oldest in California, and therefore is of some note historically. Its geology has been touched upon by a number of writers, foremost among whom are Eldridge and Arnold (07, pp. 51-62) and Kew (24, pp. 121-131), whose writings have been drawn upon freely by the present author.

The discovery well in the Sespe district was Union Oil Company's No. "Tar Creek" 1, in Sec. 28, T. 5 N., R. 19 W., S. B., which was drilled in 1887 to a depth of 965 feet. This well is on the northern flank of the Topatopa anticline. It opened up that part of the area known as the Tar Creek field. Between the time of discovery and the end of the century, the Union drilled 32 more wells in the Tar Creek field, ranging in depth from 210 feet to 1,690 feet.

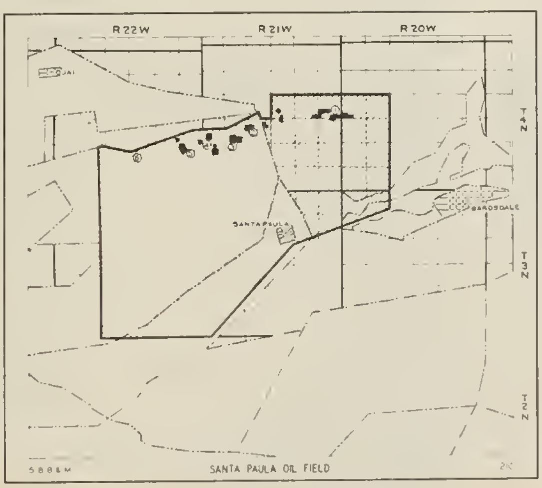
Although these wells are no longer producing, other wells have been drilled in the Tar Creek field, and in the general Topatopa Anticline area. Colima Oil Company's well No. 2, in Sec. 29, T. 5 N., R. 19 W., S. B., reached a depth of 3,545 feet, and Topatopa Oil Company's well No. 3, in Sec. 33 of the same township and range, attained a depth of 4,670 feet. The latter, drilled in November, 1937, is the deepest well in the Sespe district. Plugged back to 4,098 feet, it produced from above that depth, but now has been abandoned.

The first well in the Sespe Forks area was Union Oil Company's No. "Kentuck" 1, in Sec. 1, T. 4 N., R. 20 W., S. B. This well was drilled in 1890 to a depth of 905 feet. The first well was a small producer, but the second well came in at 500 barrels per day. The decline, however, was rapid. The most interesting feature of this particular field is that the wells are drilled along the axis of a syncline.

Discovery of production in the area lying in Secs. 23 and 26, T. 5 N., R. 20 W., S. B., is also credited to the Union Oil Company, whose first well in Sec. 23 was brought in in 1901. The oil is heavy and production small, for which reasons this part of the Sespe field has never been of importance.

* University of Southern California, Los Angeles. Manuscript submitted for publication March 30, 1941.

Acknowledgment is made of the cooperation of Mr. C. C. Thoms and Mr. E. R. Murray-Aaron, respectively Deputy Supervisor and Engineer, of the Division of Oil and Gas at Santa Paula, in furnishing information on the Sespe district. Mr. R. J. Pence and Mr. H. J. Clark of the Oil Umpire's office kindly contributed some of the production statistics. Thanks are due to the Union Oil Company through Mr. G. K. Robertson and Mr. H. E. Winter for making available the latest map showing the location of wells in the area.



Santa Paula oil field. Areas: (1) Timber Canyon; (2) Santa Paula Canyon; (3) Adams Canyon; (4) Salt Marsh Canyon; (5) Wheeler Canyon; (6) Aliso Canyon.

STRATIGRAPHY

The geology of the Sespe district has been discussed in detail by Eldridge and Arnold (07) and by Kew (24) in their respective papers on the Santa Clara Valley. The rocks of the area range in age from Eocene to Miocene, and the Sespe formation (Oligocene ?), of which this is the type locality, forms the principal outcrop.

The oldest rocks are those of the Tejon formation (upper Eocene), which outcrops in the upper part of Sespe Creek and along Coldwater Canyon, and which also constitutes the mass of San Cayetano Mountain, west of the lower part of Sespe Creek. Three lithologic types are represented: (1) dark, arenaceous shales; (2) brown to greenish quartzitic sandstones; and (3) relatively thick-bedded, white, quartzitic sandstones containing some conglomeratic members, and with partings of green and purple shale. This last is known as the Coldwater sandstone, from its exposure in the canyon of that name, a tributary of Sespe Creek.

The lowermost beds of the Tejon in this area are faulted out against the San Cayetano fault. Above, the sandstones of the Coldwater are overlain unconformably by the Sespe formation. The shales of the Tejon are considered to be the source rocks of the oil occurring in the district, and some production comes from the Coldwater sandstone as reservoir rock.

The Sespe formation, whose age is doubtfully placed as Oligocene, occupies most of the area of the district as a whole. It forms the steep walls of the gorge of lower Sespe Creek, and in the upper reaches, where the Tejon occurs in the bottom of the canyon, it is found on both sides, overlying the Eocene strata. It continues for some distance both east and west of Sespe Creek, disappearing to the east under Miocene beds a short distance west of the drainage divide between Sespe and Piru Creeks.

The Sespe formation consists principally of thin-bedded, reddish-brown sandstone containing occasional conglomerate beds, and interbedded with purplish shale. Its thickness is approximately 3,500 feet. As stated above, it unconformably overlies the Tejon formation, but grades with no apparent break into the Vaqueros beds above. Together with the Coldwater sandstone, the sandstones of the Sespe formation form most of the reservoir rocks for the accumulation of petroleum in this field.

Rocks of Vaqueros age (lower Miocene) and Modelo age (upper Miocene) occur on the extreme east side of the Sespe field, and are the rocks in which most of the wells of the Tar Creek, Topatopa, Foot-of-the-Hill, and Little Sespe Creek fields start. The Vaqueros consists of about 500 feet of sandstone and shale, grading from mottled green and purple sandstone with some shale at the base, to gray sandstone and shale in the upper part. It is generally thin-bedded.

The beds overlying the Vaqueros are traceable directly into Modelo Canyon, the type locality of the Modelo formation (upper Miocene), and hence were classed by Kew as such. Later writers, particularly Hudson and Craig (29), have suggested that the type Modelo contains lower and middle Miocene, as well as upper, and the writer's own work in Piru Canyon (Clements, T. 37) suggests that middle Miocene might be expected in this area, between the Vaqueros and Modelo; nevertheless, Kew's original designation of the beds as Modelo is here retained.

The Modelo consists of shales, with overlying sandstones. The shales are bluish and blackish gray, and as mentioned above are conformable with the underlying Vaqueros, although in other localities both to the north and south, the middle Miocene Topanga-Temblor beds intervene. Some of the shales are organic, and without question are possible source rocks of petroleum; however, there is no indication that they have served as a source of the oil of the Sespe field, which, as before stated, appears to have originated in the Eocene rocks.

CITATIONS TO SELECTED REFERENCES—Continued

SANTA CLARA VALLEY
Emmons, W. H. 21; Eldridge, G. H. 03; Kew, W. S. W. 24; Mining and Scientific Press 83a; 10; 11a; Reinhard, M. 19; Taff, J. A. 34.

SANTA SUSANA MOUNTAINS
Kew, W. S. W. 24.

SESPE OIL FIELD
Arnold, R. 15; Arnold and Kemnitzer 31; Augur, I. V. 18; Bowers, S. 88, pp. 685-686; Clements, T. 37; Eaton, J. E. 26a, pp. 16-18; Eldridge and Arnold 07, pp. 51-62; Godde, H. A. 24, pp. 16-17; 25; Hertel, Bernt and Pieper 28, pp. 371-374; Hudson and Craig 29; Jones, E. C. 97; Kew, W. S. W. 24, pp. 121-131; Kirwan, M. J. 18; Mining and Scientific Press 79a; 81; Moran, R. B. 17; Prutzman, P. W. 13; pp. 91-117; Taliaferro, N. L. 24, pp. 789-810; Thoms, C. C. 26b; 39; Vander Leck, L. 21, p. 120; Waring, C. A. 14, pp. 381-395; Watts, W. L. 00, pp. 83-95; 97, pp. 22-29.

Big Sespe Canyon Area
McLaughlin and Waring 14, p. 390.

Devilsgate Area
Eldridge and Arnold 07; Watts, W. L. 00.

Elkins Area
Brown, C. C. 26.

Foot of the Hills Wells
Eldridge and Arnold 07; Kew, W. S. W. 24.

Four Forks Area
Eldridge and Arnold 07; Jones, E. C. 97.

Happy Thought Wells
Eldridge and Arnold 07.

Ivers Area
Eldridge and Arnold 07.

Kentuck Wells
Eldridge and Arnold 07.

Little Sespe (Little Sespe Creek) Area
Kew, W. S. W. 24; Mining and Scientific Press 84.

Los Angeles Wells
Eldridge and Arnold 07.

Pole Canyon Area
Eldridge and Arnold 07.

Sespe Canyon Area
Bowers, S. 88; Goodyear, W. A. 88.

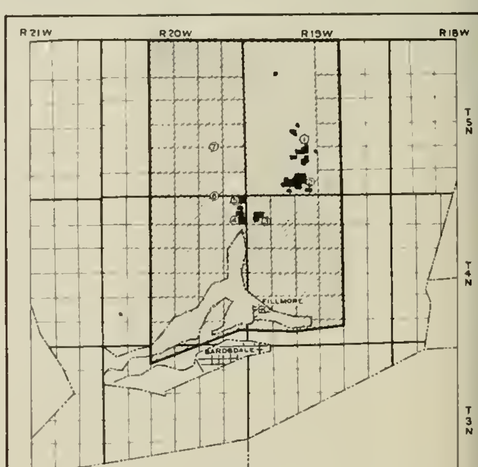
Sespi Creek
Jones, E. C. 97.

Squaw Flat Area
Van Tuyl and Parker 41.

Tar Creek Area
Prutzman, P. W. 13.

Topatopa (Tar Creek) Area
Chappuis, L. C. 38.

Union Consolidated Wells
Eldridge and Arnold 07.



Sespe oil field. Areas: (1) Tar Creek; (2) Four Forks and Topatopa anticline; (3) Little Sespe; (4) Kentuck Wells; (5) Ivers; (6) Devils Gate; (7) Big Sespe Canyon.

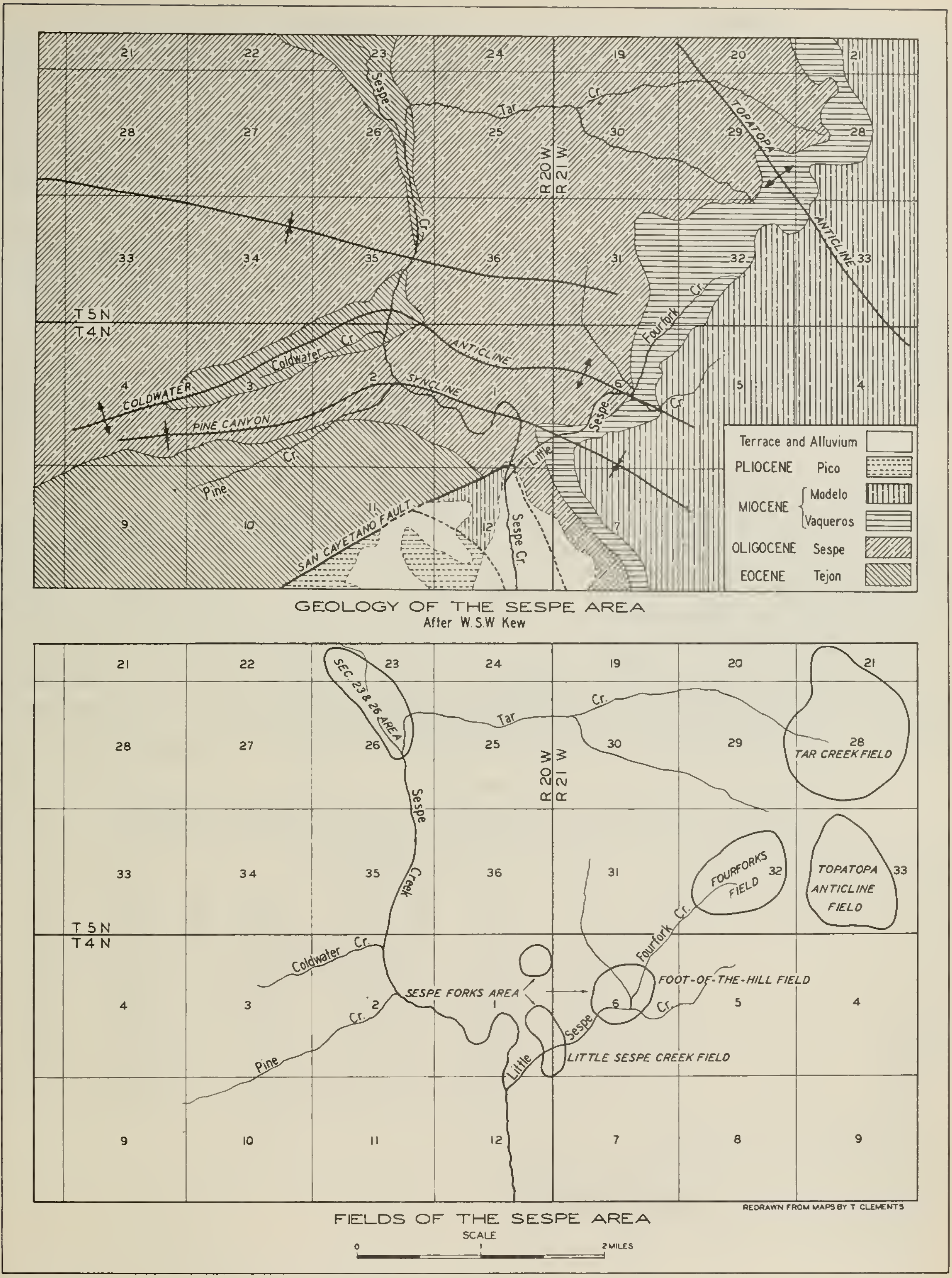


Fig. 162. Sespe area: geologic map; map of fields.

STRUCTURE

There are four important structures in the Sespe district. The first of these is the San Cayetano overthrust, which may be said to form the southern boundary of the field. This extends in a general southwest direction along the south side of San Cayetano Mountain west of Sespe Creek; it crosses the latter some 4 miles north of Fillmore, after which it swings sharply to the southeast. Along this fault, rocks of Eocene age have been thrust over Pliocene; Sespe over Miocene; and lower Miocene over upper Miocene.

A short distance to the north of the San Cayetano fault, and roughly paralleling it, is the Pine Canyon syncline, named from a tributary of Sespe Creek. Rocks ranging in age from the Eocene to the Modelo are involved in the folding, which is traceable eastward almost to Hopper Canyon. In the Sespe area the fold is highly compressed, and in many places the beds are overturned. The plunge is easterly. This syncline is of particular interest, since it is the controlling structure of the Little Sespe Creek field.

The Coldwater anticline is an asymmetrical structure half a mile to the north of, and parallel with, the Pine Canyon syncline. Like the latter, it shows a tendency to be overturned to the south, and east of Sespe Creek its plunge is in a southeasterly direction. It involves rocks of Eocene, Oligocene (?), and Miocene ages, although it can not be traced as far to the east as the syncline, apparently dying out a short distance beyond Little Sespe Creek. The Foot-of-the-Hill field and numerous scattered wells have been drilled on this structure.

The Topatopa anticline is the most important structure from the point of view of oil production, not only in the Sespe district, but also in that entire area to the east that lies north of the Santa Clara River. It extends southeastward from Topatopa Mountain, which is several miles to the north of the area under discussion, swinging more to the east after crossing Hopper Canyon, and continuing across Piru Creek, perhaps as far as Castaic Valley. This broad anticline shows relatively gentle dips, and it pitches gently to the southeast. On it in the Sespe region are located the Tar Creek and the Fourforks fields, sometimes collectively known as the Topatopa Anticline area. Production in Secs. 23 and 26 of T. 5 N., R. 20 W., S. B., is said to come from a minor flexure on the south flank of the Topatopa anticline.

PRODUCTIVE HORIZONS

The oil of the Sespe district is believed to have originated in the shales of the Tejon (upper Eocene), which are marine in origin, and which possibly may have contained sufficient organic material to serve as source beds. Certainly neither the uppermost Eocene Coldwater sandstone nor the Sespe formation contain organic shales from which the oil might have come. Furthermore, Kew (24, p. 38) states that the oil resembles the Eocene oil obtained in Simi Valley more than it does any Miocene oil of California.

In the Sespe Forks area, including the Little Sespe Creek and the Foot-of-the-Hill fields, production comes from the sandstones in the upper part of the Tejon and the Sespe. The oil occurs from the surface down, most of the wells ranging from 500 to 2,200 feet in depth; although early in 1940 one well was deepened to about 3,000 feet. The largest producer of the entire district within the last few years was completed in this area at 1,480 feet, with an initial production of 486 barrels. The gravity of the oil of the Sespe Forks area is around 25 degrees A.P.I.

The producing horizons of the Topatopa anticline, including the Fourforks and the Tar Creek fields, are in the upper Sespe and lower Vaqueros, and, as in the above-mentioned area, the oil occurs from the surface down. While the earlier wells were less than a thousand

TABLE 1[1]

MONTHLY PRODUCTION, SESPE FIELD, 1931 TO 1940, INCLUSIVE (BARRELS)

Month	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
January	3,410	7,609	5,719	6,594	8,549	8,995	8,205	9,102	8,643	10,142
February	2,968	5,938	5,259	6,403	7,470	6,709	8,066	6,574	7,864	8,884
March	3,007	6,397	7,068	7,432	9,707	9,717	7,928	6,816	8,908	8,799
April	2,730	7,595	5,860	6,790	9,492	9,550	8,667	8,984	8,722	7,668
May	3,100	6,507	6,347	7,869	11,386	9,820	11,183	8,191	10,090	7,919
June	6,720	5,946	6,103	7,622	9,278	10,013	9,922	8,572	9,768	8,039
July	6,386	6,135	9,443	9,585	10,767	9,608	11,110	9,052	9,247	7,831
August	6,045	6,011	6,289	9,094	10,101	9,215	9,776	9,935	10,173	7,788
September	6,030	5,987	8,677	9,184	10,254	8,350	9,605	9,531	9,597	8,269
October	5,766	5,908	8,675	8,511	8,811	9,293	9,934	10,167	9,426	8,427
November	4,140	5,997	7,285	7,364	6,292	8,811	9,946	7,723	9,495	7,654
December	5,487	5,929	7,220	10,465	8,212	8,957	8,474	7,553	9,451	7,274
Totals	55,789	75,959	83,945	96,913	110,322	109,068	112,816	102,200	111,384	98,694

Total, 1931-1940, inclusive: 957,090 barrels
Probable total production, discovery through 1940: 3,098,000 barrels[2]

[1] Figures for 1931 and 1940 from the Santa Paula office, Division of Oil and Gas. Figures for 1932 to 1939, inclusive, from the Oil Umpire's office, Los Angeles.
[2] Total production, from discovery through 1930, from Arnold and Kemnitzer (31).

feet in depth, a later one has reached a depth of 4,670 feet, with production, however, principally from above 4,000 feet. Section 20 Oil Company's well No. 1, drilled to 4,157 feet just north of the line between Secs. 20 and 29, T. 5 N., R. 19 W., S. B., passed through the Eocene-Sespe contact at 3,900 feet, but obtained no production. The oil of the area as a whole varies considerably in gravity—from 13 degrees to 38 degrees A.P.I.

The small production from Secs. 23 and 26, T. 5 N., R. 20 W., S. B., near the mouth of Tar Creek, has come from the upper part of the Tejon formation. The wells are from 500 to 1,400 feet deep, but have been exceedingly small producers, and the oil is low in gravity, approximately 14 degrees A.P.I. Apparently the upper part of the producing horizon has been eroded away by Sespe Creek.

PRODUCTION

Although the Sespe district has never been a spectacular producer, its long productive history of more than 50 years has made it an important contributor to the petroleum wealth of California. Production figures for the earlier years are difficult to obtain, since they were generally lumped with those of the Ventura district as a whole. Arnold and Kemnitzer (31) give the production of the Sespe field for the decade 1921-1930 inclusive as 518,000 barrels, and a total production for the field up to 1929 of 2,038,000 barrels. The accompanying table shows the production by months from 1931 to 1940 inclusive, with a total for the 10 years of 957,090 barrels. Combining the figures of Arnold and Kemnitzer for the period prior to 1929 with their figures for 1929 and 1930, and adding to them the total from the table, approximate figures are obtained for the production of the Sespe field from the discovery date through 1940, of 3,098,000 barrels of petroleum.

In December, 1940, there were 17 producing wells in the combined Sespe district. Two new wells were drilled in 1940, but neither proved productive. While the peak of production is without question past, there is no reason to believe that the district will not continue to produce commercially for some years.

CITATIONS TO SELECTED REFERENCES—Continued

PIRU OIL FIELD

Augur, I. V. 18; Godde, H. A. 24; Huguenin, E. 24; Kirwan, M. J. 18; McCollough, E. H. 34; Moran, R. B. 17; Thoms, C. C. 26b; 39; Vander Leck, L. 21.

Camulos District

Mining and Scientific Press 84.

Eureka Canyon (Eureka) Area

Eldridge and Arnold 07; Kirwan, M. J. 18; McLaughlin and Waring 14; Prutzman, P. W. 13; Taff, J. A. 34; Watts, W. L. 00.

Fortuna Wells

Eldridge and Arnold 07.

Happy Canyon

Kew, W. S. W. 24.

Hooper (Hopper Canyon) Area

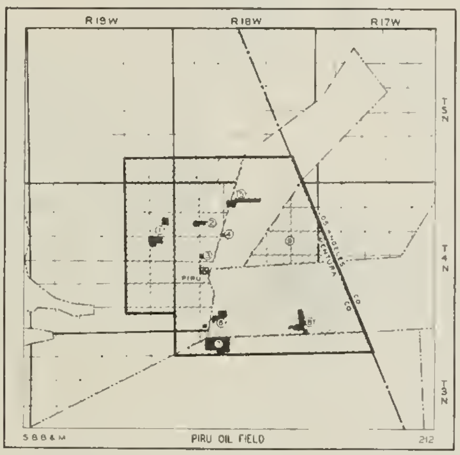
Mining and Scientific Press 84.

Hopper Canyon Area

Bowers, S. 88; Chappuis, L. C. 38a; Eldridge and Arnold 07; Goodyear, W. A. 88; Kirwan, M. J. 18; McLaughlin and Waring 14; Prutzman, P. W. 13.

Hopper Mountain Area

Van Tuyl and Parker 41.



Piru oil field. Areas: (1) Hopper Canyon; (2) Modelo; (3) Nigger Canyon; (4) Piru Creek; (5) Temescal; (6) Eureka Canyon; (7) Torrey Canyon; (8) Tapo Canyon; (9) Holser Canyon.

Modelo (Modelo Canyon) Area

Godde, H. A. 24; Kirwan, M. J. 18; Prutzman, P. W. 13.

Nigger Canyon Area

Eldridge and Arnold 07.

Piru (Piru Canyon) Area

Bowers, S. 88; Eldridge and Arnold 07; Goodyear, W. A. 88; Kew, W. S. W. 24.

San Cayetano Wells

Eldridge and Arnold 07.

Sunset Wells

Eldridge and Arnold 07.

Tapo Canyon Area

Watts, W. L. 00.

Temescal Area

Brown, C. C. 26; Kirwan, M. J. 18.

Topo (Tapo) Canyon Area

Prutzman, P. W. 13.

Torrey Canyon Area

Bowers, S. 90; Brown, C. C. 26; Eldridge and Arnold 07; Kew, W. S. W. 24; Kirwan, M. J. 18; McCollough, E. H. 34; McLaughlin and Waring 14; Prutzman, P. W. 13; Taff, J. A. 34; Watts, W. L. 00.

OAK CANYON OIL FIELD

California Oil World 42.

PIRU OIL FIELD

By H. D. Hobson *

OUTLINE OF REPORT

The Piru oil field, in so far as this paper is concerned, is considered to include three isolated currently productive areas within the general region of Piru Creek, Ventura County. These are: (1) Temescal (Lime Canyon); (2) Modelo Canyon; and (3) Hopper Canyon. Other areas within the field have been more or less commercially productive during past years, but are at present abandoned

STRATIGRAPHY

Strata exposed or accessible to the drill within the Piru field range in age from Sespe (Oligocene ?) to Recent. They range in lithology from coarse conglomerate through various types of sand or siltstone to laminated clayey and siliceous shales. The most noteworthy single characteristic of the geologic column is its variability as applied both to strata of successive ages and to equivalent beds cropping out at different localities. Because of this variability, no single stratigraphic column is typical of the entire area. The accompanying sketch map shows the location of the various stratigraphic sections to be discussed in this paper. These sections are considered to be typical at their immediate localities, but considerable location variation occurs even within limited areas. The surface sections are composite columnar sections built up from surface data. The subsurface sections show the stratigraphic column as encountered within the three currently productive areas of the field. All the strata sections occur entirely within the Monterey (middle Miocene) formation.

* Continental Oil Company. Manuscript submitted for publication June 11, 1938.

The writer is indebted to the Continental Oil Company for permission to publish the stratigraphic information incorporated herein; to Messrs. W. N. Craddock (Pacific Western Oil Corporation), F. J. Shaver (Bolsa Chica Oil Corporation), and H. A. Bardeen (Bardeen Oil Company) for information concerning areas controlled by their respective companies; to W. D. Rankin for the paleontological information upon which correlations are based; and to R. G. Green, formerly with Bolsa Chica Oil Corporation, for cooperation in obtaining and arranging data pertinent to the completion of the manuscript.

Oligocene (?) Series

Sespe Formation. This formation was named and first described by Watts (97, pp. 25-26). It outcrops in the Sespe Creek district. Sespe strata occupy a stratigraphic position between beds of known Eocene and Miocene age, according to Kew (24, p. 31). At its type locality in Sespe Creek, it consists of 3,500 feet of reddish-brown to purplish sandstone, shale, and conglomerate. The top of the Sespe formation is considered to be the base of the stratigraphically lowest fossiliferous stratum occurring above the red beds. This horizon does not always correspond with the top of the reddish-brown strata. At Akers Canyon, near the mouth of Little Sespe Creek, the top of the Sespe is considered to be the top of an iron-gray, hard, brittle, pebbly sandstone that outcrops beneath fossiliferous strata of Miocene age. Typical red clays and sands are exposed below this bed.

Miocene Series

Stratigraphically above the Sespe formation within the Piru area are strata of Miocene age. They consist of interbedded zones of sandstone and shale. This series was described by Eldridge and Arnold (07, pp. 12-22), who recognized two formations, the Vaqueros and the Modelo. Kew (24) retained these established names, but adjusted the limits of the units to conform to the classification he adopted in his preliminary report on Simi Valley (19, pp. 330-333).

The Miocene series in the Piru field consists of a conformable group of interbedded sandstones and shales, with a total thickness that ranges from 7,547 to 8,850 feet. This group includes both the Vaqueros and Modelo formations. In Akers Canyon 4,650 feet stratigraphically above the top of the Sespe formation there occurs a prominent sandstone zone in the Modelo formation, Kew's upper Modelo sand (24, p. 60). Its base was utilized as a correlative horizon from which to construct stratigraphic sections for this paper.

Vaqueros Formation. The Vaqueros formation consists of a fossiliferous sandy zone, 150 to 400 feet in thickness, that occurs at the base of the Miocene section. The sand is interbedded with silty shale and grades vertically into the silts and clay shales of the overlying Temblor formation. The lack of a definite point of differentiation between mega- and micro-fossils of Vaqueros and Temblor age makes the top of the Vaqueros indeterminable paleontologically. At Akers Canyon the top of the Vaqueros is placed at an unknown horizon within the 630-foot cartographic member shown near the base of the Akers Canyon section.

The Vaqueros formation has not been penetrated in any of the areas discussed in this paper.

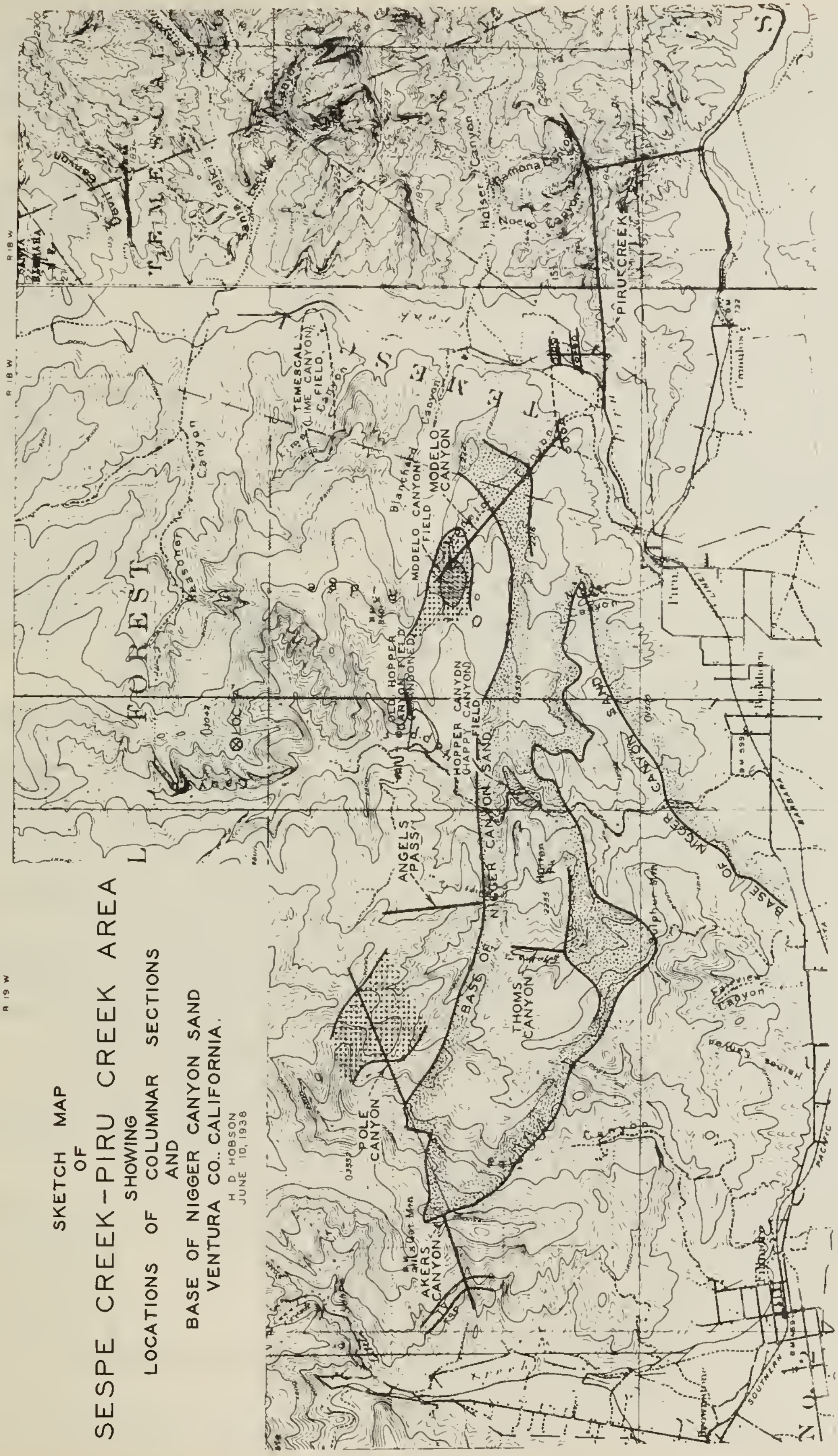


Fig. 163. Sespe Creek-Piru Creek area: sketch map showing locations of columnar sections and base of Nigger Canyon sand.

Temblor Formation. Strata of Temblor age crop out conformably above the Vaqueros formation at Akers Canyon and north along the east bank of Little Sespe Creek. Lithologically this formation consistutes a cartographic unit, which has as its distinguishing constituent dark clayey shale, and which, from lithologic characteristics, would be correlated with the Temblor Rincon shale of the coastal region. The combined thickness of the Temblor and Vaqueros formations at Akers Canyon is 1,770 feet.

Fauna derived from the portion of the section herein referred to the Temblor give but meager evidence; but microfossils from the upper 500-foot member appear to correlate with those of Temblor strata in the coastal region.

The Temblor formation has not been penetrated in any of the areas discussed in this paper.

Monterey Formation. Strata herein referred to the Monterey formation contain or are directly associated with beds containing a *Valvulineria californica* microfaunal assemblage. Where exposed, the thickness of the formation ranges from 2,848 feet to 3,020 feet.

Cartographically the Monterey consists of a group of strata of varying lithology. At Akers Canyon it consists of 2,880 feet of hard siliceous to platy shale with minor sandstone beds. At Angels Pass it consists of 2,000 feet of coarse-grained massive sandstone overlain by 973 feet of interbedded sand and shale. At Pole Canyon the formation is made up of 2,130 feet of coarse sandstone overlain by 890 feet of hard, tan, platy siliceous shale. Only a portion of the section is exposed at Modelo Canyon. Here 1,140 feet of brownish-gray, well-bedded, hard siliceous shale interbedded with gray and brownish-gray sandy shale overlie an exposed 1,708 feet of gray to buff massive sandstone. The base of the sandstone does not outcrop in Modelo Canyon.

The Monterey formation contains all the productive oil zones yet developed in the Piru field. At Hopper Canyon, production is derived apparently from about the middle of the formation. At Modelo Canyon, strata near the base are productive, and at Temescal the productive zones are likewise in the lower part of the formation. The subsurface sections show the stratigraphic column as penetrated by wells in the abovementioned areas, and the approximate positions of the oil measures as related to the complete Monterey section.

The top of the Monterey is placed at the base of Kew's upper Modelo sand throughout the district.

Upper Modelo Sand. Stratigraphically above the Monterey throughout the Piru-Sespe Creek district occurs a consistently massive, coarse-grained sandstone member. It varies in thickness from 547 feet at Angels Pass to 1,750 feet in Modelo Canyon. It is commonly oil-stained, and occasionally contains relatively thin shale partings near its top. This member is useful as a marker zone throughout the region.

Santa Margarita Formation. The Santa Margarita formation is best exposed at Modelo Canyon. Here it consists of hard, laminated, foraminiferal siliceous shale containing streaks of sand near its base, and zones of of chocolate-brown punky shale at irregular intervals throughout its thickness, the top of the member being at the base of a coarse conglomerate outcropping at the mouth of Modelo Creek.

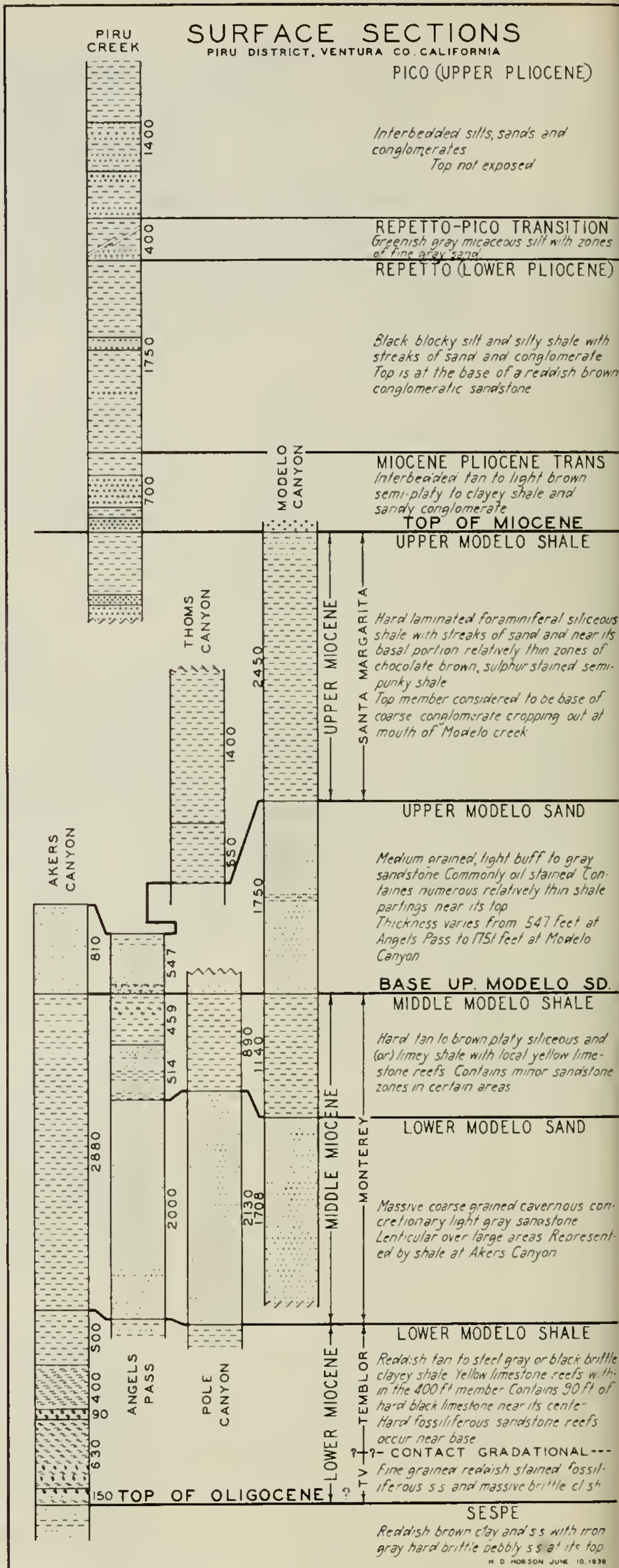


FIG. 164. Piru district: surface sections.

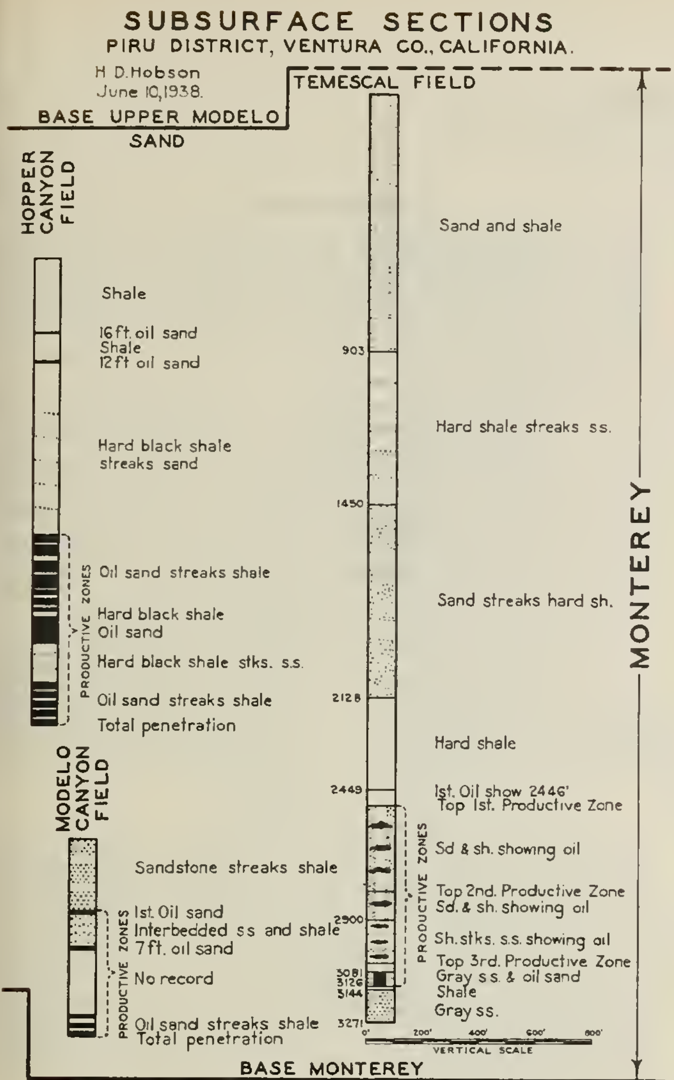


FIG. 165. Piru district: subsurface sections.

Paleontologically, the Santa Margarita of this district may be divided into two microfaunal zones. The lower zone contains a *Bolivina hughesi* assemblage; the upper is characterized by a *Bolivina hootsi* fauna.

PRODUCTIVE DISTRICTS

Three separate areas are at present producing in the Piru field. All are anticlinal structures, with oil sands confined to the Monterey formation.

Hopper Canyon

The Hopper Canyon area of the Piru field, situated in Hopper Canyon (Sec. 13, T. 4 N., R. 19 W., S. B.), Ventura County, was discovered in 1884 by the Buckhorn Oil and Transportation Company. Their well No. 1 is reported to have been drilled by the spring-pole method to a depth of 85 feet. It produced 800 barrels of 12 degrees Baume oil, and then sanded up. Since discovery, some 25 or 30 wells have been drilled in the area. Their depths, previous to a relatively recent drilling campaign by the Bardeen Petroleum Company in 1931, ranged from 100 to 2,200 feet. Average production was from 10 to 40 barrels of 12 to 17 degrees Baume oil, with considerable water. The deepest well in the field is Hopper Canyon Oil Company well No. 1. It was drilled in 1919 to a depth of 5,001 feet.

In January 1931 Bardeen Petroleum Company completed its well No. 1-B in Sec. 13, T. 4 N., R. 19 W., S. B., for an initial production of 165 barrels of 32.8 degrees Baume oil and 11 barrels of water per day from a depth of 2,434 feet. The present daily production of this well is 60 barrels of oil and 16 barrels of water.

Total production for the Hopper Canyon area during the interval between 1930 and 1937 was 192,450 barrels of 28 to 33 degrees Baume oil. Eleven wells are currently active.

Modelo Canyon

The Modelo Canyon area was discovered by the Crown Oil Company in 1897. The area is located near the head of Modelo Canyon, in Secs. 7 and 8, T. 4 N., R. 18 W., S. B., Ventura County. Initial production of the discovery well No. "Modelo" 1 was 15 barrels of 28 degrees Baume gravity oil from a depth of 605 feet. In 1924 this well produced at a rate of 3 barrels of 28 degrees Baume oil and 1 barrel of water per day. Total production to January 1, 1938, for the entire area was 1,080,000 barrels. On January 1, 1938, some 34 wells produced 60 barrels net of 29.3 degrees Baume gravity oil. Production is derived from sands in the lower portion of the Monterey formation.

Temescal (Lime Canyon)

The Temescal area was discovered by the Temescal Petroleum Company well No. "Landers" 1 (Sec. 4, T. 4 N., R. 18 W., S. B.) in 1924. The well was drilled to a depth of 1,720 feet, and had an initial production of 125 barrels of 21.4 degrees oil per day. The area is located in Sec. 4, T. 4 N., R. 18 W., S. B., and on an adjoining unsectionized portion of the Temescal Rancho, Ventura County. Present operators are Bolsa Chica and Pacific Western oil companies.

Bolsa Chica has four and Pacific Western eight productive wells in the area. Total production from 1930 to date is 1,237,000 barrels of 20 to 26 degrees gravity oil; records previous to that date are not available.

SOUTH MOUNTAIN OIL FIELD

By Loring B. Snedden*

OUTLINE OF REPORT

HISTORY

The South Mountain oil field is located on the north side of South Mountain approximately 2 miles east of the town of Santa Paula, Ventura County. Approximately 100 wells have been drilled in this field. Of these, 7 were edge wells or wildcats off the structure; about 93 were placed on production, and about 74 are still producing. The field had produced 19,500,000 barrels of oil by 1936.

The first well completed in the field was No. "South Mountain" 1 of the Oak Ridge Oil Company, in April, 1916. Following this several wells were completed at shallow depths for small volumes of oil. The first well to produce 100 barrels per day was No. "Santa Paula" 1, which was completed in July, 1917. All drilling was completed by 1930, with the exception of drilling on the Schieferle lease on the east plunge. An exploratory well is now being drilled by The Texas Company on the south limb of the structure.

DISTINGUISHING FEATURES

This field is one of the few in the State producing from the Sespe (Oligocene ?). It is one of the older fields, completed in the early stages of oil exploration in California. It is also exceptional in that the oil is peculiarly high in its paraffin content for California crude.

* Geologist, The Texas Company. Manuscript submitted for publication September 19, 1938.

STRATIGRAPHY

The South Mountain field is located on the Oak Ridge anticline; the beds exposed along the crest of the fold are approximately 1,500 to 1,800 feet stratigraphically below the top of the Sespe formation. The wells with the exception of Yale Richardson No. 5 remain in this formation.

The Sespe formation is about 7,000 feet thick in this area. The formation logged by the wells consists of red and brown shales and silts interbedded with gray sands and oil sands. Detailed correlations of individual beds between wells in the field are difficult over any considerable distance. This has suggested that many of the beds of the field are lenticular. Productive beds range in depth from 595 to 4,585 feet. Many wells have large portions of this tremendous thickness perforated.

Initial production of the wells ranged from a few barrels to 380 barrels per day. Many of the wells flowed for a considerable time after they were completed, but at present they are all on the pump. Production ranges from a few barrels per day to about 50 barrels per day.

STRUCTURE

The South Mountain field is the largest and highest structurally of a series of domes along Oak Ridge anticline, including the Shiells Canyon and Bardsdale areas of the Bardsdale field. Surface evidence would indicate that the structure is asymmetrical, the north limb having a higher dip than the south. Of the numerous surface faults observable in the field, a few have a displacement of several hundred feet. These larger faults cross the axis of the structure at an angle of about 45 degrees, striking northwest.

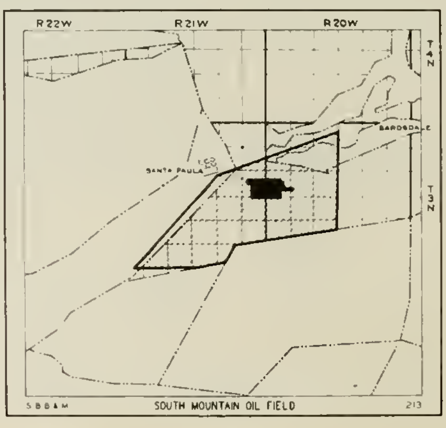
KIND OF OIL

The gravity of the oil ranges from 32.6 to 15 degrees A.P.I. Average gravity is between 24 and 26 degrees. The highest measured gas volume was about 580 M.c.f.

CITATIONS TO SELECTED REFERENCES—Continued

SOUTH MOUNTAIN OIL FIELD

Augur, I. V. 18; Brown, C. C. 26; Godde, H. A. 24; Hager, D. 15; Hudson, F. S. 24; Huguenin, E. 24; Jones, W. M. 22; Kew, W. S. W. 24; 32; Kirwan, M. J. 18; McCollough, E. H. 34; McPhee, D. 26; Moran, R. B. 17; Reinhart, P. W. 28; Taff, J. A. 34; Thoms, C. C. 26b; 39; Thomson, H. B. 22; Vander Leck, L. 21, pp. 117-119.



South Mountain oil field.

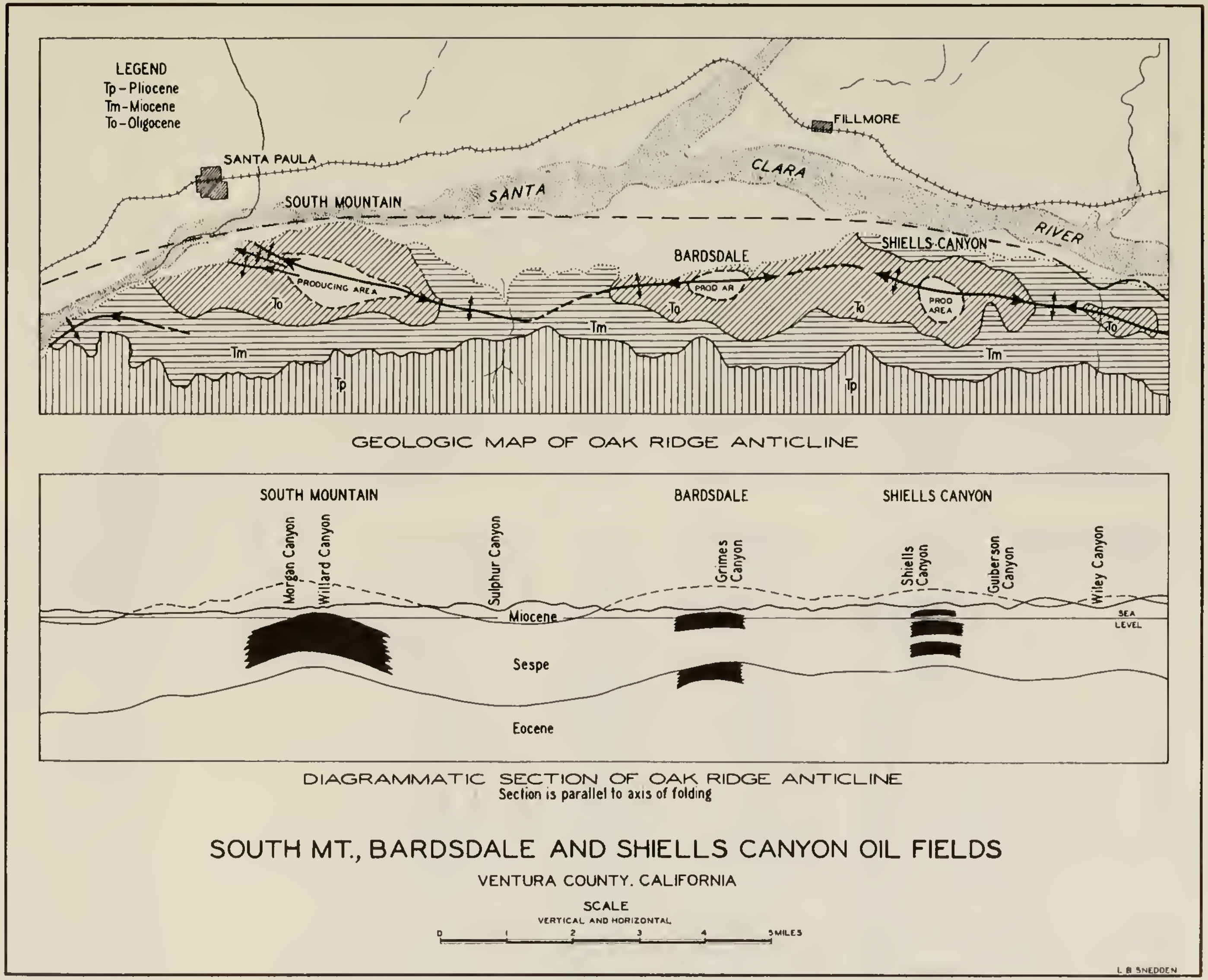


Fig. 166. South Mountain, Bardsdale, and Shiells Canyon oil fields: geologic map of Oakridge anticline; diagrammatic section.

BARDSDALE AREA OF THE BARDSDALE OIL FIELD

By LORING B. SNEDDEN *

OUTLINE OF REPORT

HISTORY

The Bardsdale area of the Bardsdale oil field, Ventura County, was discovered by the Union Oil Company well No. "Robertson" 1, in 1891. This well, though it failed to produce commercial quantities of oil because of mechanical difficulties, demonstrated the possibilities of the area.

Practically all shallow drilling was completed before 1900. In 1916 the Union Oil Company drilled No. "Robertson" 15, seeking deeper production. In 1935 the Union Oil Company again drilled for deeper production with its No. "Dryden" 10, and established production from the Eocene.

Approximately 69 wells have been drilled in the Bardsdale area. Of these 14 were edge wells, or off the structure, and were not completed. Fifty-five wells were completed, of which 38 are still capable of production. The area had produced approximately 1,363,400 barrels of oil by 1936.

DISTINGUISHING FEATURES

The Bardsdale area is probably most interesting because of its early discovery and very low rate of production decline after the initial flush production. Of the 14 shallow-zone wells completed on the Robertson lease, all are producing at the present time. Of the seven wells completed on the Fernvale lease, five are still producing.

* Geologist, The Texas Company. Manuscript submitted for publication September 19, 1938.

STRATIGRAPHY

The Bardsdale area wells are drilled in the Sespe formation, the upper part of which is a sequence of red and brown shale interbedded with poorly sorted sands. This unit is approximately 5,000 feet thick, and the wells start in the formation 1,500 to 1,800 feet below the top. Under this alternating series of sand and shale there is about 750 feet of pebbly, hard, poorly sorted, medium to fine sand. The Eocene is penetrated by the deeper wells and is a series of dark-gray, hard carbonaceous silts and silty shales, with hard, tight, well-indurated fine- to medium-grained sands.

STRUCTURE

The structure of the Bardsdale area consists of a dome on the Oak Ridge anticline. Evidence from some of the deeper wells drilled on this structure, as well as surface evidence, seems to indicate that it is asymmetrical, the north flank being steeper than the south.

PRODUCTIVE HORIZONS

At present there are two producing horizons—a shallow zone, in which the older wells were completed, from 300 to 1,900 feet below the surface, and a deep zone in the Eocene, from 5,200 to 6,800 feet below the surface.

KIND OF OIL

Oil from the Bardsdale area is high in paraffin, and is similar to the Shiells area and the South Mountain field products. It is 27 to 28 degrees gravity on the shallow zone, and 33 degrees gravity on the lower zone. Oil from the shallow zone is remarkably clean. At present it contains less than 1.5 percent of foreign matter. This is unique in view of the age of the area.

CITATIONS TO SELECTED REFERENCES—Continued

BARDSDALE OIL FIELD

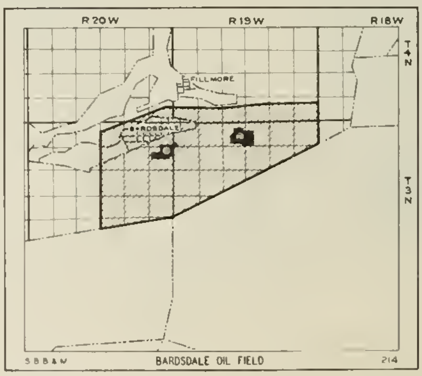
Arnold, R. 15; Augur, I. V. 18; Eldridge and Arnold 07; Godde, H. A. 24; Kirwan, M. J. 18; McCollough, E. H. 34; Moran, R. B. 17; Prutzman, P. W. 13; Thoms, C. C. 26b; 39; Vander Leck, L. 21, pp. 117-119; Watts, W. L. 00.

Bardsdale Area (Bardsdale Dome)

Augur, I. V. 18.

Garberson (Guiberson) Canyon Area

Eldridge and Arnold 07, p. 79, pl. I; McLaughlin and Waring 14, p. 393, pl. III.



Bardsdale oil field. Areas: (1) Bardsdale; (2) Shiells Canyon.

Montebello (Montebello Dome) (Shiells Canyon) Area

Augur, I. V. 18; Godde, H. A. 24; Kew, W. S. W. 24.

Shields Canyon (Shiells Canyon) Area

Edwards, M. G. 37; Kew, W. S. W. 24; McLaughlin and Waring 14.

Shiells (Shiels) Canyon Area

Brown, C. C. 26; Hoots, H. W. 36a; Taff, J. A. 34.

Willow Grove School Area

Kew, W. S. W. 24.

SHIELLS CANYON AREA OF THE BARDSDALE OIL FIELD

By Loring B. Snedden *

OUTLINE OF REPORT

HISTORY

The Shiells Canyon area of the Bardsdale oil field, Ventura County, was discovered in 1911 by the Montebello Oil Company with a well 581 feet deep that produced about 20 barrels of oil per day. All drilling on the shallow and intermediate zones was completed in the area by 1926; the majority of the wells were drilled prior to 1918. Drilling activities were resumed in 1934 with the exploration for and discovery of deeper zones. Since that time drilling has been continuous.

About 145 wells have been drilled into the shallow and intermediate zones, and 14 wells have recently been drilled to deeper horizons. Production ranged as high as 100 barrels per day on the shallow zone, 200 barrels per day on the intermediate zone, and 700 barrels per day on the deep zone. The field had produced approximately 7,000,000 barrels of oil by 1936.

DISTINGUISHING FEATURES

Distinguishing features of the Shiells Canyon area are similar to those of the Bardsdale area and the South Mountain field: (1) early production; (2) paraffin-asphalt base crude; (3) extremely low decline of production on shallow wells; and (4) production from the Sespe formation.

STRATIGRAPHY

The Sespe formation is approximately 5,900 feet thick in the Shiells Canyon area. The upper portion consists of conglomerate, sand, and red shale, and beds of green shale and dull gray silt. The lower 840 feet is very hard, compact, coarse and fine pebbly sand with no red shale beds.

The Eocene was penetrated by one well and was found to consist of dark-gray carbonaceous shale and fine- to medium-grained hard, tight, cemented sand.

STRUCTURE

The Shiells Canyon area is the third dome from the west on the Oak Ridge anticline. In structure it is asymmetrical; the axis hades 25 degrees to the south. Surface faulting is present with some effect on shallow production.

PRODUCTIVE HORIZONS

The productive horizons in the Shiells Canyon area are: (1) a shallow zone from 200 to 700 feet deep; (2) an intermediate zone ranging from 1,000 to 2,700 feet in depth; (3) a deep zone ranging from 3,200 to 4,300 feet.

KIND OF OIL

Oil from the Shiells Canyon area is paraffin-asphalt base and ranges between 32 and 34 degrees gravity.

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* Geologist, The Texas Company. Manuscript submitted for publication September 18, 1938.

DEL VALLE OIL FIELD

By R. W. Sherman*

OUTLINE OF REPORT

INTRODUCTION

The Del Valle oil field is located in the northwestern part of Los Angeles County, about 40 miles north of the center of the City of Los Angeles, in moderately rugged to very rugged terrain, where within very short distances elevations vary as much as 1,000 feet. The discovery well, R. E. Havenstrite, Operator, No. "Lincoln" 1, was completed September 8, 1940, producing 400 barrels daily of 58.0 degrees gravity oil and 10,000,000 cubic feet of gas, with tubing and casing pressures of 2,250 pounds and 2,500 pounds, respectively. The well was recompleted in the following month after the mechanical arrangement of the liner was remodeled to separate and control the excessive volume of gas. Its initial flow on recompletion was 875 barrels daily of 33.0 gravity oil and 280,000 cubic feet of gas through a 38/64-inch tubing orifice and 4,500,000 cubic feet of gas through a ⅜-inch casing orifice. The well is bottomed at 6,954 and produces from about 200 feet of Modelo sand (upper Miocene) which appears to correlate with the Third zone of the neighboring Newhall-Potrero oil field.

* Geologist, The British-American Oil Producing Company, Los Angeles. Manuscript submitted for publication March 19, 1942.

STRATIGRAPHY

Havenstrite well No. "Lincoln" 2 was completed December 31, 1940 at a total depth of 6,220 feet, producing from 135 feet of sand in the interval 6,035 to bottom, the probable equivalent of the First zone of the Newhall-Potrero field. The initial rate was 3,000 barrels daily, of 36.0 gravity oil. After the orifice was reduced from 38/64-inch to 16/64-inch, the rate of production was 450 barrels of 33.8 degrees gravity oil and 250,000 cubic feet of gas, the tubing and casing pressures being 850 and 1,250 pounds, respectively.

In Havenstrite wells No. "Vasquez" 1 and "Lincoln" 3, zones correlative with those producing in the "Lincoln" 1 and 2 wells were found to be wet. The former wells were therefore beyond the productive edge of those zones.

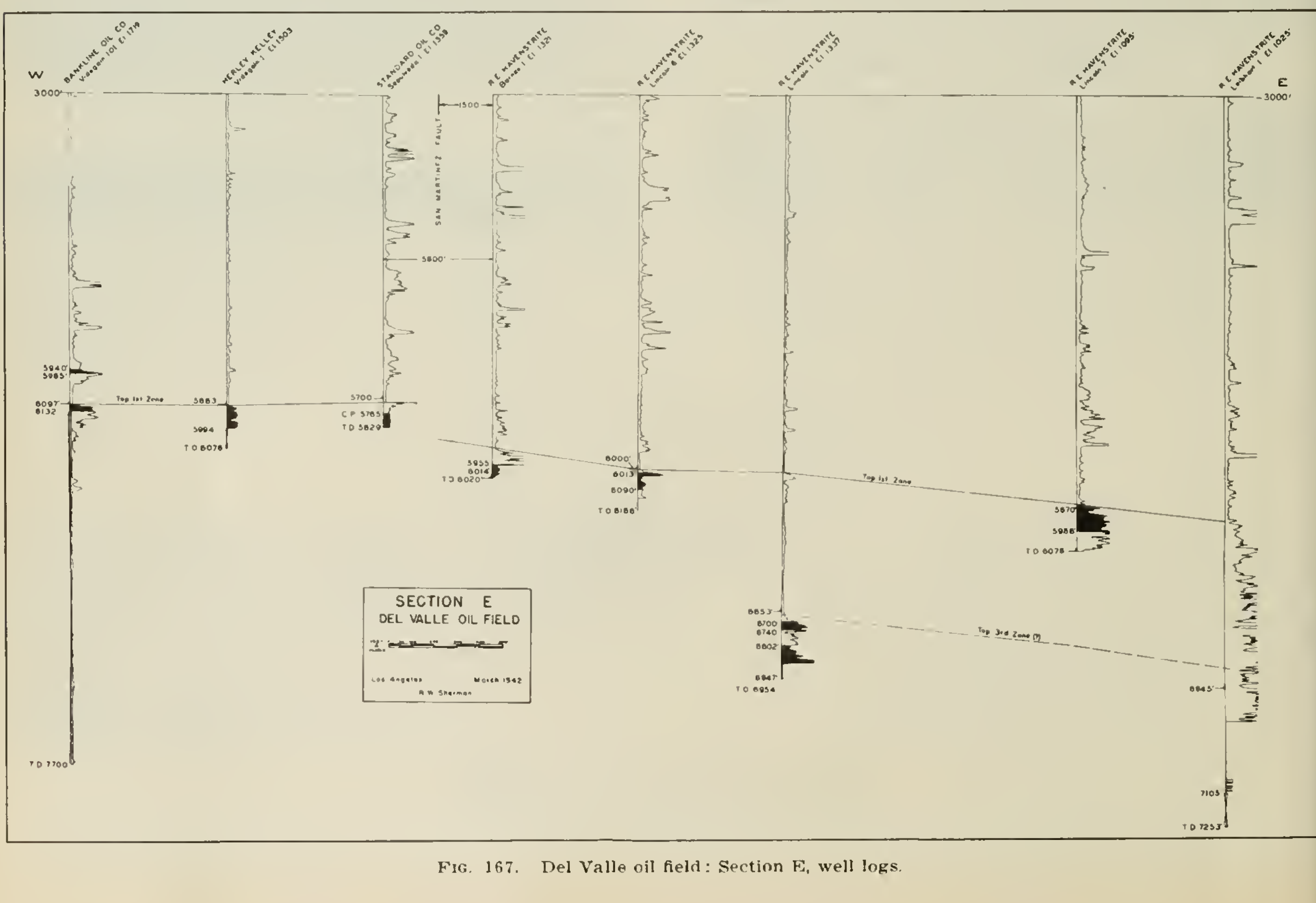


FIG. 167. Del Valle oil field: Section E, well logs.

TABLE 1

GEOLOGIC SECTION, DISCOVERY WELL LINCOLN 1—DEL VALLE OIL FIELD

AGE	FORMATION	DEPTH, FEET	THICKNESS IN FEET	DESCRIPTION
	Saugus	0 to 500?	500	Saugus buff sands, conglomerates, and silts; can not be distinguished from uppermost part of underlying Pico with which its contact is gradational.
PLIOCENE	Pico and Repetto	500 to 5700	5200	Pico and Repetto silts and siltstones sandy in the top 1,500 feet, occasional bodies of sand within the succeeding 3,000 feet, and alternating sands and shales in the bottom 700 feet; in exposed sections the predominant color of Pico is tan and light gray, of the Repetto, brown.
MIOCENE		5700 to 6954	1254	Miocene laminated gray-brown shale and about 400 feet of sand including 180 feet in producing interval 6,690 to 6,880 in discovery well; and 150 feet in an upper zone, 6040 to 6220 in second well (Havenstrite well No. "Lincoln" 2); the thickness of the Miocene in this area is probably in excess of 3000 feet.

West of San Martinez Grande Canyon the Jasper Oil Company drilled a test in search of a western extension of Del Valle anticline, which was believed to be present under the San Martinez fault, which in turn was thought to be a southward-dipping thrust. The well, now Herley-Kelley No. "Videgain" 1, was completed open hole July 3, 1941, flowing through tubing at a daily rate of 500 barrels of 31 degrees gravity oil and 2½ million cubic feet of gas. Its production comes from 100 feet of oil sand in a zone equivalent to the First zone.

The region discovered by the "Videgain" well west of San Martinez Grande Canyon is called the Videgain area; the region discovered by Havenstrite east of that canyon is called the Havenstrite area.

STRUCTURE

The main structural feature of the field is a southeastward-plunging anticline probably closed on the west against the San Martinez fault.

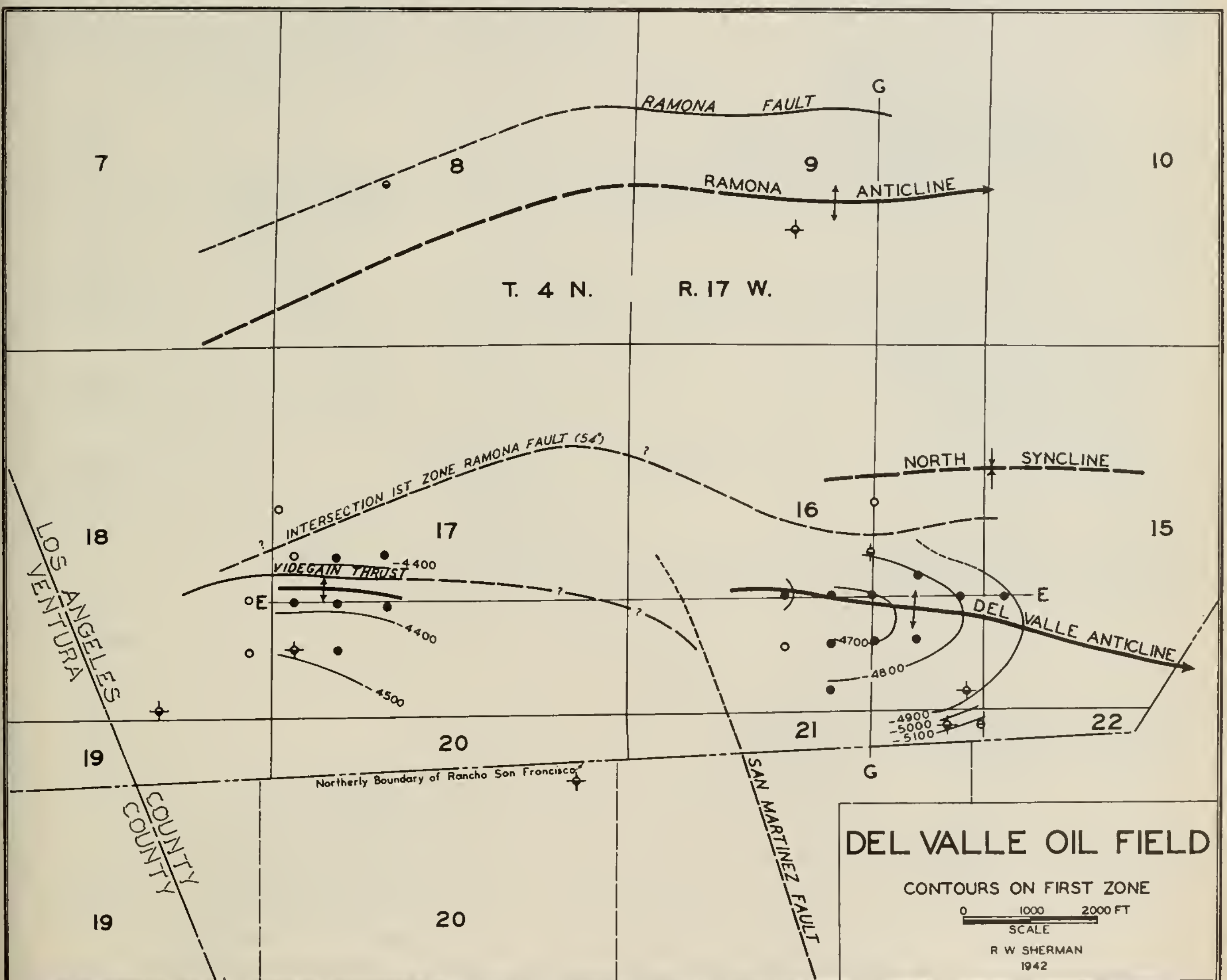


Fig. 168. Del Valle oil field: structure map.

Roughly paralleling Del Valle anticline on the north are North syncline, Ramona anticline, and Ramona fault, the latter located in the east-trending part of San Martinez Chiquita Canyon (often referred to by others as San Martinez Chiquita Canyon fault and as Holser Canyon fault).

Ramona fault is a thrust which dips about 50 degrees south, as determined by its intersection with Shell Oil Company well No. "Dougherty" 1 (see section G), but which may curve with lessening dip so as to coincide with a fault that apparently occurs in Havenstrite well No. "Lincoln" 10 in the interval 6,700 to 6,800, where duplication on the electric log indicates a thrust with a displacement of perhaps 500 feet.

North syncline is faulted at the surface in its western portion, with increasing magnitude as it approaches San Martinez fault. It is questionable whether or not this synclinal fault extends to sufficient depth to be an important feature in the control of the area of accumulation.

San Martinez fault, which the writer considers to be the extension of the Salt Canyon fault (Kew, W. S. W. 24), runs approximately N. 20° W. for several miles, from southwest of the Newhall-Potrero field into San Martinez Grande Canyon. North of the mouth of that canyon the fault is not clearly exposed, but to the south there is evidence that its plane at the surface is practically vertical and that major displacement has been largely horizontal, the beds having been pushed northward as much as 3,000 feet on its western side. Trending westward and paralleling the west arm of San Martinez Grande Canyon is a south-dipping thrust fault which Superior Oil Company well No. "Pena" 1 drilled through at about 4,200 feet, and in so doing passed from Miocene into Pliocene (Saugus). The Videgain area discovery well is located within the surface zone of influence of that fault, herein referred to as the Videgain thrust. The well was drilled out of the fault at about 1,200 feet.

Some geologists believe that this westward-trending thrust fault and San Martinez fault are one, curving rather abruptly as shown on the map, and changing in

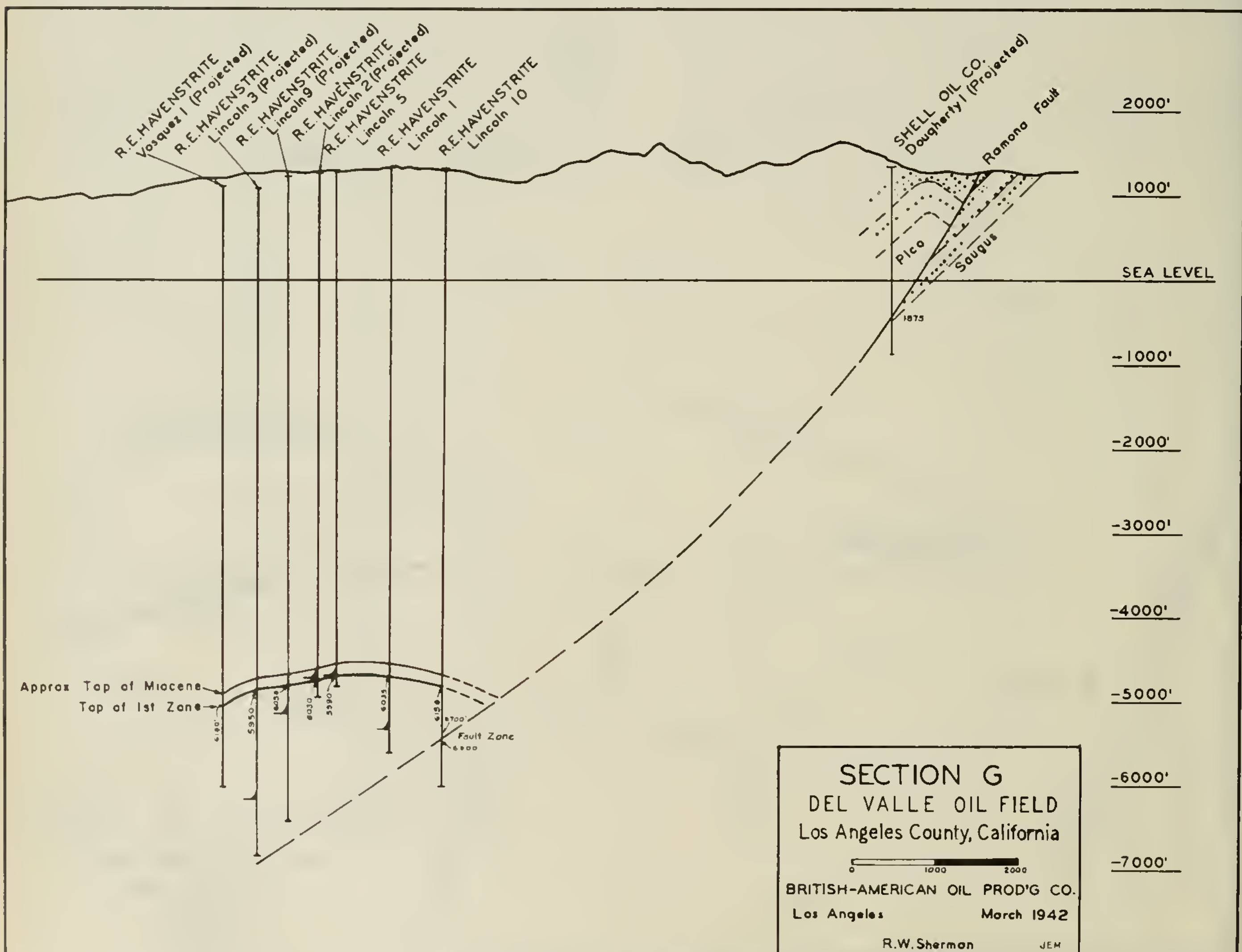


FIG. 169. Del Valle oil field: Section G, geologic section.

the curve from a nearly vertical to a southwesterly dip and then to a south dip where the fault trends westward. However, it is the writer's belief that these two faults are separate, although contemporaneous, and that the various components of force involved in them as well as in the faulted portion of North syncline are adjusted in a complicated zone in the area of the junction of all three. In this connection, the erratic and poor productive characteristics of offset wells in the Videgain area, despite the fact that all wells there are structurally higher than any in the Havenstrite area, strongly point to a structural break between the two parts of the field. Sheldon[1] and L. A. Tarbet (42) have pointed out, however, stratigraphic changes from sand to shale which may partly account for the productive differences of the two areas.

[1] Sheldon, D. H.—Development of Del Valle Oil Field, A. I. M. M. E., Los Angeles Meeting Petroleum Division, October, 1941.

The electric resistance curves shown on section E illustrate some of this depositional irregularity, showing that below the First zone the stratigraphy changes from practically all shale in the Videgain area (Bankline Oil Company well No. "Videgain" 101) to almost completely sand in the eastern part of the Havenstrite area (Havenstrite well No. "Liebhart" 1).

Of the total of 20 wells drilled to date in the field, 16 are now producing, 2 are idle, and 2 have been abandoned. The field's total present production of oil, drastically curtailed, is about 2,000 barrels daily.

CITATIONS TO SELECTED REFERENCES—Continued

NEWHALL OIL FIELD

Arnold, R. 15; Blackwelder, Thelen, and Folsom 17; Burkhart, H. W. 10; Crawford, J. J. 96; English, W. A. 14; Hertel, Bernt, and Pieper 28; Huguenin, E. 26; Kirwan, M. J. 18; 18a; Mining and Scientific Press 83; 83a; Moran, R. B. 17; Oil Weekly 37b; Pieper, Bernt, and Hertel 28; Prutzman, P. W. 10; Stockman, L. P. 37b; Thoms, C. C. 24; U. S. Geological Survey 34; Vander Leck, L. 21, pp. 129-130; Walling, R. W. 34; Wilhelm, V. H. 38; Willey, D. A. 05; Wosk, D. 40.

Del Valle Area[1]

California Oil World 40d; 40e; 41c; 42; Kew, W. S. W. 24; Sheldon and Havenstrite 41; Sherman, R. W. 41; Stockman, L. P. 41c; Tarbet, L. A. 42; Vallat, H. E. 41a; Wilhelm, V. H. 41, 41a; Wosk, D. 40.

Dewitt Canyon Area

Eldridge and Arnold 07; Prutzman, P. W. 13; Walling, R. W. 34.

East Canyon Area

Eldridge and Arnold 07; Walling, R. W. 34.

Elsmere (Elsemere, Elsmera Canyon, Elsmere Canyon) Area

Arnold and Kemnitzer 31; Eldridge and Arnold 07; Kew, W. S. W. 24; Prutzman, P. W. 04; 13; Walling, R. W. 34; Watts, W. L. 00.

Moore (Dewitt Canyon) Area

Walling, R. W. 34.

[1] Division of Oil and Gas maps now (February, 1942) show Del Valle as a separate field.

Mud Springs Canyon (Whitney Canyon) Area

Prutzman, P. W. 13; Walling, R. W. 34.

Newhall Mining District

Watts, W. L. 00.

Newhall-Potrero Area[2]

California Oil World 38; Hoots, H. W. 38; Oil and Gas Journal 41b; Porter, W. W. II 39b; Wosk, D. 40.

Pico Canyon Area

Eldridge and Arnold 07; Goodyear, W. A. 88; Hanks, H. G. 84; Jones, E. C. 97; Kew, W. S. W. 24; Mining and Scientific Press 76; 83; 83a; 84; North, E. 90; Prutzman, P. W. 04; 13; Walling, R. W. 34; Watts, W. L. 00.

Placerita (Placeritas) Canyon Area

Prutzman, P. W. 04; 13; Van Tuyl and Parker 41; Walling, R. W. 34.

Rice Canyon Area

Eldridge and Arnold 07; Walling, R. W. 34; Watts, W. L. 00.

San Fernando Mining District

Watts, W. L. 00.

Schist Area

Walling, R. W. 34.

Towsley Canyon Area

Eldridge and Arnold 07; Prutzman, P. W. 13; Walling, R. W. 34; Watts, W. L. 00.

Tunnel Area

Walling, R. W. 34.

Whitney Canyon Area

Walling, R. W. 34.

[2] Division of Oil and Gas maps now (February, 1942) show Newhall-Potrero as a separate field.

Wiley Canyon Area

Eldridge and Arnold 07; Kew, W. S. W. 24; Prutzman, P. W. 04; 13; Walling, R. W. 34; Watts, W. L. 00.

CASTAIC OIL FIELD

California Oil World 41; 41b; Stockman, L. P. 40, no. 19, p. 200; Wosk, D. 40.

NEWHALL-CASTAIC DISTRICT

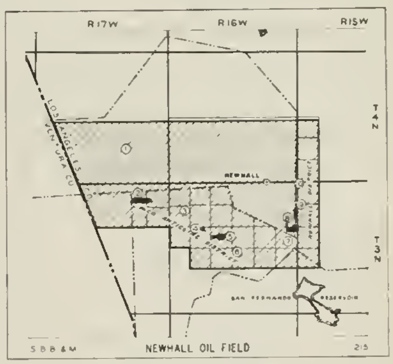
Wosk, D. 40.

SAN FRANCISCO FIELD

Stockman, L. P. 40, no. 14, p. 95, map.

RIDGE BASIN

Eaton, J. E. 39; 39a.



Newhall oil field. Areas: (1) Newhall-Potrero; (2) Pico Canyon; (3) Dewitt Canyon; (4) Towsley Canyon; (5) Wiley Canyon; (6) Rice Canyon; (7) Tunnel; (8) Elsmere; (9) Whitney Canyon; (10) Placerita Canyon.

NEWHALL OIL FIELD

By W. S. W. Kew *

OUTLINE OF REPORT

INTRODUCTION

The Newhall oil district is located about 30 miles northwest of the city of Los Angeles, near the town of Newhall, Los Angeles County. As a field, it is made up of a group of small productive areas which have varying modes of accumulation. The most important group is that situated along the Pico anticline. The areas are designated from west to east as Pico Canyon, DeWitt Canyon, Towsley Canyon, Wiley Canyon, Rice Canyon, and East Canyon. All are now either abandoned or temporarily shut down except Towsley Canyon. The other fields lie southeast of Newhall and comprise the Placerita, Whitney, and Elsmere canyons, and the Tunnel area.

Although Pico Canyon has been considered the oldest productive area in California, dating back to the use of seepage oil in 1850, the first attempt at drilling was in 1869. when a spring-pole hole reached a depth of 140 feet. The first serious drilling was not commenced, however, until 1875, when C. C. Mentry, and later the California Star Oil Works Company, started operations in Pico Canyon. The first three wells were poor, but the fourth yielded 150 barrels of 32-degree gravity oil per day, settling to 30 barrels. Later, wells were drilled in DeWitt Canyon (1882) and in Wiley Canyon (1883). The first drilling away from Pico Canyon anticline was at Elsmere Canyon in 1889 and in Whitney Canyon in 1893. Most of the areas were drilled by 1902. A concise history of the region has been written by R. W. Walling (34). The Pacific Coast Oil Company was incorporated in 1879, and after it acquired the California Star Oil Works Company it became the principal operator. This company later became the nucleus for the Standard Oil Company of California.

* District Geologist, Standard Oil Company of California, Los Angeles. Manuscript submitted for publication April 1, 1942.

STRATIGRAPHY

The Newhall district lies in the Santa Clara basin of deposition in a large depression which has existed since early Tertiary time. This large basin, occupying roughly the drainage of Santa Clara River, extends 50 miles eastward from the ocean at Ventura to a short distance beyond Newhall. Its southern margin lies along the south side of Santa Susana Mountains and Oak Ridge; its northern margin is the south slope of the higher mountains of the southern Coast Ranges. It gradually sank as sediments were carried into the basin until an immense series of strata ranging in age from Eocene to Recent had been deposited.

The total thickness of these rocks has been estimated at a maximum of nearly 44,000 feet. This figure is for the section in the western part of the basin, or west of the town of Fillmore. In the vicinity of the Pico anticline the Eocene is only partially exposed, so its thickness can not be measured. However, one well drilled in the Newhall area penetrated 1,500 feet of Eocene. The Miocene which is present in the Santa Susana Mountains is divided into two units: (1) Modelo formation (upper Miocene), maximum thickness 4,500 feet; and (2) Topanga formation, including the *Valvulineria californica* zone (middle Miocene), thickness 2,450 feet. The Sespe (Oligocene?) and Vaqueros (lower Miocene) formations have not yet been recognized in the area. The Mint Canyon formation, which is probably in part a nonmarine phase of the Modelo, is well exposed east of the Newhall district, but is not present in the Santa Susana Mountains. Several wells in the vicinity of Newhall have logged beds of probable Mint Canyon age lying beneath upper Modelo strata. A complete unbroken section of the Modelo can not be measured. The exposed strata in Towsley Canyon, comprising the upper part of this formation, aggregate 3,150 feet. To the south, on Santa Susana Mountains, an additional section extending down to the *Valvulineria californica* zone measures about 1,350 feet. The Pliocene series, comprising the Pico and Saugus formations, is completely exposed in the Pico Canyon area.

The Pico formation was defined first in 1924 (Kew, W. S. W. 24, pp. 70-71) after field work from 1917 to 1920. At that time lithology was used mainly as a basis of separation. Micropaleontology had not yet been used, and because of the lack of larger fossils at critical positions in the type section in Pico Canyon the division between the Miocene and Pliocene was not accurately placed. Furthermore, the Pliocene section had not been separated by microfaunal studies into the Repetto (lower Pliocene) and Pico (upper Pliocene). Clear statements of the basis for division of the Pliocene in southern California have been made by W. P. Woodring (38, pp. 3-4) and Stanley G. Wissler (this bulletin, pp. 212-218). It is recognized by the author that these divisions are valid when based upon microfaunal distributions. However, their use for mapping surface normal formational units is in most places not precise. Only rarely are the divisions separated by a structural break, and usually there is no change in type of sedimentation. It is recognized that at the type section of the Pico formation the faunas of the Repetto and Pico formations of the Los Angeles Basin are present, but they can not be mapped in the Newhall district except in a very general way.

The Pico formation lies apparently conformably above the Miocene on the north limb of Pico anticline, though the section of the Pico formation at the type locality in Pico Canyon includes also beds comparable in age to the Repetto formation of the Los Angeles Basin. The Pico formation, as originally described, is relatively thin, being composed of only about 4,800 feet of strata. It is made up largely of brownish-gray siltstones containing numerous small limonitic concretions. Lenticular sandstones and conglomerates are present, especially in the upper part. The Saugus formation overlies the Pico and is composed of irregularly sorted conglomerates and sands which are almost entirely of nonmarine origin. Between Pico Canyon and Santa Clara River, the type section is 4,600 feet thick. The unconformity with the Pico is excellently shown from Pico Canyon eastward. However, the truncation of the lower beds in the Pico is not present to the west, and north of Santa Clara River the contact between the two series is difficult to distinguish. Here nonmarine beds occur in the upper part of the Pico and a fauna comparable to that in the upper Pico is found in the basal Saugus.

As originally mapped, the contact between the Pico and the Modelo (Miocene) was placed at the base of gray and brown silts containing beds of gray sandstone and conglomerate. Below this contact the formation is mainly a hackly brown silty shale with well-bedded grayish-brown sandstones and some conglomerate. Essentially this division represents a change in lithology between the softer grayish silty shales and the noticeably brown silty shale series. No definite evidence of an unconformity is present in Pico Canyon, though it is thought that there is some truncation of the underlying strata west of Towsley Canyon.

A re-examination of this Pico Canyon section (*see* cross-section A-A′) has shown that Pliocene beds, as determined by H. L. Driver and W. H. Holman by means of Foraminifera extend below the original contact, including an additional 1,900 feet of section. The contact between the Pliocene and Miocene, as closely as can be determined, would fall within the brown shale directly below the base of the prominent white sandstone so well exposed in Pico Canyon, and which can be traced eastward for many miles. The fauna in these additional lower beds is rare but definitely of lower Pliocene age. Further to complicate the situation, a foraminiferal fauna comparable to that found in the Repetto formation of the Los Angeles Basin occurs in the beds above the original base of the Pico formation, extending above the original base of the section for at least 2,000 feet. Therefore, the Pico formation as originally described includes in its lower part a fauna of Repetto age, and in the upper part a fauna of Pico age as referred to the section in the Los Angeles Basin.

STRUCTURE

Pico Anticline

In the south side of this large basin the Pico anticline is one of the major structural features. It extends from a short distance west of Pico Canyon, along the north flank of the Santa Susana Mountains, to San Fernando Pass, a distance of 9 miles. It is a comparatively narrow fold and is paralleled on the south side by a closely compressed syncline. The dip of the flanks is seldom less than 40 degrees, in many places steeper. In fact, the north limb is commonly overturned except at Pico Canyon where the south limb is the steeper. Surface studies suggest that the axial plane dips southward. However, wells so far drilled do not indicate this, and the structure may be fairly symmetrical. The highest structural part of the anticline is located in the vicinity of Rice Canyon. The fold is extremely even-crested and comparatively little difference in structural elevation is present, along the greater part of its length. There is definite closure on the fold at both ends, though the eastern plunge is more abrupt, probably due to the faulting in San Fernando Pass. At the western end where the best production has been found, the plunge is more gradual, starting at Moore Canyon and continuing across Pico Canyon to the Salt Canyon fault, against which the fold terminates. The surface trace of the axis is in general very straight and uniform as to beds exposed.

Faulting is comparatively rare for such a closely folded structure. The majority of the faults are cross-faults, of the normal type, and with relatively little displacement, the maximum amounting to about 500 feet. The largest of these faults is in the DeWitt and Moore canyons area. These faults cross the axis to the south side and become strike faults. They may play some part in the lack of any oil accumulation on the south flank of the anticline in Pico Canyon.

PRODUCING AREAS

General Statement

The developed productive areas along the anticline are localized mainly in the canyons which cross the fold. There is no reason to believe that production would not be found in the intervening areas, and it was probably only the ruggedness of the country which prevented development when drilling was in progress. Pico Canyon field extends eastward to the higher ridges, but here greater drilling depth is necessary to reach the better sands, which in the early days of drilling was a material deterrent factor.

No development in Pico Canyon has taken place since 1916, when Standard Oil Company well No. "P.C.O." 41 was drilled. In Wiley Canyon several wells were put on production in 1917 by the same company. In Rice and East canyons very little production was ever developed and all the wells are abandoned at the present time. Drilling in Towsley Canyon, on the other hand, has continued spasmodically up to the present, though it did not begin until about 1890. With the shutting down of the Standard Oil Company's wells in Pico and Wiley canyons in May 1940, Towsley Canyon is the only locality on this large anticline that is at present producing oil.

Pico Canyon

The oil in Pico Canyon comes from three zones designated by Walling (34) as the Top, Central, and Lower zones. At least the upper two zones may have been penetrated in the Newhall-Potrero field to the northwest. Most of the wells were drilled to the Central zone, their completion depths ranging from 500 to 2,000 feet. The Lower zone wells, of which there were four, reached a depth greater than 2,000 feet. No attempt was made to cement off water, so that production troubles were many. The oil is of good quality and varies in gravity from 33 to 42 degrees. The initial productions varied, the highest recorded being 88 barrels per day. At the time the field was shut down there were 26 wells on production yielding a total of 50 barrels per day.

Towsley Canyon

In Towsley Canyon a number of shallow wells obtained a production of less than 30 barrels per day of a heavy (19 degrees) oil with considerable water. The depth of the productive zone is usually less than a thousand feet. The last well drilled was in 1940.

Towsley Canyon has been the only place along this large anticline where any serious attempts have been made to find a deep oil zone. In 1929 The Consolidated Oil Company started a well a short distance north of the axis, on the Hammon lease. After various ownerships, it was finally drilled to a depth of 5,225 feet by J. E. O'Donnell. For practically the entire depth the dips in cores were greater than 70 degrees. Several attempts were made to produce the well as drilling progressed. The best showing was between 3,915 and 3,990 feet, where a pumping test gave 20 to 75 barrels a day gross fluid composed of 24 degrees gravity oil, with 60 to 75 percent cut. The well has now been abandoned.

Another deep test south of the surface trace of the anticlinal axis has recently been abandoned at a depth of 7,056 feet. It was drilled jointly by Barnsdall Oil Company, Wilshire Oil Company, and Bandini Oil Company, and is known as No. "Limbocher" 1. Strata, all of which are correlated with the Modelo formation, were penetrated without much encouragement for production. Dips were uniformly high, varying from 55 to 85 degrees. Before abandonment several tests were made of the sands indicated by the electric log to have some porosity. They yielded salt water without oil.

Fig. 170. Newhall oil field: map.

Wiley Canyon

Production in Wiley Canyon comes from wells less than 2,000 feet deep, located close to the surface trace of the axis. The greatest initial flow from any one well was 109 barrels per day. When shut in, in May 1940, the average yield from the nine wells was less than 1 barrel per day, and at least an equal amount of water. The gravity of the oil was 28 degrees. As in Towsley and Pico canyons, the wells start near the top of the typical platy Miocene shale, which they penetrated for an average depth of 1,200 feet. No definite oil zones have been recognized.

Elsmere Canyon

Elsmere Canyon field comprises about 60 acres in and near Elsmere Canyon, Sec. 12, T. 3 N., R. 16 W., S. B. The field was first discovered in 1889 by the Pacific Coast Oil Company (later Standard Oil Company of California). Thirty-three wells were drilled but at present only six are producing.

The only operator at present is the E. A. Clampitt Company, which has a number of holes less than 840 feet deep that yield about two barrels per day each of 14-16 degrees gravity oil, with 75 percent water. The oil has accumulated in west-dipping beds against a fault which trends in a northwesterly direction along Elsmere Canyon. No production has been found north of the fault. The rocks exposed at the surface are a part of the Pico formation, probably the lower part, and rest unconformably upon rocks of middle Eocene age. The latter are well exposed in Elsmere Canyon a short distance east of the field. Seepages of oil occur at a few places in the Eocene. The oil from the wells occurs in both the Pliocene and Eocene, and it is quite probable that the oil in the basal Pliocene was derived from the underlying Eocene. Although the records are poor, it is thought that a number of the wells produced directly from the Eocene.

Whitney Canyon and Placerita Canyon

North of Elsmere Canyon two groups of wells have been drilled by a number of small companies at various times since 1893. A few of the early wells drilled by the Republic Petroleum Company came in for about 250 barrels per day. Most of them were small producers, usually less than 25 barrels per day. The wells are comparatively shallow, commonly being less than 1,500 feet deep. The oil here was accumulated on a northwestward-dipping series of Saugus beds (uppermost Pliocene and Pleistocene) and a thin section of Pico formation (Pliocene) overlying unconformably the middle Eocene. In the Whitney Canyon area a north-trending fault lies a short distance east of the wells. Whether or not this is the major factor in the concentration of oil here is not known. It is possible that the oil has migrated into the Pliocene beds from the underlying Eocene, or lenticularity of the beds has been the controlling factor. The production is apparently obtained from all three formations. The oil from the Pliocene is about 14 degrees gravity, whereas that from the Eocene is 30 degrees. In some of the early wells drilled, gravities of a greenish oil are reported to be as high as 40 degrees.

All the wells in Whitney Canyon and Placerita Canyon have been idle or abandoned since 1937. In the former area, the last production was about 375 barrels per month of 13-degree gravity oil from two wells. In the Placerita area the wells each made about a barrel a day of 26-degree gravity oil.

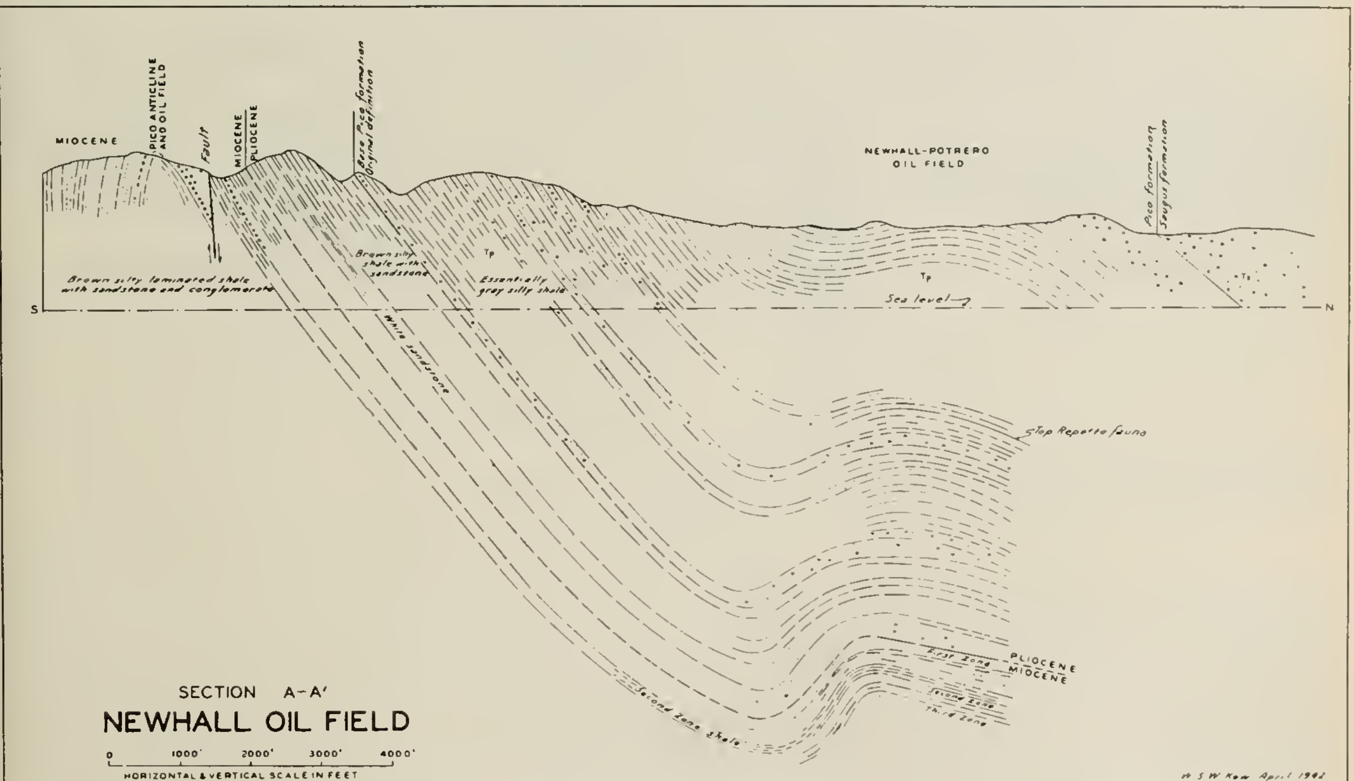


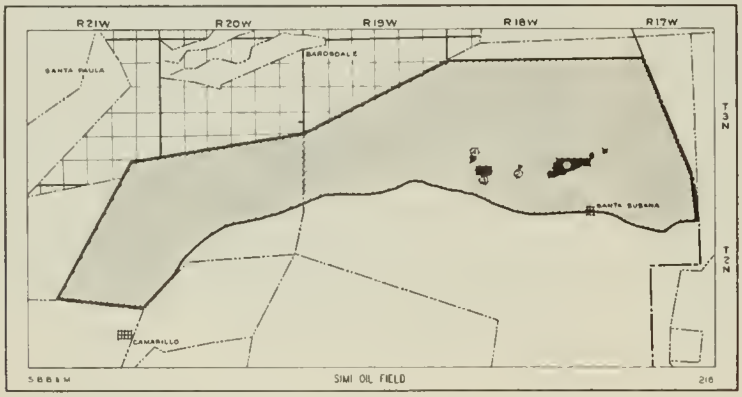
FIG. 171. Newhall oil field: cross-section.

Tunnel Area

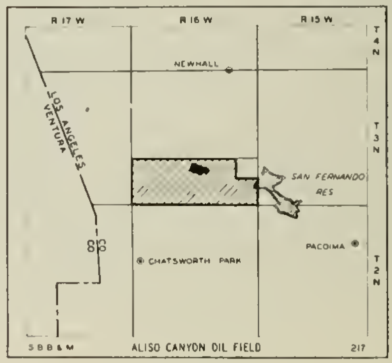
A relatively small productive area lying directly north of the crest of San Fernando Pass and situated on both sides of U. S. Highway 99 has been known as the Tunnel area. Formerly the north portal of a tunnel through the pass lay at the south edge of the productive area. This tunnel has now been superseded by a deep road cut. The San Fernando Refining Company, located at the Pass, processes the crude from this general area.

The structure in this oil-producing area is that of a westward-dipping series of Pliocene and Miocene strata cut by a fault which trends in a northwesterly direction along the canyon in which the old State highway is located. The wells on the east side of this canyon, though grouped in the Tunnel area, probably are more closely related structurally with Elsmere Canyon. No information is available to determine whether there is any arching of the beds against the fault to effect the main accumulation. The oil sand occurs in the basal beds of the upper Pliocene (Pico formation), ranging in depth from 650 to 1,700 feet. Two wells were drilled below the Pliocene into the Mint Canyon formation (upper Miocene), where oil-stained sands occur for over 300 feet. They were tested but yielded little or no oil. The Southern California Drilling Company well No. "Needham" 4, which lies at the west edge of the productive area, penetrated the Mint Canyon formation and reached the top of the Eocene at 2,747 feet. Eocene sediments are continuous to bottom of the well at a depth of 4,400 feet. This formation is to be correlated with that found in the vicinity of Elsmere Canyon, which can be referred to the Domengine horizon (middle Eocene). Thirty-one wells have been drilled in the area, but at present only 20 wells are producing. The yield is 4 to 10 barrels per day of 16 to 22 degrees gravity oil from each well.

CITATIONS TO SELECTED REFERENCES—Continued



Simi oil field. Areas: (1) Tapo Canyon; (2) Simi; (3) Canada de la Brea; (4) Scarab.



Aliso Canyon oil field.

SIMI OIL FIELD

Arnold, R. 15; Augur, I. V. 18; Godde, H. A. 24; Howell, G. 22; Kew, W. S. W. 19; 24; 32; Kirwan, M. J. 18; Menken, F. A. 40a; Moran, R. B. 17; Stipp and Tolman 34; Taff, J. A. 34; Thoms, C. C. 26b; 39; U. S. Geological Survey 34.

Brea Canyon (Cañada de la Brea) Area

Kew, W. S. W. 19; Mining and Scientific Press 84; Vander Leck, L. 21.

Camulos District

Mining and Scientific Press 84.

Scarab Area

Kew, W. S. W. 19; Taff, J. A. 34.

Simi Area

Kew, W. S. W. 19; 24.

Tapo Canyon Area

Eldridge and Arnold 07; Kew, W. S. W. 19; 24; Vander Leck, L. 21.

ALISO CANYON OIL FIELD

Hoots, H. W. 39; 39a; Porter, W. W. II 39b; Vallat, H. E. 41a; Wilhelm, V. H. 39a.

Bull Canyon Area

McLaughlin and Waring 14, p. 394.

OXNARD AREA

Hoots, H. W. 38; Moran, R. B. 40; Thoms, C. C. 26b; Van Tuyl and Parker 41.

SIMI OIL FIELD

By T. F. Stipp [*]

OUTLINE OF REPORT

INTRODUCTION

The Simi oil field is situated in the foothills of the Simi Valley, about 2 miles north of the town of Santa Susana, in Ventura County. It is of minor importance with respect to the quantity of oil produced, but of interest for the reason that it is one of the few fields of California from which oil is obtained from strata of Eocene age. The Eocene section at this locality is relatively complete and highly fossiliferous; and it has proved to be very useful in determining the Eocene sequence in California.

This paper is limited to a brief description of the geology and oil-producing conditions of the Simi field as revealed by the work of F. B. Tolman and the writer since 1928. The reader who desires further information is referred to the published works of Kew, Nelson, Clark, McMasters, and others, all of whom have contributed to the knowledge of the Simi field or adjacent areas.

HISTORY OF DEVELOPMENT

Available records indicate that the first drilling in the area of the Simi oil field was done by the Simi Oil Company between 1900 and 1902. Five wells were drilled in steeply dipping strata near an oil seep in the first canyon, locally known as Oil Canyon, west of Las Llajas Canyon. These wells were said to range in depth from 1,125 to 1,725 feet, and to have yielded small production of 30 gravity oil.

In 1912, the Petrol Company drilled a prospect well in Tapo Canyon. This well produced a fair quantity of light oil, and led to the drilling of additional wells. The Santa Susana Syndicate, another pioneer in the field, drilled several wells east of Tapo Canyon in 1913 and in succeeding years. The property of the Petrol Company was eventually acquired by the Doheny-Pacific Petroleum Company, and later by the Pan American Petroleum Company. The field was developed chiefly prior to 1922, with a total of 50 wells drilled to depths varying from a few hundred feet to 3,000 feet. The Richfield Oil Company, successor in interest to the Pan American Petroleum Company, eventually obtained control of the field, and renewed development work in 1929. One well was deepened, and three were completed in sands that had not been previously developed. The initial production of these wells averaged about 50 barrels of 28 to 38 gravity oil, and new information concerning the stratigraphy and structure of the field was obtained. However, the production rate of these wells declined rapidly, and further drilling was considered uneconomic. The properties were finally subleased. Charles, Hoxie, and Wilmer Anderson, after obtaining a lease on the properties formerly operated by the Santa Susana Syndicate, drilled in recent years several producers east of Tapo Canyon. In 1928 the Shell Oil Company drilled a comparatively deep well near the foot of Oil Canyon, but failed to obtain production due to the unfavorable location of the well.

The largest producing well of record was drilled in 1913 by the Santa Susana Syndicate. This well, designated as No. 1, was drilled on the West lease, just east of Tapo Canyon. It was completed at a depth of 718 feet, and according to the log, flowed for 5 months, with a daily production rate 30 days after production of 250 barrels of 30 gravity oil. Several wells located on the Tapo lease are reported to have had initial production rates of over 100 barrels.

The present production of the field is very small. Approximately 50 wells are producible, with an average daily production of 2 barrels per well.

STRATIGRAPHY

Although a more or less complete geologic section ranging in age from Cretaceous to Recent is exposed in the Simi Valley district, only those formations which occur in and near the Simi field are discussed in this paper. The sedimentary series is shown below:

QUATERNARY
- Alluvium
- Terrace deposits

UPPER EOCENE TO MIOCENE
- Sespe formation

EOCENE
- Llajas formation
- Santa Susana—"Martinez" formation, undifferentiated

CRETACEOUS
- "Chico" formation

The accompanying geological map shows the areal extent of these formations in the vicinity of the Simi oil field.

Cretaceous

"Chico" Formation. The oldest rocks which outcrop within the area are massive brown or buff sandstones and olive-colored shales of the Upper Cretaceous "Chico" formation. This "formation" occurs extensively east and south of the Simi Valley and is well exposed in Santa Susana Pass. It is presumed to have a total thickness of 5,000 feet. The "Chico" undoubtedly underlies the younger formations of the Simi field, but has not been reached by the drill. So far as is known, it is without importance as a source of petroleum, and none has been found in it.

* United States Geological Survey. Manuscript submitted for publication January 20, 1940.

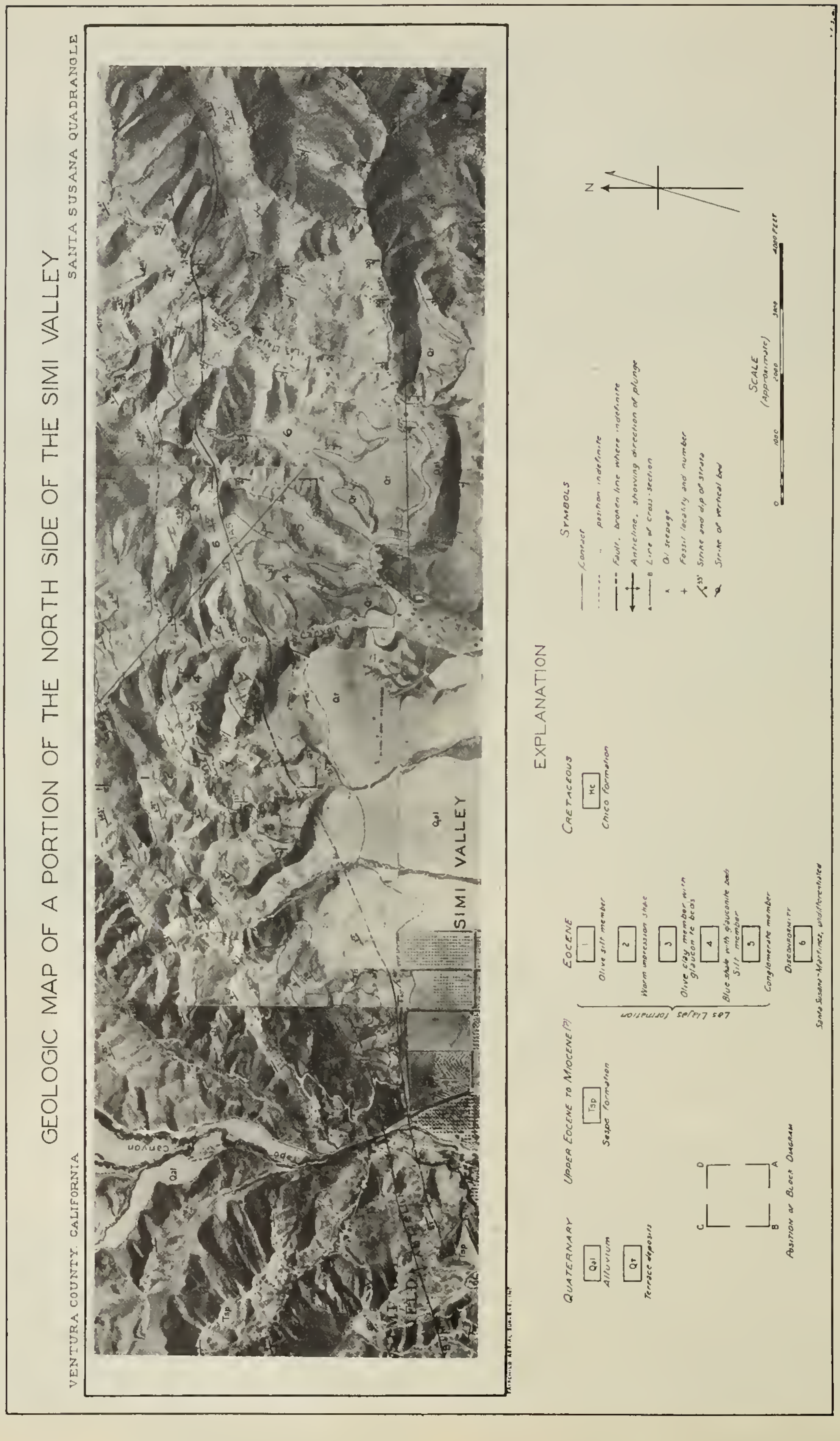


FIG. 172. North side of Simi Valley: aerial photographic and geologic map.

Eocene

The Eocene strata of the Simi district constitute one of the most complete sections of that epoch known in California, and have proved to be of great assistance in determining the Eocene sequence. At the time the accompanying map was made, the study of the fossils had not been completed and final correlations had not been made. For convenience, tentative names were then assigned to mappable units, and these names were used on the map and in the following discussion.

Santa Susana-"Martinez" Formation, Undifferentiated. Overlying the Cretaceous sandstones and shales without appreciable change of dip, but with implied disconformable contact, are 3,600 feet of conglomerates, sandstones, and shales with calcareous layers and concretionary beds. Three divisions are recognizable, beginning with the lower: 800 feet of conglomerates with interbedded sandstones and shales containing "Martinez" megafossils; 2,000 feet of blue shale in part calcareous and with few fossils other than Foraminifera; and 800 feet of gray silty shales grading upward into siltstone and finally sandstone. The thickness figures are approximate. Megafossils occur at certain horizons in all three divisions and Foraminifera are common throughout the shales. Since deposition was continuous, no unconformity and no important lithologic break occurs, and no mappable contact can be found, the beds were grouped together as Santa Susana-"Martinez," undifferentiated, pending more detailed cartographic and stratigraphic studies. This group of strata is not productive of oil.

Llajas Formation. The Llajas formation rests with slight discordance upon an erosional surface of the Santa Susana formation. It consists of 1,800 feet of conglomerate, sandstone, siltstone, and shale. Glauconite "reef" beds are present at certain horizons. The Llajas formation provides the reservoir strata from which the oil in the Simi field is produced. Five main divisions were found to be locally mappable but are not yet considered to be of sufficient regional significance to warrant the application of geographic names. The Llajas formation is described from the top to the base of the section, as follows:

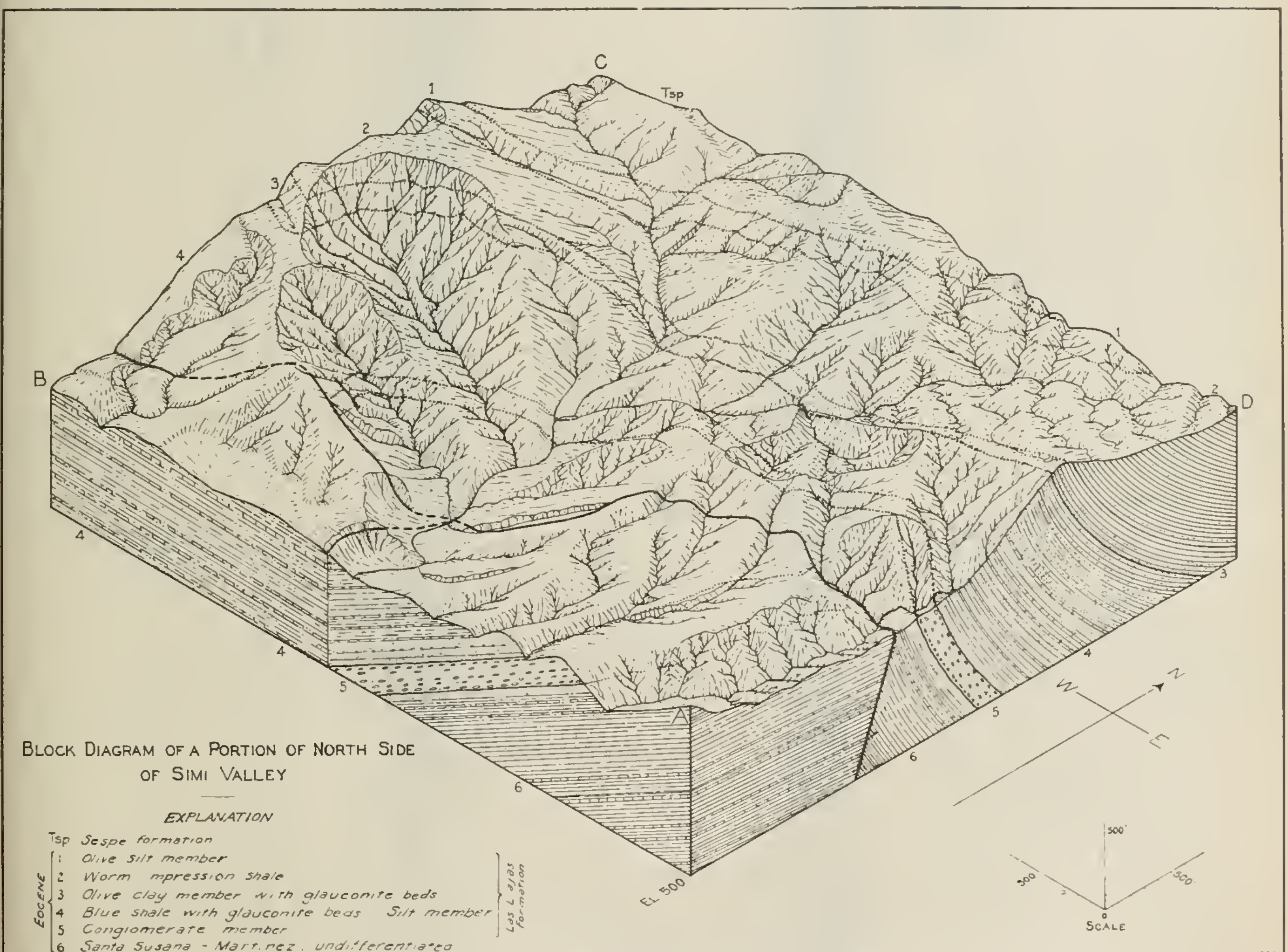


FIG. 173. North side of Simi Valley: block diagram.

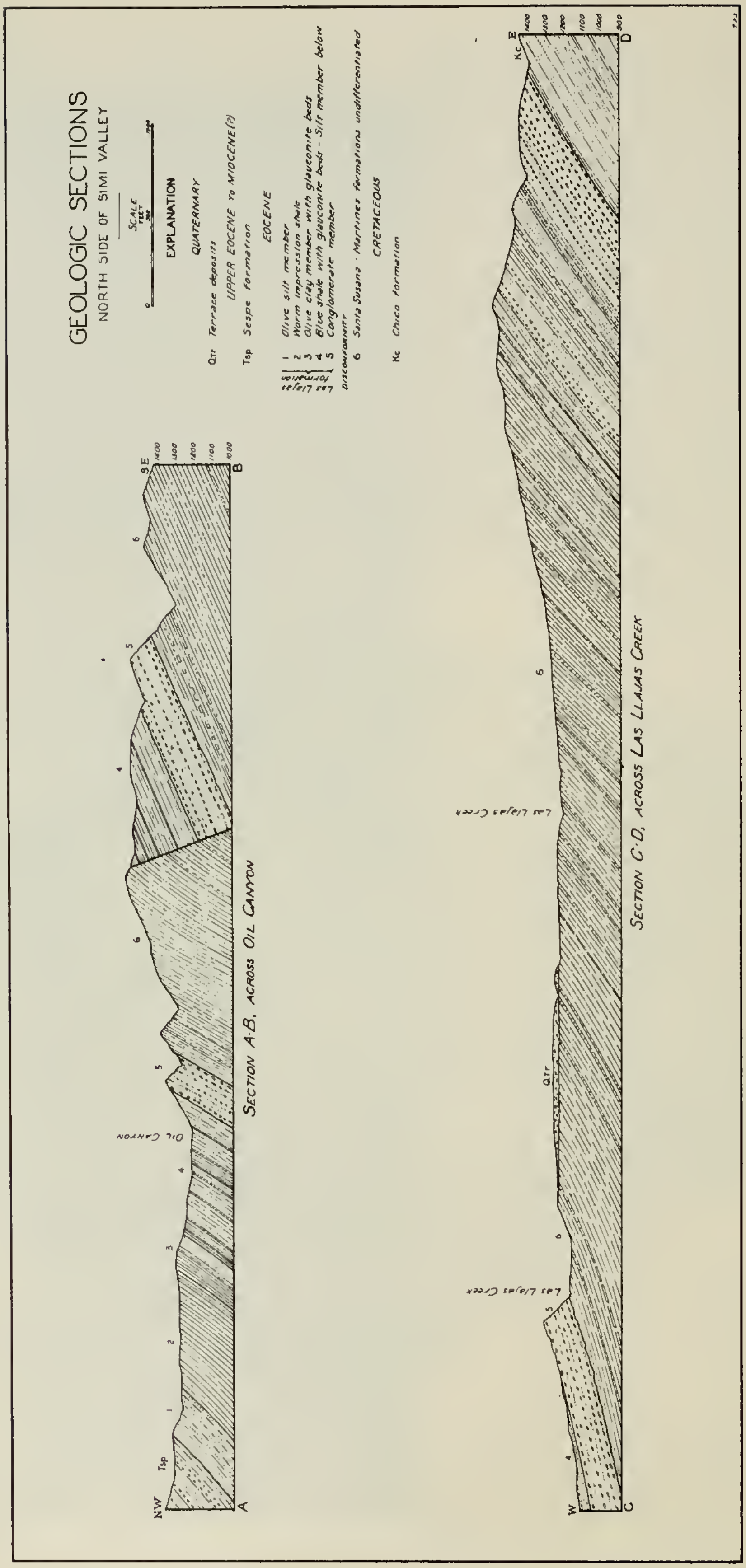


FIG. 174. North side of Simi Valley: geologic sections.

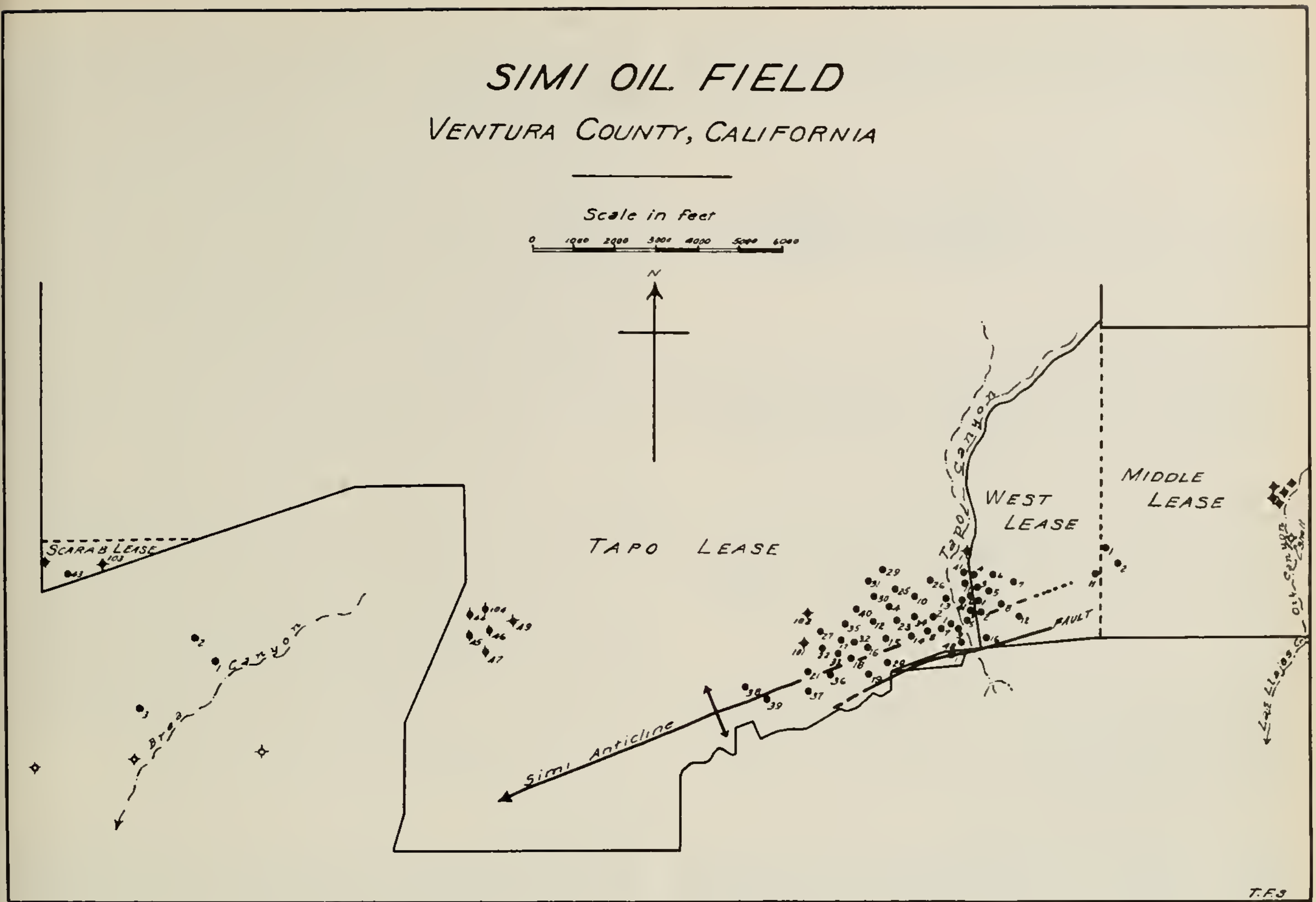


FIG. 175. Simi oil field: map.

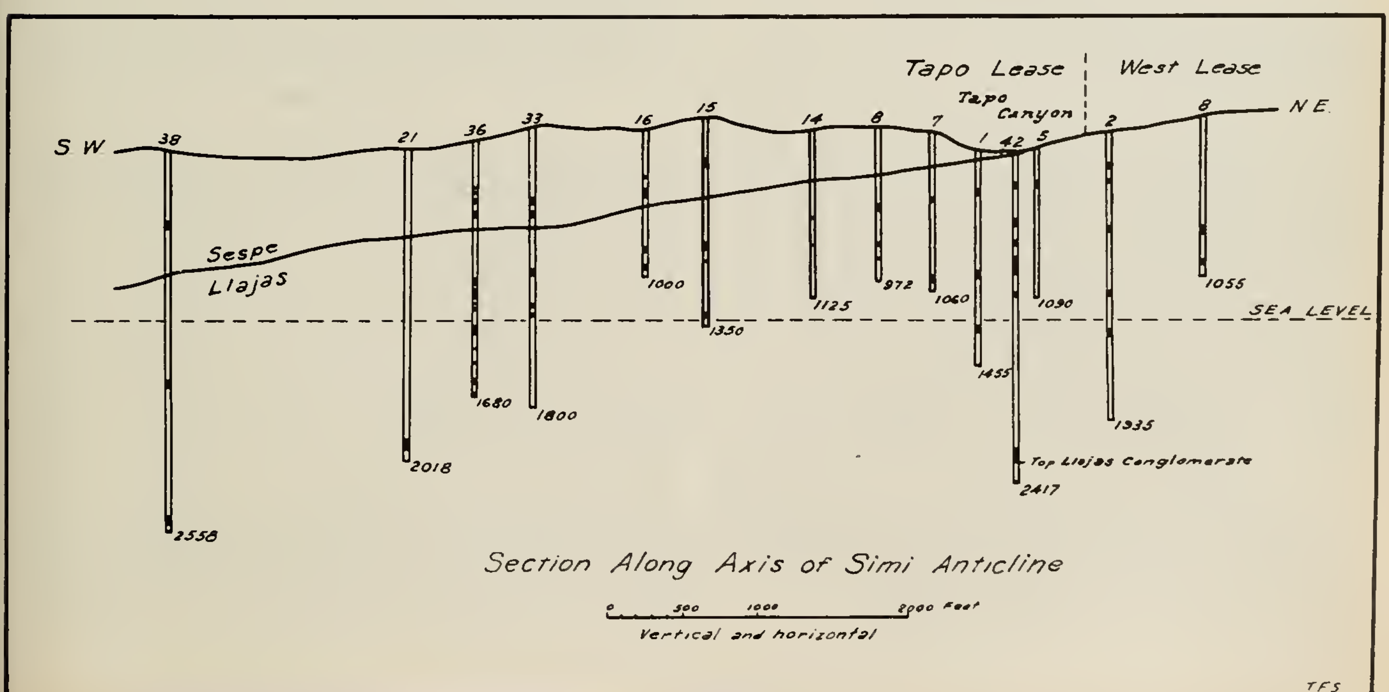


FIG. 176. Simi oil field: section.

Olive Silt Member (TLL1)

Well-bedded olive-colored silts grading up into micaceous silty shales in the center and back into olive to buff, banded, fine sands just below the Sespe contact. Occasional fossil horizons throughout. Thickness 170 feet.

Llajas Worm Impression Shale Member (TLL2)

Dark gray to bluish shales and silty micaceous shales containing occasional silt beds. The shales are nearly always mottled with worm impressions. Foraminifera are common in core samples, but are leached in outcrop samples. Megafossils rare. Thickness 630 feet.

Clay Shale Member (TLL3)

Dark-gray clay shale containing prominent glauconite "marker reef" at base, followed by two minor glauconite beds in the middle of the section. Mollusca and orbitoids are abundant in the reefs, and Foraminifera are common throughout. Thickness 120 feet.

Llajas Blue Shale Member (Upper Division of TLL4)

Bluish-gray micaceous shale, becoming somewhat silty toward the top. Fossiliferous throughout, especially in the several glauconite beds which make their first appearance in this member. None of these glauconites is as prominent as the main glauconite "marker reef" at the base of the clay shale member. Thickness 160 feet.

Llajas Silt Member (Lower Division of TLL4)

Well-bedded series of rapidly alternating silts and thick beds of micaceous silty shale, the whole member containing numerous calcareous sandstone reefs in which megafossils and Foraminifera are abundant. Thickness 585 feet.

Llajas Conglomerate Member (TLL5)

Medium-grained, comparatively well-bedded, gray sandstone, interspersed with occasional conglomerate lenses, the sandstones finer grained and better sorted than the underlying beds. Four fossiliferous layers present toward the top, the upper two layers of which contain an assemblage differing from the lower two layers. Thickness 40 feet.

Medium to coarse sandstone with interbedded conglomerate, the cobbles of which average 2 to 3 inches in diameter. Cross bedding common in upper part and local erosion surface occurs at top. Thickness 30 feet.

Conglomerate containing boulders up to 1 foot in diameter interbedded with occasional coarse sandstone lenses. Thickness 70 feet.

The Llajas formation contains a rich middle Eocene molluscan, brachiopod, echinoid, coral, cephalopod, crustacean, and foraminiferal fauna. The flora is represented by occasional leaf imprints; also fossil wood of the conifer type, bored by teredos, is abundant and ranges throughout members 3 to 5. Small amounts of amber, supposed to be the first found in California, occur through the same stratigraphic range. The section described above occurs in Oil Canyon and its side canyons, and is the best and most accessible section in the area. The accompanying block diagram shows the occurrence and extent of the beds described.

F. B. Tolman, in a set of correlation charts recently presented before the Pacific Section of the American Association of Petroleum Geologists, showed the stratigraphic relationship of the Paleocene-Eocene strata of the Simi Valley to other California sections.

Upper Eocene to Miocene

Sespe Formation. The Sespe formation, considered by most of the earlier geologists to be of probable Oligocene age, overlies the Llajas formation and outcrops in the Simi field east and west of Tapo Canyon. It consists in the Simi district of several thousand feet of sediments assumed to be of continental origin. The lower part includes brown conglomerates, sands, and clays with interbedded gravels; the middle part red, brown, yellow, and white sands, clays, and gravels; and the upper part brown and yellow sandstones with interbedded colored sands and clays. The material composing the strata is in general poorly sorted, cross-bedded, and loosely consolidated. Fossils are rare or absent. At one locality plant remains resembling reeds were found in the basal beds. The lower Sespe beds appear to be conformable with the Olive silt member of the upper Llajas formation. In passing upward from the silts, the strata become coarser, lighter in color, and barren of fossils. The Sespe formation is considered to range from upper Eocene to lower Miocene on the basis of its stratigraphic position and the occurrence of mammalian remains.

In the western part of the Simi oil field the lower Sespe sands contain oil, but are commercially unproductive. Oil has been produced in small quantities from a group of wells completed in the Sespe on the west side of the Simi field, and from the wells in the Scarab field. The oil is of lower gravity than that produced from the Eocene strata of the Simi field, but is believed to be of the same origin.

Quaternary

Terrace deposits of sand and gravel, composed of fragmental material from the older formations, and cemented together by caliche, overlie the older rocks in patches in the eastern part of the area. These sands and gravels dip gently southward and merge with the valley alluvium. They are assumed to have accumulated in Pleistocene time.

Gravels, sands, and clays of Recent age occur along the streams and on the northern side of the Simi Valley.

STRUCTURE

The Simi oil field is situated on the Simi anticline, an asymmetric westerly plunging structure which closely parallels the north side of the Simi Valley. From Tapo Canyon westward the structure is well expressed and is characterized by dips up to 35 degrees on the north flank and somewhat steeper dips on the south flank. It can be traced along the north side of the Simi Valley for 5 or more miles. Eastward from Tapo Canyon the axis of the structure can be traced for only a short distance, from which point the structure is more clearly represented by uplift due to faulting. The anticline has a westerly plunge of 8 to 10 degrees in the Simi field.

South of the Simi anticline and roughly parallel to it in the vicinity of Tapo Canyon is a prominent fault, here referred to as the Las Llajas fault. This fault is expressed by steep and discordant dips, by offset strata, and to some extent topographically. The accompanying block diagram shows the structural conditions along the fault in the area east of the field. The fault can be traced eastward several miles where movement along the fault plane has been much greater than in the vicinity of the Simi field. The Las Llajas fault, or associated faulting, has modified the structure in the Simi field, and may have controlled or affected accumulation of petroleum. Some of the more recent wells have penetrated fractured and slickensided strata, and in one well a part of the Eocene section was missing. Steep dips on the south flank of the anticline and the presence of faulting have caused the productive area to be quite narrow on the south limb of the fold.

Attempts to contour the oil sands in the productive part of the field have not been successful, due to lenticularity of the oil sands, and perhaps inaccurate well logs. From a study of the logs it was found that the Sespe-Llajas contact is recognizable with certainty in some wells, but could not be definitely located in others. At this horizon the sandier, loosely consolidated Sespe strata lie upon harder sandstones, shales, and calcareous shales of the fossiliferous Eocene. Oil sands occur both above and below the contact in certain wells, and in many wells a sulphur-water sand was logged in basal Sespe strata. The productive oil sands appear to be quite lenticular and of no great lateral extent.

The accompanying maps and diagrams show some of the structural details of the field.

OCCURRENCE OF PETROLEUM

Active seepages of oil occur in Oil Canyon where steeply dipping oil-saturated sands outcrop. These seepages are from the Llajas conglomerate, or from beds stratigraphically just above. A few seepages occur at other points higher in the Llajas formation, and are associated with minor faulting.

Oil has accumulated in the sandstones and siltstones of the Llajas formation, and, in the westerly portion of the Simi field, in the sands at or near the base of the Sespe formation. The oil which is found in Sespe strata is of lower gravity than that found in underlying strata of the Llajas formation, and is apparently commercially unproductive.

As noted above, the productive oil sands are lenticular and of limited lateral extent. As a result, there is a lack of uniformity in the occurrence and thickness of the oil sands, with a consequent variation in well production and gravity of the oil produced. For these reasons the depth, thickness and productivity of the oil sands, and the gravity of the oil, may not be accurately predicted in advance of drilling.

The earlier wells drilled in the Simi field were completed with cable tools at irregular depths. The practice was to complete the well as soon as production was obtained, without attempting to develop the entire productive zone. The more recent wells were put down with rotary equipment, the strata were adequately cored, and new information concerning the subsurface conditions was obtained. It was found possible to correlate closely the strata penetrated by the wells with the surface exposures. Well No. "Tapo" 42, drilled in 1929, cored the Llajas formation and obtained production from oil sands located just above the conglomerate member at the base. The depths and thicknesses of the lithologic members of the Llajas formation in this well are as follows:

250- 400 feet—Olive silt member
400-1030 feet—"Worm impression" shale member
1030-1155 feet—Clay shale member
1155-1320 feet—Blue shale member
1320-2290 feet—Silt member
2290-2410 feet—Conglomerate member

The oil sands productive in the older wells were found in this well between the depths of 600 and 1,200 feet, but were cased off and the oil sands between 2,290 and 2,300 feet were produced. Initial production of the well was 23 barrels of 28 gravity oil. Several additional wells were later drilled to the same horizon and obtained similar production. The productive sands in "Tapo" 42 are the same as those outcropping in Oil Canyon in which the active seeps are found, and it is believed that this horizon should be productive over a considerable area.

A group of five wells drilled in the early history of the field on the northwest side of the Tapo lease encountered oil sands in the Sespe formation. One of these, No. 44, completed in 1922, produced for a short time. Oil sands comprising a total thicknes of about 100 feet were found between the depths of 2,145 and 2,330 feet. In 1930, a sixth well, No. 49, was drilled to the depth of 4,480 feet without finding more than oil showings in the Llajas formation. The Sespe-Llajas contact was found at 2,690 feet. Oil sands were found in the basal Sespe, but were not produced. These wells are located too far down the north flank of the structure to determine the westerly limits of the field, and it is not known how far production may extend down the plunge of the anticline.

CHARACTER OF THE OIL

The oil produced in the Simi field varies in gravity from 28 to 38 degrees, depending to some extent on the location of the well and the depth of the oil sand. The average gravity is approximately 32 degrees.

The oil is reported to be of asphaltic base, and of high gasoline and kerosene content. Its lubricants are said to have unusual viscosity. Crude oil analyses may be found in United States Geological Survey Bulletin 753, by W. S. W. Kew (24). A more recent analysis, furnished by the Richfield Oil Company, is as follows:

CRUDE OIL ANALYSIS—SIMI OIL FIELD

	Percent	*Gravity Degrees*
Gasoline cut (420° F)	33.24	52.0
Kerosene cut	11.42	38.5
Gas oil cut	5.54	31.7
Residium	49.80	18.1
	100.00	

Gravity 31.9°
Sulphur 0.61%
M & B S 0.6 %

CONEJO OIL FIELD

By JOHN C. MAY*

OUTLINE OF REPORT

HISTORY

The small, shallow Conejo field, comprising about 40 productive acres, is located in Sec. 4, T. 1 N., R. 20 W., and Sec. 33, T. 2 N., R. 20 W., S. B., at the foot of the Conejo grade on U. S. Highway No. 101, in Ventura County. Prospecting was stimulated by the presence of several oil springs, in and adjacent to the field. Oil was discovered here in 1892 by the Union Oil Company of California in their well No. "Calleguas" 1, Sec. 33, T. 2 N., R. 20 W., S. B. The oil body was found between 60 and 80 feet.

DISTINGUISHING FEATURE

The Conejo field is unique among California oil fields, for the production comes from volcanic rocks.

STRATIGRAPHY

The field is situated in a volcanic series commonly called the "Conejo volcanics", which are composed of basalt flows and pyroclastics with minor intruding, fine-grain basalt and andesite dikes. The volcanics overlie the Topanga (upper lower Miocene) and extend into the Monterey (middle Miocene), at least as late as Luisian time.

Olivine basalt underlies the field. It is dark reddish-gray in color, vesicular and amygdaloidal, and contains abundant plagioclase, olivine, augite, and sometimes pyrite. The reddish color is the result of the olivine weathering to iddingsite. The vesicles, from 2 mm to 2 cm in size, are sometimes filled with chalcedony. The olivine basalt is considered the reservoir rock of the field.

A reddish-brown to purplish agglomerate overlies the olivine basalt. It is made up of angular fragments of fine-grain andesite and basalt 2 to 30 cm in size in a hard, fine-grain, well-cemented groundmass. The agglomerate shows some bedding.

Intrusions of diabase and basalt in the Topanga formation south of the field are thought to have been feeders to the thick igneous flows and flow breccias of the Conejo district.

STRUCTURE

The geological structure of the field is monoclinal, dipping north 20 to 25 degrees, into the syncline separating the Mugu Point-Conejo homocline from the Camarillo anticline.

Accumulation was caused by the seepage of oil into vesicles and fissures of the olivine basalt. If the accumulation was aided by faulting, definite evidence is lacking.

PRODUCTIVE HORIZONS AND KIND OF OIL

The oil is found in irregular concentrations from a depth of 20 feet down to 300 feet. Gravity of the oil ranges from 14 to 22 degrees, evidently increasing with depth.

International oil developers well No. "Powell" 2P in Sec. 33, T. 2 N., R. 20 W., S. B., now idle, is the deepest well in the field, and is still in volcanic rock at 3,060 feet. On a test at 2,645 feet the well flowed fresh water with a small amount of 22 degrees gravity yellowish-green oil and some gas.

The field proper has 53 wells which have pumped an estimated production of 25,000 barrels of oil. The oil seems partially refined, from its yellowish-green color and appearance. This may be due to its occurrence in volcanic rock. It is low in gasoline content and the wells produced little gas. At the present time the wells are worked at irregular intervals.

* Geologist, Tide Water Associated Oil Company. Manuscript submitted for publication January 2, 1940.

CITATIONS TO SELECTED REFERENCES—Continued

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SAN MIGUEL ISLAND
Bremner, C. St. J. 33.

SANTA ROSA ISLAND
Petroleum World 32.

SANTA CRUZ ISLAND
Bremner, C. St. J. 32; Goodyear, W. A. 90b; Rand, W. W. 31.

ANACAPA ISLAND
Watts, W. L. 00.

CALABASAS REGION
Kew, W. S. W. 24.

SANTA MONICA MOUNTAINS
David, L. 39a; 40b; Hoots, H. W. 31; 32b; Soper, E. K. 38.

SAN FERNANDO VALLEY
Chappuis, L. C. 40; Kew, W. S. W. 24; Kirwan, M. J. 18; Mining and Scientific Press 79a; 81; Vander Leck, L. 21.

SAN GABRIEL MOUNTAINS
Arnold and Strong 05; Brown and Kew 32; Hill, M. L. 30; Kew, W. S. W. 24; Oakeshott, G. B. 37.

SAN BERNARDINO MOUNTAINS
Vaughan, F. E. 22; Woodford and Harriss 28.

Chapter X

Santa Maria Basin and Southern Coast Ranges

CONTENTS OF CHAPTER X

CITATIONS TO SELECTED REFERENCES—Continued

SANTA MARIA BASIN AND SOUTHERN COAST RANGES

Arnold and Kemnitzer 31; Canfield, C. R. 39; Clark, B. L. 30; Eldridge, G. H. 01; Fairbanks, H. W. 98; Herold, C. L. 38; Menken, F. A. 40a; Porter, W. W. II 32; Stock, C. 20; Stockman, L. P. 36f.

Alameda County

Crawford, J. J. 96; Irelan, W. Jr. 88b; 88c; McLaughlin and Waring 14; Mining and Scientific Press 86; Prutzman, P. W. 10; Stalder, W. 41; Vander Leck, L. 21; Watts, W. L. 00.

Contra Costa County

Crawford, J. J. 96; Goodyear, W. A. 88; Irelan, W. Jr. 88c; Laizure, C. McK. 27; McLaughlin and Waring 14; Mining and Scientific Press 66; 66a; Prutzman, P. W. 10; Stalder, W. 41; Vander Leck, L. 21; Watts, W. L. 94; 00; Weber, A. H. 88.

Monterey County

Angel, M. 90; Bell, H. W. 18; Collom, R. E. 18; Crawford, J. J. 94; 96; Fairbanks, H. W. 00; Goodyear, W. A. 88; Hawley, H. J. 17; Irelan, W. Jr. 88c; Laizure, C. McK. 25c; Lawson, A. C. 93; McLaughlin and Waring 14; Petroleum World 35; 36a; Preston, E. B. 93; Prutzman, P. W. 10; Reiche, P. 37; Stalder, W. 24; Trask, P. D. 26; Vander Leck, L. 21; Waring and Bradley 16; Watts, W. L. 00.

San Benito County

Boalich, E. S. 22; Bradley and Logan 19; Crawford, J. J. 94; Irelan, W., Jr. 88c; Laizure, C. McK. 26c; McLaughlin and Waring 14; Mielenz, R. C. 39; Petroleum World 36a; Preston, E. B. 93; Prutzman, P. W. 10; Vander Leck, L. 21; Watts, W. L. 00.

San Francisco County

Irelan, W. Jr. 90; Lawson, A. C. 95; Vander Leck, L. 21.

San Luis Obispo County

Anderson and Martin 14; Angel, M. 90; Arnold and Johnson 10a; Bell, H. W. 18; California Oil World 34a; Collom, R. E. 18; Crawford, J. J. 94; 96; Fairbanks, H. W. 00; Franke, H. A. 35; Goodyear, W. A. 88; Irelan, W. Jr. 88c; Laizure, C. McK. 25b; Logan, C. A. 19; McLaughlin and Waring 14; Mining and Scientific Press 92; Petroleum World 36a; Prutzman, P. W. 10; Tucker, W. B. 21; Vander Leck, L. 21.

San Mateo County

Branner, Newsom, and Arnold 09; Goodyear, W. A. 88; Huguenin and Castello 20; Irelan, W. Jr. 88c; McClintock, H. H. 23; McLaughlin and Waring 14; Mining and Scientific Press 65c; 86; 88a; Prutzman, P. W. 10; Senior, S. P. Jr. 29; Stalder, W. 41; Taff, J. A. 34; Vander Leck, L. 21; Watts, W. L. 90; 00.

Santa Barbara County

Angel, M. 90; Arnold and Anderson 07a; 07c; Bell, H. W. 18; Collom, R. E. 18; Cooper, J. G. 97; Crawford, J. J. 94; 96; Goodyear, W. A. 88; Gore, F. D. 23; Hilgard, E. W. 85; Huguenin, E. 19; McLaughlin and Waring 14; Mining and Scientific Press 81; Petroleum World 36a; Prutzman, P. W. 04; 10; Reed, R. D. 29; Tucker, W. B. 21; 25a; U. S. Geological Survey 34; Vander Leck, L. 21; Watts, W. L. 97.

Santa Clara County

Bell, H. W. 18; Collom, R. E. 18; Crawford, J. J. 96; Franke, H. A. 30; Goodyear, W. A. 88; Huguenin and Castello 20; Irelan, W. Jr. 88c; McLaughlin and Waring 14; Mining and Scientific Press 65d; 65h; 65n; 66; 66c; 87; Prutzman, P. W. 10; Taff, J. A. 34; Vander Leck, L. 21; Watts, W. L. 90; 00; Weber, A. H. 90.

Santa Cruz County

Branner, Newsom, and Arnold 09; Crawford, J. J. 94; 96; Goodyear, W. A. 88; Huguenin and Castello 20; Irelan, W. Jr. 88c; Laizure, C. McK. 26; Mining and Scientific Press 65d; 66c; Stalder, W. 41; Vander Leck, L. 21; Watts, W. L. 90; Weber, A. H. 88.

LOMPOC OIL FIELD

By T. W. Dibblee, Jr.*

OUTLINE OF REPORT

HISTORY

The Lompoc oil field, situated on the south flank of the Purisima Hills and about 6 miles north of Lompoc in Santa Barbara County, was discovered by the Union Oil Company of California in 1903. The discovery well, No. "Hill" 1, located near tar seeps in Purisima Canyon, was drilled to 2,550 feet and completed with an initial production of 225 barrels of 19 degrees gravity oil per day. Union Oil Company of California, which controls the major portion of the land in the area, developed the field in a westerly direction from the discovery well, drilling 37 wells, of which 28 are known to have produced.

In the extreme west end of the field, Pacific Oil Fields Co., Ltd., drilled eight wells which are said to have produced a small amount of oil before they were abandoned in 1916.

Some distance east of the discovery well Pinal Dome Corporation drilled three wells, but these produced only a few barrels a day for a short time.

The Union Oil Company shut in all of its producing wells in the field in May, 1922, because of insufficient demand for this low gravity crude. Since that time there has been only occasional small production.

The field was dormant until 1928 when the Union Oil Company drilled its No. "Purisima" 19 to test the axial part of the "Purisima anticline" exposed immediately north of the field. This well, drilled to 4,310 feet, was a dry hole as was also Barnsdall Oil Co. No. "Careaga" 1, drilled in 1932 to 5,331 feet at a location about 1½ miles to the east along this same structure.

At the east end of the field, in the vicinity of the old Pinal Dome wells, Vaqueros-Major Oil Company (later taken over by O. C. Field Gasoline Corporation) drilled its No. "Union Annex" 1 in 1930 to 2,997 feet and completed it for an initial of 600 barrels of 22.5 degrees gravity oil per day, cutting 4 percent. This well proved to be the only commercial producer in this part of the field, as three subsequent wells drilled in this same area produced mostly water.

Activity was renewed in the west end of the field from 1934 to 1936 by the completion of several small producers by the York Oil Company. These wells were taken over by Alphonso E. Bell Corporation in 1937.

To date a total of 57 wells has been drilled in the Lompoc field, of which 13 are abandoned producers and 8 are dry holes. Since 1929, dry gas and some oil have been injected into the producing zone for purposes of storage and improving future production.

STRATIGRAPHY

The geologic formations of the Lompoc field and the adjacent Purisima Hills are shown in the accompanying columnar section. These formations thicken rapidly from the field to the north and east, a fact which suggests that this producing area lies near the southwestern margin of the major Miocene-Pliocene basin of sedimentation of the Santa Maria district. This is especially true of the Sisquoc formation (see cross section B-B'). The Monterey formation is known to thicken from 1,000 feet in Union Oil Company well No. "Purisima" 19 easterly to at least 2,000 feet in O'Donnell No. "Hellen" 1 at the extreme east end of the field.

The Lospe(?) formation, encountered in Union Oil Company No. "Purisima" 19 and perhaps in No. 11, is the oldest formation penetrated in the Lompoc field. The Lospe(?) is probably underlain by the Franciscan, as wells drilled in the adjacent Burton Mesa area to the west entered the Franciscan after passing through a few hundred feet of "Lospe" conglomerate and red beds.

STRUCTURE

The subsurface structure of the Lompoc field is not definitely known due to the fact that most of the wells were drilled with cable tools, and only limited formational data were collected. The accompanying structure contour map represents the author's attempt to interpret existing well logs and the exposed surface geology. The top of the productive Monterey shale is encountered at depths of 2,200 feet to 3,000 feet. Accumulation within this formation appears to be controlled by several closed anticlines. Productive limits of the field have been determined on all but the south side. The present proved area amounts to about 2,200 acres and lies mainly within the minus 2,100-foot contour.

Because of the pronounced northward thickening of the sedimentary section, the axis of the anticline of the Lompoc field lies some distance south of the exposed surface axis of the "Purisima anticline," which roughly follows the crest of the Purisima Hills (see map and cross sections). This condition explains why all wells drilled along the latter axis were failures.

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* Geologist, Richfield Oil Corporation. Manuscript submitted for publication January 20, 1941.

The writer is indebted to Mr. A. E. Bell, Mr. O. C. Field, Mr. H. W. Hoots, Mr. F. E. Dreyer, and the Union Oil Company of California for information used in preparing this report, and to Richfield Oil Corporation for permission to publish it.

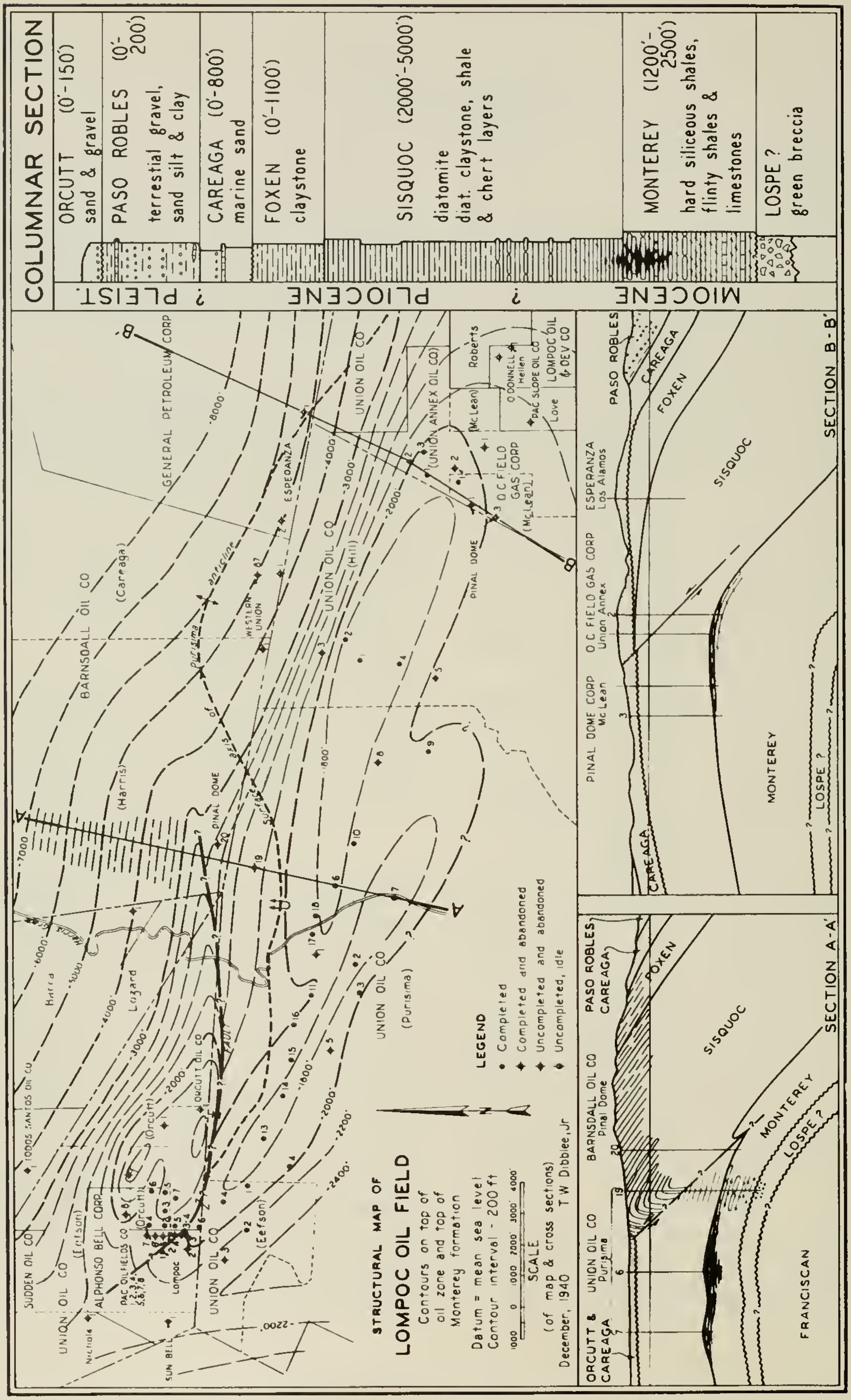


FIG. 177. Lompoc oil field: structure map; columnar section.

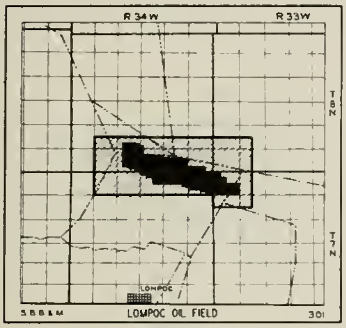
PRODUCTION

The oil of the Lompoc field comes from a single zone occurring in the uppermost part (*Bolivina hughesi* zone) of the Monterey shale. The top of the producing zone is approximately the top of the Monterey, although some oil may occur locally in the basal part of the overlying Sisquoc formation. The oil occurs in one or more intervals of highly fractured, brittle, cherty and siliceous shale within the upper 500 feet of the Monterey. (See cross-section A-A'.) The productivity of each well appears to be determined in large part by the degree of fracturing and the thickness of the producing interval. Such a relation might account for the failure of some wells to produce commercially even though favorably located structurally and adjacent to good producers.

Initial daily production of wells has ranged from a few barrels to 790. The oil varies from 15 to 24 degrees A.P.I. gravity and averages about 19 degrees. At the time of the shut-down in 1922, the daily average production was about 1,430 barrels of oil from 25 wells, or an average of 57 barrels per well. The field has had a very slow decline, due to generous well spacing. One well, Union Oil Company No. "Hill" 4, flowed for 20 years, the record for a flowing producer in California. Available data indicate a gas-oil ratio of about 300.

The absence of production figures prior to 1916 prevents an accurate statement of the total production, but the field is estimated to have produced about 7,900,000 barrels of oil prior to January 1, 1940.

CITATIONS TO SELECTED REFERENCES—Continued



Lompoc oil field.

LOMPOC OIL FIELD

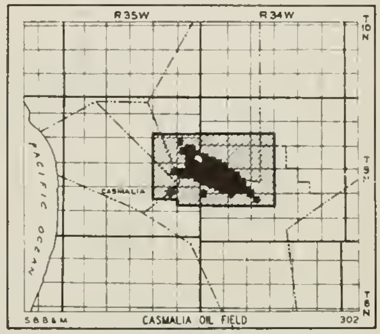
Arnold, R. 15; Arnold and Anderson 07a; 07c, pp. 104-107; Bell, H. W. 18; Bowman, F. F. Jr. 31; Collom, R. E. 17; 18; 29; Dolman, S. G. 30; 31a; Hodges and Johnson 31; Hoots and Herold 35, pp. 158-159; McCabe, R. E. 25; McCollough, E. H. 34; McLaughlin and Waring 14; Prutzman, P. W. 13; Ries, H. 30; Taff, J. A. 34; Vander Leck, L. 21, pp. 105-106; Van Tuyl and Parker 41, p. 81.

Purisima Hills (Lompoc) Oil Field

Vander Leck, L. 21, pp. 105-106; Van Tuyl and Parker 41.

CASMALIA (CASMALIA HILLS) OIL FIELD

Bell, H. W. 18; 20; Collom, R. E. 17; 18a; 29; Dolman, S. G. 30; Edwards, M. G. 37; Masser, E. H. 22; McCabe, R. E. 25; McCollough, E. H. 34; Porter, W. W. II 33; Prutzman, P. W. 13; Taff, J. A. 34; Vander Leck, L. 21, pp. 102-104; Van Tuyl and Parker 41.



Casmalia oil field.

CASMALIA OIL FIELD

By William W. Porter II*

OUTLINE OF REPORT

HISTORY

Although the Casmalia oil field, Santa Barbara County, was prospected as early as 1900, actual development dates from 1917. Doheny Pacific Petroleum Company completed its well No. "Soladino" 2 on January 6, 1917, and shortly thereafter Nos. 1, 3, 4, and 5. These wells produced from 375 to 432 barrels of 9 degrees oil per day. The principal development (1917 and 1918), was made by Doheny Pacific and Associated Oil Companies. The Escolle property on the east plunge of the structure was developed by the Union Oil Company.

The probable productive area of the anticline is slightly more than 3 miles long, and averages slightly more than three-quarters of a mile in width. Proven productive area is about 1,200 acres, the western half of which is operated by the O. C. Field Gasoline Corporation; the east half is held in four parcels by Richfield Oil Corporation, Associated Oil Company, Escolle estate, and Soladino Land and Cattle Company.

Of the 67 existing wells, many probably can never be restored to production. For the past 12 or 15 years all but about 15 wells have been shut in. In 1926 all operations were shut in with the exception of a few Escolle lease wells in the east part of the field. About 10 wells in the west part of the field were put on production in 1930 by the O. C. Field Gasoline Corporation, and, with others subsequently put on production, are being produced to supply oil for its Casmite refinery. During the past 15 years, only 6 wells have been drilled in the field, and three of these were abandoned.

It is estimated from available figures that the Casmalia field has produced about 7,500,000 barrels of oil; recoverable reserve is estimated to be at least 10,000,000 barrels, and perhaps 20,000,000 barrels, from present producing formations.

STRATIGRAPHY

The surface formation at Casmalia consists of a punky clay shale on the west, and of blocky diatomite down the east plunge, where younger beds occupy the surface. Both shales are of lower Pliocene (Sisquoc) age, according to micropaleontological information.[1] The thickness of this formation penetrated by wells varies from 80 to more than 1,800 feet, depending on position on structure and topographic elevation. At the base of this blue-gray shale is 750 feet of brown, platy Miocene shale which in some wells produces oil and water. Siliceous cherty shale occurs below the brown platy shale and carries oil. All wells in the field at present produce either from the chert zone or from the platy brown shale zone above it. Production is found at depths between 1,500 and 2,500 feet from the surface.

The cherty shale is presumably correlative with the prolifically productive chert zone of the Monterey in the Santa Maria Valley field.

STRUCTURE

The oil accumulation occurs in a simple asymmetrical anticline whose steep north flank dips into the Santa Maria Valley synclinal basin; the south flank dips gently to the San Antonio Valley. Throughout most of the field the anticlinal axis plunges gently east. It is ultimately closed by a west plunge in the area west of the Southern Pacific Railroad. Several areas of slight closure exist east of the west ultimate closure, and these give a chain- or sausage-like appearance to flank contours. Production on the east plunge occurs on structure contours below those which close around the west plunge.

Several faults are known but they apparently do not govern the location of oil accumulations on the structure.

KIND OF OIL

Gravity of the oil varies from 23 degrees A.P.I. at the east end of the field to 10 degrees A.P.I. near the center, and declines to 8.5 degrees A.P.I. in the western half of the field. The crude is high in resins and sulphur, and is particularly suitable for the manufacture of asphalt products such as cork cementing bond for refrigeration, waterproofing for concrete, roofing, saturants and coatings, road oils, and paving asphalt. It has also been used satisfactorily in the manufacture of lamp-black and gilsonite.

The 8.5 degrees A.P.I. crude yields 84.2 percent asphalt of 80 penetration, D.C. standard 77 degrees Fahrenheit, after 55 minutes on Brown evaporator. The higher gravity crude at the east end of the field contains more gasoline.

* Consulting Geologist, Los Angeles, California. Manuscript submitted for publication July 4, 1938. Revised July, 1941.

[1] Charles Reiter Canfield.

SANTA MARIA (ORCUTT) OIL FIELD

By F. E. Dreyer*

OUTLINE OF REPORT

HISTORY

The Santa Maria or Orcutt oil field in Santa Barbara County was discovered in 1902 by the Western Union Oil Company on what is now Shell Oil Company's Graciosa lease. Following the discovery there was a period of intense activity for 4 or 5 years, then a quiet period until the war boom of 1917 and 1918. Since 1922, the field has been partially shut in and very little development work has been done.

The estimated proven acreage is 3,373—about three-quarters of which is controlled by the Union Oil Company. There has been a total of 321 wells drilled, with 64 abandonments, and the recovery of oil to date has been something over 50,000 barrels per acre.

DISTINGUISHING FEATURES

Although the Santa Maria field has become simply another of California's larger oil fields, when it was discovered there were many unique features that made oil news. The first large California gusher was brought in when No. "Hartnell" 1 blew in and flowed 10,000 barrels a day for several months. The deepest wells in the world were being drilled in the field, to a total of 5,000 feet. A feature that is remarkable today is that wells drilled 35 years ago are still producing 50 to 100 barrels a day of clean oil.

STRATIGRAPHY

The Sisquoc formation outcrops over the higher parts of the structure with the younger beds lapping up on the flanks.

The following table shows the geologic section present:

Age	*Formation*	*Thickness in feet*
Recent and Pleistocene	Alluvium and gravels	0- 150
	Terrace deposits	0- 100
	Unconformity	
Pliocene	Careaga	0- 300
	Unconformity	
	Foxen siltstone	0-1200
	Unconformity	
	Sisquoc diatomite	1800-2200
	Unconformity	
Miocene	Monterey	2150±
Miocene (?) (and older)	Lospe	1200-2400
Jurassic (and older)	Franciscan	

STRUCTURE

The structure of the Santa Maria field appears to be essentially an asymetric dome, with the south and southwest flanks having gentle dips, while the steeply dipping north and northeast flanks are complicated by two faults having large displacements. It is very possible that these faults are the actual boundaries of a south- and southwest-dipping monocline, and that the apparent dip reversals to the north and east are simply dips caused by drag against the fault. There are several east-trending minor faults with surface displacements up to several hundred feet.

PRODUCTIVE HORIZONS

There are three producing horizons in the Santa Maria field.

The First oil zone is basal Sisquoc sand and fractured shale. This zone is only productive far out on the south flank of the structure.

The Second oil zone consists of fractured hard siliceous shale and chert. The top of the zone is from 400 to 500 feet below the top of the Monterey.

The Third oil zone consists of interbedded brown shale and oil-saturated sand at the base of the Monterey. The top is 500 to 600 feet below the Second oil zone. The age of these sands has always been questionable, but recent work definitely proves that they occur in the lower part of the *Valvulineria californica* zone.

KIND OF OIL

The gravity of the oil ranges from 14 to 19 degrees Baume in the First zone, to 24 to 29 degrees in the Third zone.

* Union Oil Company of California. Manuscript submitted for publication February 10, 1940.

WEST CAT CANYON AREA OF THE CAT CANYON OIL FIELD

By CHARLES MANLOVE *

OUTLINE OF REPORT

HISTORY

The West Cat Canyon area of the Cat Canyon oil field is located about 12 miles southeast of the city of Santa Maria, Santa Barbara County. It lies mainly in the N½ Sec. 26 and the S½ Sec. 23, T. 9 N., R. 33 W., S. B. Acreage in the field is now held by the Union Oil Company of California, the Palmer Stendel Oil Corporation, the Gilmore Oil Company, and the Standard Oil Company of California.

Development of this area began in 1908 with the drilling of the No. "Palmer" 1 well (now Palmer Stendel Oil Corporation's No. "Blochman" 1) by the Palmer Union Oil Company. The well was drilled to a depth of 3,200 feet, and initially produced 150 barrels per day (14 to 16 degrees Baume oil) from the oil sand near the base of the Pliocene Sisquoc formation, but, after being cleaned out, suddenly began to flow at the phenomenal rate of 6,000 to 10,000 barrels per day. For 2 years thereafter it flowed steadily at the rate of 1,400 to 1,500 barrels per day (Orcutt 12, p. 43). Later the well sanded up and was finally abandoned. No. "Palmer" 2, drilled in 1909 by the same company, also was completed as a relatively small producer, but later produced as much as 8,500 barrels per day; it is a small but steady producer at the present time. Union Oil Company's No. "Bell" 5 flowed for a time at the rate of 5,000 to 6,000 barrels per day. Other wells of the area had initial productions of from 150 to more than 300 barrels per day, some having a tendency to flow for a time. Most of the area has been fairly well developed, except for the Union Bell and Blochman tracts on the structurally highest portions.

Most wells on the Union Bell and Blochman tracts are now shut in. Many wells in the northwestern and northeastern parts of the area, on the Standard, Gilmore, and Palmer Stendel properties, have been abandoned on account of water and sand trouble. At present only five wells (Palmer Stendel Oil Corporation's Nos. "Blochman" 2, 1A, 3, 5, and 8) are producing. These wells produce 8,000 to 10,000 barrels of 11 to 16 degrees Baume oil, which is bought by the Union Oil Company of California and pumped directly to the Gilmore Oil Refinery in the field.

* Union Oil Company of California. Manuscript submitted for publication June 17, 1938.

CITATIONS TO SELECTED REFERENCES—Continued

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Gracioso (Santa Maria) Oil Field
Burkhart, H. W. 10.

La Graciosa (Santa Maria) Oil Field
Eldridge, G. H. 03.

Orcutt (Santa Maria) Oil Field
Van Tuyl and Parker 41.

CAT CANYON OIL FIELD

Arnold, R. 15; Bell, H. W. 18; Collom, R. E. 17; 18; 29; Dolman, S. G. 30; 39; Gore, F. D. 22; Masser, H. L. 22; McCabe, R. E. 25; McCollough, E. H. 34; McLaughlin and Waring 14, p. 403 et seq.; Mining and Scientific Press 10; 11a; Porter, W. W. II 38; Prutzman, P. W. 13; Ries, H. 30; Robertson, G. D. 29; Smith, H. D. 13; Taff, J. A. 34; Vander Leck, L. 21, pp. 104-105.

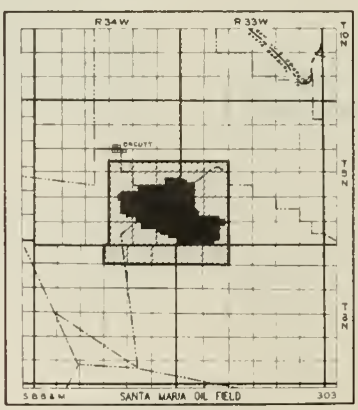
East Cat Canyon Area
Van Tuyl and Parker 41.

Gato Ridge Area
Arnold and Anderson 07c; Kemnitzer, L. E. 36; Oil Bulletin 31; Porter, W. W. II 39b; Van Tuyl and Parker 41.

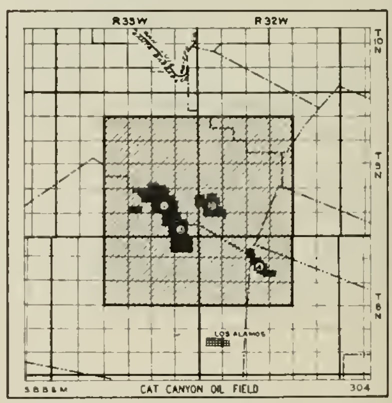
Las Flores (West Cat Canyon) Area
Wilhelm, V. H. 39a.

Los Alamos (Los Alamos Rancho) Area
Bell, H. W. 18; Collom, R. E. 18.

West Cat Canyon Area
Hoots, H. W. 39.



Santa Maria oil field.



Cat Canyon oil field. Areas: (1) West Cat Canyon; (2) East Cat Canyon; (3) Los Alamos; (4) Gato Ridge.

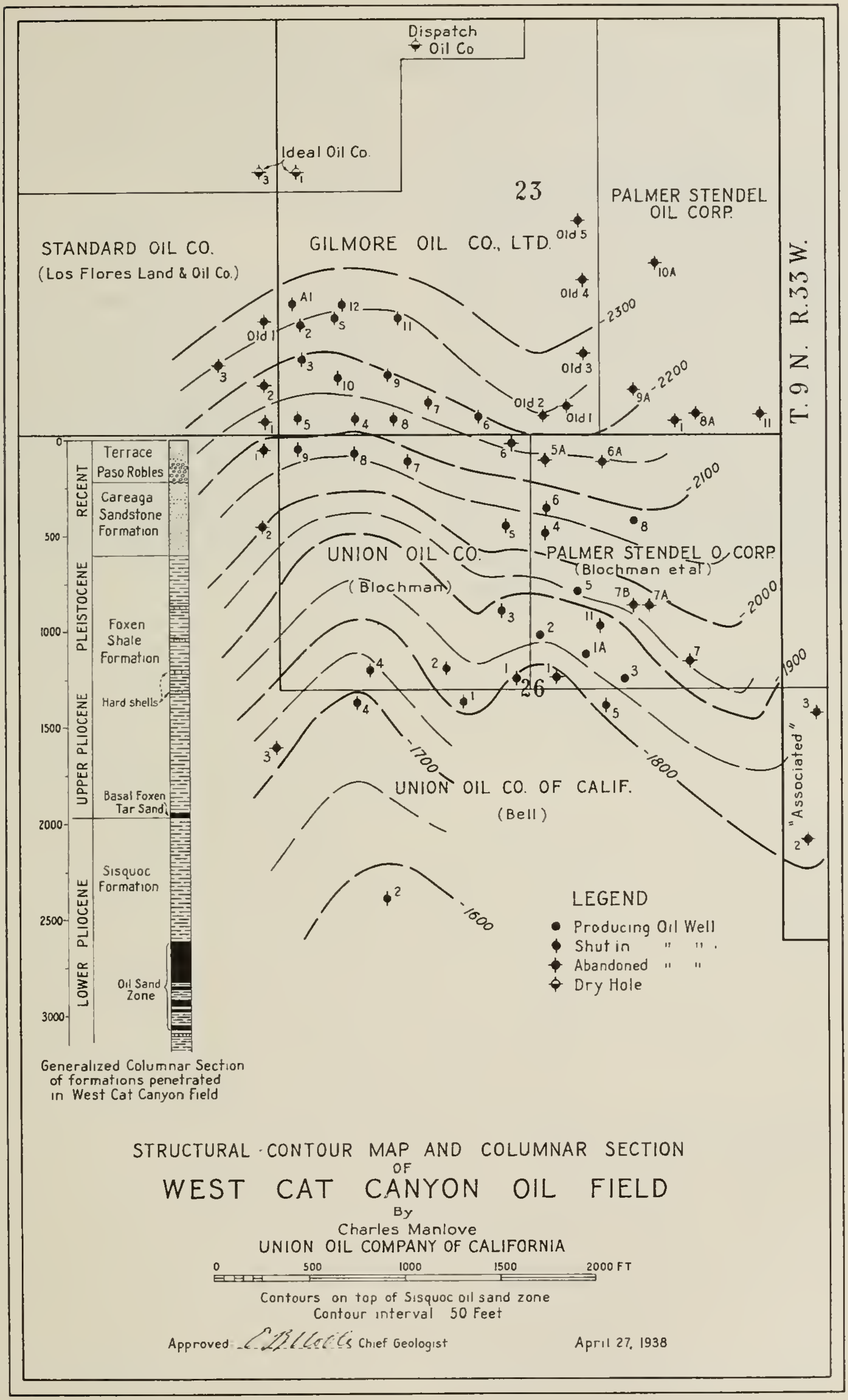


Fig. 178. West Cat Canyon area of the Cat Canyon oil field: structure map; columnar section.

STRATIGRAPHY

The majority of the wells in the West Cat Canyon area were drilled to depths varying from 3,000 to 3,500 feet, according to structural location. The deepest well in the field is No. "Las Flores" 3 (SE¼ Sec. 22, T. 9 N., R. 33 W., S. B.) which was deepened in 1917 by the Union Oil Company to a depth of 4,581 feet. The wells penetrate a few feet of relatively thin sandstone-terrace capping and 300 feet of the Paso Robles formation, consisting of clay shales, brown to yellow sandstone, thin fresh-water limestone beds, and white siliceous-shale gravel beds. Unconformably below the Paso Robles formation lies 400 feet of the Careaga sandstone formation, characterized in outcrop by fine yellow and white sand with a fossiliferous, calcareous sandstone "reef" ("sand dollar bed") near the middle. Below the Careaga sandstone formation is 1,350 feet of the Foxen shale formation, consisting of gray shale with occasional thin sandstone beds. A bed of tar sand about 25 feet in thickness occurs at the base of this formation. A thickness of 1,300 feet or more of the Sisquoc formation has been penetrated in the West Cat Canyon wells. The upper silty and diatomaceous shale interval of the Sisquoc formation between the base of the Foxen tar sands and the top of the Sisquoc producing oil sand zone has an average thickness of 650 feet in the field. The lower Sisquoc oil sand zone is 500 to 600 feet in thickness; it consists of beds of oil sand, ranging in thickness from 5 to 200 feet, separated by beds of blue and brown shale of the same range of thickness.

No well in the area is definitely known to have penetrated the middle Miocene Monterey formation, although Union Oil Company's No. "Las Flores" 3 may have reached it. The information from the driller's log, which is the only available information, is too meager to establish this fact.

STRUCTURE

The structural features of this area are quite as interesting as the longevity and peculiarly high initial production of some of its wells. There is no evidence of the structure at the surface, although the gently flexed Las Flores and Gato Ridge Pliocene anticlines on either side of it may be determined from the dips of outcropping formations. Structural contours on the top of the Foxen tar sand or the lower Sisquoc oil-sand zone show the structure of the area to be a northwest-plunging anticlinal nose developed on the north flank of the northwest-trending Las Flores anticline. Since there is no evident structural closure, the accumulation and retention of the oil is thought to be effected mainly by the lensing nature of the sands of the lower Sisquoc oil-sand zone.

EAST CAT CANYON AREA OF THE CAT CANYON OIL FIELD

By Rodman K. Cross*

OUTLINE OF REPORT

HISTORY

The East Cat Canyon area of the Cat Canyon field is situated in T. 9 N., R. 32 W., S. B., 13 miles southeast of Santa Maria in Santa Barbara County. The area was discovered by the Brooks Oil Company in 1909, when their well No. 1, drilled with cable tools to a depth of 2,615 feet, was completed pumping an initial daily rate of 150 barrels of 10 degrees A.P.I. gravity oil from lower Sisquoc (lower Pliocene) sands.

The first test for oil in this immediate district was made by the Recruit Oil Company, a subsidiary of the Associated Oil Company, in 1904. This well, now known as the Gilmore Oil Company, Ltd., No. "Associated" 1 was drilled to 3,563 feet. Heavy oil entered the 4-inch hole at this point and was allowed to stand over night. The oil, chilled by contact with the drilling fluid, became too viscous to permit the lowering of tools to bottom, and resulted in the abandonment of the hole.

Other early operators active between 1909 and 1914, included the Pinal Dome Oil Company, New Pennsylvania Petroleum Company, and the West Oil Company. These ventures failed to produce commercial amounts of oil largely because of mechanical difficulties, although in most instances favorable indications were logged.

The Palmer Union Oil Company completed its first well in 1915 and was closely followed by the United Consolidated, Union of California, Henderson, Stone-Goodwin, and Santa Maria oil companies, in the development of the East Cat Canyon area. The Palmer Union and Brooks oil companies were the most active operators in the early period of drilling from 1909 to 1919. This decade marked the drilling of 21 wells by means of cable tools to depths ranging from 2,500 to 4,200 feet, to test the productivity of the lower Sisquoc sands. The second period of drilling started in 1924 and was carried through to 1929 by the Brooks, Palmer Union, R. & G., Golconda, and Marland interests. This revival witnessed the use of rotary equipment in addition to cable tools and the exploration of possible production from the Miocene strata. Four serious attempts were made to find production in the Monterey formation: the first by the Marland Oil Company in 1926; the second by the Golconda Oil Company in 1928; the third, the Palmer Union deep test (No. "Stendel" 20) which was carried to a depth of 7,200 feet in 1929; and the fourth, by the Winnan Oil Company in 1929. Heavy oil showings were obtained in the Monterey formation in each of these tests, but the oil was either too heavy or of insufficient quantity to be commercial.

Upon the completion of its discovery well in 1909 the Brooks Oil Company constructed a 6-inch pipe line to a branch of the Pacific Coast Railroad located near Blockman, about 2 miles to the northwest, and shipped oil by rail during 1910. In 1911 the Associated Oil Company contracted the Palmer Union production from the West Cat Canyon area and built an 8-inch pipe line from its Lewis Station in Cat Canyon to the Careaga Station, where it tied into the main Santa Maria-Gaviota line which had been constructed in 1907. The Brooks pipe line was redirected to the Lewis Station in 1911 and the major part of the East Cat Canyon crude was shipped through it to the Associated Oil Company's marine terminal at Gaviota. Because of the high viscosity of the oil, it was found necessary to blend it with sufficient distillate at the initial shipping station to raise the gravity from 10 degrees to 16 degrees A.P.I., and to heat the oil to 160 degrees Fahrenheit, to prevent plugging of the line.

The field has been idle since 1930 due to insufficient demand for heavy crude except during the years 1935 to 1937 inclusive when minor amounts of oil were trucked out by the Dolly Adams' interests. To date 54 wells have been drilled, of which 12 were dry holes, 2 are abandoned producers, 2 were converted into water wells, and the remaining 38 are shut in.

STRATIGRAPHY

The Paso Robles (Pleistocene) formation consists of interbedded ill-sorted conglomerate, sand, and clay of continental origin with common thin, fresh-water limestone beds at the base. The conglomerate is composed largely of siliceous shale pebbles, which distinguish it from the black igneous pebble conglomerate of the upper member of the Careaga (upper Pliocene) formation. The latter ranges in thickness from 50 to 250 feet and is in part marine. The lower member of the Careaga, 350± feet thick, is composed of yellow-buff, loose, fine-grained sand marked locally at the top by a 1- to 4-foot calcareous sandstone bed which contains abundant *Dendraster* sp.

The Sisquoc (lower Pliocene) formation is 1,800 to 2,500 feet thick and lies disconformably below the Careaga. The top of the formation is encountered in wells at depths ranging from 300 to 1,500 feet, and crops out up plunge where Howard Canyon crosses Gato Ridge. The Sisquoc consists largely of interbedded siltstone and claystone in the upper part, grading downward into coarser-grained sediments. The lowermost beds of sand appear to buttress up-dip against the Monterey (Miocene) formation and thereby form a stratigraphic trap for the retention of oil.

The Palmer Union Oil Company in its No. "Stendel" 20 well took random cores from depths between 3,176 and 7,199 feet. Serpentinous metamorphics and slickensided black shale were logged from 4,428 to 4,868 feet, below siliceous shales of the Monterey formation. The

* Geologist, Richfield Oil Corporation. Manuscript submitted for publication January 1, 1940.
The writer is indebted to F. E. Bedichek, L. T. Thompson, G. L. Fuller, R. Sturgeon, S. G. Dolman, and H. W. Hoots for information which aided in the preparation of this paper, and to the Richfield Oil Corporation for permission to publish it.

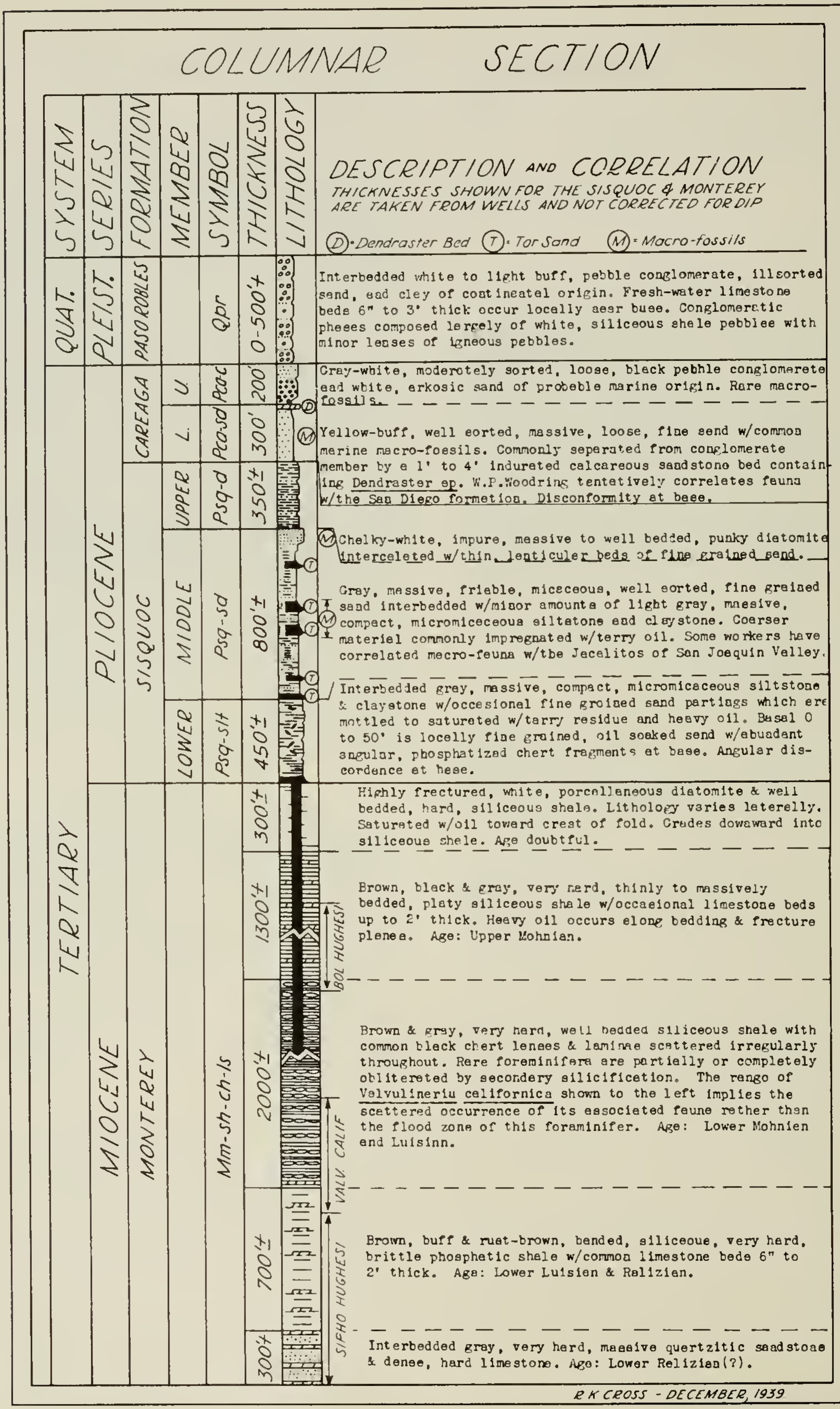


FIG. 179. East Cat Canyon area of the Cat Canyon oil field: columnar section.

age of the subjacent greenish-gray quartzitic sandstone, dark-gray shale, and hard, fine-grained massive sandstone encountered from 4,868 feet to bottom is questionable. A fragment of *Pecten andersoni* has been reported at a depth of 6,550 feet, but the identification is doubtful.

STRUCTURE

The East Cat Canyon area is situated down the northwest plunge of the Gato Ridge anticline a distance of 3 miles from the surface apex of the fold. The surface geology is expressed in the Paso Robles (Pleistocene) and Careaga (upper Pliocene) formations. These strata arch around the northwesterly plunge of this gentle upwarping and, to the southwest, pass into the shallow syncline which separates the two Cat Canyon areas.

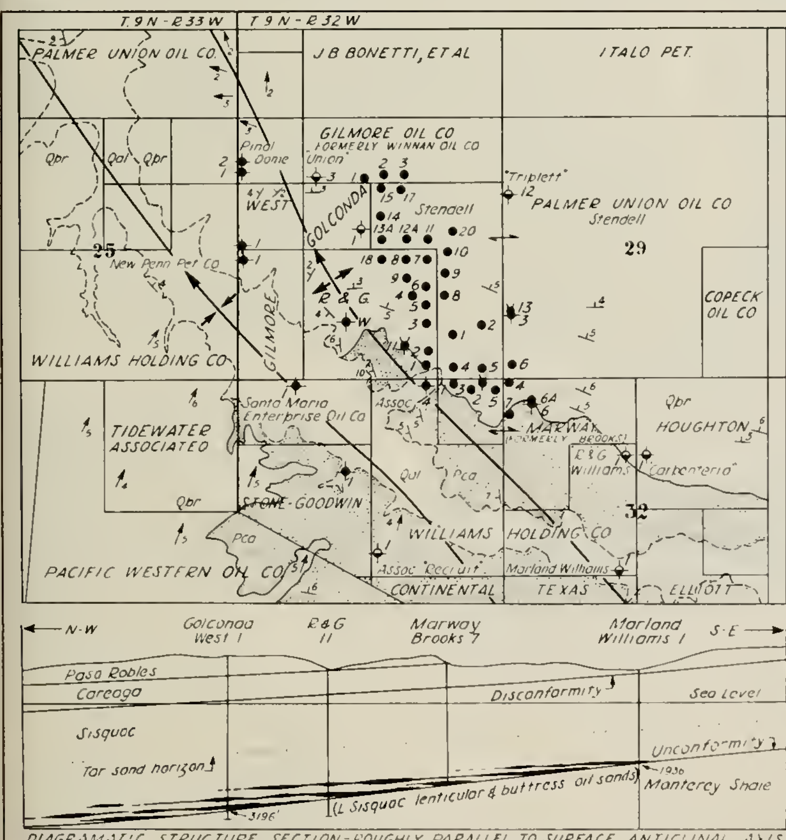
PRODUCTION AND KIND OF OIL

The bulk of production is taken from lower Sisquoc sands which buttress up-dip against the Monterey formation. These sand beds, apparently lenticular in character, range from thin stringers up to 200 feet in thickness.

The oil in the majority of the East Cat Canyon wells is 10 degrees A.P.I. gravity and cannot be effectively produced by pumping because of the high viscosity of the crude. Experimentation with gas lift augmented by heat treating and dilution with distillate has made production of this heavy oil possible. The wells are generally tubed high with 4¼-inch tubing. A 1-inch flow line is wired to the tubing and screwed into the flow head at bottom. Distillate is mixed with gas at the rate of 2 barrels per hour and superheated to 240 degrees Fahrenheit. This mixture is then forced through the flow line under average pressures of 650 to 700 pounds per square inch. Initial pressures commonly as high as 1,200 to 1,500 pounds per square inch are sometimes necessary to start the flow. The crude, upon reaching the surface, is passed through Trumble gas traps to remove the gas and distillate which are then piped to the compressor and from there back to the well.

A few of the structurally higher wells pump 12 degrees gravity oil although considerable rod and tubing trouble results from a 4 to 5 percent cut of sand. Some operators believe that small production is obtained from the Monterey formation in several of the early cable-tool wells. Later wells, however, drilled to test the productivity of the siliceous shale, have found only non-commercial quantities of 8 degrees gravity oil in these underlying Miocene strata.

Initial daily production of individual wells ranges from 10 to 300 barrels of 9 to 12 degrees A.P.I. gravity oil. The average daily production per well for the entire field during productive periods from 1916 to 1937 amounted to about 68 barrels. The absence of production figures prior to 1916 prevents an accurate statement of the total production, but this figure is thought to closely approach 3,750,000 barrels.



GEOLOGICAL MAP OF THE EAST CAT CANYON OIL FIELD
T9N-R32W S.B.B.&M. - SANTA BARBARA CO
DECEMBER, 1939 - RODMAN K CROSS
SCALE IN FEET: 2000 1000 0 2000 4000 6000

LEGEND

PLEISTOCENE	Qpr	PASO ROBLES
PLIOCENE	Pca	CAREAGA
	Psq	SISQUOC
MIOCENE	Mm	MONTEREY

● PRODUCING WELL — IDLE PRODUCING WELL — ABANDONED PRODUCING WELL — ABANDONED NON-PRODUCING WELL — WATER WELL

PRODUCTION STATISTICS

YEAR	R & G	PALMER UNION	MARWAY Gwin	MARWAY Shell	GILMORE Winnan	STONE-GOODWIN	TOTAL PROD
1916		46,186					46,186
17	18,605	65,711					84,356
18	24,859	62,584	3,816				91,259
19	37,572	27,005	9,724				74,301
20	52,216	44,233	11,317				107,766
21	25,580	42,660	9,854				78,094
22		33,144	8,897				42,041
23		26,216	10,260	33,535			70,011
24		29,354	11,765	48,914			90,033
25	62,286	34,590	73,951	42,076			212,903
26	222,051	?7,352	87,956	16,907		9,386	413,652
27	350,120	229,569	69,903			2,714	652,306
28	266,937	336,784	54,188		72,500		730,409
29	85,787	218,417	29,861		59,155		393,220
30	30,507	148,646	12,549				191,702
31							
32							
33							
34							
35		3,900	16,980				20,880
36		1,100	25,510				26,610
37	16,601	70,130	11,560				98,29.
TOTAL	1,193,121	1,497,621	448,09.	14,432	131,655	12,100	3,424,020
AVERAGE DAILY PRODUCTION PER WELL PER LEASE	83±bbls	66±bbls	47±bbls		24±bbls	60?bbls	68±bbls FIELD AV

Production figures prior to 1916 not available

FIG. 180. East Cat Canyon area of the Cat Canyon oil field: map; diagrammatic structure section; production statistics.

GATO RIDGE AREA OF THE CAT CANYON OIL FIELD

By Rodman K. Cross *

OUTLINE OF REPORT

HISTORY

Gato Ridge is a prominent topographic and anticlinal feature situated about 3½ miles north of Los Alamos in the Santa Maria district, Santa Barbara County. In 1904, an unsuccessful well, the No. "Pezzoni" 1, was drilled here by the Recruit Oil Company. The first published geologic report on the area was by Ralph Arnold and Robert Anderson (07c) of the United States Geological Survey. This report influenced the location of numerous wildcat wells in the area, and drilling started in 1911.

Nearly all of these early wells recorded numerous showings of heavy oil, and several of them produced small quantities of a 9 to 16 degrees A.P.I. gravity crude for a limited period. The Shaw Ranch Oil Company No. 1 and the Standard Oil Company No. "Shaw" 3, drilled in 1915 and 1916 respectively, are said to have developed small production of heavy oil from a depth of about 3,000 feet. The discovery of the field, however, is generally credited to the Barnsdall-Rio Grande Oil Companies, who completed their No. "Tognazzini" 1 on July 23, 1931, for 1,098 barrels per day of 13+ degrees A.P.I. gravity oil. The well was drilled to a depth of 6,512 feet but was plugged to 2,550 feet and completed from an 800-foot zone of fractured Monterey (Miocene) shale. Drilling reached a peak during 1937 with the completion during this year of nine producing wells and one dry hole. Prior to December 1. 1939, a total of seventeen producers and two dry holes had been completed.

* Geologist, Richfield Oil Corporation. Manuscript submitted for publication January 15, 1940.

The writer is indebted to C. W. Johnson, L. E. Kemnitzer, and H. W. Hoots for information which aided in the preparation of this paper, and to the Richfield Oil Corporation and Barnsdall Oil Company for permission to publish it.

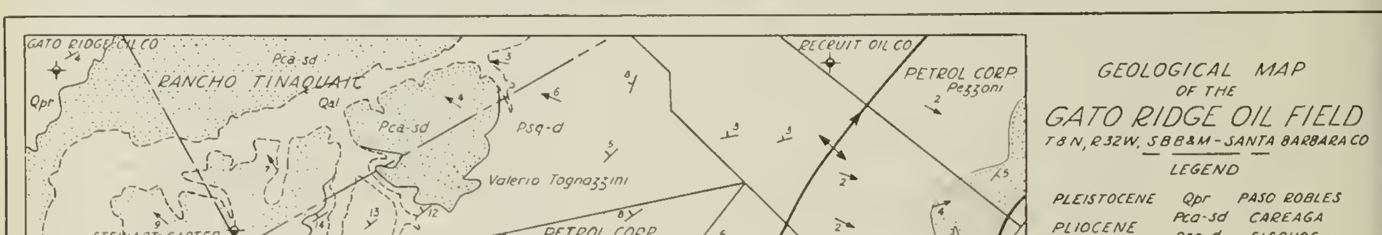


FIG. 181. Gato Ridge area of the Cat Canyon oil field: map; longitudinal structure section; well data.

STRATIGRAPHY

The stratigraphic column is divisible into four cartographic units: (1) Paso Robles formation (Pleistocene); (2) Careaga formation (upper Pliocene); (3) Sisquoc formation (lower Pliocene); and (4) Monterey formation (Miocene). The reader is referred to the accompanying columnar section for lithologic descriptions and correlations of these units. The Monterey formation, topped in wells at depths ranging from 1,725 to 2,500 feet, unlike its counterpart in the Santa Maria Valley field and elsewhere, is not readily divisible into traceable lithologic members nor can it be effectively zoned by micropaleontologists. The bulk of this formation is very hard, and, presumably because of secondary silicification, almost all trace of micro-organisms has been obliterated. It consists of highly fractured, porcellaneous diatomite and moderately hard, siliceous sandy shale in its upper part, and grades downward through very hard, massive to thin-bedded, gray and brown, siliceous shale with chert intercalations, into dense gray quartzitic sandstone. The base of the Monterey has not been penetrated at Gato Ridge, and the age and character of subjacent strata are unknown due to the presence throughout much of the Santa Maria district of a basal Monterey unconformity.

STRUCTURE

The Gato Ridge anticline, reflected at the surface in marine Pliocene sediments, lies near the northeastern edge of the Pliocene embayment of the Santa Maria district. This is indicated by: (1) a pronounced thickening of Pliocene beds southwestward; (2) unconformities accounting for the absence of strata which are present down the regional southwest dip; and (3) lateral changes in the lithologic character of these sediments. A buttress-overlap unconformity exists between the Pliocene and Miocene by reason of which, at Gato Ridge, successively older strata of the overlying Sisquoc formation (lower Pliocene) are encountered down dip and, at least in some areas, these overlap the truncated edges of more steeply dipping Monterey shale (Miocene) strata.

Structural closure of the Sisquoc-Monterey contact within the producing area is about 350 feet. The subsurface structure within the Monterey formation differs considerably due to pre-Sisquoc deformation. Dips from cores taken in the Monterey commonly range from 10 degrees to vertical. The most plausible interpretation appears to be that of a tight, sharply crenulated and faulted fold conforming generally to the Pliocene axis. Some geologists suggest that the structure in the Miocene is a steep southward-dipping homocline broken by a pre-Sisquoc fault which roughly parallels the Pliocene anticlinal axis. Until additional subsurface data are available, however, the exact nature of the structure within the Monterey formation is open to question.

PRODUCTIVE HORIZONS

Production is obtained from two zones. The upper comprises the basal Sisquoc sand and is restricted to the northwest plunge in the vicinity of the O. C. Field wells. This zone to date has yielded only small amounts of heavy oil and the flour-like texture of the sand seriously hampers production by pumping.

The second oil zone, the objective of most Gato Ridge wells, occurs irregularly distributed throughout the upper 2,000± feet of fractured Monterey siliceous shale and porcellaneous diatomaceous shale. Production from the Monterey appears to be controlled by the effective porosity, resulting chiefly from fracturing of the shale, and the structural elevation. Initial daily production of individual wells ranges from 50 barrels to 2,600 barrels of 12 to 13+ degrees A.P.I. gravity oil; daily potentials in excess of 4,600 barrels per day have been established by use of a 6-inch pump and an 8-foot stroke.

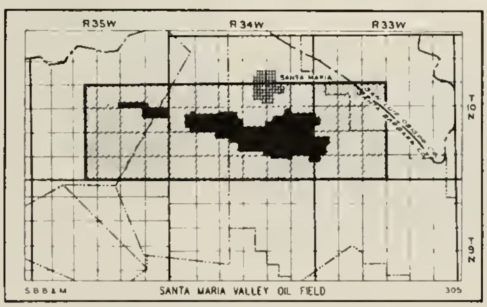
KIND OF OIL

The oil, averaging about 13+ degrees A.P.I. gravity, yields 11 percent gasoline, 22 percent gas-oil, 63 percent asphalt, and 5 percent sulphur. The asphalt is reputed to form an excellent base for roads and roofing materials.

CITATIONS TO SELECTED REFERENCES—Continued

BETTERAVIA AREA
Stockman, L. P. 40, no. 12, p. 63.

SANTA MARIA VALLEY OIL FIELD
Canfield, C. R. 39; Dolman, S. G. 30; 39; Edwards, M. G. 37; Frame, R. G. 38; Hoots, H. W. 38; Oil Weekly 37b; Petroleum World 37c; Porter, W. W. II 37; 38; 39b; Stockman, L. P. 36e; Van Tuyl and Parker 41; Wilhelm, V. H. 38.



Santa Maria Valley oil field

SANTA MARIA VALLEY OIL FIELD

By CHARLES R. CANFIELD *

OUTLINE OF REPORT

HISTORY

The Santa Maria Valley oil field is located in the central part of the Santa Maria Valley in the northwestern corner of Santa Barbara County. The field contains about 5,000 acres of proven or semiproven land. It is slightly over 7 miles long, east and west, and about 2 miles wide, north and south.

From 1912 until the middle part of 1934, approximately 37 wildcats and core holes were drilled in the Santa Maria Valley in search of oil. On July 15, 1934, the Union Oil Company of California brought in the discovery well No. "Moretti" 1, for 50 barrels of 16 degrees gravity crude. However, the fact that another important California oil field had been discovered was not established until March 31, 1936, when the Union Oil Company brought in No. "Adam" 1 for 2,376 barrels. Since the completion of the discovery well in 1934, over 135 wells have been drilled in the field; of these only 10 have been dry holes.

DISTINGUISHING FEATURES

The distinguishing features of the Santa Maria Valley field are as follows: (1) overlap type of trap, with 3,000+ feet of closure on top of the Miocene; (2) production from Miocene, both shale and sand; (3) water drive as a motive power (oil-gas ratio averages only 200:1); (4) low gravity crude (12 to 17.5 degrees Baume), with asphalt base and 4 percent sulphur content.

* Geologist, Stanolind Oil and Gas Company, Midland, Texas. Manuscript submitted for publication June 29, 1939.

STRATIGRAPHY

Most of the following stratigraphic nomenclature for the field has been established by the writer, and in various stages of perfection, has been used successfully for over four years. It is based on a detailed study of more than 175 wells, wildcats, and core holes drilled in the valley. The formations and lithologic subdivisions are shown on the accompanying chart. A brief description of the stratigraphic units found in the field is given below.

Basement Rock

The so-called "Franciscan" basement rock (probably Cretaceous) is moderately folded, faulted, and slightly altered. The rocks vary somewhat in character, but for the most part are of three general types: (1) calcite-veined hard greenish-gray pyritiferous and calcareous sandstone (the main rock); (2) gouge-like steel-gray pyritiferous clay-shale; (3) impure serpentine (dikes and veins).

Monterey Formation

Overlying the "Franciscan" with profound unconformity is the Monterey formation. At present, the term "Monterey" is used to include all of those Miocene beds in the field that lie between the Santa Margarita (?) and "Franciscan." The formation is divisible into seven lithologic zones.

Siltstone and Shell Zone. This zone, the lowest member of the Monterey, is composed essentially of soft to hard gray siltstone, medium-grained sand, and cavernous calcareous sandstone, or "shell." The zone contains a rare foraminiferal fauna characterized by *Valvulineria ornata* and *Uvigerinella obesa.*

Oil Sand Zone. Overlying the siltstone and shell zone by moderate unconformity is a basal sand of the Monterey shale section. It consists of oil-saturated soft to hard fine silty to coarse calcareous sand, containing *Siphogenerina* and *Cassidulina.* This zone is locally absent in the central part of the field, and is very thin in the western part.

Dark-Brown Zone. Overlying the oil sand zone with local disconformity occurs a section of moderately hard, dark chocolate-brown semiplaty foraminiferal shale carrying species of *Siphogenerina.* It is equivalent to a part of the *Valvulineria californica* zone of the San Joaquin Valley.

Buff and Brown Zone. A section of moderately hard, interbedded, chocolate-brown semiplaty and buff-colored phosphatic shales overlie the dark brown zone. A disconformity of sometimes as much as 150 feet separates the two zones. The buff and brown zone is characterized by *Baggina californica* and represents the lower part of the same zone as found in the San Joaquin Valley.

Bentonitic-Brown Zone. Disconformably above the buff and brown zone occurs a section of moderately hard light to dark brown shale, in part thinly laminated and fissile, and in part siliceous and banded. This bentonitic-brown zone is characterized by the presence of streaks and thin beds of variously colored bentonite.

Cherty Zone. Disconformably above the bentonitic-brown zone occurs the cherty zone, a section of fractured, hard, light to dark brown, platy or banded, partly siliceous shale that contains numerous bands of brownish-black and brownish-gray chert. Both the cherty and bentonitic-brown zones are characterized by *Bolivina tumida*, with restricted occurrences of large species of *Bulimina*, *Bulimina uvigerinaformis*, and *Valvulineria robusta*.

Arenaceous Zone. The highest Monterey beds found in the field consist of fractured hard dark brown platy shale, carrying rare to abundant remains of mashed arenaceous Foraminifera. The zone is not present everywhere in the field.

Santa Margarita (?) Formation

In certain parts of the field, above the arenaceous zone, there occurs a section of hard brown semiplaty shale, devoid of nearly all foraminiferal remains. Because of their position in the section, the shales have been called Santa Margarita (?), but it is possible that they may be a younger part of the Monterey. It is suspected that a small disconformity exists between the so-called Santa Margarita (?) and the Monterey, as indicated by the local presence of a thin basal sand. However, there does not appear to be any appreciable discordance between the two formations.

Sisquoc Formation

The Sisquoc formation rests on top of the Monterey, or Santa Margarita (?) with sharp unconformity. The formation consists in part of fossiliferous, moderately indurated, light greenish-gray diatomaceous or punky siltstone, and in part of fine, oily, silty sand. It is characterized by "zones" of *sporbo*, or black phosphatic pellets, and by an interrupted recurring foraminiferal fauna (*Buliminella elegantissima*, *Nonionella miocenica*, and *Virgulina californiensis*).

"Foxen" Formation

Unconformably above the Sisquoc occurs the so-called "Foxen" formation. The "Foxen" may be divided into four lithologic units, which from top to bottom are: (1) gravel members; (2) fine sand members; (3) siltstone members; and (4) tar sand members. The formation is fossiliferous and usually light olive-gray in color. The foraminiferal fauna is characterized successively from top to bottom by *Elphidium hughesi*, *Bulimina pulchella*, *Uvigerina foxeni* n. sp., and unrecognizable arenaceous species.

Paso Robles Formation ("Blue Gravels")

The brackish water gravels immediately overlying the "Foxen" are called Paso Robles. The formation consists of interbedded unconsolidated blue gravels, sands, and clays, containing abundant Monterey shale and chert fragments.

Alluvium and Stream Gravels ("Yellow Gravels")

The youngest formation in the Santa Maria Valley field is the so-called alluvium and stream gravels. The formation consists of interbedded unconsolidated yellowish-brown sands, gravels, and clays, with pebbles and grains of igneous rock and quartzite. They represent the surface deposits that have filled the valley in late geologic time.

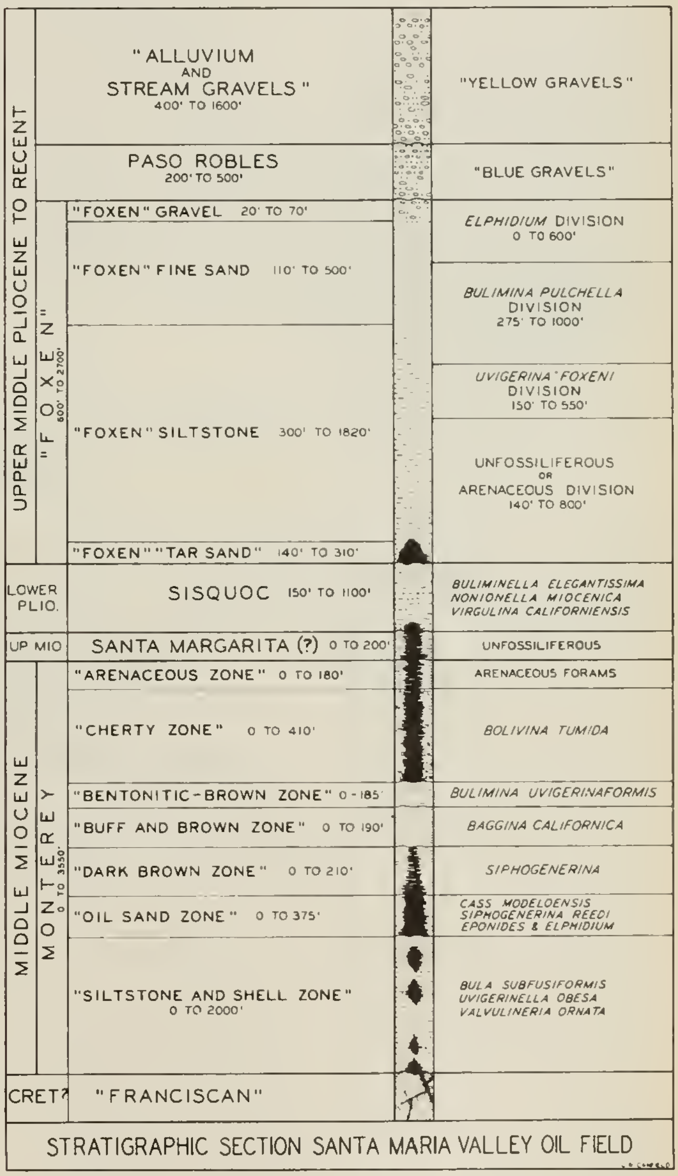


FIG. 182. Santa Maria Valley oil field: stratigraphic section.

STRUCTURE

The field is located on the north limb of the Santa Maria Valley syncline. Over an old irregular surface of a basement rock, called the "Franciscan", the Miocene overlaps northward, buttresses against the overlying Sisquoc, and finally pinches out to the north where the Sisquoc and "Franciscan" come together. Folding and faulting somewhat complicate the Miocene section, which also contains no less than six disconformities.

PRODUCTIVE HORIZONS

The Miocene is the oil-producing formation of the Santa Maria Valley field. It is usually completely penetrated and left open in producing wells. The oil is produced principally from the Santa Margarita (?), and the arenaceous, cherty, dark brown, and oil sand zones of the Monterey. The buff and brown zone is apparently impervious, except where faulted and fractured.

KIND OF OIL

Only heavy asphaltic oil is found in the field. The crude varies from 12 to 17.5 degrees Baume gravity. It contains about 4 percent sulphur, and has only a relatively small percentage of natural gasolines and distillates. The oil is usually clean, cutting around 1 percent, but in a few wells, water has been encountered up to as much as 45 percent. The gas-oil ratio is low, being only about 150 to 200 cubic feet to each barrel of oil.

Between April 15, 1937 and June 30, 1938, the field has produced 3,000,000 barrels of oil. The present curtailed production of the field is 10,000 barrels per day. The potential is 100,000 barrels per day.

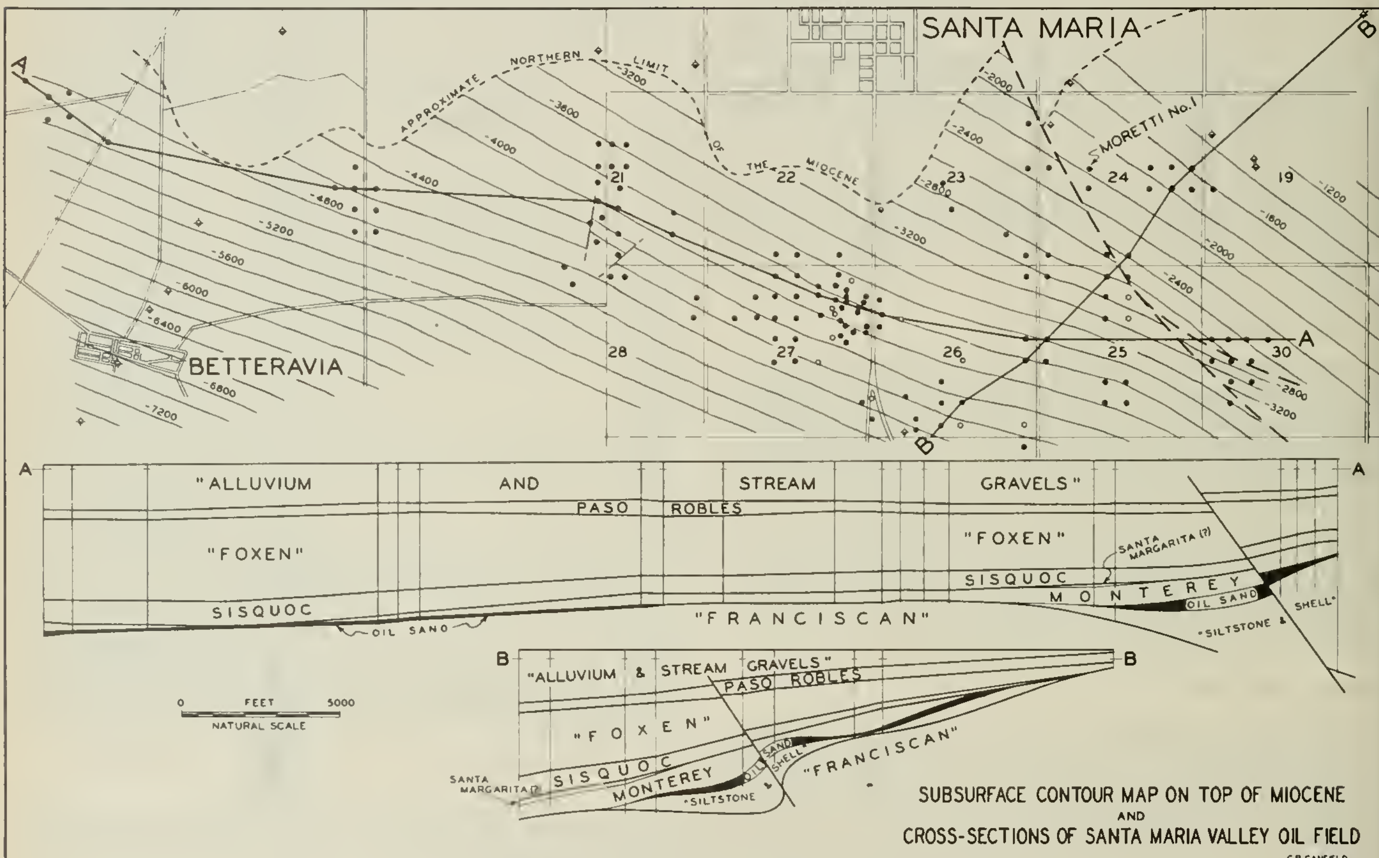


FIG. 183. Santa Maria Valley oil field: structure map; cross-sections.

GEOLOGY OF HUASNA AREA

By N. L. Taliaferro *

OUTLINE OF REPORT

INTRODUCTION

The Huasna district lies in the central part of the Nipomo quadrangle in southern San Luis Obispo County. It takes its name from Huasna River, a tributary of the Cuyama, and from the Mexican grant of 1817 of the same name. The Nipomo quadrangle and much of the Branch Mountain quadrangle to the west have been mapped by students of the University of California under the direction of the writer. Since the results of this work will be published in full in the future only a brief account of the structure and stratigraphy will be given here.

As early as 1898 prospectors were attracted to this district by the extensive seepages, and since that time a total of 31 wells have been drilled. These wells have ranged in depth from approximately 300 feet to 7,238 feet, the latest and deepest having been completed late in 1941. The locations of all these wells and the depths of a few are shown on the accompanying map. Although the results have not been particularly encouraging thus far, the wells that have been drilled can not be said to have condemned the district as a whole, since the majority either have been unfavorably located or have not been carried to a sufficient depth to afford a conclusive test. It is highly improbable that gusher production could be obtained but there are local areas within the district that are worthy of further tests.

STRATIGRAPHY

Pre-Miocene

Sediments and volcanics ranging in age from Upper Jurassic to Recent are exposed within and on the borders of the district. The Franciscan-Knoxville group of Upper Jurassic age is represented by the usual assemblage of clastic and chemical sediments, volcanics, ultrabasic intrusives, and pneumatolytic contact schists. These beds are exposed beneath the Miocene along the Nipomo front in the southwestern part of the quadrangle and below the Cretaceous on Jollo and Alamos Creeks along the eastern border and again beneath the Cretaceous near the center of the northern margin of the quadrangle. They are unconformably overlain by the Lower Cretaceous in the eastern part and by Miocene sediments and volcanics in the western part.

The Lower Cretaceous is represented by fossiliferous conglomerates, sandstones and shales not over 200 feet thick. These beds are unconformably overlain by a great but unknown thickness of Upper Cretaceous clastic sediments, shales, sandstones, and conglomerates. Fossils are very scarce and the exact stage of the Upper Cretaceous represented is, as yet, unknown; but from the meager evidence available it is believed that both the Asuncion and Pacheco groups are represented.

No Eocene sediments are known to be present; it is possible that some of the uppermost beds of the very thick section supposed to be entirely of Upper Cretaceous age might be Paleocene.

The Miocene is represented by fully 9,000 feet of clastic, chemical, and organic sediments and volcanics. There were strong orogenic movements in this region as well as in many other parts of the Coast Ranges during the Eocene, and a great thickness of Cretaceous sediments was removed from the Nipomo ridge, which extends through the southwestern part of the quadrangle, exposing Franciscan rocks. Cretaceous sediments were not removed from the northeastern part of what became the Huasna basin and thus Miocene sediments rest on Franciscan rocks on the southwest and on Cretaceous sediments on the northeast. The contact between Franciscan and Cretaceous is buried beneath the Miocene sediments of the Huasna basin; its exact position is not known but it is believed that Cretaceous beds underlie a fairly large part of the basin.

Miocene

The earliest known Tertiary sediments in the region are red, land-laid beds of Sespe type that lie beneath fossiliferous Vaqueros sediments. These are either late Oligocene or lower Miocene in age; they are included here with the Miocene, although they may be older. Because of subsequent faulting and folding, the exact extent of the basin in which these red silts, sandstones, and conglomerates were deposited is not known. However, they occur in the northern part of the quadrangle where they rest on Upper Cretaceous sandstones and are overlain by fossiliferous Vaqueros; along the central part of the west side of the Nipomo quadrangle where they rest on the Franciscan; and along the Cuyama River. They were found at a depth of 7,100 feet, beneath the Vaqueros, in a well drilled between Phoenix Creek and Clapboard Canyon, in Sec. 11, T. 32 S., R. 14 E., M. D. Marine Miocene beds rest directly on Cretaceous sediments along the east side of the Huasna basin without any intervening red beds. These Sespe-type continental red beds have a maximum thickness of 600 feet in the Nipomo quadrangle; to the east, in the Branch Mountain quadrangle, they are over 3,000 feet thick. These red sediments are not shown on the accompanying sketch map since they outcrop at the surface outside the limits of the area shown. However, they are known to be present beneath the Miocene along the western side of the area.

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Manuscript submitted for publication February 20, 1942.

Downwarping at the beginning of the Miocene (or in the late Oligocene) permitted the sea to spread through the Huasna basin between the Nipomo ridge on the southwest (Franciscan basement) and La Panza Island (granitic and Upper Cretaceous basement) on the northeast. The Vaqueros sea spread over an area of considerable topographic relief and, naturally, first flooded the lowlands, and, as downsinking continued, gradually spread over larger areas. For this reason the thickness, as well as the character of the Vaqueros, varies considerably. On the northeast side of the Huasna basin (southwest side of La Panza Island) the sea did not reach the present location of the lower Miocene outcrops until late in Vaqueros time, and left but a thin record of fine-grained sandstones 100 to 200 feet thick. On the southwest the sea spread over the more diversified topography of Nipomo ridge and here there is a much greater range both in thickness and lithologic types. So great was the relief along this margin of the basin that it is not unusual to find middle Miocene sediments resting directly on the Franciscan only a short distance from a considerable thickness of Vaqueros. Along this margin the thickness of the Vaqueros varies from nothing to as much as 1,500 feet and the lithologic types from fine sands and silts to coarse conglomerates and serpentine slide breccias.

There was local volcanism during the Vaqueros resulting in coarse augite dacite agglomerates between Tar Springs and Arroyo Grande Creeks but maximum volcanism did not begin until after the deposition of the Vaqueros. The maximum thickness of volcanics is found along the Nipomo front, southwest of Los Berros Creek where there is a variable thickness of rhyolite tuffs and sediments overlain by at least 2,000 feet of pyroxene andesite, basalt, and olivine basalt flows, which are in turn overlain by siliceous middle Miocene sediments. The rhyolite tuffs are preesnt along the western border of the Nipomo quadrangle north of Tar Springs Creek but the andesites and basalts are not. The thickness of the rhyolite tuff varies greatly, depending on the proximity to submarine centers of explosion. Since the explosions were submarine the distribution of the ash depended chiefly on ocean currents and there is rapid variation in thickness, an even greater variation than in the case of most subaerial explosions. The andesite and basalt flows were followed by intrusions of soda rhyolites which occur in both the basic volcanics and the sediments as sills, dikes, and plugs. These were in turn followed by sills of analcite diabase.

All of the volcanics are confined to the southwest side of the Huasna basin, none being present along the northeast side. How far beneath the basin they extend is not known; a well drilled to a depth of 5,627 feet a short distance west of Phoenix Creek encountered a sill of analcite diabase and a considerable thickness of rhyolite tuff.

There is no unconformity between the Vaqueros and the overlying organic and siliceous Miocene shales. In fact, deposition appears to have been continuous within the Huasna basin throughout the Miocene, although there were uplifts on the margins in the upper Miocene, resulting in an influx of coarser detritus.

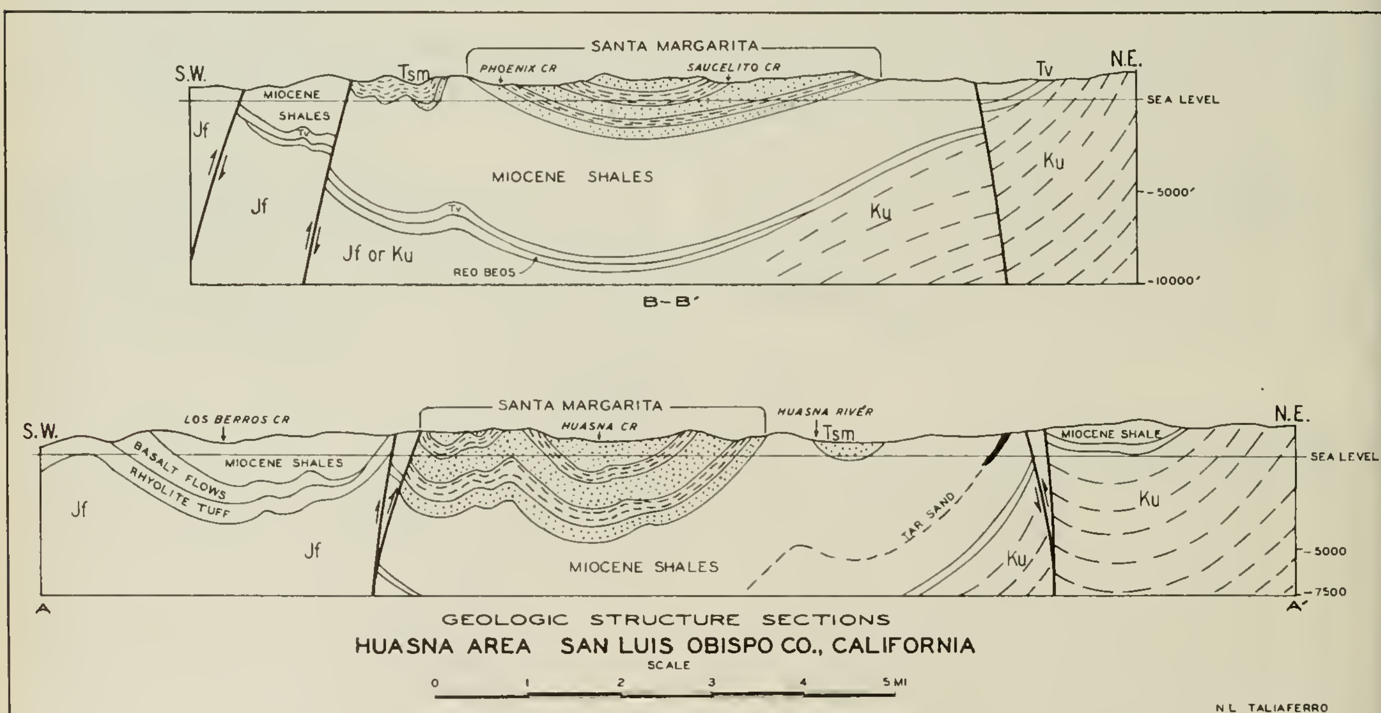


FIG. 184. Huasna area: geologic structure sections.

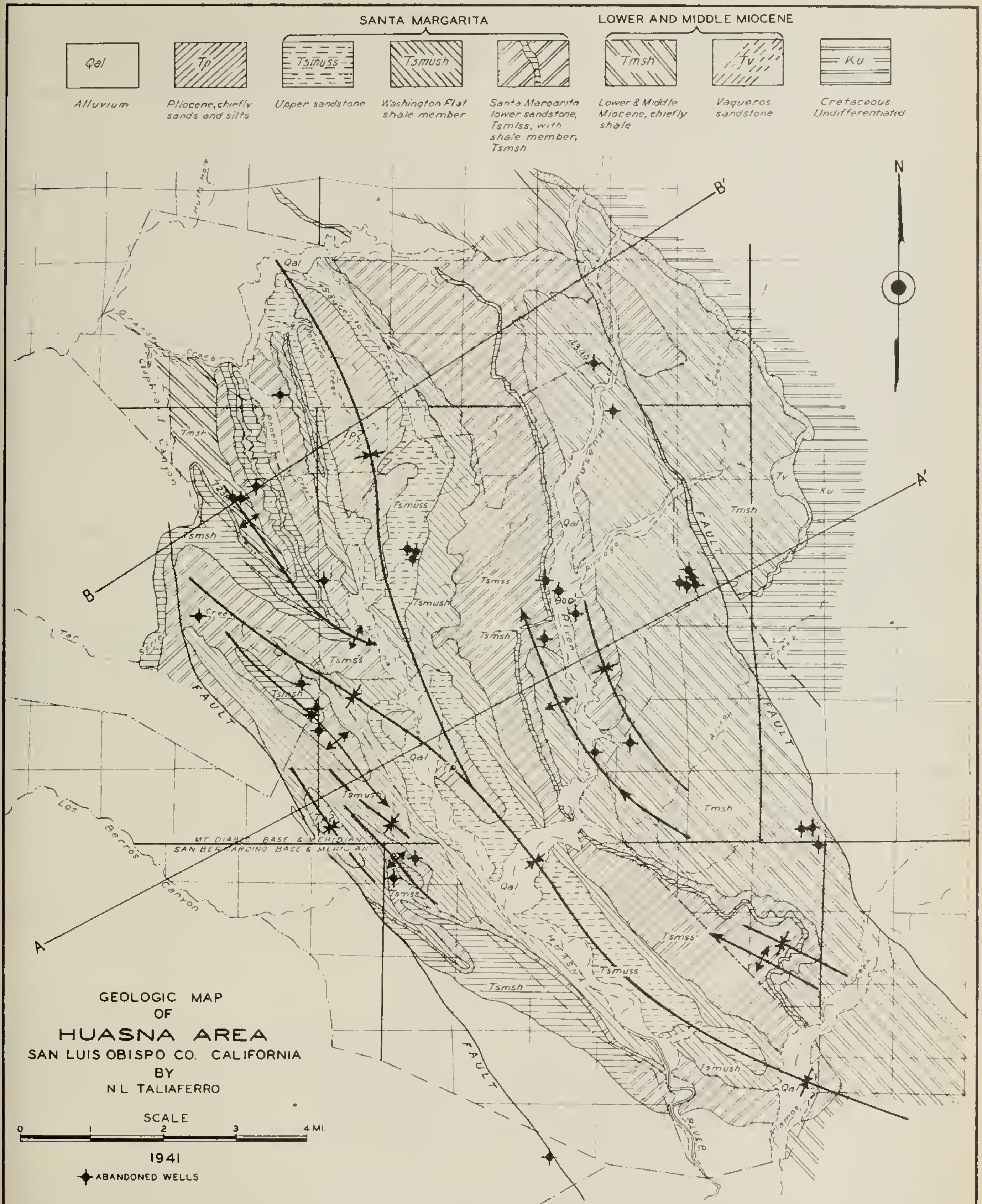


FIG. 185. Huasna area: geologic map.

During the early phases of andesitic and basaltic volcanism along a part of the western margin of the basin foraminiferal marls and silts accumulated in regions wholly or partially free from volcanism. These marls and silts were followed by siliceous shales, impure cherts, and occasional siliceous magnesian limestones. The silts, marls, volcanics and siliceous sediments are, for convenience, referred to as middle Miocene although the upper part of this thick shale sequence may be upper Miocene. These shales have variable outcrop thickness. Along Aliso Creek, on the east side of the basin, they have an outcrop thickness of 5,250 feet but the base is concealed beneath the eastern fault; they are probably over 7,000 feet thick in this region. North of Arroyo Grande Creek they are 5,750 feet thick. In a deep well drilled in Sec. 11, T. 32 S., R. 14 E., M. D., the Vaqueros was encountered at a depth of 7,050 feet. Since this well started just below the Santa Margarita contact it passed through more than 7,000 feet of "middle" Miocene shales; these shales are much thicker here than at the outcrops to the north and east. It is probable that these beds are thicker in the central part of the basin than along the margins. The information available from wells indicates that this is the case.

The beds between the Vaqueros and the first "Santa Margarita" sandstones are of middle and lower upper Miocene age; they represent all the foraminiferal stages from the Zemorrian through the Luisian. Seepages are numerous in these shales and the sandstones occasionally interbedded with them are usually impregnated with tar at the outcrop. They are an adequate source of oil.

The appearance of the first thick coarse sandstones is taken as the beginning of the Santa Margarita but unfortunately these sandstones do not appear at the same horizon everywhere throughout their full extent in the Nipomo quadrangle. The most valuable unit for the purpose of correlation is the lowermost shale member in the Santa Margarita. When the lowermost Santa Margarita sandstone lenses out, resulting in a gradational shale on shale contact, it is possible to carry the contact onward to the next appearance of the lowermost Santa Margarita sandstone. Hence it is believed that the contact shown between the "middle" Miocene shales and the Santa Margarita is essentially a time contact throughout the entire area.

In the Huasna district the Santa Margarita consists of sandstones, silts, and siliceous shales, the latter being lithologically indistinguishable from the underlying middle Miocene shales. Siliceous shales and silts predominate in the southern and western part of the basin and sandstones in the eastern and northern part, indicating an uplift of a part of La Panza Island in the upper Miocene.

Fossils from the lowermost Santa Margarita sandstone indicate a Cierbo age. Thus the Santa Margarita, as mapped in the Nipomo quadrangle, is equivalent to the Cierbo and younger beds of the standard San Pablo section of the San Francisco Bay region. The Briones stage of the San Pablo is, therefore, included in the shales mapped as "middle" Miocene.

There is no unconformity between the "middle" Miocene shales and the Santa Margarita. The uplifts on the margins of the Huasna basin, which resulted in an influx of coarser detritus into the basin, did not disturb the basin in which deposition was continuous.

Several sections of the Santa Margarita were carefully measured with the plane-table. A 4.5-mile section measured across Phoenix and Saucelito Creeks, south of Arroyo Grande Creek, gave a thickness of 2,000 feet, not including the upper 600 feet of highly fossiliferous sandstones in the trough of the syncline. Paleontologists have not agreed on the age of these uppermost sandstones, some placing them in the uppermost Miocene, others in the lowermost Pliocene. They are shown on the accompanying map as Pliocene but the writer regards them as either uppermost Miocene or as transitional between the Miocene and the Pliocene. If they are uppermost Miocene the total thickness of the Santa Margarita is 2,600 feet in this part of the basin.

There is a very complete Miocene section in the Huasna region, starting with the pre-Vaqueros red beds (which may be Oligocene) and continuing through the Santa Margarita. Deposition was continuous and there are no breaks or unconformities within the Huasna basin where a thickness of 8,000 to 10,000 feet of Miocene sediments and volcanics accumulated. However, to the east, on the margin of La Panza Island, there is at least one important unconformity. This will be described in a future paper on the Nipomo and Branch Mountain quadrangles.

Pliocene

The only undoubted Pliocene in the Huasna basin occurs along Huasna Creek, just north of its junction with Huasna River, in the trough of the long Huasna syncline. Here there are approximately 600 feet of tightly folded abundantly fossiliferous silts and sands that are equivalent to the Etchegoin as originally defined in the Coalinga region. No fossils indicating a Jacalitos age have been found, unless the beds in the trough of the syncline between Phoenix and Saucelito Creeks are Jacalitos. However, as previously stated, they are regarded by the writer as uppermost Miocene. The Etchegoin-Santa Margarita contact is so poorly exposed that it is impossible to determine the exact relations. There is no marked difference in attitude between the two but since some of the upper Santa Margarita beds appear to be missing it is believed that slight uplift and erosion occurred between the Santa Margarita and the Etchegoin.

There are no continental Paso Robles sediments in the Huasna basin. If any were ever deposited they have been removed by erosion. There are many relatively thick terrace deposits, especially along Huasna Creek, Huasna River, Suey Creek, and Cuyama River.

Seepages

There are a number of seepages in the Huasna district, some of which are of considerable size. Three types of seepages may be recognized: outcropping tar sands, seepages directly from the source shales, and seepages along fault zones. The majority of outcropping oil sands occur along the east side of the basin, west of the strong fault between Cretaceous and Miocene. These oil sands, which are not far above the base of the section, dip westward and should be present beneath at least a part of the basin. No favorably located wells have reached these sands. Estimates as to the depth at which these oil sands should be reached, based on surface measurements, are in error because of basinward thickening of the sediments.

The outcropping oil sands indicate that oil-bearing horizons might occur in depth but seepages from fractured shales have no significance except that the shales are capable of generating oil; they do not necessarily indicate the presence of productive horizons.

STRUCTURE

The three dominant structural features of the Huasna district are the two roughly parallel faults near the eastern and western margins of the basin and the great Huasna syncline that runs from the northwest to the southeast corners of the Nipomo quadrangle. The two bounding faults are approximately 9 miles apart in the northern part of the area and approach within 5 miles of each other in the southern part. In the north the Huasna syncline is moderately open, the dips not being over 30 degrees, but to the south, where the faults are closer together, it is tightly compressed.

The two faults are near but not on the original margins of the basin. They are high-angle-thrust faults developed in the late Pliocene as a result of the strong compression of the entire region. Their position is, in part, determined by marginward thinning of the sediments; strong folds first formed at these points of initial irregularities caused by thinning, and these finally yielded by high-angle thrusting from each side toward the basin. On the east Cretaceous and Franciscan are thrust westward; on the west "middle" Miocene shales and the Franciscan basement on which they rest are thrust eastward over upper Miocene sediments.

Several anticlines formed on the flanks of the major syncline. A strong anticline, whose crest trends obliquely to the trough of the major syncline, plunges into the central part of the syncline and dies out. This anticline, which lies between Phoenix Creek and Clapboard Canyon, plunges toward the southeast and is completely closed in that direction. However, it has no closure whatever toward the north. The southeastern end is fairly symmetric but the northwestern end is highly asymmetric, the western limb being almost vertical, passing northward into a fault. All of the wells drilled on this anticline thus far have been on the asymmetric, faulted northern end; the writer does not regard them as adequate tests of this particular fold.

There is another well-marked anticline on the eastern flank of the Huasna syncline. This fold develops on the steep eastern limb of the syncline and crosses Huasna River near the eastern boundary of the Huasna grant. Both limbs are steep on the southeast, but become somewhat gentler toward the northwest, in which direction the anticline plunges. It dies out on the eastern limb of the Huasna syncline. It has strong closure on the northwest but none on the southeast. There may be a small amount of surface closure on the southeast but this unquestionably does not exist at depth. Thus neither of the two strongest anticlines are closed. The best chance of obtaining production on these folds would be in lensing sands on their plunging ends. Neither of these folds have been adequately tested as the wells that have been drilled on them either have been unfavorably located or have not been drilled to a sufficient depth. Small production might be obtained from the plunging ends of these folds.

There are two small anticlines having surface closure in the upper part of the Santa Margarita between Huasna Creek and the western fault, and a very small amount of oil has been obtained from two wells on these anticlines. The oil appears to have come from the lower sandstone in the Santa Margarita. Both these folds are very narrow crested and steep limbed. Wells drilled even a short distance from the crest failed to produce oil.

There is a great thickness of organic Miocene shale capable of generating oil, and a number of seepages and outcropping tar sands. Large production could not be expected but there are local areas within the Huasna district that are worthy of being tested.

HUASNA AREA DEVELOPMENT

By Vernon L. King*

OUTLINE OF REPORT

INTRODUCTION

Huasna area, named from a Spanish grant, lies 12 miles east of Arroyo Grande, in southern San Luis Obispo County. It comprises an area about 6 miles by 20 miles in extent, that lies between the southern end of Santa Lucia Mountains and the northern flank of San Rafael Range, both within the Coast Range province. Huasna River, the principal intermittent stream, drains south to the Cuyama—Santa Maria River system.

Throughout the Huasna area are several exposures of oil sands and seepages in connection with evident anticlinal structure. Oil operators were attracted to the region in 1898, and since that time 30 wells have been drilled. Several have produced heavy oil or gas. One well is now drilling to test showings found in an adjoining well drilled last year.

Structurally, Huasna area is a synclinal basin filled with Miocene sediments. The upper, middle, and lower divisions are locally known as Santa Margarita, Monterey, and Vaqueros formations, respectively. The Monterey (and possibly Vaqueros shale also) rests upon Cretaceous along the eastern border of the basin, and upon Franciscan on the west, with faulting evident along both contacts. Several en echelon anticlines exist within the area of Miocene beds on both edges of the elongated basin.

EAST SIDE ANTICLINES

Huasna River

On the flank of the Huasna River anticline in the northeastern portion of the area, the Steiger well was drilled to a depth of 1,100 feet without oil showings. During 1930, Midwest Oil and Refining Company drilled a well located in Sec. 34, T. 31 S., R. 15 E., M. D., to a depth of 4,390 feet. At 2,000 feet, tests indicated 100,000 cubic feet per day of gas. Oil and gas showings were reported at 3,650 feet but were never tested because of water trouble. It is thought that the Cretaceous was encountered.

* Petroleum Geologist, Los Angeles, California. Manuscript submitted for publication August 26, 1941.

Three miles south of the above-mentioned development, oil sands are exposed in the upturned edges of Monterey shale, near its contact with the Cretaceous. One of the five wells drilled during the period 1898 to 1900, the Harkness-Squires No. 4, located in Sec. 13, T. 32 S., R. 15 E., M. D., was reported as a 15-barrel well from a depth of 800 feet. In 1925 some of the old drilling equipment still remained and there was evidence of oil at the location.

Porter Ranch

Porter Ranch anticline is 3 miles south of the North Porter Ranch. It is a well-developed fold in middle Miocene shales, and has an active seepage where Huasna River crosses the axis. During 1930, Union-Calpet well No. "Rust" 1, in Sec. 34, T. 32 S., R. 15 E., M. D., found only minor showings of brea at shallow depths, and was drilled to a depth of 4,156 feet with no further indication of oil. In 1937, the Union Oil Company well No. "Porter" 1, located in Sec. 22, T. 32 S., R. 15 E., M. D., on the northern plunge of the same structure, was abandoned after drilling to 5,110 feet in middle Miocene brown shale, with no evidence of oil sand. The Vaqueros was not reached in either of these wells.

Alamos Creek

Alamos Creek anticline is a prominent structure that crosses Alamos Creek about 3 miles east of Adams Ranch. No wells have been drilled on it, but 2 miles to the north, near the head of Rocky Canyon, two shallow wells known as Downer No. 1 and No. 2 were drilled during 1898. A third well, Clarion No. 1, in Sec. 25, T. 12 N., R. 32 W., S. B., was drilled to 1,700 feet in 1919, but oil showings were reported.

WEST SIDE ANTICLINES

North Huasna

North Huasna anticline is the largest fold on the west side of Huasna Basin. During 1909 the Bedicagk-Phoenix well in Sec. 36, T. 31 S., R. 14 E., M. D., was drilled near the axis of the Huasna Basin syncline. A showing of oil at 3,470 feet was reported, but the well was finally abandoned at 3,675 feet because of water trouble. In 1930 the Union Oil Company "Chandler" well, in Sec. 12, T. 32 S., R. 14 E., M. D., located about half a mile east of the surface axis, was drilled to 5,627 feet and bottomed in lower Miocene or Vaqueros formation. No showings were encountered and the well was abandoned. In 1940 the Tex Harvey Corporation well No. "Gilmore Community" 1, was drilled in Sec. 11, T. 32 S., R. 14 E., M. D., near the surface axis, to a depth of 4,518 feet; 7-inch casing was cemented at 3,520 feet. Subsequent tests between 3,529 and 4,412 feet obtained gas and some light oil in sufficient quantity to warrant a second well which is now being drilled west of the first location.

Tar Springs

Tar Springs anticline extends southeastward from Tar Springs Ranch, so named because of seepages and outcropping oil sands in the vicinity. During 1898, Doheny interests drilled to 875 feet and obtained gas in a flowing water well. Several other wells were drilled without obtaining production. The area lay dormant until 1927, when Barneberg No. 1, Sec. 25, T. 32 S., R. 14 E., M. D., was drilled to 4,499 feet. Good oil showings were reported, but the well never produced. In 1930 the Texas Pacific Oil Company well, located in the same section, was abandoned at 4,450 feet because of mechanical trouble. Barneberg No. 2, located nearby, was completed at 3,945 feet, as the first producer in that area. With 6¼-inch casing, cemented at 3,484 feet, the well has produced about 10,000 barrels of 16 degrees A. P. I. oil. Water troubles developed and the well is now standing idle. Slightly north of the above development, Superior Oil Company, in Sec. 24, T. 32 S., R. 14 E., M. D., drilled a well to 6,504 feet during 1940. The formation was reported to be extremely hard middle Miocene shale. Slight shows of gas in shale were noted, but no zone worthy of a production test was found and the well was abandoned.

Meridian

Located on the Meridian anticline, 4 miles southeast of Tar Springs Ranch, Hancock Oil Company well No. "Scherer-Dickes" 1, Sec. 30, T. 12 N., R. 33 W., S. B., was the second well to obtain production. This well was first drilled to 3,359 feet, 10¾-inch casing was cemented at 621 feet, and a liner run for a bailing test which showed heavy oil and considerable water. When cleaned out, the hole was deepened to 5,591 feet, plugged back to 4,941 feet, and tested below 3,800 feet, producing 40 barrels per day of heavy oil and considerable water. After casing was perforated between 900 and 2,200 feet, a pumping test yielded 80 barrels per day of 8½ degrees A. P. I. oil and 250 barrels per day of fresh warm water. The project now stands idle.

Adams Ranch

Adams Ranch anticline is a sharp fold in the southern part of the area. A seepage of tar was found where Huasna River cuts across the axis, but the structure has not been drilled.

DATA ON WELLS DRILLED IN HUASNA AREA

By Vernon L. King

Index No.	Company or name of well	Location			Depth (feet)	Date	Structure*	Remarks
		Sec.	T.	R.				
1	Midwest Oil & Refining Co.	34	31	15	4,390	1930	A	Gas at 2,000 feet; small amount gas and show of oil below 3,650 feet
2	Stieger	35	31	15	1,100	?	M	No showing
3	New Huasna No. 1	13	32	15	?		M	Oil and gas produced
4	New Huasna No. 2	13	32	15	?	1899	M	Show of oil and gas
5	New Huasna No. 3	13	32	15	Shallow	to	M	No oil or gas
6	Harkness-Squires No. 4	13	32	15	800+	1900	M	Reported 15-barrel well
7	Harkness-Squires No. 5	13	32	15	400±		M	Water well
8	Harkness No. 1	15	32	15	800	1901?	S	Reported heavy oil
9	Harkness No. 2	15	32	15	900	1901?	S	?
10	Harkness No. 3	15	32	15	1,700	1901?	S	Water well
11	Union Oil Porter No. 1	22	32	15	5,110	1937	A	No tests
12	Bedicagk	18	32	15	?	1899?	S	Four shallow wells; no oil; deepest 1,000 feet
13	Bedicagk-Phoenix	36	31	14	3,675	1909	S	Showing at 3,470
14	Union Oil Co. Chandler	12	32	14	5,627	1930	Flank	Had several good shows on ditch in fractured shale
15	Tex Harvey Corp. Gilmore Comm. No. 1	11	32	14	4,518	1940	A	Showing of gas and oil on test
16	Oil Boys	18	32	15	800?	1904	M	
17	Doheny No. 1	22	32	14	875	1898	Flank	Some gas—with water
18	Superior Oil Co.	24	32	14	6,504	1940	NE Flank	Abandoned; showings in shale; test unwarrented
19	Barneberg No. 1	25	32	14	4,499	1927	A	Show of oil; never produced
20	Barneberg No. 2 or Trustee No. 1	25	32	14	3,945	1933	A	6¼-inch 3484 C; has produced approximately 10,000 barrels with considerable water
21	Texas Pacific No. 1	25	32	14	4,450	1930	A	Abandoned because of mechanical trouble
22	Majestic	26	32	15	3,000	1904?	S	Reported show of oil and gas
23	Bedicagk	27	32	15	1,200±	1900?	A	Made gas and showed some oil
24	Union and Cal-Pet Rust No. 1	34	32	15	4,156	1930	A	Showings in shale
25	Downer No. 1	31	33	16	600	1898	Fault	No showing
26	Downer No. 2	31	33	16	300	1898	Fault	No showing
27	Clarion	25	12	32	1,700	1919	Fault	Oil showing
28	Wilhelm	30	12	33	700	?	Flank	No data available
29	Hancock Oil Co. Scherer-Dickes No. 1	30	12	33	5,591	1939	A	Plugged to 3,750 feet; 75 barrels per day; extremely heavy oil
30	Associated Oil Co.	16	11	33	1,434	1918	Fault	Encountered serpentine
31	Tex Harvey No. 2	11	32	14	6,140	1941	A	Fractured shale zones 3,500-3,700; 5,000-5,300; 5,800-6,140; to be tested

* A-anticline; S-syncline; M-monocline.

CITATIONS TO SELECTED REFERENCES—Continued

HUASNA AREA

Arnold and Anderson 07a; 07c; Bell, H. W. 18; Collom, R. E. 18; McLaughlin and Waring 14; Vander Leck, L. 21.

Tar Springs District

Stockman, L. P. 40, no. 22, p. 119.

ARROYO GRANDE (EDNA) OIL FIELD

By Max L. Krueger *

OUTLINE OF REPORT

HISTORY

This area has been referred to as the Tiber field, Edna field, and Arroyo Grande field; its southeastern extension is known as the Oak Park area.

The Arroyo Grande field proper is located about 3 miles north of the town of Pismo on either side of Pismo Creek. All of the producing territory falls within the southwestern corner of the old Spanish land grant of Rancho Corral de Piedra, San Luis Obispo County.

The Arroyo Grande field was reportedly discovered in 1906; the discovery well is said to have been drilled to 3,172 feet, where it was completed as a producer in the second oil zone. Later, a number of 1,000 to 1,400 foot wells were drilled in the Pismo Creek area, which produced rather small quantities of 14 degree Baume gravity oil from the upper oil zone. Early development was made by the Associated Oil Company; the present producing company is the Dolly Adams Oil Company. This last company is pumping about 8 of the old wells, while some 12 wells are standing shut-in. A number have been abandoned. The map shows that as many as 30 wells have been drilled in and around the Arroyo Grande field. In 1934 the Taft Well Drilling Company drilled a deep test, No. "Adams" 4, to a depth of 4,275 feet without commercial results.

The Elberta No. 1 well is given credit as the discovery well for the Oak Park area. Completed in 1927 for an initial production of 200 barrels per day of 16 degrees gravity oil, it soon dropped to 40 barrels per day because of mechanical difficulties. It is now abandoned.

Prior to 1929 the J. D. Martin No. A-1 well was drilled in the Oak Park locality. Little information is available for this well, but it is reported to have been completed with an initial production of 400 barrels per day of 22 degrees gravity oil. Numerous other wells were subsequently drilled in the Oak Park area; a number were unsuccessful, and at present no more than three wells are producing.

* Geologist, Union Oil Company of California. Manuscript submitted for publication May 31, 1938.

DISTINGUISHING FEATURES

The enormous deposits of dry tar sands, which form precipitous cliffs adjacent to the Arroyo Grande field proper and to the north, are some of the most interesting features of this area. The so-called "bituminous rock" is a sand whose interstices are impregnated with tar-like petroleum residium. Because of the super-resistance to erosion of these inspissated oil sand deposits, topographic prominences have been developed. This "bituminous rock" has previously been mined for road surfacing material and the supply is practically inexhaustible. Figures estimating the amount of oil whose residue has come to rest in these permeable sands would be enormous and almost unbelievable.

Oil production on the north flank of the large Pismo syncline at Arroyo Grande and Oak Park, at points not far from its axis, is another geological feature of interest regarding this area.

STRATIGRAPHY

The Monterey formation of Miocene age and the overlying Santa Margarita formation (Pismo) are the only two important stratigraphic intervals. There is some doubt regarding the proper age assignment for the Santa Margarita, inasmuch as its upper part (according to foraminiferal data) seems to have affinities with the Sisquoc formation of lower Pliocene age. Its lower part seems to be correlative with the Santa Margarita (upper Miocene) in its type locality.

The Monterey consists of white to light-colored diatomaceous and siliceous shales, which vary from massive to well stratified, and from punky to slabby to firm. These are overlain unconformably by conglomerates and coarse sands of the Santa Margarita formation. High in the Santa Margarita there are some interbeds of diatomaceous shale, and one "barren zone" is present about 1,500 feet above the base of the formation.

It is in the Santa Margarita (Pismo) formation that the previously mentioned "bituminous rock" occurs at the surface.

Under normal conditions the Monterey shale would be underlain by the Franciscan basement complex in this locality. No well has yet been drilled into these basement rocks in the Arroyo Grande-Oak Park area, but the complex has been encountered in wells drilled in adjoining areas.

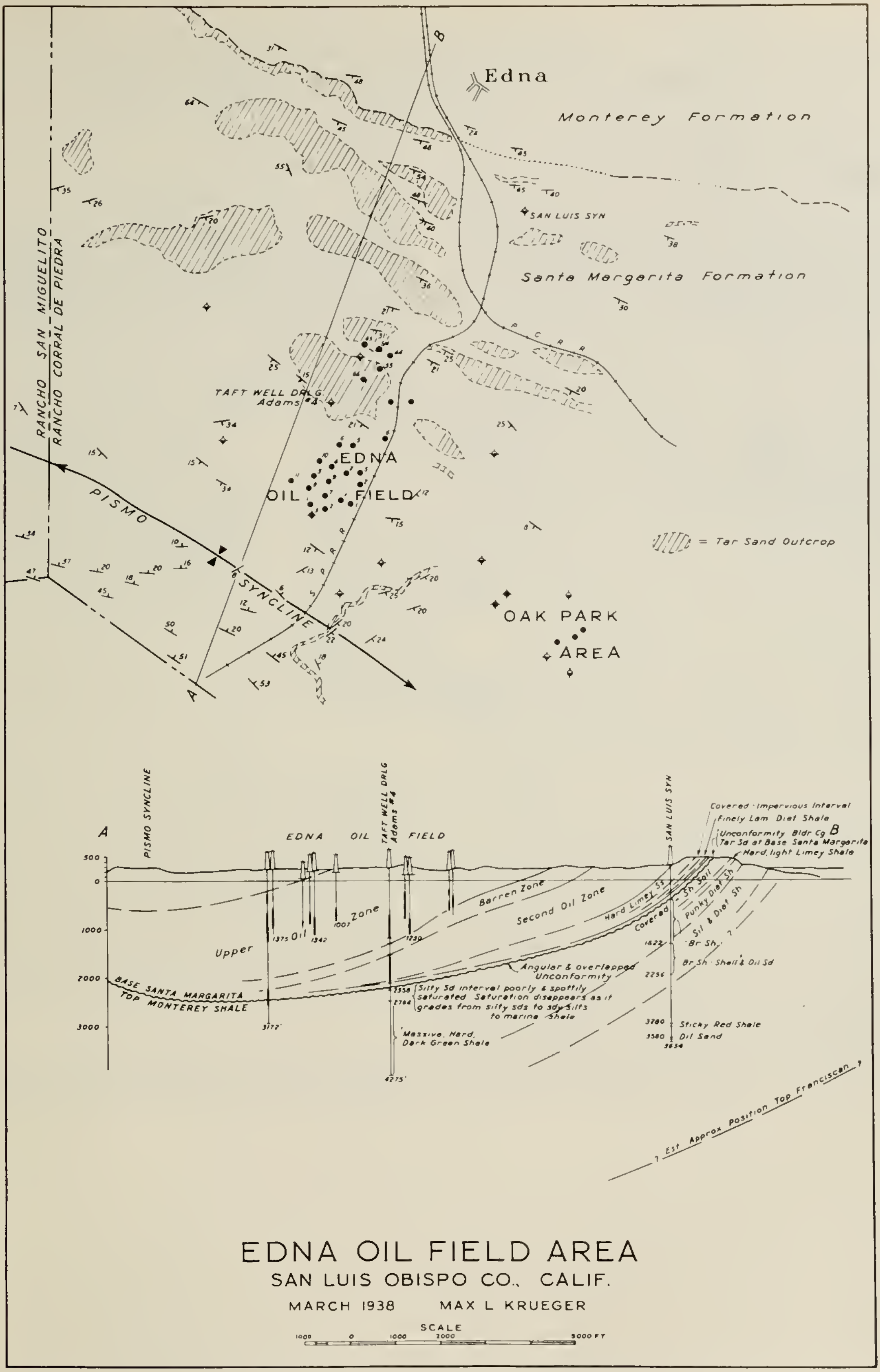


FIG. 186. Arroyo Grande (Edna) oil field: map; structure section.

STRUCTURE

Structure from which the Arroyo Grande field produces is apparently monoclinal, as the field is situated on the north flank of the well-known Pismo syncline. A barren zone, which can also be found on the surface, separates the upper and second oil zones in the Pismo Creek area. Because of poor surface exposures in the Oak Park area, there is a slight difference of opinion as to the detail of the structure in that locality; there is nothing, however, which definitely indicates that the subsurface structure is any more intricate than it is in the area adjacent to Pismo Creek. The wells in this area are somewhat deeper than those in Pismo Creek, and the Santa Margarita-Monterey contact occurs at a greater depth.

Oil evidently originated in the underlying petroliferous Monterey shales, and, because of unconformable conditions, has subsequently migrated into the overlying porous Santa Margarita formation. A general lack of impervious members within the Santa Margarita has no doubt allowed the oil to diffuse through this immense porous interval until it has finally been poorly "sealed" by surface inspissation.

CONCLUSION

The lack of argillaceous layers within the Santa Margarita, which would form an impervious seal for oil migrating into it from the underlying Miocene shales, is no doubt the geological feature which kept this area from assuming major importance as an oil producing region.

CITATIONS TO SELECTED REFERENCES—Continued

ARROYO GRANDE OIL FIELD

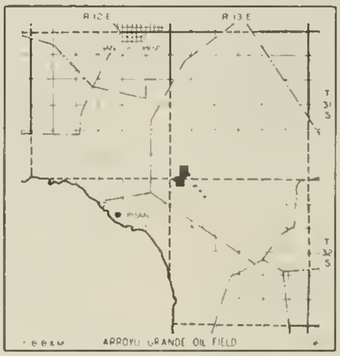
Arnold and Anderson 07a; 07c; Bell, H. W. 18; Collom, R. E. 17; 18, Dolman, S. G. 30; Laizure, C. McK. 25b; Vander Leck, L. 21; Van Tuyl and Parker 41

Edna Area (Old Tiber, or Tiber Field)

McLaughlin and Waring 14; Taff, J. A. 34; Van Tuyl and Parker 41.

Oak Park Area

Franke, H. A. 35.



Arroyo Grande oil field.

CALIENTE RANGE, CUYAMA VALLEY, AND CARRIZO (CARISA, CARISSA, CARRISA, CARRISSA) PLAIN

American Association of Petroleum Geologists 41; Arnold and Johnson 10a; Dougherty, J. F. 40; Eaton, J. E. 39c; Eaton, Grant, and Allen 41; English, W. A. 16; Levorsen, A. I. 41; McLaughlin and Waring 14, pp. 429-430; Oil Weekly 37b; Prutzman, P. W. 04, map op. p. 14; Vanderhoof, V. L. 39; Vander Leck, L. 21.

SAN JUAN (SAN JUAN CREEK) REGION

Vander Leck, L. 21.

CALIENTE RANGE, CUYAMA VALLEY, AND CARRIZO PLAIN

By J. E. Eaton *

Caliente Range and environs furnish the best Miocene record for California. There are locally exposed in one homoclinal section 16,600 feet of Tertiary strata, of which some 13,800 feet are Miocene. The Miocene series is almost continuously fossiliferous in the maximum section through the Vaqueros and Temblor, and by combining the faunas of this and other sections an essentially complete faunal succession is obtainable from the horizon of *Turritella inezana* var. *hoffmani* upward to above that of *Astrodapsis tumidus*. The University of California at Los Angeles has at present 110 collections of mollusks and echinoids from 38 consecutive Miocene horizons in the district. Foraminiferal faunas occur in much of the series, and their relation to the macrofaunas can be determined.

At Caliente Mountain the exposed succession is apparently conformable from its base up through approximately 1,100 feet of Oligocene (?), 4,500 feet of Vaqueros, 4,700 feet of Temblor, and 4,600 feet of Monterey. The unconformity which locally exists elsewhere in the State between the Temblor and the Monterey, causing upper portions of the former and basal portions of the latter to be missing in parts of California, appears to be represented by continuous deposition in much of Caliente Range where there is as much as 1,000 feet of the transitional upper *Baggina robusta* and *Turritella carisaensis* var. *padronesensis* zones.

Marine members in Caliente Range grade southwest and northeast to nonmarine beds, the marine lower Vaqueros changing to a nonmarine upper Sespe facies in the former, and the marine Monterey to various nonmarine facies in the latter direction. This gradation, in combination with terrestrial vertebrates locally present, allows portions of the Caliente Range marine record to be correlated with the mammalian record elsewhere. Basic flows and sills in the district, which prepared for and inaugurated the Monterey type of deposition, and nonmarine facies on the northeast, suggest coincidence of vulcanism with the unconformity between the Temblor and the Monterey which is locally present in some districts, and help to explain changes between these stages.

The district is part of a peculiarly long, deep, and narrow structural trough or graben about 300 miles in length and 20 in width extending from the Santa Cruz region southeast to Caliente Range and then eastward through the San Emigdio district; this trough developed in the upper Oligocene (?) and sank rapidly throughout the Miocene. The marine record for these times is apparently complete along the axis of the trough, and is locally of great thickness. The particular district seemingly emerged at the close of the Miocene, as subsequent series are thin and nonmarine. The area was profoundly deformed and eroded during the Quaternary revolution, for the existing sediments were steeply tilted, locally overturned and overthrust, and largely removed along the axis of the Caliente Range uplift and borders of the trough. Extensive alluvial fans developed in the late Pleistocene, in part contemporaneous with and fringing broad lakes in Carrizo Plain and northwestern Cuyama Valley; these fans are now being dissected.

Conditions requisite for the occurrence of major oil or gas fields appear to be absent in the exposed areas, because of the deep erosion of the larger anticlines. Small or moderate accumulations of a commercial nature may exist in certain less eroded portions. A few oil seeps are present. Most of the eleven wells drilled for oil in the district have been poorly located as regards structure.

The geological significance of Caliente Range and environs is that its unequaled marine record is located centrally with respect to the Tertiary system in California, and that the grading of bathyal marine to neritic marine, and finally to nonmarine facies provides an association of forminiferal, molluscan, echinoderm, and mammalian faunas which should help toward solving various problems. Here, in a few miles, nearly every facies of the California Miocene, physical and faunal, marine and continental, is visible in a manner not elsewhere available. Because of its key features the writer recommends that workers spend at least several weeks in the district before arriving at conclusions on regional Miocene problems of the State.

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This article is an abstract of Mr. Eaton's longer paper published in the July 1939 issue of the California Journal of Mines and Geology, State Mineralogist's Report 35, Californa State Division of Mines.

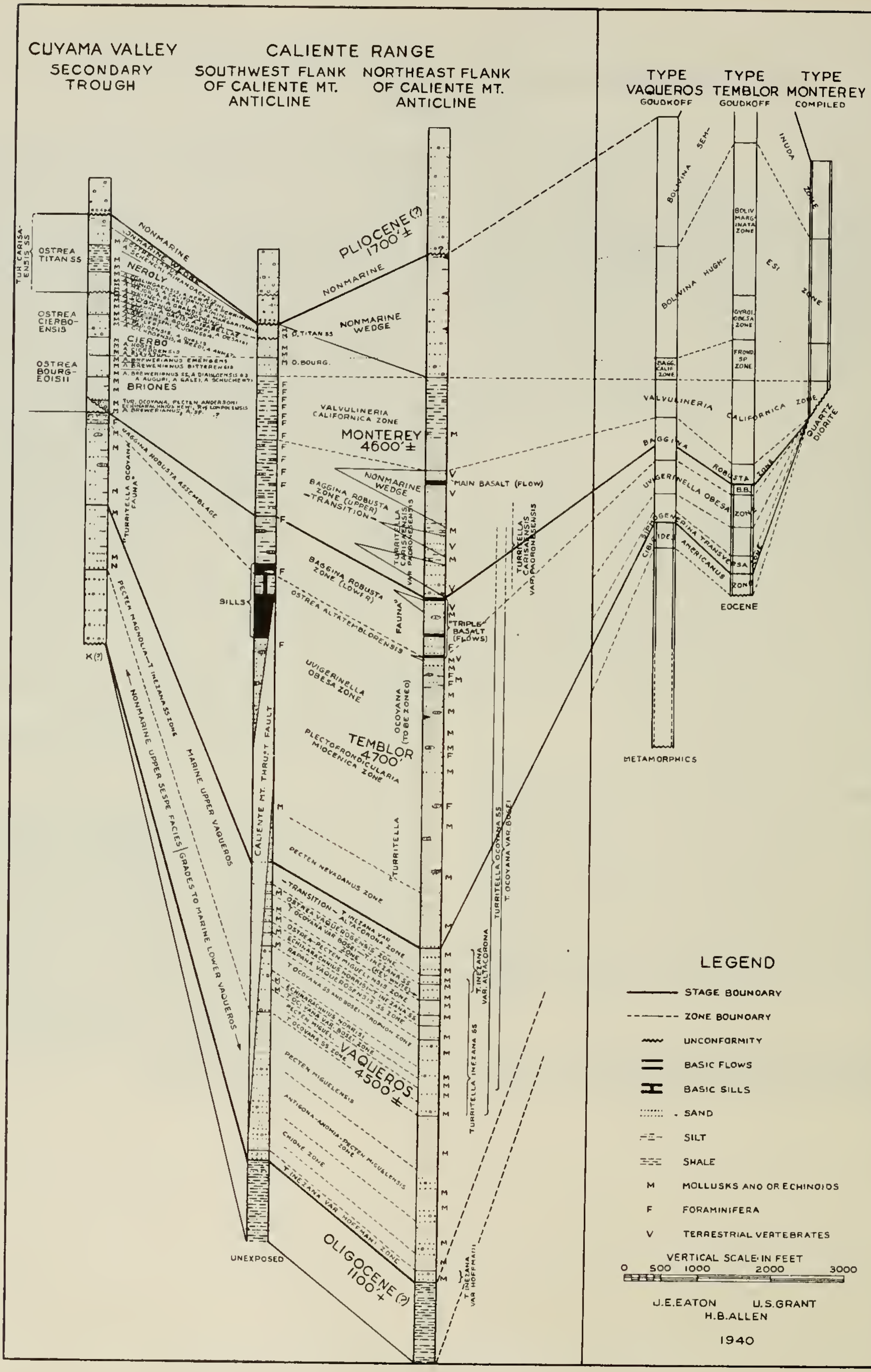

FIG. 187. Cuyama Valley, Caliente Range: columnar sections.

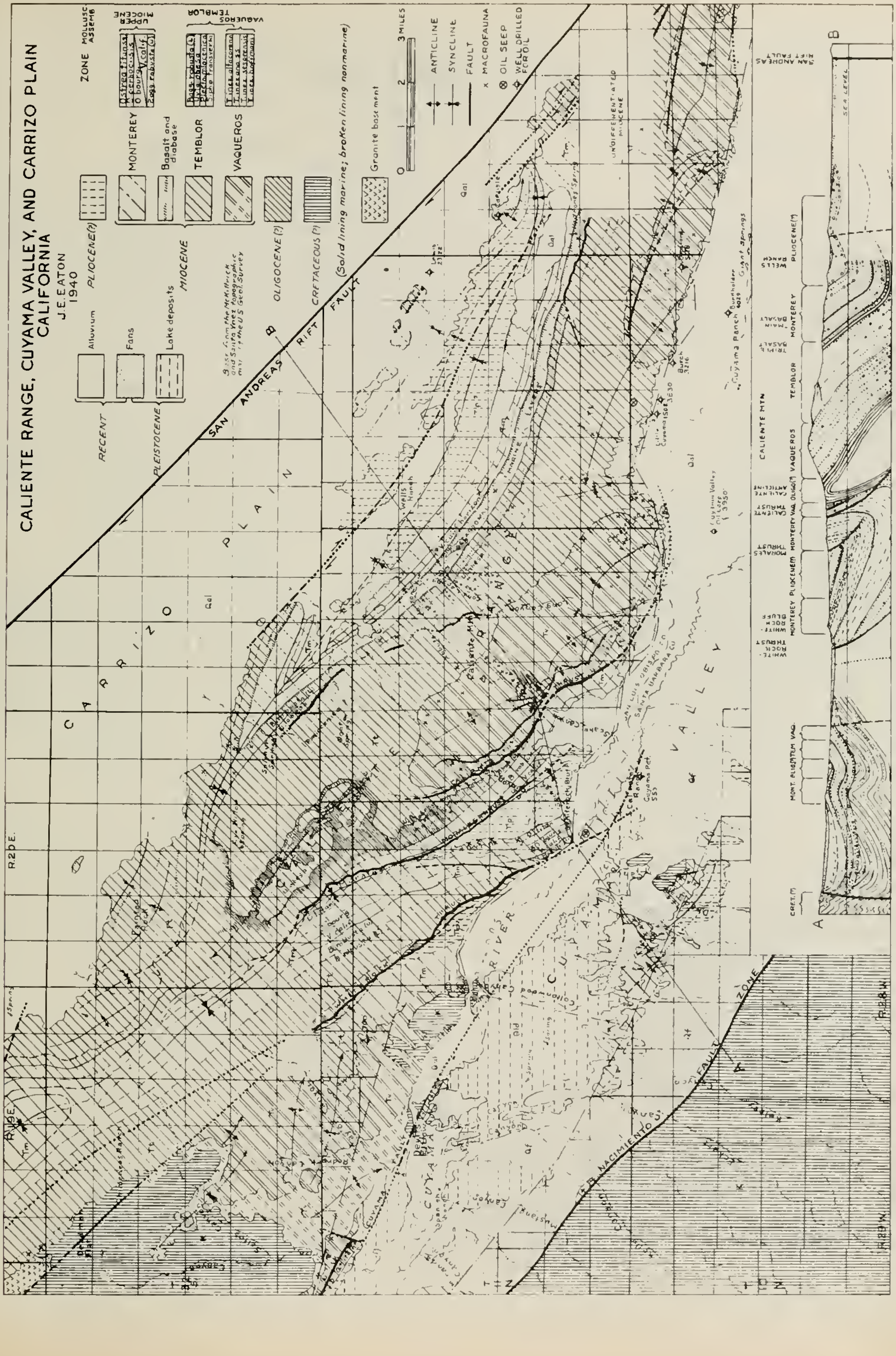

FIG. 188. Caliente Range, Cuyama Valley, and Carrizo Plain: geologic map; cross-section.

BRADLEY-SAN MIGUEL DISTRICT

By N. L. Taliaferro *

OUTLINE OF REPORT

INTRODUCTION

The area here designated as the Bradley-San Miguel district includes practically all of the Bradley and San Miguel quadrangles, an area of approximately 500 square miles. These two quadrangles are part of a group of eight that have been mapped by students of the University of California, under the direction of the writer, during the past 12 years. Only a brief statement of the stratigraphy and structure of the area will be given, as a detailed account will appear in a future paper.

Because of the scale and method of reproduction (black and white instead of colors) of the map that has been prepared for this brief report, it has been necessary to combine several of the units actually separated in field mapping, and to omit a number of details. Several units in the Santa Margarita east of the Salinas Valley have been combined under the symbol *Tsmss*, and the various terrace deposits and alluvium have, for the sake of simplicity, been included under the symbol *Qtal*. Most of the minor folds in the thick Miocene shales east of the Salinas Valley have been omitted. However, it is believed that the accompanying map, notwithstanding the omissions and combinations, adequately represents the distribution of the important units and the major structural features.

Cross-sections have not been prepared for this paper, as the structure is adequately shown on parts of cross-sections I, II, III, IV, and V on plate 11 of this bulletin. Because of the scale and method of reproduction of these sections it was necessary to generalize them and to omit lithologic variations.

* Professor of Geology and Chairman of Department of Geological Sciences, University of California, Berkeley, California. Manuscript submitted for publication March 20, 1942.

The writer wishes to acknowledge his indebtedness to the 220 students, each of whom have spent a summer somewhere in the eight quadrangles mapped. Thanks are also due to R. E. Turner, C. M. Gilbert, C. E. Van Gundy, J. F. Wilson, and B. C. Lupton, all of whom have assisted the writer in the field at various times.

STRATIGRAPHY

General Statement

Most of the major divisions recognized in the Coast Ranges either outcrop at the surface or are present beneath the surface in the two quadrangles included in the accompanying map. Sur series, Santa Lucia granodiorite, Franciscan, and Cretaceous rocks are exposed in a comparatively small area in the northeastern part of the San Miguel quadrangle. Because of the impossibility of showing all of these, as well as at least five Tertiary units, in this small area without the use of colors, they have been omitted. Cretaceous sediments crop out from beneath the Tertiary in the southern part of the Bradley quadrangle, and both the Cretaceous and Franciscan are present to the south and west of the area shown. Paleocene sediments are present in a small area in the northern part of the Adelaide quadrangle beneath the Vaqueros but they appear to have been removed by erosion over most of the Bradley quadrangle prior to the deposition of the Miocene.

From evidence afforded by three wells, the basement beneath the Miocene, between the northeast corner of the San Miguel quadrangle and the San Antonio River, is concluded to be Santa Lucia granodiorite and Sur crystallines. This is a part of the Gabilan mesa, as previously defined by the writer (*see* page 121). Southwest of San Antonio River the basement on which the Tertiary sediments rest is made up of Franciscan and Cretaceous rocks.

The various units will be briefly discussed and their lithology and distribution described, even though they do not outcrop at the immediate surface over the area shown on the accompanying map.

Ancient Crystalline Rocks; Sur Metamorphics and Santa Lucia Granodiorite

These rocks outcrop at the surface in the northeast corner of the area and are present beneath the Miocene over about 440 square miles in the San Miguel and Bradley quadrangles. Exposed in a narrow belt along the southwest side of Cholame Valley there are ancient recrystallized rhyolites and granodiorite. To the northeast along Middle Mountain and the San Andreas fault there are small discontinuous areas of granodiorite, marble, and schist; boulders and blocks of these rocks are abundant in the coarse Miocene sediments both to the east and west. A well near the head of Vineyard Canyon passed through coarse upper Miocene breccias largely made up of great blocks of granodiorite; the granodiorite lies at a depth of about 3,300 feet in the Cholame Hills. A well drilled to a depth of 5,972 feet near the mouth of Vineyard Canyon, 11 miles to the southwest, also encountered similar coarse breccias; the depth to the granodiorite surface near San Miguel is approximately 6,000 feet. In a well near the Branch

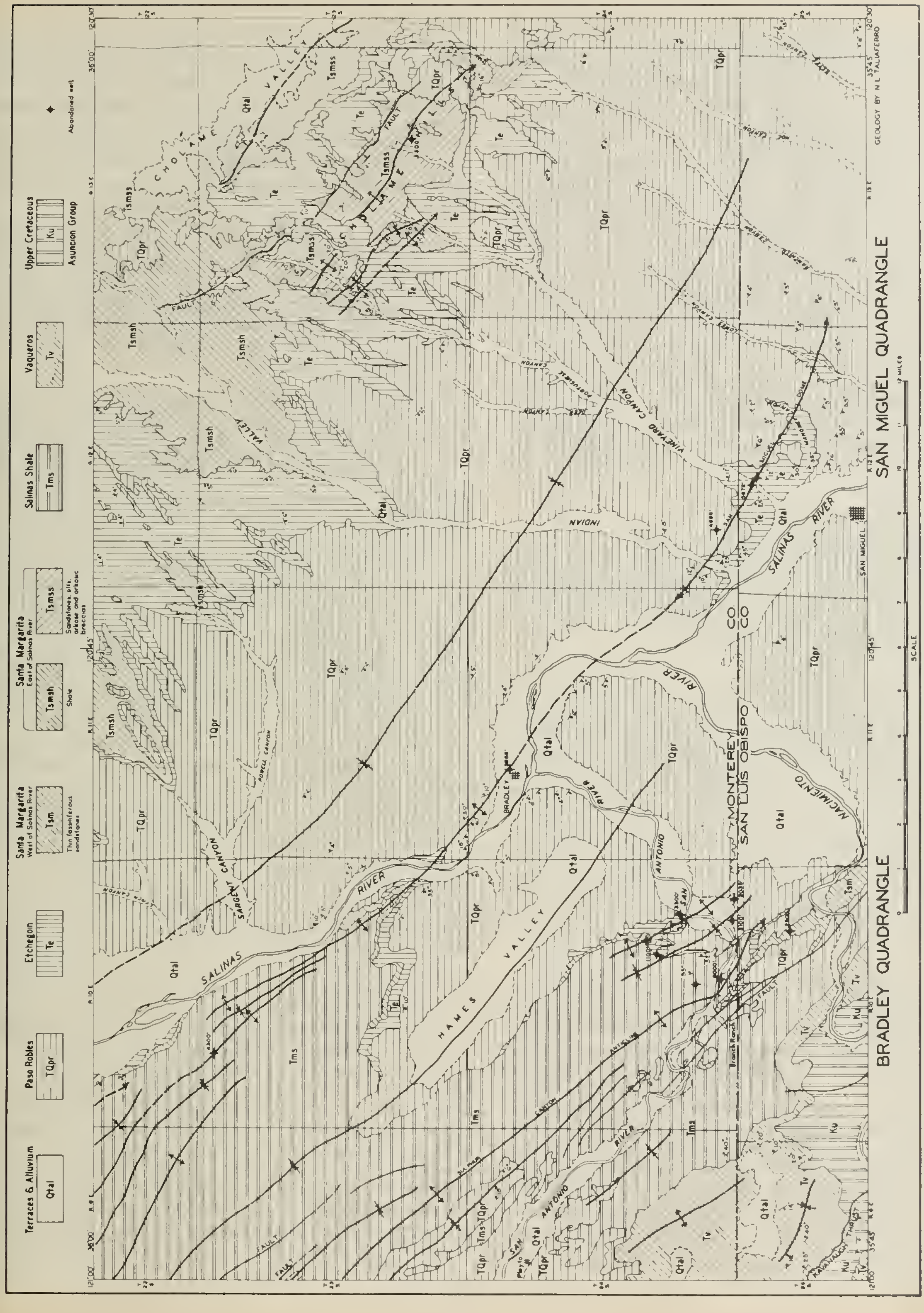

FIG. 189. Bradley and San Miguel quadrangles: geologic map.

Ranch on the San Antonio River granodiorite was encountered beneath marine Vaqueros at a depth of approximately 9,000 feet (8,986 feet). Thus from Cholame Hills southwestward to the San Antonio River the depth to the granodiorite and crystalline schist surface increases from 3,300 feet to 9,000 feet in 20 miles, an average slope of 3 degrees, or 285 feet to the mile. Aside from data obtained from these three wells, little is known regarding the depth to the granodiorite surface. The surface is probably somewhat irregular, but the well data and the character of the folding indicate a definite westward slope of the crystalline bedrock surface. There is a westward increase in the thickness of the Tertiary sediments corresponding to this westward tilt, and a change in the nature of the folding. East of the Salinas River, where the crystalline rocks lie at depths of less than 6,000 feet, the apparent shortening due to folding is very slight; folds such as the San Miguel dome and the complex, ill-defined Vineyard Canyon anticline appear to be due to faulting in the bedrock. West of the Salinas River, where the depth to the crystalline surface ranges from 6,000 to 9,000 feet, the sediments are more strongly folded, at least at the surface.

Franciscan Group—Upper Jurassic

Typical Franciscan rocks, sandstones, cherts, shales, volcanics, and serpentines, are exposed in the extreme northeast corner of the San Miguel quadrangle and again to the west and south of the Bradley quadrangle. These rocks were eroded from the Gabilan mesa in the late Cretaceous and early Tertiary.

Cretaceous

Upper Cretaceous sediments are exposed in the extreme northeast corner of the San Miguel quadrangle where they rest unconformably on the Franciscan, and again in the southwest corner of the Bradley quadrangle where they appear from beneath the Vaqueros. Southwest of Tierra Redonda Mountain late Upper Cretaceous sandstones and shales are thrust over the Vaqueros. Cretaceous sediments were eroded from the Gabilan mesa in the Bradley-San Miguel area during the Eocene. However, to the northwest considerable thicknesses of late Upper Cretaceous rocks (Asuncion group) are found over much of the northwestward extension of the Gabilan mesa.

Eocene

No sediments of Eocene age are known in either the San Miguel or Bradley quadrangles. However, Paleocene beds, resting disconformably on late Upper Cretaceous sediments, occur in a faulted syncline in the northern part of the Adelaida quadrangle a short distance south of the southern boundary of the Bradley quadrangle. In this region the Paleocene has a thickness of 1,300 feet and consists of sandstones, clay-shales, and conglomerates lithologically indistinguishable from the Cretaceous sediments. Paleocene sediments appear to have been removed by erosion over nearly all of the Santa Lucia Range and Salinas Valley region; it is possible, however, that a few concealed remnants may be present beneath the Miocene. There is no evidence that any Eocene beds younger than the Paleocene ever were deposited over the region.

Miocene

General Statement. An unusually thick and complete section of Miocene sediments is exposed in the Bradley-San Miguel area. However, there is considerable variation both in thickness and lithology from one part of the area to another. Surface observations and the records of deep wells combine to furnish a reasonably accurate picture of the surface on which the Miocene was deposited and the changes that took place during deposition.

There is a marked difference both in thickness and lithology eastward from the San Antonio River. Although this change in character and thickness is gradual, the Miocene sediments may be divided for convenience into two geographic divisions, namely, the areas east and west of the Salinas River. Much of the marine lower part of the Miocene section grades eastward into land-laid beds.

The oldest Miocene sediments known are red land-laid beds lying beneath the marine Vaqueros in the extreme southern part of the Bradley quadrangle. These red Sespe-type sediments thicken southward in the Adelaida quadrangle where they are over 700 feet thick. They were deposited in a basin that extended from about the center of the Adelaida quadrangle northwestward through the southwest corner of the Bradley quadrangle and onward along the present drainage of the Nacimiento River. These sediments may, of course, be Oligocene in age; they are included here in the Miocene for convenience only. Vertebrate fragments have been found but they are not sufficiently numerous or well preserved for age determination. In the present brief paper, these beds, as well as the marine Vaqueros, will be considered as lower Miocene, although the writer is aware that the Vaqueros is regarded by some as upper Oligocene.

At the beginning of the Miocene (upper Oligocene of some writers) the area was one of considerable relief, due to Eocene faulting, folding, uplifts, and erosion. A ridge made up of granodiorite and crystalline schists (part of the Gabilan mesa) extended through most of the San Miguel quadrangle; this was highest and of greatest relief along the present site of the Cholame Hills, and sloped gently southwestward. All of the Bradley quadrangle was essentially a broad valley, although there was considerable local relief. West of the Bradley quadrangle and southwest of the Nacimiento River rose a rugged range made up, in the north, of granodiorite, marble, and crystalline schists and, in the south, of Franciscan and Cretaceous rocks. Immediately prior to the beginning of Vaqueros time this entire area stood above sea-level. Gradual subsidence took place and the Vaqueros sea spread northward, first flooding the topographically lower areas and gradually spreading over the higher regions as subsidence continued. The Vaqueros sea covered most of the Bradley quadrangle, but does not appear to have spread any farther northeast than the present course of the Salinas River. As subsidence continued during the Miocene, more and more of the region was covered by the sea until, at the end of the Miocene, the entire area was flooded. Unfortunately, however, subsidence was not continuous throughout the area and there were emergences resulting in unconformities.

Vaqueros. The Vaqueros outcrops only in the southwestern corner of the Bradley quadrangle, where it rests unconformably on late Upper Cretaceous sediments. However, in a deep well near the Branch Ranch on the San Antonio River, the Vaqueros rests directly on Santa Lucia granodiorite. Vaqueros also was encountered in a deep well in the southeastern part of the Bradley quadrangle, west of the Salinas River. A well near the town of Bradley was not drilled to a sufficient depth to reach the Vaqueros. A deep well, drilled on the San Miguel dome in Vineyard Canyon, 2 miles northeast of San Miguel and a mile east of the Salinas Valley, did not encounter marine Vaqueros but passed from marine middle Miocene sediments into land-laid sediments.

The greatest outcrop thickness of the Vaqueros is 1,250 feet southwest of Tierra Redonda Mountain in the southwest corner of the Bradley quadrangle. However, to the northwest it thins to less than 300 feet. In the deep well on the San Antonio River, previously mentioned, the Vaqueros is said to be 1,700 feet thick. The Vaqueros consists of sandstones, conglomerates, and sandy shales; limestones occur to the southwest but are not present in the area under consideration.

From the evidence available, it is fairly certain that the marine Vaqueros thins toward the northeast and passes into land-laid beds somewhere near or slightly west of the Salinas River. No oil seepages are known in the Vaqueros at the outcrop, but oil may occur in the Vaqueros over a part of the Bradley quadrangle; the source would be in the overlying organic shales. At the surface the Vaqueros sandstone is sufficiently porous to act as a reservoir, but where deeply buried and well cemented it might be relatively impermeable. In the deep well drilled through the Vaqueros on the San Antonio River the sandstones appeared to contain oil in places but were too tightly cemented to be an adequate source.

Salinas Shale. The name Salinas shale was given by English (19) to the silty, limy, organic, and siliceous shales lying above the Vaqueros and below the Santa Margarita. The Vaqueros grades upward into silty calcareous marls which in turn grade upward into siliceous shales and impure cherts. The highest member in this formation is a rather pure diatomite. It is well exposed beneath later beds a short distance west of the Salinas Valley, here and there beneath upper Miocene and Pliocene beds about the Hames Valley syncline, and in Oro Fino Canyon. It is not continuously exposed because of overlap by later sediments. It has been quarried in Buttle Canyon, on the southwest flank of the Hames Valley syncline, where it is exceptionally pure.

The Salinas shale is exposed over much of the western half of the Bradley quadrangle, west of Salinas River. It appears to be thickest along and east of San Antonio River, where it is at least 8,000 feet thick. However, it thins rapidly westward and less rapidly eastward, and in the latter direction it becomes increasingly sandy. East of the Salinas River it is only known in wells; it appears to pass eastward, on the westward-sloping Gabilan mesa, into alternating marine shales and coarse sands and finally into coarse, probably land-laid conglomerates.

The thickest section of the Salinas shale lies between the San Antonio and Salinas Rivers where it accumulated continuously in a sinking trough. It thins rapidly both to the northeast and southwest.

These shales are, in general, moderately to rather strongly organic and small seepages occasionally occur; they appear to be a fairly adequate source of oil. A small amount of oil was obtained in the upper part of these shales in the old Pleyto well on the San Antonio River on a sharp anticline on the west flank of the Hames Valley syncline. It is possible that production might be obtained either in fractured shales or in stray sands interbedded with the shales, in properly located wells. There are at least two large closed structures in the Salinas shale in the northwestern part of the Bradley quadrangle that might prove productive; none of the wells drilled in this area have reached the Vaqueros. Showings of oil have been obtained in sandstones interbedded with the Salinas shale in wells drilled on the San Miguel dome but no commercial production has been obtained. This dome has strong surface closure, but, as will be shown later, it is probable that this closure does not exist at depth.

Santa Margarita. The Santa Margarita outcrops at the surface at a number of places in the Bradley quadrangle and is exposed over a rather large area in the northwestern part of the San Miguel quadrangle. It is largely concealed beneath the Etchegoin and Paso Robles formations over a wide area between the Cholame Hills and the Salinas River. The term Santa Margarita is a useful one for cartographic purposes but it can not be said to be a definite time horizon from one part of the area to another. It is possible that some of the Santa Margarita in the Cholame Hills is equivalent to a part of the Salinas shale west of the Salinas River. However, its delineation serves a useful purpose and indicates, at any particular place, the first arrival of coarse detritus resulting from uplifts on the margin of the basin in which the Salinas shale was deposited.

On the west side of the Salinas River the Santa Margarita is thin, varying from less than 50 to about 400 feet in thickness. Here it consists of fine to coarse white fossiliferous sandstones that are in striking contrast to the siliceous Salinas shales and diatomites on which it rests. Two distinct and strongly contrasting relations exist between the Salinas shale and the Santa Margarita sandstone in the Bradley quadrangle. Along the Nacimiento River in the southern part of the quadrangle, the contact between the two is clearly gradational. Thin sandstones appear interbedded with the siliceous Salinas shales and there is a gradual increase in number and thickness of the sandstone interbeds and a decrease in the shale layers until the section consists entirely of rather coarse fossiliferous Santa Margarita sandstones. To the northwest along the San Antonio River the Santa Margarita sandstones rest unconformably on a lower horizon of the Salinas shale and the basal beds contain abundant debris of the underlying siliceous shales. West of the deep well near the Branch Ranch at least 1,500 feet of Salinas shale were removed prior to the deposition of the Santa Margarita. Farther northwest, and west of the San Antonio River, gently inclined Santa Margarita sandstones rest on steeply tilted Salinas shale. These apparently contradictory relations indicate that deposition within the main basin was continuous, but movements occurred on the margin of the basin, resulting in a strong unconformity.

East of the Salinas River the thickness of the Santa Margarita is much greater, at least 2,500 feet, and there are a number of strongly contrasted lithologic units. The lowest member exposed in the Cholame Hills on the crest of a faulted and irregular anticline (called Vineyard Canyon anticline by English) consists of fossiliferous sandstones and conglomerates. In addition to the usual porphyry, quartzite, and granodiorite debris in the conglomerates, there are abundant small pebbles of foraminiferal limy and siliceous Salinas shale, indicating uplift and erosion of the Salinas shale prior to the deposition of the Santa Margarita. The exact source of the Salinas shale debris is not yet known; this is a part of a larger problem whose solution must await further regional studies. Unfortuntaely, much of the evidence is buried beneath later formations. The lower Santa Margarita sandstone, as exposed in the Cholame Hills, grades upward into a siliceous shale lithologically much like the siliceous shales in the upper part of the Salinas shales; however, these Santa Margarita shales are younger than lithologically similar Salinas shales. The writer regards these high Santa Margarita shales of the San Miguel quadrangle as equivalent to the McLure shale of Reef Ridge, McLure Valley, and the Castle Mountain Range. The upper Santa Margarita or McLure shale attains its greatest thickness and widest distribution in the drainage of Indian Valley in the northern part of the San Miguel quadrangle, where it is 700 feet thick. It thins southward in the Cholame Hills and southwestward over the Gabilan mesa. To the south and east it is largely replaced by coarse arkosic sandstones and breccias, although thin shale members persist even in the midst of the coarse debris. Volcanic ash and bentonite layers are present at several horizons both in the McLure shale and in the coarse sandstones into which it grades. There is no unconformity at the base of the McLure shale in the San Miguel quadrangle such as that in the Castle Mountain Range.

The character and relations of the Santa Margarita clearly indicate that local diastrophism occurred in the upper Miocene, resulting in uplift, both by folding and faulting, of the margins of the basin, but that deposition was continuous within the main basin in which the Miocene sediments accumulated.

Etchegoin—Pliocene

Etchegoin sands, silts, shales, and conglomerates are widely exposed in the San Miguel quadrangle and outcrop in relatively small areas in the Bradley quadrangle. The relation between the Etchegoin and the Santa Margarita is very similar to that between the Santa Margarita and the Salinas shale, conformable within the basin and unconformable on the margins. In the northwestern part of the San Miguel quadrangle it is very difficult to determine the exact contact between the Santa Margarita and the Etchegoin as there is no angular discordance and there are shales, interbedded with fossiliferous Etchegoin sandstones, very similar to those in the Santa Margarita. However, to the east in the Cholame Hills, fossiliferous Etchegoin sands rest on both McLure shale and fossiliferous Santa Margarita sandstones with an angular discordance of as much as 30 degrees. West of the Salinas River the Etchegoin overlaps across the Santa Margarita and rests on various horizons of the McLure shale. Between the upper Miocene and the Pliocene there were obviously strong local movements both to the east and west of the present Salinas Valley, but little disturbance in the intervening area.

The Etchegoin is very fossiliferous and large collections have been made from it. According to Professor B. L. Clark, these are Etchegoin in the restricted sense; the Jacalitos stage of the lower Pliocene does not appear to be represented. If this is true the Pliocene sea did not invade this region at as early a time as it did the Santa Maria district to the south or the Coalinga and Waltham Canyon region to the northeast, where there is an abundant Jacalitos fauna. This would indicate that the Bradley-San Miguel region was slightly uplifted and locally folded and faulted at the close of the Miocene and that it was not again submerged until the Etchegoin stage of the Pliocene.

The thickness of the Etchegoin varies widely in the Bradley-San Miguel district, being thickest just east of the Salinas River and thinning rapidly westward and less rapidly eastward. In the Cholame Hills it is approximately 900 feet thick; in the deep well on the San Miguel dome, in Vineyard Canyon, it is reported to have been 1,800 feet thick. West of the Salinas River it is rarely over 500 feet thick, thinning rapidly westward toward the Santa Lucia Range.

There is a tar sand at the base of the Etchegoin where it rests unconformably on organic Salinas shale, along the west bank of the San Antonio River in the southwest corner of Sec. 11, T. 24 S., R. 10 E., M. D. This seepage previously has been reported as being in the Paso Robles (English, W. A. 19, p. 240), but the writer has collected many Etchegoin fossils from this particular tar sand. Tar sands were encountered at this horizon at a depth of 1,320 feet in a well drilled in the southwest corner of Sec. 36, T. 24 S., R. 10 E., M. D., but no production was obtained. Over most of the area the Etchegoin is not buried to a sufficient depth to be regarded as a probable source of oil.

After the deposition of the Etchegoin the entire region was uplifted and the western part strongly folded and thrust-faulted. Faulting and minor folding also took place east of the Salinas River, but the decreasing depth to the rigid crystalline bedrock prevented strong folding over most of the Gabilan mesa. This late Pliocene diastrophism caused a complete and final withdrawal of the sea from the area and outlined the present major topographic features such as the Santa Lucia Range and the subsidiary ridges on its flanks. Preceding movements, such as those in the upper Miocene and between the Miocene and the Pliocene, although strong locally, were mere forerunners of this much stronger diastrophism. The writer regards the late Pliocene orogeny as the strongest and most pronounced phase of the compressional movements that began in the upper Miocene. Folds initiated in the upper Miocene became greatly accentuated and often overturned and thrust-faulted in the late Pliocene.

Paso Robles—Plio-Pleistocene

As a result of the late Pliocene orogeny the entire region was uplifted above sea-level and the Santa Lucia Range to the west and the Castle Mountain Range to the east were formed by overfolding and thrusting on their margins. These greatly elevated ranges were rapidly attacked by erosion, resulting in a flood of debris into the intervening lowlands. These orogenic sediments, carried from the rapidly uplifted highlands by streams of high gradient, were spread over the flood plains, to become the Paso Robles formation.

The Paso Robles is made up of coarse conglomerates, sandstones, silts, clays, and fresh-water limestones. During the early stages of the deposition of the Paso Robles, and before trunk drainage was well established, the region abounded in shallow-water lakes in which thin fresh-water limestones were depoisted. These are abundant in the lower part but are rare or entirely lacking in the upper part of the Paso Robles.

The Paso Robles formation covers wide areas in both the Bradley and San Miguel quadrangles, being especially well developed in a broad belt on both sides of the Salinas Valley, except in the northern part of the Bradley quadrangle where the Salinas shale extends as far east, on the surface, as the Salinas River. It is probable that, at one time, the Paso Robles covered practically the entire area, except possibly the extreme northeast part of the San Miguel quadrangle and the southwest corner of the Bradley quadrangle.

There is a definite decrease in the coarseness of the Paso Robles debris both from the east and the west toward an indefinite zone east of the Salinas Valley, indicating a source both to the east and west, outside of the limits of the area shown on the accompanying map. This has resulted in an irregular and often ill-defined strip of clay, resulting in a poor clayey soil east of the Salinas River. The Paso Robles varies in thickness from place to place, owing both to original variation and subsequent removal; it has a maximum thickness of about 1,200 feet.

The Paso Robles overlaps all older formations and, in the Cholame Hills and west of the Salinas River, rests on them with marked unconformity. However, between the Cholame Hills and the Salinas River there is no angular discordance between it and the underlying Etchegoin. Although the Etchegoin is marine and the Paso Robles continental, many phases of both are similar lithologically, and it is frequently difficult to draw a satisfactory contact between them where an angular discordance does not exist.

No seepages are known in the Paso Robles in the Bradley-San Miguel area, and it is highly unlikely that any oil could be obtained from it even where it rests on organic Miocene sediments, as it is never very deeply buried.

After the deposition of the Paso Robles there was another period of deformation, probably in the mid-Pleistocene. In some parts of California, especially in southern California, this was as strong, or possibly stronger than the late Pliocene orogeny, but in this region and northward the late Pliocene deformation was the stronger. The folds and faults formed in the earlier period were merely accentuated during the latter. Over most of the San Miguel and the eastern half of the Bradley quadrangle the dips in the Paso Robles are very low, excepting locally on faults and sharp flexures representing faulting in the bedrock. Westward in the Bradley quadrangle the dips in the Paso Robles increase, but they are not as high as in the underlying Etchegoin. Immediately adjacent to faults and folds, dips in the Paso Robles may be as much as 45 degrees, but they decline rapidly away from such structural features. Frequently both the Santa Margarita and Etchegoin are overlapped and the Paso Robles rests directly on the Salinas shale or even the Vaqueros. In the Bryson quadrangle to the west the Paso Robles overlaps all the Tertiary sediments and rests on the Cretaceous.

Terraces are numerous, but since these have been described previously (*see* page 149) they will not be discussed here.

STRUCTURE

As previously stated, diastrophism took place in the upper Miocene, between the Miocene and the Pliocene, in the late Pliocene, and again in the mid-Pleistocene. In fact, there were several earlier diastrophisms, but since the evidence for these lies outside of the area under discussion, they will not be considered here except to point out that the zone of faulting that runs roughly parallel with the San Antonio River in the central part of the Bradley quadrangle first came into existence in the Eocene, or at least between the deposition of the Paleocene and the Vaqueros. On one side of this fault the basement is Santa Lucia granodiorite and Sur crystalline schists, and on the other Franciscan and Cretaceous. This fault locally marks the extreme western edge of the Gabilan mesa. It is a part of that wide and complex zone of faulting, formed in the Eocene and active at various times since, that has been called the Nacimiento fault. This is not a single continuous fault zone, but a line of en echelon faults.

During the various late Tertiary diastrophisms the beds were rather strongly folded and faulted. One of the strongest and most continuous folds is the Bradley-San Miguel anticline which passes through the town of Bradley and dies out a few miles east of San Miguel. North of Bradley this fold is complex and consists of several minor crests in the Salinas shale. From the point where it crosses the Salinas River north of Bradley southward it is wholly within the Paso Robles and Etchegoin and is a comparatively simple fold. The southern end of this fold is the asymmetric San Miguel dome which has a strong surface closure in the Paso Robles. This has a very gentle northeastern limb which rarely dips more than 8 degrees, and usually dips even less. The southwestern limb is steeper, especially along a narrow zone about half a mile southwest of the crest where the dips suddenly increase to as much as 80 degrees, and just as suddenly decrease to 10 degrees or less. This is essentially a narrow true monoclinal flexure on the southwestern limb due, in all probability, to local faulting in the bedrock resulting in a sudden flexing of the overlying Tertiary sediments (*see* Taliaferro, N. L., this bulletin, plate II, cross-section II). On the surface this is a very promising structure, and four wells have been drilled on or near its crest, but no production has been obtained. Although there is surface closure, probably no closure exists at depth because of the westward slope of the bedrock surface, which lies at a depth of 6,000 feet, and the eastward thinning of the sediments. These two factors combined nullify the slight northeastward dip. Furthermore, the marine Miocene beds grade eastward into continental beds beneath this fold. This fold appears to be due in large part to faulting in the bedrock.

Superficially the Vineyard Canyon anticline in the Cholame Hills appears to be a favorable structure, but detailed mapping shows that there is no true and continuous crest, and that there are several faults present. Like the San Miguel dome this irregular fold appears to be due to faulting in the bedrock, possibly complicated by a very irregular pre-Miocene surface. Furthermore, the greater part of the beds beneath this fold are arkosic sandstones and conglomerates. The granodiorite surface lies at a depth of approximately 3,300 feet beneath the crest of this irregular and poorly defined fold. There is little or no possibility of obtaining oil in the Cholame Hills.

Three wells have been drilled on or very close to the crest of the small sharp Pleyto anticline that crosses the San Antonio River in Sec. 26, T. 24 S., R. 10 E., M. D., one of which obtained a small quantity of heavy oil in the Salinas shale. This very sharp and narrow fold does not appear to be a particularly favorable structure.

Several wells have been drilled on the Sulphur Canyon anticline that crosses the San Antonio River near the Branch Ranch. One well was drilled to a depth of about 9,000 feet and encountered granodiorite at a depth of 8,986 feet. However, since this well was located about 1,500 feet east of the crest, and the axial plane of the anticline dips westward, the well was some distance east of the crest when it entered the Vaqueros. Although some of the sandstones in the Vaqueros contained oil they were not sufficiently porous to yield commercial production.

There are several folds in the Salinas shale in the northwestern part of the Bradley quadrangle and some of these have strong closure, at least on the surface. The only deep well drilled in this area did not reach the bottom of the Salinas shale and hence did not afford an adequate test of the region. Production might be obtained in favorably located wells in this region, either from stray sandstones in the Salinas shale or in the Vaqueros. The amount obtained would depend on the porosity of the sands in this region.

Although a number of wells have been drilled and much of the area eliminated from consideration, there is still the possibility of developing small production in certain parts of the Bradley-San Miguel district.

CITATIONS TO SELECTED REFERENCES—Continued

SALINAS VALLEY

Dorn, C. L. 32; English, W. A. 19; Hamlin, H. 04; Reed, R. D. 25; Van Tuyl and Parker 41.

BRADLEY-SAN MIGUEL AREA

Bell, H. W. 18; Collom, R. E. 18; McLaughlin and Waring 14; Stockman, L. P. 36b; Vander Leck, L. 21.

Pleyto Region

McLaughlin and Waring 14; Vander Leck, L. 21.

SAN ARDO DISTRICT

McLaughlin and Waring 14; Vander Leck, L. 21; Watts, W. L. 00a.

TYPE LOCALITY OF THE VAQUEROS FORMATION

By Richard R. Thorup*

OUTLINE OF REPORT

INTRODUCTION

The type area of the Vaqueros formation is situated about half way between San Francisco and Los Angeles, 10 miles west of the Salinas Valley town of King City. Los Vaqueros Valley and the upper part of the adjoining Reliz Canyon, which are in T. 20 S., R. 6 E., M. D. (Junipero Serra quadrangle), constitute the type area.

Two streams drain the region: Vaqueros Creek and Reliz Creek. These two drainage areas are separated by a sinuous, narrow ridge known as "The Divide." The fossil "reefs" exposed on The Divide in the Reliz Canyon road, which Loel and Corey, for convenience, called the "*Dosinia* reef," have been the principal collecting ground for the type Vaqueros formation.

HISTORICAL REVIEW

Hamlin (04, p. 14) originally proposed the name "Vaquero" for sandstones occurring between the basement complex and the Monterey shale in the region of Los Vaqueros Valley. The fauna recorded by Hamlin and by later workers has become known as the "*Turritella inezana*" fauna. The stratigraphy of the type area has been described subsequently in only two papers. Loel and Corey (32) presented an indefinite faunal definition and estimated the thickness of the beds containing the "Vaqueros" fauna to be 400 feet. R. M. Kleinpell (38) stated that the type Vaqueros formation is 4,000± feet thick and extends from the basement complex to the Monterey shale, though he recognized the presence of Eocene foraminifers in the district. Several non-stratigraphic papers concerning the type area have appeared in print. Anderson and Martin (14) and Wiedey (28, 29) presented some paleontologic information. Schenck (35a) suggested the possibility that the Vaqueros formation of California might be Oligocene in age. Eaton, Grant, and Allen (41) compared the geologic column of the type Vaqueros with the Vaqueros of the Caliente Range. Taliaferro (this bulletin, p. 137) recorded the presence of Eocene beds in the Vaqueros Valley district. The writer (Thorup, R. R. 41) proposed a restricted definition for the type Vaqueros formation and named five new formations in the Vaqueros Valley area.

* Graduate student, Stanford University. Report prepared under the direction of Professor Hubert G. Schenck. Manuscript submitted for publication February 27, 1942.

STRUCTURE AND STRATIGRAPHY

The portion of the Santa Lucia Mountains directly bordering the west side of the Salinas Valley, near the towns of King City and Greenfield, consists of about 8,000 feet of folded and faulted upper Tertiary sedimentary rocks. West of this area, near the basement complex, in Los Vaqueros Valley and Upper Reliz Canyon, are exposed, stratigraphically below the Monterey shale, the 6,000 feet of lower Tertiary sandstones and shales with which this report is concerned. These strata have been separated into six formations.

The dominant structural trend of this portion of the Santa Lucia Mountains is northwest. The easterly part of this belt consists of numerous anticlines and synclines in the Monterey shale and overlying formations. Toward the basement complex, in the region of the type area, the structure of the underlying strata becomes complicated by faulting, as well as folding. At the western edge of Los Vaqueros Valley, these strata dip northeastward from the basement complex, and are folded into the Leigh syncline. The axis of this syncline trends in a northwesterly direction near the center of Los Vaqueros Valley. Its northwestern and eastern extensions are terminated by two faults. The first of these faults has brought the basement complex into fault contact with sedimentary rocks. The other fault, named the Vaqueros fault, has cut off the eastern limb of the syncline a short distance east of the axis. This normal fault trends northwest, and has a lateral displacement of more than a mile. It has been traced from the Leigh Ranch to a point 2 miles south of the Berry Ranch, where it splits into three branches. Reconnaissance field work indicates that it probably extends beyond the present known limits.

East of the Vaqueros fault the structure is dominantly anticlinal. Near the Sandholdt Ranch occurs the Sandholdt dome. This is a faulted, or collapsed dome that has several minor offsets on the western flank. South of this dome is the Berry Nose, which consists of a series of steeply dipping sediments, with a prominent structural bend near the Berry Ranch. North of the Sandholdt dome at "The Narrows," immediately north of the Leigh Ranch, is a structural arch, with a small outlier of Santa Lucia quartz diorite exposed in the center.

DESCRIPTION OF FORMATIONS

Basement Complex

The basement complex consists of the Sur series metamorphic rocks, named by Trask (26), which crop out in the northern portion of the area, and the Santa Lucia quartz diorite, named by Lawson (93), which is exposed in the southern portion.

Sedimentary Rocks

Junipero Sandstone. The oldest sedimentary formation in the Vaqueros Valley area is the Junipero Sandstone, named by the writer (Thorup, R. R. 41). It consists of 0 to 125 feet of white to light-gray, coarse

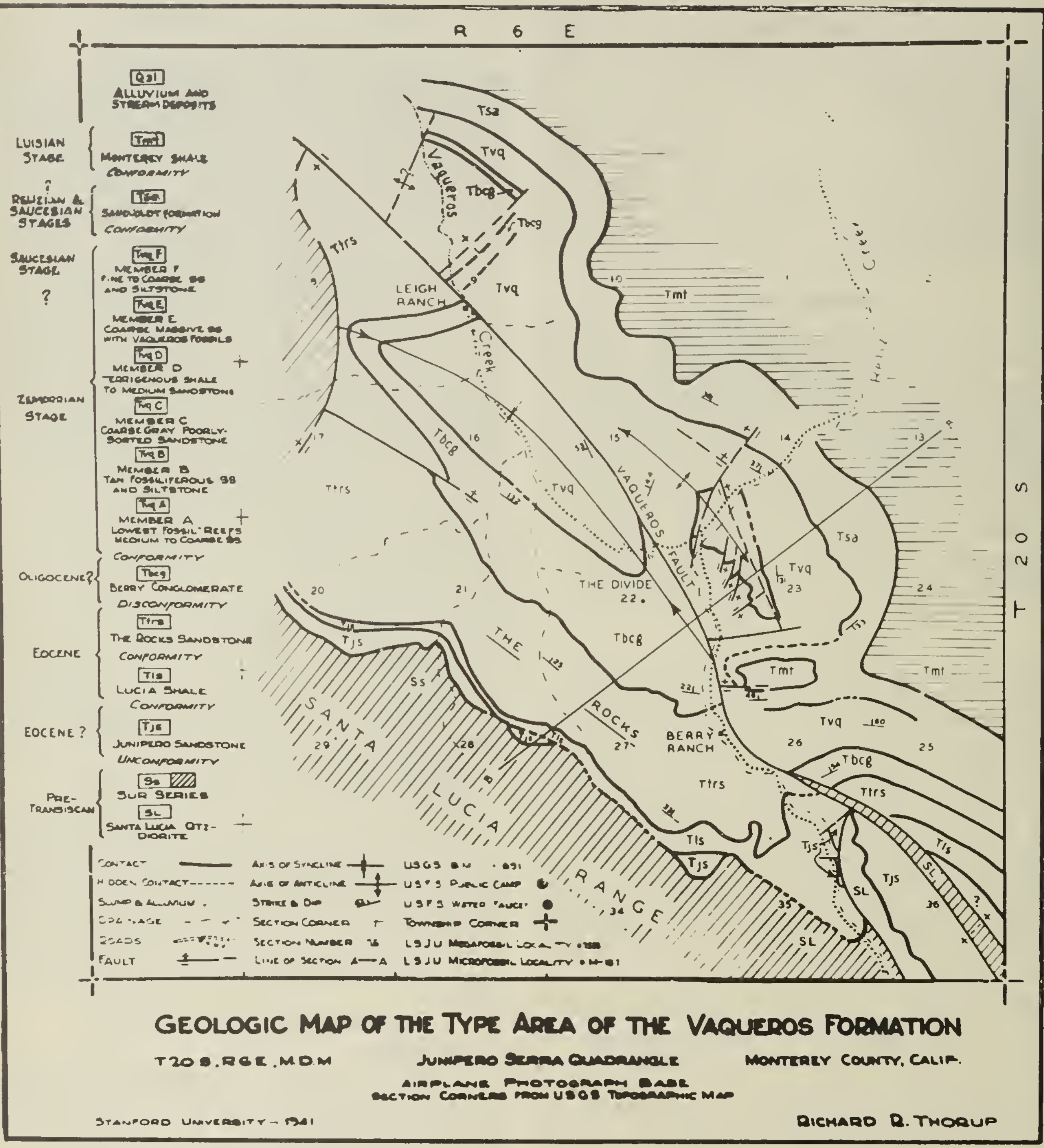

FIG. 190. Type area of the Vaqueros formation: geologic map.

to pebbly, feldspathic, unfossiliferous sandstone. It lies unconformably on the basement complex and has a basal conglomerate which averages 8 feet in thickness. The boulders are composed of material from the Sur series and the Santa Lucia quartz diorite. The Junipero is conformably overlain by the fossiliferous Lucia shale. Because of this conformable relationship, an Eocene age is assigned to this sandstone. The Junipero sandstone outcrops as isolated patches of white, massive sandstone in the western portion of the district, usually at an elevation of 2,000 to 3,000 feet.

Lucia Shale. The Lucia shale, named by the writer (Thorup, R. R., 41), consists of 150 to 500 feet of greenish-gray to steel-gray, thin-bedded, nodular mudstone and shale, and crops out in the western and southern portions of Los Vaqueros Valley region. The Lucia is gradational with both the underlying Junipero sandstone and the overlying The Rocks sandstone. The upper 70 feet of the formation are maroon mudstone with several intercalations of thin sandstone beds toward the upper part. Foraminifera occur throughout the Lucia shale and indicate a middle Eocene age, approximately equivalent to Laiming's Zone C of the Eocene.

The Rocks Sandstone. Conformably overlying the Lucia shale is a thick-bedded, massive sandstone, which, because of its tendency to form a rugged topography has been labelled "The Rocks" on the Junipero Serra topographic sheet. The writer proposed this name as a formational name (Thorup, R. R., 41) for this distinctive sandstone. The Rocks sandstone consists of about 1,500 feet of tan, massive, thick-bedded, fine- to medium-grained, usually well-sorted, unfossiliferous, feldspathic sandstone. The massive ledges along the western edge of Los Vaqueros Valley form spectacular topography. The formation is thought to be Eocene because of its conformable relationship with the subjacent Lucia shale.

Berry Conglomerate. Overlying The Rocks sandstone disconformably are 1,100 feet of conglomeratic sandstone of probable continental origin, called the Berry conglomerate (Thorup, R. R. 41), for typical exposures near the Berry Ranch. The conglomerate is usually white, poorly sorted and poorly bedded, angular to subrounded, friable, commonly stained brown on weathered surfaces, feldspathic, and considerably cross-bedded. Red beds appear in the upper portion of the formation. Boulder beds are common, and isolated boulders occur frequently in the poorly sorted formation. The coarse material is composed of Santa Lucia quartz diorite, the Sur series, and a considerable quantity of smooth, well-rounded felsitic material, probably derived from reworked pre-Eocene conglomerates. The upper part of the Berry conglomerate appears to grade into the Vaqueros formation. The contact of the two is placed at the lowest occurrence of the finer-grained sandstone. This sandstone often carries marine fossils. No fossils have been found in the Berry conglomerate. This formation is assigned an Oligocene age because of its conformable relationship below the Vaqueros formation. The log of The Texas Company's well No. "Dunphy" 1, Sec. 30, T. 19 S., R. 7 E., M. D., suggests that the Berry conglomerate was reached at a depth of about 4,300 feet and that the well was bottomed in this formation.

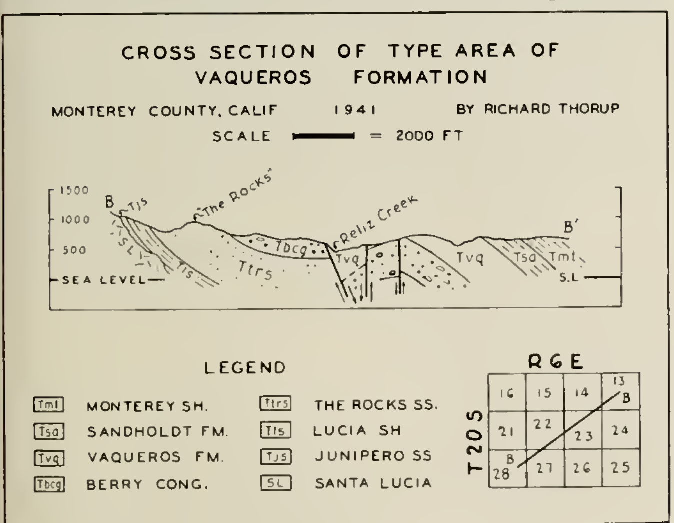

Fig. 191. Type area of the Vaqueros formation: cross-section.

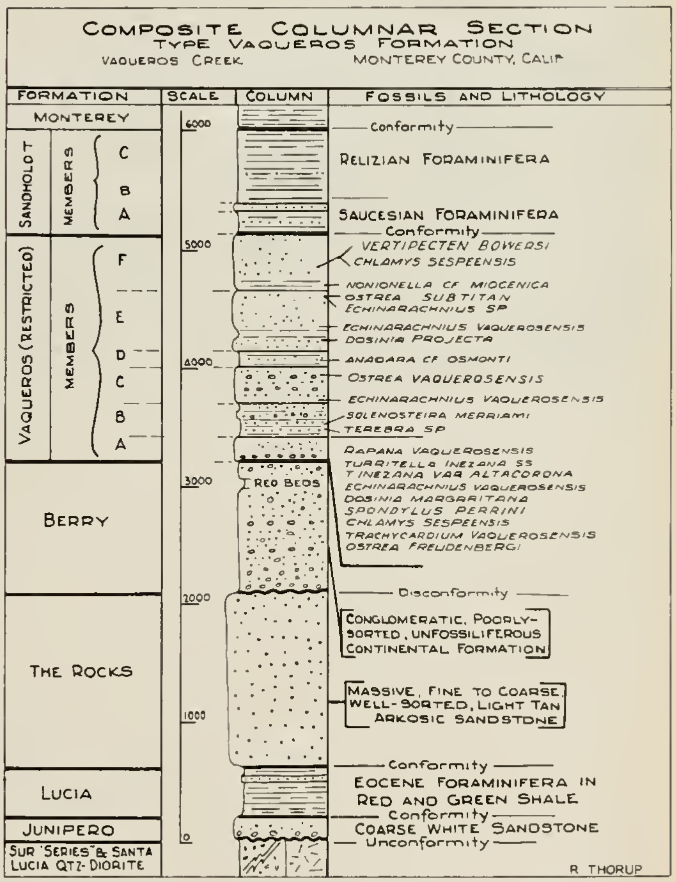

Fig. 192. Type area of the Vaqueros formation: composite columnar section.

Vaqueros Formation. The type Vaqueros formation, as defined herein, is restricted at the base by the marked change in character of the underlying continental beds. The succeeding 2,000 feet of strata consist of marine sandstone and interbedded siltstone containing "Vaqueros" fossils. Six members have been mapped within the Vaqueros formation in the area surrounding the Berry and Sandholdt ranches. Because of a marked change in lithologic facies in the Leigh Ranch district by which an almost uniform texture of fine-grained sandstone occurs throughout the entire formation, the mapping of members was found to be unsatisfactory in this area. Nevertheless, correlations were attempted between this section and the sections to the south.

Member A (lowest member) consists of 200 feet of bluish-gray massive sandstone, and includes the "*Dosinia* reef," with *Turritella inezana*, which Loel and Corey stated occurred 30 feet below the Monterey shale, but which actually occurs at least 1,900 feet below the Monterey shale. This series of "reefs" has been traced for 7 miles.

Member B consists of from 180 to 250 feet of tan siltstone, weathering gray, interbedded with fossiliferous sandstone "shells."

Member C is composed of from 250 to 400 feet of white to gray, coarse to pebbly, friable, biotitic, feldspathic sandstone. This member contains several echinoid reefs.

Member D is a unit of siltstone from 70 to 150 feet thick, which alters into fine-grained sandstone along the strike. The siltstone carries abundant collophane pellets but no identifiable microfossils.

Member E consists of about 500 feet of white to gray, coarse to pebbly, iron-stained, massively bedded, well to poorly sorted, feldspathic sandstone. It contains *Ostrea titan subtitan* and broken echinoid remains in its uppermost portion.

Member F (upper member) is composed of from 500 to 600 feet of buff to white, very fine- to medium-grained, arkosic, friable sandstone. The lowermost 150 feet of the member is a tan, sandy shale with several yellowish arenaceous limestone beds. Two hundred feet from the top of the member a characteristic assemblage of pectens was found throughout the entire area, which was used for purposes of correlation between the three sections. The pectens include *Vertipecten perrini*, *Vertipecten bowersi*, *Pecten vanvlecki*, and *Chlamys sespeensis*. The upper 40 feet of the Vaqueros formation consists of a white, medium- to coarse-grained, friable biotitic sandstone. No shale interbeds were observed in this portion.

The Vaqueros formation is gradational with the overlying Sandholdt formation. The upper member is considered to be of lower Saucesian age, while the lower members have been placed by Kleinpell in the Zemorrian stage.

Sandholdt Formation. The name Sandholdt formation was given by the writer (Thorup, R. R. 41) to about 950 feet of clay-shale containing a minor amount of interbedded sandstone in the lower portion. The formation occurs stratigraphically between the sandy Vaqueros formation and the overlying porcellaneous and cherty Monterey shale.

The Sandholdt formation has been separated into three members in this district. The lowest member (A) consists of 125 feet of bluish-gray sandy clay and siltstone and interbedded yellowish-orange limestone beds, and contains lowermost upper Saucesian foraminifers. Member B is composed of about 75 feet of tan to dark-gray, medium-grained, biotitic, friable sandstone containing several thin beds of dark-gray clay-shale which carry upper Saucesian foraminifers. Member C includes 750 feet of clay and calcareous shale with interbedded thin yellowish-orange arenaceous limestone beds occurring every 25 feet. The foraminifers at the base of Member C are upper Saucesian, and at the top are Relizian. The fossils at the base of the overlying Monterey shale are lower Luisian. The Monterey shale has been restricted at its base in this area to the lowermost-occurring cherts and porcellaneous shales.

SOLEDAD QUADRANGLE*

By L. F. Schombel **

OUTLINE OF REPORT

PHYSICAL FEATURES

Parts of three topographic units of the California Coast Ranges are included in the Soledad quadrangle—the Santa Lucia Range, the Salinas Valley, and the Gabilan Range. These units have the northwest trend common throughout the Coast Ranges.

The area has an elevation ranging from approximately 100 feet in the Salinas Valley to 4,465 feet in the Sierra de Salinas. The topographically high areas, generally underlain by pre-Tertiary rocks, are covered by soil and heavy brush and exposures are poor. In contrast, exposures are excellent in the low hills underlain by Tertiary beds in the vicinity of the Arroyo Seco. In the Salinas Valley the older rocks are covered by Quaternary alluvium.

GENERAL GEOLOGY

The oldest formation exposed in the Soledad quadrangle is the Sur series (Paleozoic?), comprised of metamorphics consisting chiefly of quartz-biotite schist with marble lenses. The Santa Lucia series, which is an igneous complex varying in composition from quartz diorite to granite, intruded the Sur series. Volcanic dikes of lower Miocene age in turn have intruded the Santa Lucia series in the Gabilan Range. Lying unconformably on the Sur series and the Santa Lucia series are Tertiary sediments including basal Monterey (Miocene) sandstone, Monterey shale, Santa Margarita (Miocene) sandstone, Poncho Rico (Pliocene?) sandstone, and Jacalitos (Pliocene) sandstone and shale. The Paso Robles (Plio-Pleistocene) continental beds rest with angular unconformity on the older sediments.

There is evidence of two periods of Tertiary diastrophism in the area. Stress in post-Jacalitos, pre-Paso Robles time (upper Pliocene) resulted in faulting of the Sur and Santa Lucia series, and in intense folding of the Tertiary sediments. The incompetent Monterey shale was severely deformed, being compressed into numerous tight northwest-trending folds. Later, in Pleistocene time, movement along the major faults of the area tilted the Paso Robles beds.

EXPLORATION FOR OIL AND GAS

The presence of oil seeps in the Monterey shale resulted in early prospecting for petroleum in the Soledad quadrangle. Several wells were drilled, but the only production was a little gas from the Jones well No. "Harriman" 1 in Sec. 20, T. 19 S., R. 6 E., M. D. This well was started in 1925 and was drilled to a depth of 4,610 feet. The writer was unable to obtain a log of the well, but apparently it was drilled entirely in Monterey shale. The Jones well No. "Harriman" 2, also started in 1925, located in Sec. 21, T. 19 S., R. 6 E., M. D., was abandoned at 150 feet. The most recent tests were made by the Texas Oil Company in 1928 and 1929. Two wells were located on a small anticline in Secs. 11 and 13, T. 19 S., R. 5 E., M. D., their objective apparently being the middle Miocene (Luisian) sand which crops out in Basin Creek. The No. "Lewis" 1 well was drilled to a depth of 4,537 feet, finishing in silty shale (upper Relizian) with 90-degree dips. Only a few thin sandstone streaks were cored. The Arroyo Seco well was then drilled to a depth of 4,265 feet, bottoming in silty shale (upper Relizian) that dips 45 degrees. This well also cored only thin sandstone beds.

* *Editor's Note:* This report, together with the geologic map of the Soledad quadrangle, represents an abstract of a thesis by Mr. Schombel, prepared to fulfill the requirements for a Master's degree at the University of California. The investigation was made during the years 1938 and 1939.
The Soledad quadrangle lies within that part of the Coast Ranges described by N. L. Taliaferro in his paper "Geologic History and Structure of the Central Coast Ranges of California", published in Part Two of this bulletin. As exploration for oil and gas has been carried on in the southwestern part of the Soledad quadrangle, the salient results of Mr. Schombel's detailed work should be of particular interest in this bulletin.
Acknowledgments: The writer is grateful to Drs. N. L. Taliaferro and Bruce L. Clark of the University of California, and Dr. H. G. Schenck of Stanford University, for assistance in the work. Unpublished theses by L. C. Herold and H. W. Lee were also consulted.

** Assistant Seismologist with the Shell Oil Company. Manuscript submitted for publication June 9, 1941.

CITATIONS TO SELECTED REFERENCES—Continued

SOLEDAD QUADRANGLE

Andrews, P. 36; Conkling, H. 33; Hamlin, H. 04; Kleinpell, R. M. 38; Nickell, F. A. 31; Reed, R. D. 33; Vander Leck, L. 21, p. 82 et seq.; Waring, G. A. 15, p. 61.

JOLON FIELD

Prutzman, P. W. 04.

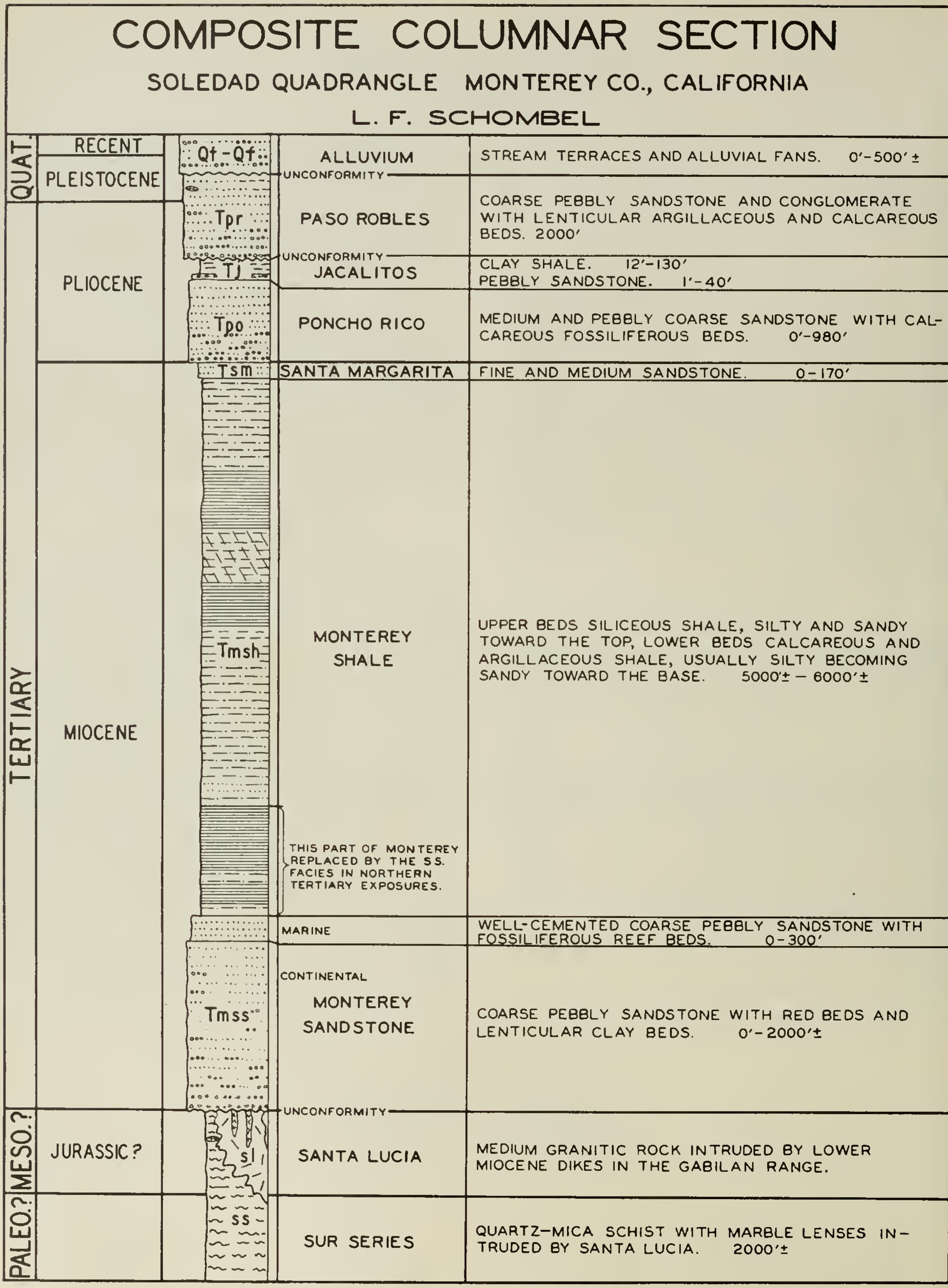

FIG. 193. Soledad quadrangle: composite columnar section.

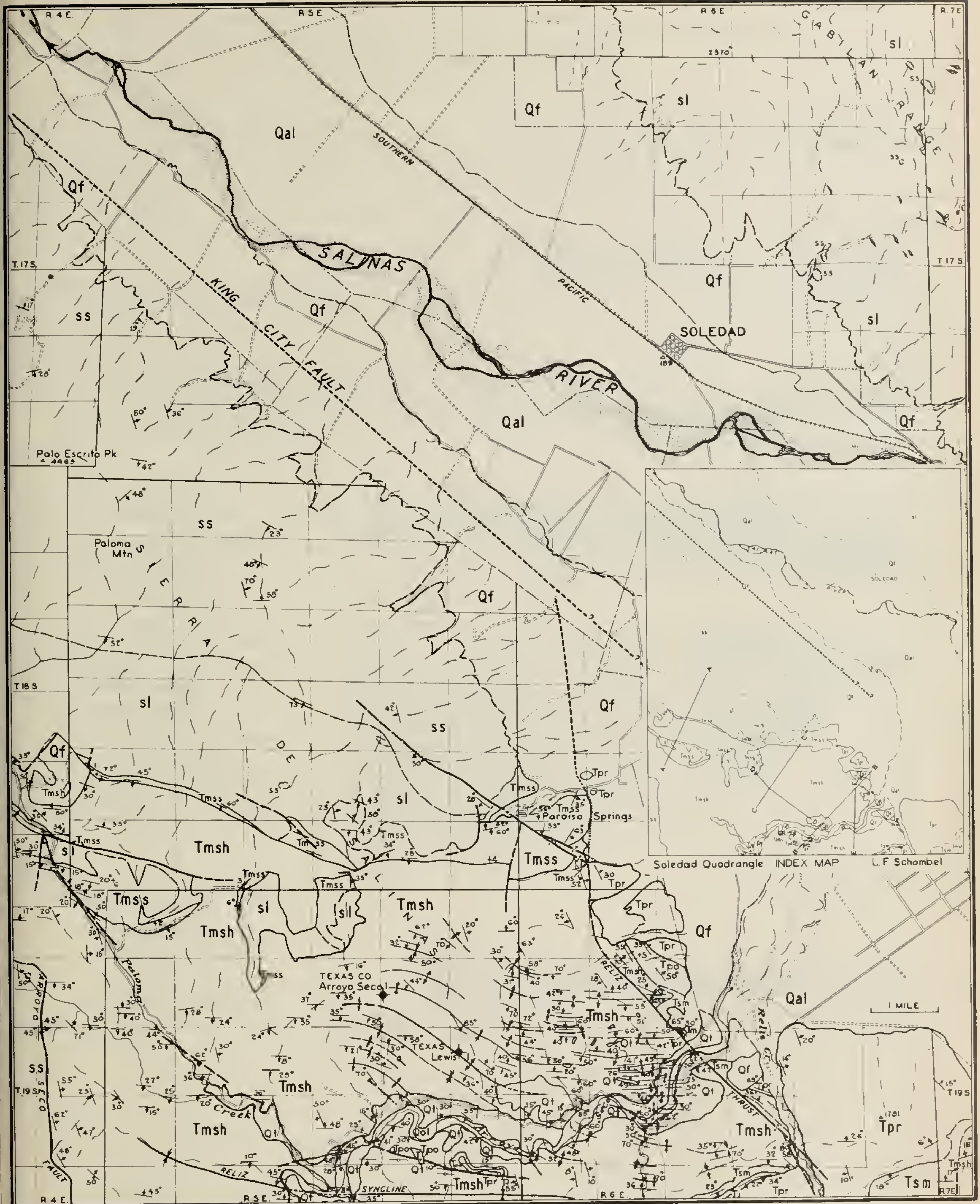

FIG. 194. Soledad quadrangle: geologic map; index map.

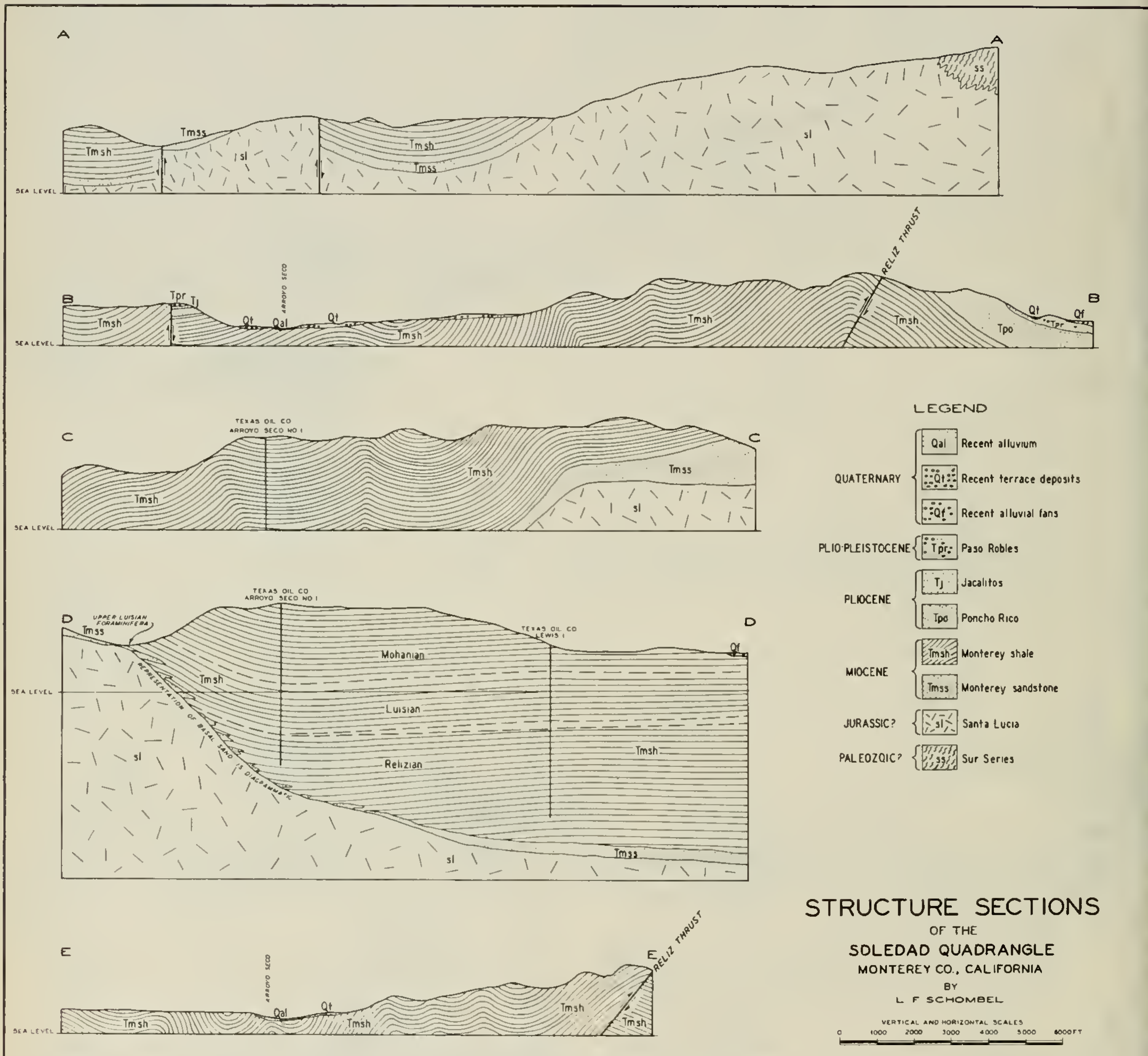

Fig. 195. Soledad quadrangle: structure sections.

CANTUA-VALLECITOS AREA

By E. R. Atwill*

OUTLINE OF REPORT

The Cantua-Vallecitos area covers a west-trending strip of territory 27 miles long by about 10 miles wide, extending from Fresno County on the east into San Benito County on the west. It is on the northeast flank of the Diablo Range, and is some 25 miles north of the town of Coalinga.

VALLECITOS DISTRICT

History

Inasmuch as the wells drilled in the Vallecitos district proper are separated by some 20 miles from those drilled in the Cantua district, and as the two districts are not closely related structurally, it seems best to deal with them separately. Included in the discussion of the Vallecitos district are the foothills to the east as well as the Vallecitos district proper.

The writer takes the privilege of quoting freely from the report of Anderson and Pack (15) to supplement his own knowledge with respect to the history of well development in this region.

The presence of oil seeps in the Vallecitos district has been known for the past 60 years or more. In the decade prior to 1900 and up to 1912, many shallow wells were drilled or dug by hand. One present major operator, the Union Oil Company of California, drilled a series of five wells ranging from 700 to 1,200 feet in depth. The remaining development work, involving some 8 or 10 wells, was carried on by independent operators, the deepest well being 1,800 feet, and the shallowest about 70 feet. All of the wells were located in the immediate vicinity of one or another of the many oil seeps which still may be found in most of the formations exposed here. In some cases very small quantities (1 to 5 barrels per day) of 23.5 to 36 degrees Baume gravity oil were recovered for short periods of time.

* Research Geologist, Union Oil Company of California. Manuscript submitted March 10, 1938; figures revised November 6, 1939.

CITATIONS TO SELECTED REFERENCES—Continued

TEMBLOR RANGE

Grimes, F. C. 25; Henny, G. 38c; Hudson and White 41.

LONOAK-PRIEST VALLEY-PARKFIELD-CHOLAME DISTRICT

Lonoak Region

Laizure, C. McK. 25c.

San Lorenzo District

McLaughlin and Waring 14.

Waltham, Priest, Bitterwater, and Peachtree Valleys

Arnold and Anderson 10; Clark, B. L. 40; Pack and English 14; Watts, W. L. 00.

Parkfield District

Collom, R. E. 18; English, W. A. 19; Goodyear, W. A. 88; Laizure, C. McK. 25c; McLaughlin and Waring 14; Mining and Scientific Press 87a; Stockman, L. P. 36b; Watts, W. L. 00; 00a.

Cholame Hills Region

Goodyear, W. A. 88; Mining and Scientific Press 87a; Stockman, L. P. 36b.

CANTUA-VALLECITOS AREA

Anderson, R. 11; Anderson and Pack 15; Condit, D. D. 30; Dodd, H. V. 39; Oil Weekly 37b; Petroleum World 36a; Stalder, W. 22; Vallat, H. E. 41a, p. 1164; Vander Leck, L. 21, pp. 70 et seq.; White, R. T. 40.

Cantua Creek and Panoche Creek Region (*see* Cantua-Vallecitos Area)

Ciervo (Cierbo) Anticline

Anderson and Pack 15; Stalder, W. 22.

Big Panoche District

Anderson and Pack 15; McLaughlin, R. P. 15; Watts, W. L. 00.

Panoche Creek Region

Anderson, R. 11; Condit, D. D. 30; Vallat, H. E., 41a, p. 1164; White, R. T. 39.

Monocline Ridge

Anderson and Pack 15, p. 19; Petroleum World 36a.

LITHOLOGIC DESCRIPTION OF CANTUA-VALLECITOS AREA

Qal

ALLUVIUM

Detrital material. Yellow clays, ill-sorted and poorly consolidated sands and gravels.

(Unconformity)

Ttu

TULARE FORMATION

Predominantly light-gray to buff-colored, fine grained, clayey sand with numerous irregular lenses of ill-sorted gravel. Occasional yellow-brown clay beds.

(Unconformity)

Tej

ETCHEGOIN-JACALITOS GROUP

Thin-bedded to massive and cross-bedded, fine to coarse, bluish-gray to gray sandstones with numerous pebbly lenses. Sandstones interbedded with reddish-brown to tan and mottled clay layers.

NOTE: Upper 500'<u>s</u> may include equivalent of portion of San Joaquin Clays as recognized in region south of Coalinga.

(Unconformity)

Tsm

SANTA MARGARITA FORMATION

Gray to greenish-gray, massive, fine to coarse or pebbly, carbonaceous and fossiliferous sandstone with interbedded dark-grey to light-gray clay shales and bentonitic clays in middle portion.

(Unconformity)

Tbb
Tt

"TEMBLOR" FORMATION (Incl. Big Blue member)

<u>Big Blue</u> (Tbb) - reddish-brown to greenish-gray ill-sorted serpentinous sands and conglomerates, interbedded with similarly colored clay shales and soft bentonites. OIL MEASURE in basal portion in Cantua district.

<u>Temblor</u> (Tt) - predominantly gray to greenish-gray, massive, medium to coarse or pebbly, fossiliferous and carbonaceous sandstones interbedded with dark gray sandy shales. Upper middle portion in Cantua district composed of interbedded reddish-brown to greenish-gray clay shales and silty sandstones. Poor OIL MEASURES scattered through upper 700' of formation. Upper one-third in Vallecitos district composed of siliceous diatomaceous shale.

(Unconformity)

Tk

"KREYENHAGEN" FORMATION

Siliceous, buff to dark brown and gray-brown, well bedded diatomaceous and foraminiferal shale with numerous sandstone dikes. Very sandy and glauconitic near base. In certain areas, formation is overlain unconformably by Tumey formation of Oligocene age. Consists of upper shale interval unconformably below "Temblor", and is characterized by abundant <u>"Leda"</u> <u>washingtonensis</u> at top. Lower portion is sand, gritty to pebbly and fossiliferous near base.

(Unconformity?)

Td

DOMENGINE FORMATION

Gray to buff-colored, medium to coarse and gritty, massive to poorly bedded and cross-bedded quartzose sandstone (with irregular but persistent lenses of well-rounded black chert pebbles and occasional fossilized wood fragments near base in outcrop). Sand becomes finer in well sections.

(Unconformity)

Th

ARROYO HONDO FORMATION (Incl. Cantua Member)

Upper 150'± in outcrop consists of whitish-gray, massive but cross-bedded quartzitic sandstone. Probable equivalent of "Gatchell" sand in Coalinga area. Beneath this sandstone occurs an interval of bluish-gray, silty clay-shale, "blocky" in appearance with occasional thin layers of fine grained sand. Very foraminiferal.

<u>Cantua Member</u>: Huge lenticular yellow-brown sand body, coarse to medium grained, massive to thick-bedded with large reddish-brown sandstone concretions in lower part. Occasional dark bluish-gray foraminiferal shale layers throughout. Member is seldom found in well sections.

Lower portion of formation is clay-shale like that above Cantua member.

(Unconformity?)

Tmg?-Tmz?

MEGANOS or MARTINEZ FORMATION

Blue-grey silty clay-shale, foraminiferal and "blocky" in appearance. Continuous presence in outcrop is questionable and interval involved is thin.

(Unconformity)

Kcm

MORENO FORMATION

Dark-gray to black and maroon-colored, siliceous but locally calcareous, foraminiferal shale cut by numerous sandstone dikes. Sandstone beds and lenses become prominent in lower portion.

(Conformity)

Kcp

PANOCHE FORMATION

Uppermost portion is blue-gray to buff-colored, massive sandstone with abundant hard sandstone concretions of varying size. Sandstone grades downward into arenaceous clay shale.

FIG. 196. Cantua-Vallecitos area: lithologic description.

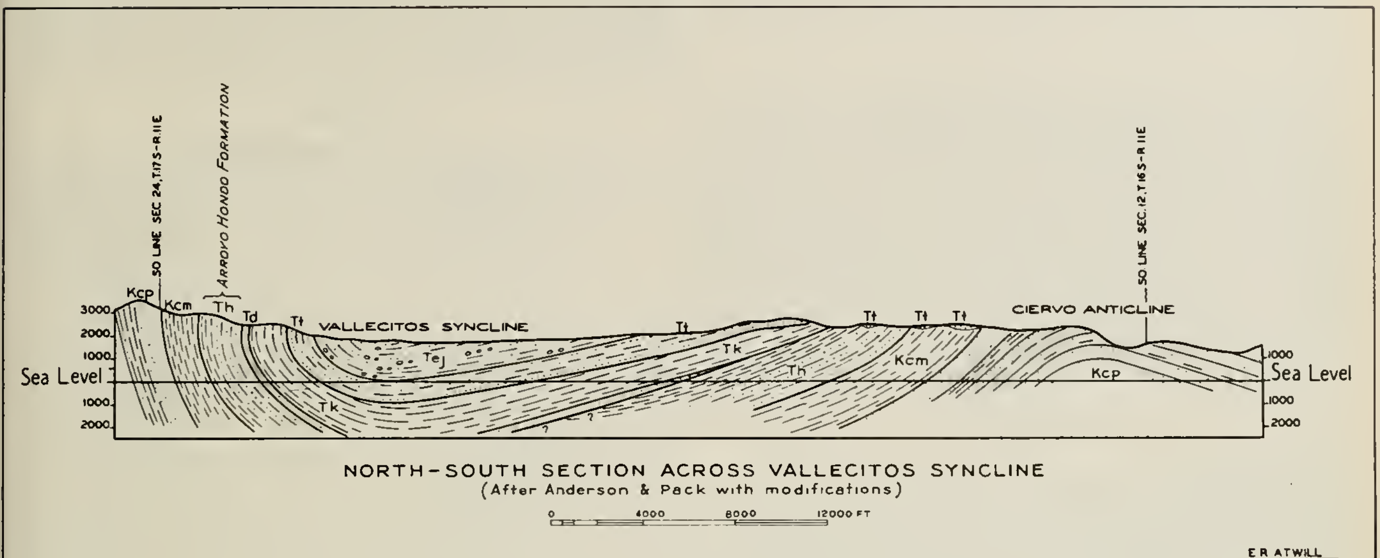

Fig. 197. Vallecitos syncline: north-south section.

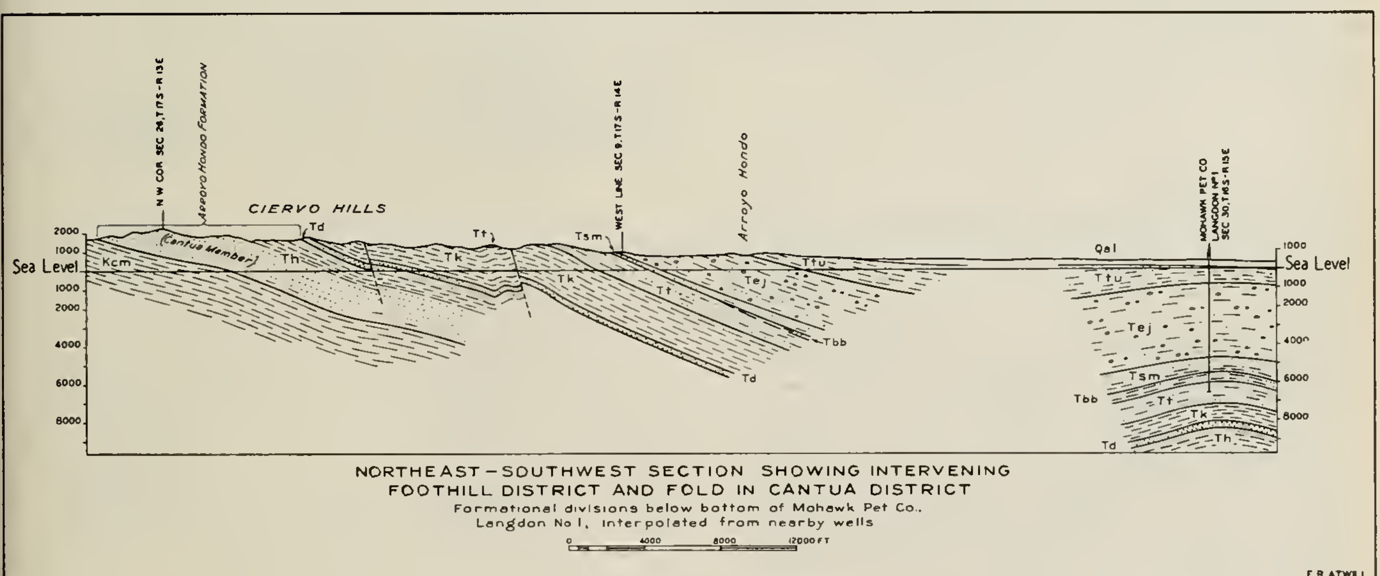

Fig. 198. Cantua district: northeast-southwest section.

No appreciable amount of drilling was done in the foothill district between Cantua and Vallecitos during this early period. There is a record of only one well, drilled to 2,005 feet by the Cantua Oil Company in 1909; it apparently encountered no oil sands, though some gas showings were reported. More recent and deeper tests in this general intervening district have been drilled by the Superior Oil Company, the Seaboard Oil Corporation, and the Western Gulf Oil Company, but they also failed to encounter any showings of oil.

Structure

The structure confined geographically to the Vallecitos district is a completely inclosed west-trending synclinal basin as Anderson and Pack (15, pp. 167-178) have suggested. Actually, however, this syncline extends much farther west. At one time it probably formed one of the main channels connecting the San Joaquin Valley Tertiary embayment with the sea. The dips on the south flank of the syncline vary from 35 degrees in the youngest beds to vertical or overturned in the older beds. On the north flank, where the beds come under the influence of the Ciervo anticline, the dips are predominantly more gentle. At the west end of the basin, though, they become almost as steep as on the south flank.

The slight oil accumulation which has been indicated here may be the result of partially brea-sealed sand outcrops, or of sedimentary gradation (from pervious to impervious beds) on the flanks of the Vallecitos syncline. No particular geologic feature appears to be present that would cause commercial quantities of oil to collect.

The structure of the intervening district is for the most part monoclinal. A few minor, rather tightly compressed folds accompanied by strike faults can be mapped; but they may be only superficial.

CANTUA DISTRICT

History

The Cantua district is restricted to the flat country in the general vicinity of Cantua Creek. Drilling in this district was started in 1933 by the Western Gulf Oil Company as a result of favorably interpreted geophysical and core hole work. The depths of two of the wells drilled exceeded 8,500 feet, and although oil sands were encountered in the Temblor and Domengine formations, no commercial production has been obtained.

In the S. P. Land No. 3 well, a daily production of some 400 barrels of 37 degrees oil with a similar amount of water was swabbed for a few days from the Temblor formation at about 6,500 feet. Increasing water trouble, however, finally led to the abandonment of the well. A later well drilled nearby failed to indicate showings of sufficient importance to justify a test.

Altogether, six comparatively deep wells ranging from 6,578 feet to 8,868 feet in depth have been drilled and abandoned in this district (five by the Western Gulf Oil Company and one by the Mohawk Petroleum Company) in the four years from 1933 to 1937.

Structure

The structure in the Cantua district is thought to be anticlinal. A northwest-trending, gently folded structure, which finds but slight expression in outcrop, can be mapped by geophysical or core hole methods. Dips on the flanks range from 3 to 7 degrees, and, although a definite southeast plunge to the fold is present, the northwest plunge has not been well established. Oil accumulation, such as it is, may result from either an inadequate sedimentary trap on the long southeast plunge, or from a small amount of actual closure on the anticline, or both.

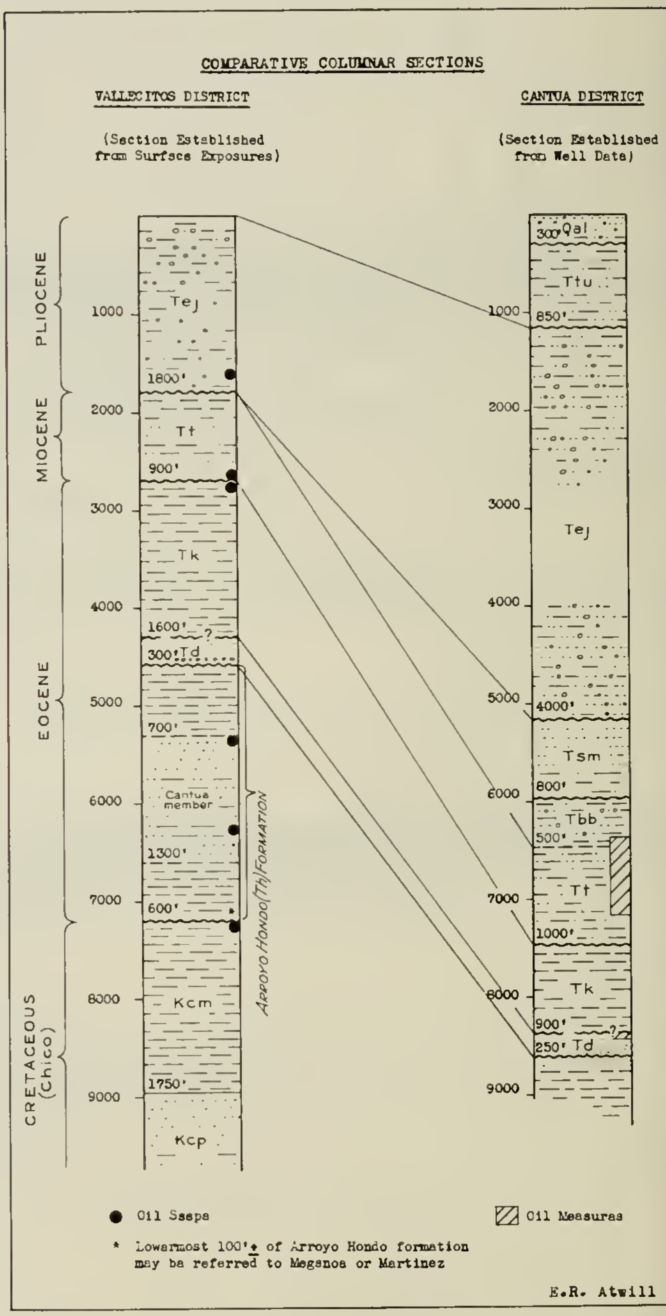

Fig. 199. Cantua-Vallecitos district: comparative columnar sections.

SARGENT OIL FIELD

By James Michelin*

OUTLINE OF REPORT

HISTORY

The Sargent oil field, Santa Clara County, is located approximately 2 miles northwest of Sargent Station on Highway 101. The nearest town of any size is Gilroy, about 7 miles north of the field.

Drilling in this area dates back to 1886 and was undoubtedly initiated as a result of the discovery of rather large seepages of oil along La Brea Creek. However, the importance of the area up to 1904 can be judged by the fact that only 20,000 barrels of oil had been recovered. Between 1904 and 1920 a total of about 10 producing wells and 6 dry holes were drilled. No more drilling was done in the immediate area of the field until 1927 and 1928, during which years the Continental Oil Company drilled three non-commercial wells. Another well was drilled by the Sargent Oil Company in 1932, but so far as is known, it was not a commercial producer.

The peak of production was attained in 1909 during which year the State Mining Bureau records a production of 63,780 barrels of oil. It is estimated that the field has produced, to January 1, 1941, a total of 600,000 barrels of oil. At present there are eight wells producing approximately 700 barrels of oil per month. The gravity of the oil ranges from 11 to 19 degrees, the average reported for the present producing wells being 17 degrees.

STRATIGRAPHY

The stratigraphy of this area has never been worked out in detail to the writer's knowledge. William F. Jones (11) has apparently made a number of subdivisions of the Pliocene and Miocene in this area and has given an interpretation of the structure. However, he admits his stratigraphic interpretation is not based on good fossil evidence, but rather on lithologic similarities to certain beds described in the Santa Cruz and San Francisco folios.

If the necessary detailed stratigraphic work is ever done in this area it is probable that much of what Jones has classified as Miocene will prove to be Pliocene. The reconnaissance map accompanying this report shows merely two subdivisions of the Tertiary, namely the Pliocene and Miocene. A hasty examination of the Miocene rocks indicates an approximate thickness of 2,500 feet. The upper portion consists of diatomaceous shales; the middle section contains some clay shales, which may be equivalent to the Temblor; and the lower section consists of heavy-bedded, hard, coarse, buff-weathering sandstones. These beds are all confined to the area west of the north-trending fault shown on the map.

The base of the Pliocene (?) section consists of a fine-grained, sometimes conglomeratic, bluish sandstone about 1,500 feet in thickness. This rests on the Franciscan formation, and is probably confined entirely to the area east of the north trending fault. Continental Oil Company wells No. 1 and No. 2 penetrated this formation and encountered Franciscan schist directly below it. It is also probable that what was logged as brown shale in the bottom of Continental Oil Company well No. 3 below this sand was also the Franciscan. Above this member there are approximately 4,000 feet of blue shales and blue- and buff-colored sandstones. Beyond the area shown on the map are about 1,500 feet of younger beds, some of which are possibly of fresh-water origin.

STRUCTURE

The productive area of the field is confined to about 75 acres at the head of the northwest-southeast plunging syncline which is probably cut by two faults, one along La Brea Creek, and another trending in a general northerly direction. The map accompaning this report shows these two faults, as well as the attitude of some of the beds in this area. Two sections, A-A and B-B, are also shown and the writer wishes to point out that section A-A is based on very old and very meager records.

PRODUCTIVE HORIZON

The productive horizon in the Sargent field is the sand described above as being at the base of the Pliocene section, and definitely not what Jones indicates as lower Miocene. The oil found here no doubt had its origin in the diatomaceous shales of the Monterey group found immediately west of the north-trending fault. The chances for extending this field in any direction are considered very poor. The probability of deeper production is equally poor.

The chances of finding new fields in this general province are limited by several factors. Immediately north of the area and trending in a general northwest direction the Franciscan formation outcrops. About 3 miles south of this line of outcrop, and trending in the same general direction, is the San Andreas fault south of which there are patches of granitic rocks. As pointed out previously, east of the north-trending fault shown on the map there are apparently no organic Miocene shales, at least as far east as the Associated Oil Company Murphy well just off the east edge of the map. This would appear to indicate that the most favorable prospecting areas would be confined to the area of Miocene rocks west of the north-trending fault. Assuming a suitable structure containing porous members exists in this latter area, it still may have the disadvantage of a limited drainage area in view of the Franciscan outcrop to the north and the San Andreas fault to the south.

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* Geologist, Los Angeles, California. Manuscript submitted for publication May 26, 1941.

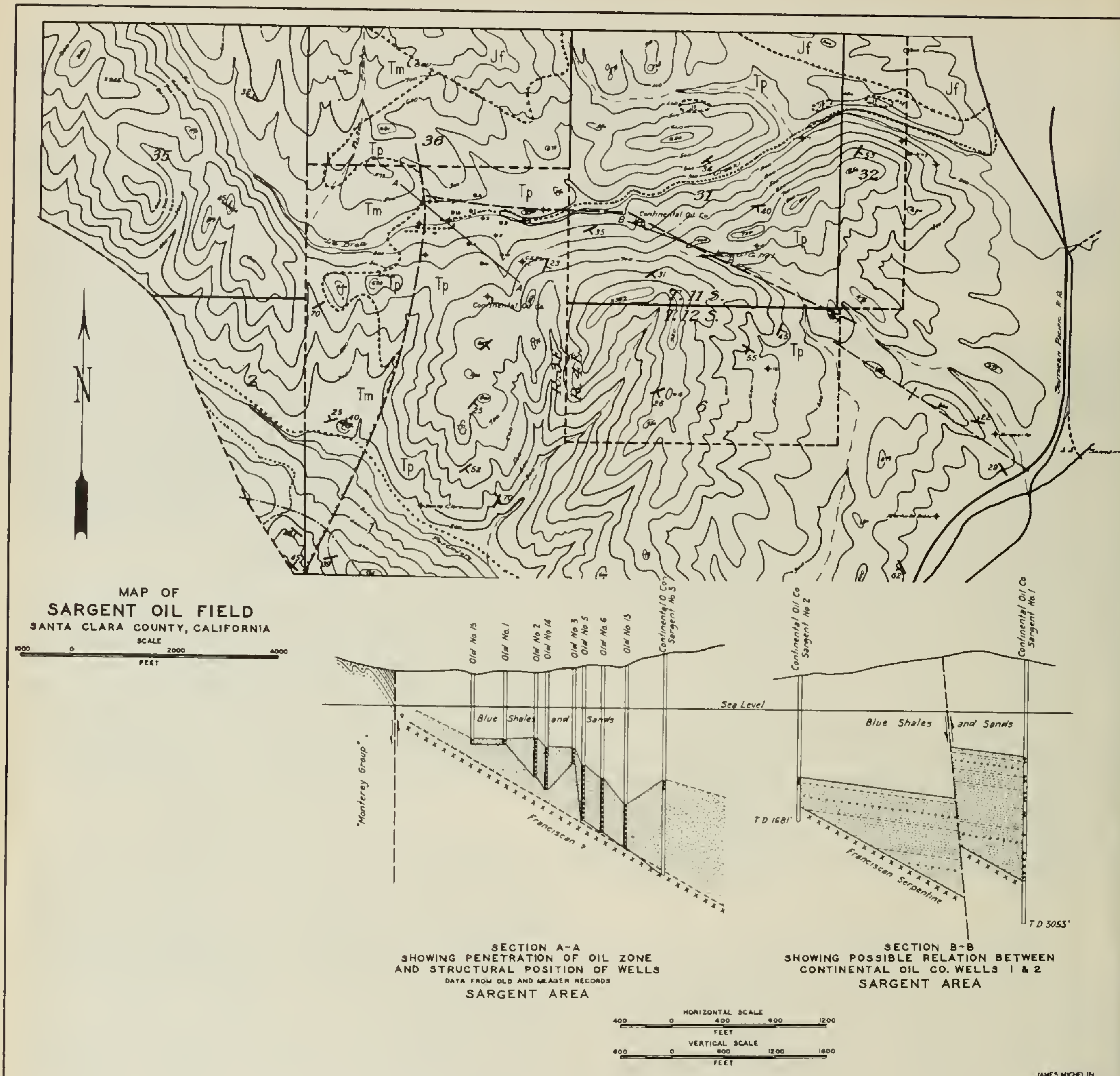
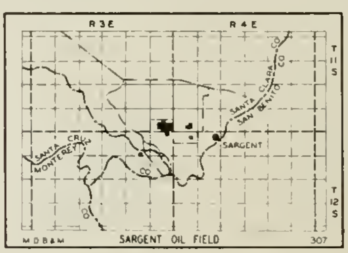


FIG. 200. Sargent oil field: map; cross-sections.

CITATIONS TO SELECTED REFERENCES—Continued

HOLLISTER FIELD
Prutzman, P. W. 04.

SARGENT (SARGENTS, SARGENT RANCH) OIL FIELD
Bell, H. W. 18; Collom, R. E. 18; Dolman, S. G. 30; Franke, H. A. 30; Gore, F. D. 22a; Hanks, H. G. 84, p. 289; Jones, W. F. 11; McLaughlin and Waring 14; Prutzman, P. W. 04; Stalder, W. 41; Taff, J. A. 34; Vander Leck, L. 21, p. 66; Watts, W. L. 90; 00.



Sargent oil field.

MOODY GULCH OIL FIELD

By Max L. Krueger *

OUTLINE OF REPORT

HISTORY

Moody Gulch is the site of some of the earliest oil development activity in the state. Most of the production is encountered in a small 10-acre area, within the Gulch, just southeast of the center of Sec. 8, T. 9 S., R. 1 W., M. D. The Gulch is a westerly branch of Los Gatos Creek; it is located about 2 miles south of Alma, Santa Clara County.

The earliest drilling apparently took place about 1880. Wells averaged between 1,000 and 1,250 feet in depth and produced from 10 to 40 barrels per day of greenish 40 to 45 degrees Baume oil. Old records show that the maximum number of wells on production at any one time varied from 14 to 16. Total production of the Moody Gulch field up to 1921 was in excess of 85,000 barrels of oil. Most of the drilling was completed prior to 1912, although occasional shallow wells and one fairly deep test, the Strader Oil Company, 2,900-foot well (1930) have been drilled since that time. The Strader well was drilled 1,500 feet northwest of the old producing area. Only intermittent production of a few barrels per month has been pumped from the old shallow wells during recent years.

Fate has decreed that this early site of exploration and high-gravity oil production is soon to be obliterated by the new Santa Cruz-Los Gatos state highway. Clearings for the new road show that the oil field will be buried beneath a 100- to 200-foot fill when the new highway is completed. All wells are now being cemented and finally abandoned.

DISTINGUISHING FEATURES

The distinguishing features of the Moody Gulch field are: (1) the occurrence of a greenish high gravity oil (40 to 45 degrees Baume) of a reported paraffin-type base; (2) the occurrence of this oil in the San Lorenzo shales of Oligocene age, (3) the association of igneous rocks, of intrusive origin, with the San Lorenzo shales in this locality, and (4) the location of the field in the crushed zone about 1 mile southwest of the San Andreas fault zone.

STRATIGRAPHY

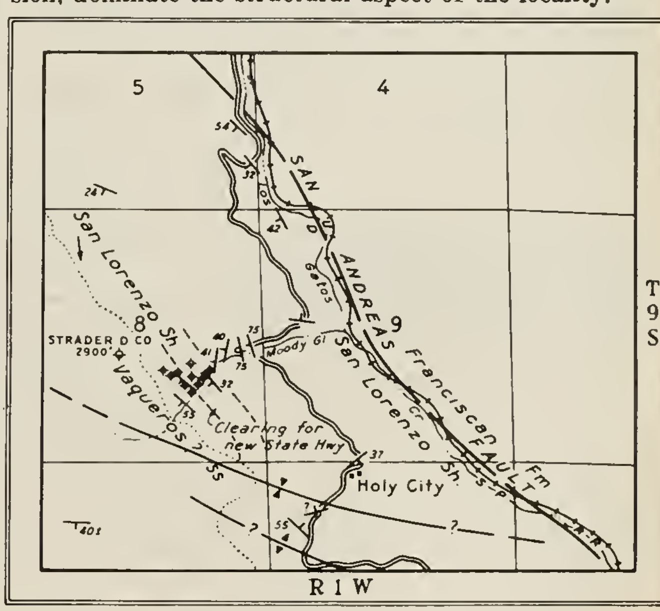
The old producing area occurs within the outcrop of the San Lorenzo shales of Oligocene age. These consist of steel-gray to brownish-gray to black, nodular, hard, fine-grained shale with interbeds of hard, calcareous, medium-grained sandstone. Andesite, basalt, and altered serpentinized rocks occur as intrusives in this district. Because of the small horizontal extent of these intrusives, no attempt has been made to show them areally on the accompanying sketch map of the Moody Gulch field. Exposures within the area are exceptionally poor because of the thickness of the vegetation; no continuity of well-exposed outcrops can be found in this locality.

Farther to the northwest, seepages of light oil are to be found within the confines of the San Lorenzo; it seems that it is within reason to assume that the oil found at Moody Gulch is indigenous to the San Lorenzo shales, and that it occurs as seepage-oil in this highly inclined and contorted area. Surface seepages of oil have been reported from this locality, though they are not visible today.

Overlying the San Lorenzo shale is a massive sand interval. Field mapping has shown that this arenaceous interval probably occupies the stratigraphic niche of the Vaqueros sand; it may, however, prove to be of upper Oligocene age.

STRUCTURE

The structure of the area is that of a highly inclined monocline dipping 30 to 90 degrees to the southwest; it is highly contorted and squeezed because of its proximity to the San Andreas fault zone. Intrusive igneous rock, classified as basalt (dolerite) and andesite, have been found both on the surface, and in cores from below 2,000 feet in the Strader Oil Company well. Some authors stress the occurrence of a fault just southwest of the field, and consider its presence the reason for this small oil occurrence. The fault, however, is not clearly evident in the field, and its presence as a "dominant feature" is doubtful. General relationships suggest that squeeze folding, faulting, and other contorted intricacies, further complicated by igneous intrusion, dominate the structural aspect of the locality.



MOODY GULCH OIL FIELD
SANTA CLARA CO., CALIF.
MAX L KRUEGER MARCH 1938
SCALE
0 1000 2000 4000 6000 FT

Fig. 201. Moody Gulch oil field: map.

* Geologist, Union Oil Company of California. Manuscript submitted for publication May 31, 1938.

HALFMOON BAY DISTRICT

By RICHARD R. CRANDALL*

OUTLINE OF REPORT

HISTORY

The Halfmoon Bay district, San Mateo County, is situated on the coast 30 miles south of San Francisco. It comprises a structural and sedimentary basin of considerable extent, from Moss Beach (the approximate northerly limit) to Pescadero, a distance of 20 miles. Cahil Ridge and the Santa Cruz Mountains delimit the area on the east, and the western edge is covered by the Pacific Ocean at an unknown distance from the shore.

Seepages of high-gravity oil and gas from the Pliocene and Miocene sediments and showings in shallow water wells have encouraged sporadic attempts to obtain commercial production that date from 1867. Wells producing from 25 to more than 200 barrels daily have been developed in four areas, namely Purisima Creek, Purisima anticline, Tunitas Creek, and La Honda area. The oil, which is of uniformly high gravity, has been refined locally for the high gasoline content.

* Geologist and Petroleum Engineer, Los Angeles. Manuscript submitted for publication May 27, 1938; revised February 21, 1941.

SIGNIFICANCE AND DISTINGUISHING FEATURES

The Halfmoon Bay district is the most northerly sedimentary basin in California that has afforded commercial production of high-gravity oil and gas. The district is distinguished by the great thickness of sedimentary strata in the block, especially in the Pliocene and upper Miocene sections, concerning which there is relatively little detailed knowledge.

STRATIGRAPHY

General Statement

Sediments exposed in the district rest upon a basement complex of granodiorite, and comprise 26,000 feet of Cretaceous, Eocene, Oligocene, Miocene, and Pliocene strata.

The basement complex delimits the area on the north and east. Cretaceous sediments outcrop in the vicinity of Pescadero and consist of shales, sandstones, and conglomerates that are not known to be petroliferous. The Eocene and Oligocene strata are not present on the outcrop in this particular district, although they are probably present at depth.

Miocene

Vaqueros Formation. The Vaqueros formation, as classified by Branner and others, is now considered to be Temblor in age, at least in the northern portion of the district under discussion. The series is essentially sandstone.

Temblor Formation. The Temblor formation consists of 200 to 2,000± feet of sandstones overlain by a series of argillaceous, calcareous, and organic shales, exceeding 400 feet in thickness, that carries foraminiferal zones markedly similar to those of the Rincon shale of Santa Barbara and Ventura Counties. The basal sandstones carry a Temblor megafauna and should constitute an excellent reservoir for petroleum, under proper conditions.

CITATIONS TO SELECTED REFERENCES—Continued

MOODY GULCH OIL FIELD

Crawford, J. J. 96; Dolman, S. G. 30; Franke, H. A. 30; Goodyear, W. A. 88, pp. 94-96; Gore, F. D. 22a; Hanks, H. G. 84; Jones, E. C. 97; McLaughlin and Waring 14; Mining and Scientific Press 79a; 79b; Stalder, W. 41; Taff, J. A. 34; Vander Leck, L. 21, p. 64; Watts, W. L. 90; Weber, A. H. 90.

LOS GATOS REGION

McLaughlin and Waring 14, p. 470; Petroleum Engineer 35; Vander Leck, L. 21, p. 64.

HALFMOON BAY DISTRICT (PURISIMA CANYON FIELD)

Gore, F. D. 22a; Grimes, F. C. 25a; Hanks, H. G. 84, pp. 301-302; Stalder, W. 41; Taff, J. A. 34; Vander Leck, L. 21, pp. 62-63; Van Tuyl and Parker 41; Watts, W. L. 00.

Purisima—San Gregorio Oil Fields

McClintock, H. H. 23; Mining and Scientific Press 86.

RINCON HILL WELL

Irelan, W. Jr. 90.

Monterey Shale. The Monterey shale, possible source sediment for petroleum, overlies the Temblor shales, presumably in gradational contact, and consists essentially of organic, argillaceous, calcareous, and siliceous shales with minor sandy facies. These beds are best exposed along Butano Ridge east of Pescadero. No complete section was found, because of faulting and overlapping by the Purisima formation. Although insufficient field work has been done to define accurately the lower contact with the Temblor, the total thickness will be measured in thousands of feet.

Volcanics. A series of basic intrusives and extrusives, consisting of diabase, basalt, and mud flows, agglomerates, and associated volcanic facies, has been mapped in and above the Miocene sediments in the easterly portion of the district. The occurrence of these strata is somewhat localized. The volcanics were not observed to affect the Pliocene sediments. Their effect on possible accumulation of petroleum in the Miocene strata is not known.

Pliocene

Purisima Formation. The Purisima formation of the Mio-Pliocene is probably the most important sedimentary series in the district to consider in an evaluation of oil and gas possibilities. The series, which exceeds 9,500 feet in thickness in the vicinity of Purisima Creek, and thins rapidly to the north and south, contains adequate source sediments and reservoir rocks to afford important accumulations of petroleum on structure and, in addition, rests upon the organic Miocene sediments with the consequent probability of accumulation from that source. The formation can be roughly divided into three lithologic units termed lower, middle, and upper. The lower Purisima is very probably Miocene in age; the middle Purisima is roughly equivalent to the Sisquoc formation of Santa Barbara County in age, being lowermost Pliocene or uppermost Miocene; and the upper Purisima is definitely Pliocene.

The lower Purisima rests upon the Miocene and older rocks with pronounced local unconformity and consists essentially of medium- to coarse-grained, gray to buff sandstone with minor beds of intercalated gray, brown, green, argillaceous, organic, and calcareous shales and siltstones together with some conglomerate. It overlaps the Miocene and older rocks and is, in turn, apparently overlapped by the middle Purisima in a few localities. A maximum thickness of some 4,500 feet is attained in the southerly portion of the basin; thinning is apparently rapid to the north and east. The marked decrease to some 300 feet in thickness in the vicinity of Halfmoon Bay may be due to faulting or to a gradation of the sandstones to siltstones and shale, which, in the absence of sufficient detailed mapping, may have been included in the middle Purisima.

The lower Purisima is impregnated with petroleum at many localities on the outcrop, and also in La Honda oil field, where small wells located on a westerly dipping monocline, yield high-gravity oil. The formation was not recognized in cores taken in the Wilshire Oil Company well No. "Cowell" 1, to a depth of 7,982 feet.

The middle Purisima consists essentially of diatomaceous, organic, calcareous, and argillaceous shales and siltstones with thin beds and lenses of fine- to medium-grained sandstone. The best exposures of the series are to be found on Pomponio Creek, in the southern portion of the district, where the thickness will average 2,600 feet.

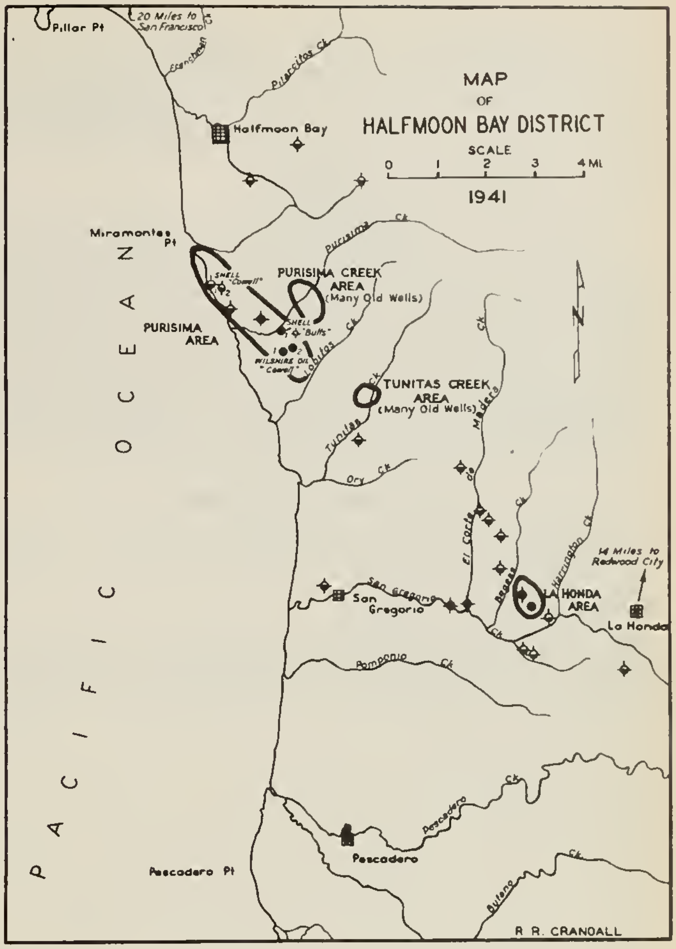


FIG. 202. Halfmoon Bay district: map.

The assemblage of Foraminifera in cores taken to a depth of 7,982 feet in the Wilshire Oil Company well No. "Cowell" 1, indicates that the middle Purisima is equivalent in age to the Sisquoc formation of Santa Barbara County.

The upper 2,500 feet of the middle Purisima has yielded the greater proportion of the petroleum produced in the area to date from wells drilled on the Purisima anticline and in the Purisima Creek and Tunitas Creek areas. The productive zones occur in thinly bedded sandstones and in sandy and fractured shales.

The upper Purisima is a lithologic unit comprising medium- to coarse-grained sandstones, sandy shales, mudstones, and shales that rest with apparent conformity upon the middle Purisima shales. The contact has been placed, solely as a matter of convenience in mapping, at the base of the sandstones that overlie the middle Purisima shales. The top of the upper Purisima is not exposed, due to the fact that the series extends under the Pacific Ocean, but the unit exceeds 3,000 feet in thickness near Purisima Creek and thins toward the south.

Quaternary and Recent

The Quaternary and Recent sediments consist of terrace material, soils, and alluvium deposited by the various streams of the area. The terrace deposits are often saturated with high-gravity oil where they rest on the petroliferous middle Purisima at favorable structural and stratigraphic positions.

STRUCTURE

The district is complicated by a number of folds and faults that trend generally northwest. Several of these mapped structural and stratigraphic features should be capable of trapping commercial quantities of petroleum. One of the dominant upwarps is the Purisima anticline, which extends from Pillar Point southwest for 11 miles to Tunitas Creek where it dies out in a westerly dipping monocline. The fold is asymmetric, is complicated by several faults, and has at least two local domes.

PRODUCTIVE HORIZONS

The middle and lower Purisima have yielded the oil and gas produced in the area to date.

Middle Purisima Oil Zones

This unit is petroliferous throughout and should afford commercial production, under proper structural conditions, when adequate reservoir beds are present. The Wilshire Oil Company wells on the Purisima anticline encountered a productive zone some 1,500 feet below the top of the middle Purisima that is probably similar to those zones yielding small production in the Purisima Creek and Tunitas Creek areas. Small flowing wells of high-gravity oil were secured from well-saturated but fine-grained and silty oil sands and fractured shales. The wells were completed flowing some 30 barrels per day, but fell off rather rapidly to a fairly settled production of from 5 to 8 barrels. Considerable gas was present and the failure of the wells to maintain their initial production is ascribed to the lenticular character of the thin sand bodies as well as to the low permeability of the sands.

Lower Purisima Oil Zones

The lower Purisima is often saturated with petroleum on the outcrop and has yielded small production of high-gravity oil in La Honda field. The structure in this locality is monoclinal, the oil sands occur some 1,800 to 2,400 feet below the apparent top of the unit, and no sustained production has been developed. No other wells have been drilled in the district, at favorable structural locations, to test the lower Purisima.

MOUNT DIABLO REGION

By Charles M. Cross*

The Mount Diablo uplift in central California, about 30 miles east of San Francisco, includes the area southeast of Mount Diablo peak almost to Corral Hollow on the south side of T. 3 S., R. 4 E., M. D., in Alameda and Contra Costa Counties.

The uplift is a broad anticlinal fold culminating in the diapiric fold which forms Mount Diablo proper. The rocks involved include 26,000 feet of Mesozoic sedimentaries which are in fault contact with older metamorphics and intrusives around the periphery of Mount Diablo. These Mesozoic formations (ranging from Knoxville to Moreno) are overlain by 8,400 feet of Eocene and Oligocene, and at least 2,500 feet of Miocene and Pliocene (Taff, J. A. 35). The north and east flanks of the uplift dip uniformly away from the axis, forming a monocline which extends out towards the Sacramento and San Joaquin rivers until the exposed rocks are covered by alluvium. On the south flank, north of Tassajaro, compression has resulted in the development of a small, sharply folded anticline and syncline, the latter being overturned. For a short distance south of these folds the younger Tertiary beds are overturned, dipping to the northeast before resuming their normal southerly dip.

The search for oil and gas in the Mount Diablo region, so far, has not resulted in the discovery of commercial quantities of either, activities having been largely confined to the testing of areas in the vicinity of surface seepages. Such seepages encouraged the drilling, many years ago, of a few shallow wells in Oil Creek south of Stewartville in the Moreno (Upper Cretaceous) formation.

Except for the wells in Oil Creek, most of the prospecting for oil has been carried on in the southerly portion of the area, the geology of which has been described by Robert Anderson and R. W. Pack (15).

In 1908 and 1910 two wells were drilled on the crest of the anticline near Altamont in Secs. 20 and 27, T. 2 S., R. 3 E., M. D. These wells, drilled entirely in Panoche (Upper Cretaceous) rocks, reached depths of 1,090 and 2,878 feet without encountering commercial quantities of oil or gas.

From 1917 to 1932, ten wells were drilled to depths of 200 to 1,500 feet on the southeasterly end of the uplift, in Secs. 14 and 15, T. 3 S., R. 3 E., M. D. This area has been referred to as the Hamilton Ranch. Several of these wells yielded some oil and gas, but not in sufficient quantities to insure commercial production. This oil came from the westerly dipping Cretaceous beds at or near the unconformable contact with the overlying gentler-dipping upper Miocene and Pliocene rocks. These wells were drilled on account of surface seepages from the exposed Cretaceous rocks.

In 1936, a test well was drilled to 5,925 feet in Sec. 13, T. 3 S., R. 3 E., M. D., near the southeasterly limit of the anticline, without showings of oil or gas.

* Tide Water Associated Oil Company. Manuscript submitted for publication December 8, 1939.

CITATIONS TO SELECTED REFERENCES—Continued

BERKELEY HILLS
Clark, B. L. 33.

MINER (MINOR) RANCH FIELD
Arnold, R. 08a; McLaughlin and Waring 14, pp. 442-443; Stalder, W. 41; Vander Leck, L. 21; Wagner, P. 26b; Watts, W. L. 00.

SAN PABLO REGION
Lalzure, C. McK. 27.

MOUNT DIABLO REGION
Allen, V. T. 39; Clark, B. L. 31; 35; 40; Clark and Campbell 39; Goodyear, W. A. 88, p. 65; Laizure, C. McK. 27; Pulitz, Newton, and Klein 39; Richey, K. A. 38; 40; 40a; 40b; Stalder, W. 41; Taff, J. A. 35; Vander Leck, L. 21, pp. 60-61.

TESLA REGION
Allen, V. T. 39; Anderson and Pack 15; McLaughlin and Waring 14; Vander Leck, L. 21.

ANTIOCH REGION
Vander Leck, L. 21.

Chapter XI

San Joaquin Valley and Bordering Foothills

CONTENTS OF CHAPTER XI

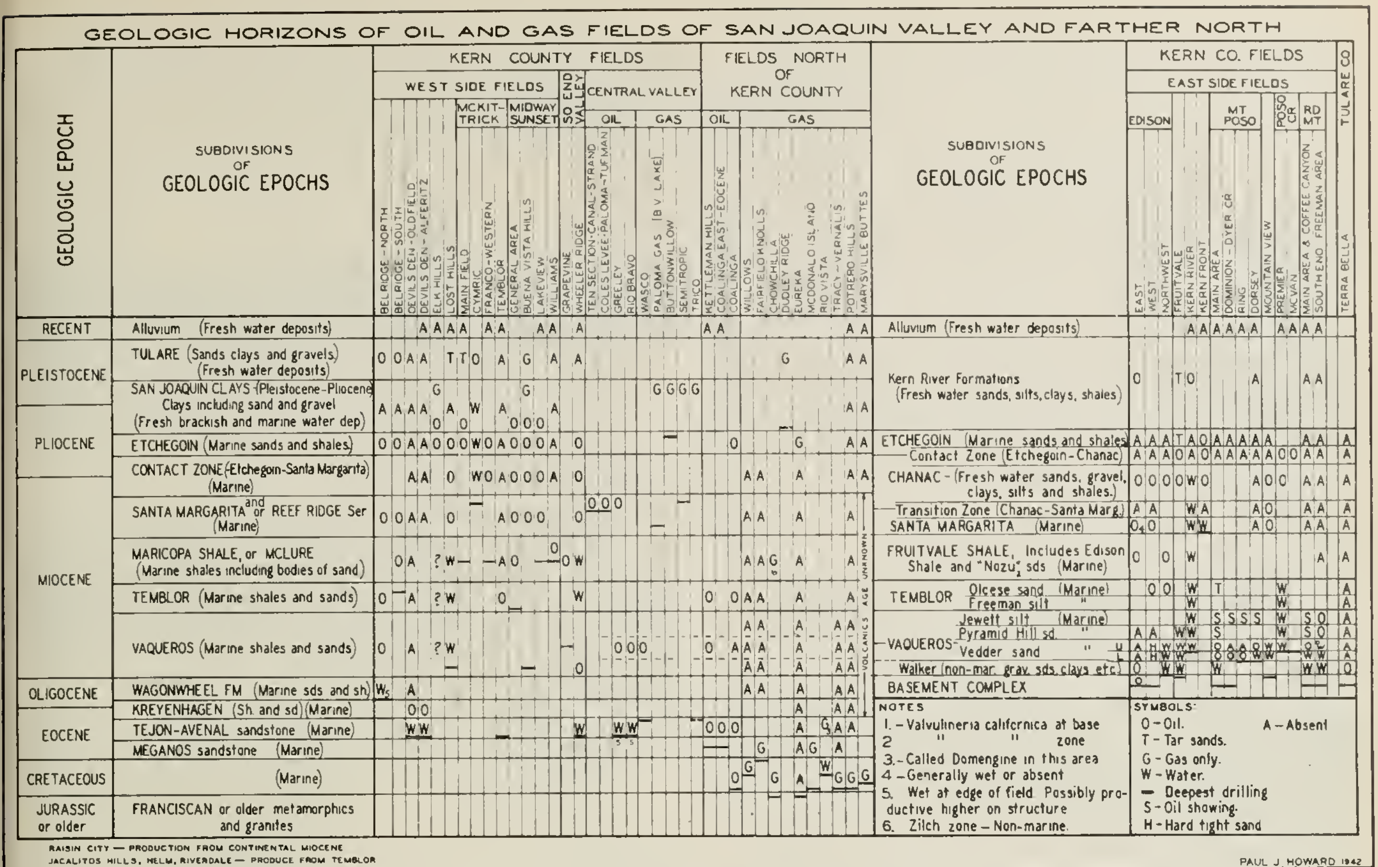


FIG. 203. San Joaquin Valley: chart of geologic horizons in the oil and gas fields.

CITATIONS TO SELECTED REFERENCES—Continued

SAN JOAQUIN VALLEY AND BORDERING FOOTHILLS

Allen and Jacobs 11; Anderson, F. M. 05; 08; Anderson, R. 12; Anderson and Pack 15; Arnold and Kemnitzer 31; Barbat and Galloway 34; Barbat and von Estorff 33; Blake, W. P. 64; Cadle, A. 28; California Oil World 34; 36; 37b; 38a; 38b; Clark, B. L. 29; 35; Cooper, A. S. 11a; Eaton, J. E. 35a; 37a; Eldridge, G. H. 01; Engineering and Mining Journal 10; English, W. A. 28; 39a; Fortune 38; Fox, L. S. 28; 29; Gaylord and Hanna 25; Gester, G C. 17; Goudkoff, P. P. 39; Hanna and Garrison 25; Henny, G. 27; 30b; 38d; Hoots, H. W. 27; 30; Hoots and Herold 35; Kleinpell and Cunningham 34; Laiming, B. 39; 40; Lynton, E. D. 31; McCollough, E. H. 34; McLaughlin and Waring 14; Menken, F. A. 40a; Miller, H. C. 29; Mills, B. 35; 38; Mining and Scientific Press 00c; 11c; Musser, E. H. 36; Oil and Gas Journal 41; 41d; Oil Weekly 37b; Olson, W. S. 41; Parson, B. E. 31; Petroleum Engineer 35; Petroleum World 35; 36; Pilsbry, H. A. 34; 35; Prutzman, P. W. 10; Reed, R. D. 33; Rogers, G. S. 17; Rousselot, N. A. 35; Sanders, T. P. 38; Schenck, H. G. 40a; 40c; Smith, M. B. 38; 38a; Standard Oil Bulletin 36; Stevens, J. B. 24; Stockman, L. P. 30b; 35i; 36j; 38; Stulken, E. J. 41; Taff, J. A. 34; Taff and Hanna 26; Uren, L. C. 37; U. S. Geological Survey 34; Watts, W. L. 00; Wilhelm, V. H. 32; 38; Woodward, W. T. 40.

Fresno County

Boalich, E. S. 20; Bradley, W. W. 16a; Crawford, J. J. 94; 96; Durrell, C. 40; Goldstone, E. M. 90; Goodyear, W. A. 88; MacDonald, G. A. 41; Mining and Scientific Press 86; 00c; 00d; Parsons, H. G. 00a; Prutzman, P. W. 04; Vander Leck, L. 21; Watts, W. L. 93; 94; Willey, D. A. 05.

Kern County

Anderson and Hanna 25; Angel, M. 90; Brown, G. C. 16; Crawford, J. J. 94; 96; English, W. A. 21a; Ferguson, R. N. 18; 18a; Godde, H. A. 28a; Goodyear, W. A. 88; Howard, P. J. 39; Mining and Oil Bulletin 24a; 25; Mining and Scientific Press 88; 00b; 00c; 09b; 10a; Parsons, H. G. 00; Prutzman, P. W. 04; Starke, E. A. 24; Stockman, L. P. 36i; 36m; 37a; Tucker, W. B. 21; Vander Leck, L. 21; Watts, W. L. 94; 00; Willey, D. A. 05.

Kings County

Arnold and Anderson 08b; Boalich, E. S. 20; Bradley, W. W. 16b; Crawford, J. J. 96; Franke, H. A. 30a; Stalder, W. 31; Vander Leck, L. 21; Watts, W. L. 94; Willey, D. A. 05.

Madera County

Erwin, H. D. 34; Laizure, C. McK. 28; Vander Leck, L. 21.

Tulare County

Crawford, J. J. 96; Durrell, C. 40; Ferguson, R. N. 18a; Franke, H. A. 30b; Laizure, C. McK. 22; Mining and Scientific Press 65a; Van Couvering, M 27; Vander Leck, L. 21; Watts, W. L. 93; 94.

COALINGA OIL FIELD

By Max Birkhauser*

OUTLINE OF REPORT

WEST SIDE FIELD

History

The Coalinga West Side field, Fresno County, was discovered in 1901. Its most prolific well, the Silvertip, located in SE¼ Sec. 6, T. 21 S., R. 15 E., M. D., reached the Temblor sands in September 1909, and came in as a gusher, producing 20,000 barrels per day.

Structure

In the West Side field, Tertiary sediments form an east-dipping monocline, and lie unconformably upon Cretaceous rocks. The West Side area is separated from the other areas of the Coalinga field by a syncline. Most of the oil comes from the Temblor sands, where it was trapped by unconformably overlapping Pliocene strata. A minor amount of oil is produced from the basal beds of the Etchegoin.

Productive Horizons

Old records show that in Sec. 12, T. 20 S., R. 14 E., M.D., and the adjacent region, three oil zones are present.

Zone A, also referred to as a tar sand, varies in thickness from 20 to 100 feet. This sand was found to be non-productive in many wells, but in some wells a small amount of 14 degrees Baume oil was obtained.

In Zone B., oil of 13 to 14 degrees Baume gravity is produced by the shallower wells; wells that reach this horizon at an approximate depth of 2,000 feet produce oil ranging from 17 to 18 degrees Baume.

Zone D lies 50 to 100 feet below Zone B in shallow wells, and 300 to 350 feet below Zone B in the deeper wells. The oil has a gravity of 14 to 15 degrees Baume. The deeper wells, it appears, produce only from this zone. It is considered the best producing horizon in the West Side field, and is probably correlative with the lower producing sand in the East Side field.

* Geologist, Shell Oil Company. Manuscript submitted March 7, 1938; permission to publish granted by Shell Oil Company, S. Belither, President.

OIL CITY FIELD

History

The Oil City field is located in the south part of Sec. 17, T. 19 S., R. 15 E., M.D., and in the southerly adjoining Sec. 20. Development of this field started in 1898, and it is reported that the largest well showed an initial production of 700 barrels of oil per day. In 1900 the average production was between 15 and 20 barrels per well. In 1936, however, the combined production from all wells drilled in Sec. 17 totaled only 4 to 6 barrels per day.

Distinguishing Features

The Oil City field is separated from the West Side field by a syncline; it lies on a southeast-plunging, asymmetric anticline which is open toward the northwest. It is the only oil field in California in which production was found in the Cretaceous.

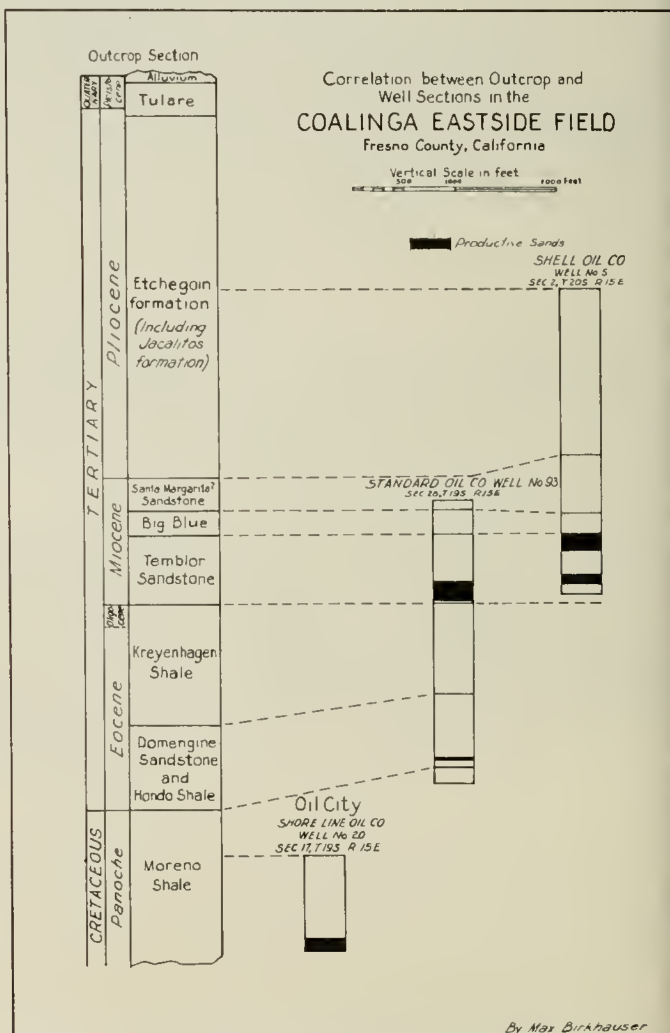


Fig. 204. Coalinga Eastside oil field: correlation between outcrop and well sections.

Stratigraphy

Wells drilled in Sec. 17 start in the purple shale of the Upper Cretaceous (Moreno shale), and produce from the same formation. Some wells in Sec. 20 are located in the overlying Hondo shale, but they also produce from the Moreno. The wells vary in depth from 300 to 1,700 feet.

Kind of Oil

The oil is greenish or brownish in color, and has a gravity as high as 48 degrees Baume. It has a paraffin base, and differs from the oil produced from the younger formations of the East Side field in that respect.

EAST SIDE FIELD

History

The first wells in the East Side field were drilled in Sec. 21, T. 19 S., R. 15 E., M. D., in 1901. During 1902 and 1903 the California Oilfields, Ltd., produced 485,696 barrels of oil from 19 wells. Production records show that the best production was obtained in Sec. 34, T. 19 S., R. 15 E., M. D., where one well yielded an initial production of 7,000 barrels per day. Other large producers are located in Sec. 27; some of these wells had an initial production of 3,000 to 4,000 barrels per day. During 1937 a number of wells still were capable of producing 300 barrels of oil per day, though most of the wells now yield between 50 and 100 barrels per day.

Distinguishing Features

The Coalinga East Side field is separated from the West Side field by a syncline; it lies on a southeast-plunging, asymmetric anticline which is open toward the northwest. The producing sands are exposed a short distance north of the field. It is the most northerly field in the San Joaquin Valley.[1]

[1] *Editor's note:* Since this manuscript was submitted, new fields have been discovered farther to the north.

Stratigraphy

Production in the East Side field is obtained from the Temblor sandstone (middle Miocene). These reservoir rocks rest on foraminiferal beds of the Kreyenhagen shale, which are believed to be the source rock for the oil. The Temblor is overlain by a series of red, blue, and green serpentinous clay shales locally known as the Big Blue. Occasionally a stringer of oil sand occurs in the lower part of the Big Blue, and it is possible that in a few wells production was obtained from this sand.

Oil sands of considerable thickness are found in outcrops of the lower part of the Etchegoin formation. The same sands were picked up in wells drilled in Sec. 27, T. 19 S., R. 15 E., M. D., but apparently no effort was made to test this horizon, though some operators were of the opinion that a fair amount of oil could have been produced from these beds.

EAST COALINGA EXTENSION

History

Eocene production was first found south of Coalinga in the Kettleman North Dome field; it was this occurrence which led to the exploration of the East Coalinga Extension, or Coalinga Nose, where discovery was made in 1938 by the Petroleum Securities well No. "Gatchell" 1, located in Sec. 18, T. 20 S., R. 16 E., M. D. This well came in as a very large producer, with an estimated initial production of more than 10,000 barrels per day.

Stratigraphy

Production comes from a 500-foot sand body lying a short distance below the base of the Kreyenhagen shale. It appears to be slightly older than the Domengine sand of the outcrop section. The top of this sand was encountered at a depth of 6,831 feet in the discovery well.

Another Eocene pool was discovered by Amerada Petroleum Corp. in Sec. 17, T. 19 S., R. 16 E., M. D.

COALINGA EAST EXTENSION AREA OF THE COALINGA OIL FIELD

By L. S. Chambers *

OUTLINE OF REPORT

HISTORY

The East Coalinga Extension (East Coalinga Eocene pool, or East Coalinga field) consists of two areas closely related geologically and joined by a narrow belt of production.

The accompanying maps show the relationship between the two areas. The crestal area of the southern structure is approximately 1,600 feet higher than the highest portion of the northern structure. That portion south of the saddle is called the Gatchell or Discovery area, and the portion north of the saddle is called the Amerada or Northeast area.

The Gatchell area comprising the main part of the field is located on the Coalinga anticline, which is a southeastward-plunging nose that joins with the Kettleman Hills line of folding. Closure is effected up dip by the pinch-out of the producing Gatchell sand. The Amerada area is on a secondary eastward-plunging fold on the east flank of the Coalinga anticline, which crosses the north-trending cut-out line of the Gatchell sand about 6 miles north of the axis of the main field. Both areas produce from the same sand horizon and have a continuous but tilted water table extending upward from approximately —7,700 at the north end of the field to approximately —7,100 at the south end of the field.

The Amerada area has approximately 450 feet of productive closure. This includes 220 feet of gas cap, which covers a large part of the area, and approximately 230 feet of oil sand. The Gatchell area, which is 1,600 feet structurally higher, originally had no gas cap. Because of the tilted water table, this area has a maximum of 1,830 feet of productive closure on the east flank, which diminishes to 1,300 feet as the south end of the field is approached.

The gravity of the oil produced varies according to the structural positions of the wells. In the southern area the oil ranges from 33 to 27 degrees, and in the northern area from 27 to 25 degrees A. P. I. Free gas and distillate are produced by some wells in the Northeast area, but wells completed within the gas cap area with the gas blanked off produce oil at low gas ratios.

The discovery well of the southern field, Petroleum Securities Company No. "Gatchell" 2, was completed June 26, 1938. This test was drilled jointly by Petroleum Securities Company, Seaboard Oil Company, and Honolulu Oil Corporation. Shortly after this discovery, the Petroleum Securities Company was dissolved and its assets distributed to its stockholders. They have since carried on their operations in this venture through Robert S. Lytle, Operator.

The No. "Gatchell" 2, now No. 1-18F, was drilled on the assumption that the top 600 feet of 713 feet of the Avenal sand in No. 4-18J at Kettleman Hills was equivalent to the top 40 feet of 150 feet of Eocene sand exposed in outcrop (*Spiroglyphus* reef). The well was located with the idea of penetrating a substantial sand section as far up dip as possible. Old wells drilled through the Eocene sand considerably up dip from the discovery well suggested that the sand there was too thin or too tight for substantial production. In the light of subsequent drilling, the idea of a simple progressive cut-out has been considerably altered. While K. N. D. A. No. 4-18J at the northwest end of Kettleman Hills was drilling in the Eocene at the time No. "Gatchell" 2 was spudded, the original Eocene play at East Coalinga was started on the assumption that there would be as much Eocene sand under Kettleman Hills as there was in outcrop to the west on Reef Ridge, which greatly exceeded the section in outcrop at Oil City to the north of East Coalinga.

There have been 120 producing wells completed in the Gatchell area as of June 1, 1941; 6 wells are drilling and 4 wells have been abandoned as dry holes.

The discovery well of the Amerada area, Amerada Petroleum Corp. well No. "S. P. L." 7-17, was completed April 24, 1939. This well was drilled after the trend of the cut-out line of the Gatchell sand had been established in the Discovery area. It was drilled on the projection of this cut-out line across a broad nose suggested by conditions in the old West Side Coalinga field and supported by geophysical work some distance to the east. The Amerada area now has 64 producing wells, 5 drilling, and 3 abandoned.

The indicated productive acreage for the two areas is roughly 3,700 acres, of which 2,500 acres is in the Gatchell area and 1,200 acres in the Amerada area. At the present time there is a total of 184 producing wells in the entire field.

The accompanying maps show a total north-south length of approximately 7¾ miles with a maximum width of 1½ miles for the East Coalinga field.

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* Chief Geologist, Seaboard Oil Company of Delaware. Manuscript submitted for publication July 3, 1941.
The writer is indebted to Frank M. Taylor, A. W. Vitt, Stanley Siegfus, and others for data used in preparing this paper; and to the management of R. S. Lytle, Operator, Seaboard Oil Company of Delaware, and Honolulu Oil Corporation for permission to publish, and cooperation in preparing this article.

STRATIGRAPHY

It is obvious from the accompanying cross-section (Kettleman Hills through East Coalinga to the outcrop) that there is considerable thinning from Kettleman to outcrop in nearly all horizons, and in some of the formations there is considerable lateral change in character.

Tulare and Etchegoin Clays

The Tulare (Pleistocene) and Etchegoin (Pliocene) clays, silts, sands, and gravels retain about the same characteristics, but thin and are cut out entirely as the older beds are brought to the surface at the northern limits of the East Side field.

Reef Ridge and McLure Brown Shale

At Kettleman, the McLure brown shale is overlain by about 600 feet of gray shale ("Reef Ridge") believed to be a Miocene-Pliocene transition. The relation of this shale to the Santa Margarita sands of outcrop is not definitely known, although the shale appears to be the equivalent in part. Apparently both the McLure brown shale (1,250 feet at Kettleman North Dome and 944 feet at the Petroleum Securities' Ladd well) and Reef Ridge shale are represented by about 150 feet of Santa Margarita sands in the old East Side field. The McLure shale at Kettleman and in the Ladd well is a hard, dark, siliceous brown shale. A very few cores of this formation have been taken at East Coalinga; the correlations shown are based largely on electrical logs.

Temblor

The Temblor at Kettleman Hills consists of 1,250 feet of hard sands with minor shale breaks. Production is found at various horizons through the entire sandy section at locations sufficiently high on structure. As the Temblor approaches the East Side field, the entire section above the upper Variegated zone changes to the "Big Blue" shale. The main East Side production is found just below this member, although some production has been found through the entire remaining Temblor section. The total Temblor thickness in No. 1-18F (No. "Gatchell" 2) was approximately 1,060 feet. In outcrop, however, this thickness is approximately 800 feet including 250 feet of Big Blue shale.

Vaqueros

The Vaqueros in K. N. D. A. 4-18J at the north end of Kettleman is 384 feet thick. This formation thins out entirely before reaching No. 1-20F (northwest corner Sec. 20, T. 20 S., R. 16 E., M. D.). The sandy portions of this horizon are productive at Kettleman Hills.

Kreyenhagen

The Kreyenhagen shale keeps its same characteristics, being hard, brittle, and brown to black in color. It is approximately 1,200 feet thick at Kettleman, 1,050 feet thick in the Discovery area, and approximately 830 feet thick in outcrop. An erosional unconformity at the top of this formation is indicated by the presence of the *Leda* zone both at Kettleman and at No. 1-20F, and the absence of this zone in the wells to the north.

Canoas and Green Sand

At the base of the Kreyenhagen shale, the Canoas, or *Marginulina asperuliformis* zone, is represented by approximately 30 feet of limy gray shale and brown shale with a 10-foot bed of tight glauconitic "green sand" interbedded with siltstone at its base.

Grit Zone

Below the "green sand" occurs a thin bed (approximately 5 feet) of siltstone with large angular quartz and chert grits. This "grit zone" is believed equivalent to the Domengine reef of outcrop at Oil City, although some geologists believe the entire Canoas section including the "green sand" is equivalent to that horizon.

Arroyo Hondo Section

The Arroyo Hondo section includes the formations from the base of the "grit zone" to the top of the "Moreno shale."

Northwest of the Gatchell pinch-out line, this formation consists of a uniform gray siltstone approximately 900 feet thick. In outcrop this formation is reduced to 650 feet.

In the Gatchell area, the Arroyo Hondo has three major divisions, the *Turritella* silt, Gatchell sand, and lower Hondo shale.

Turritella Silt. Below the "green sand" and "grit zone," but above the Gatchell sand occurs the *Turritella* silt, which varies rapidly in thickness (20 to 300 feet). This siltstone becomes sandy and thins out away from the pinch-out line of the Gatchell sand. It may be equivalent in part to the 149 feet of novaculitic sand found in the upper part of the Avenal in No. 4-18J.

Gatchell Sand. The Gatchell sand is the productive horizon of the East Coalinga field, and occurs below the *Turritella* silt and above the basal Hondo shale. It varies rapidly in thickness (0 to 700 feet in the Gatchell area, and 0 to 800 feet in the Amerada area).

This sand is believed equivalent to the Avenal sand of Kettleman Hills, although the top of the Avenal at Kettleman may be slightly higher in the section.

In the East Coalinga field, except for a tight portion of varying thickness at the very top, the upper one-third of this sand is a medium-coarse-grained clean quartz sand. The sand becomes more silty and less permeable in the lower two-thirds, due to the presence of anauxite or kaolinite as a grain filling. At Kettleman the entire section is relatively fine grained and silty, with streaks of so-called novaculite. Only thin fingers are permeable enough to be productive.

Hondo Shale. The Hondo shale at the base of the Gatchell sand is a uniform, gray, firm siltstone, identical to the section north and west of the Gatchell sand limits. It is about 500 feet thick in the Discovery area. Its thickness at Kettleman is not known.

Moreno Shale

The Moreno shale (Upper Cretaceous) is a relatively uniform chocolate-brown clay-shale, containing some streaks of fine tight sand. Its thickness is about 750 feet in the Discovery area. This formation overlies sandstones and shales of the Panoche series (Middle Cretaceous).

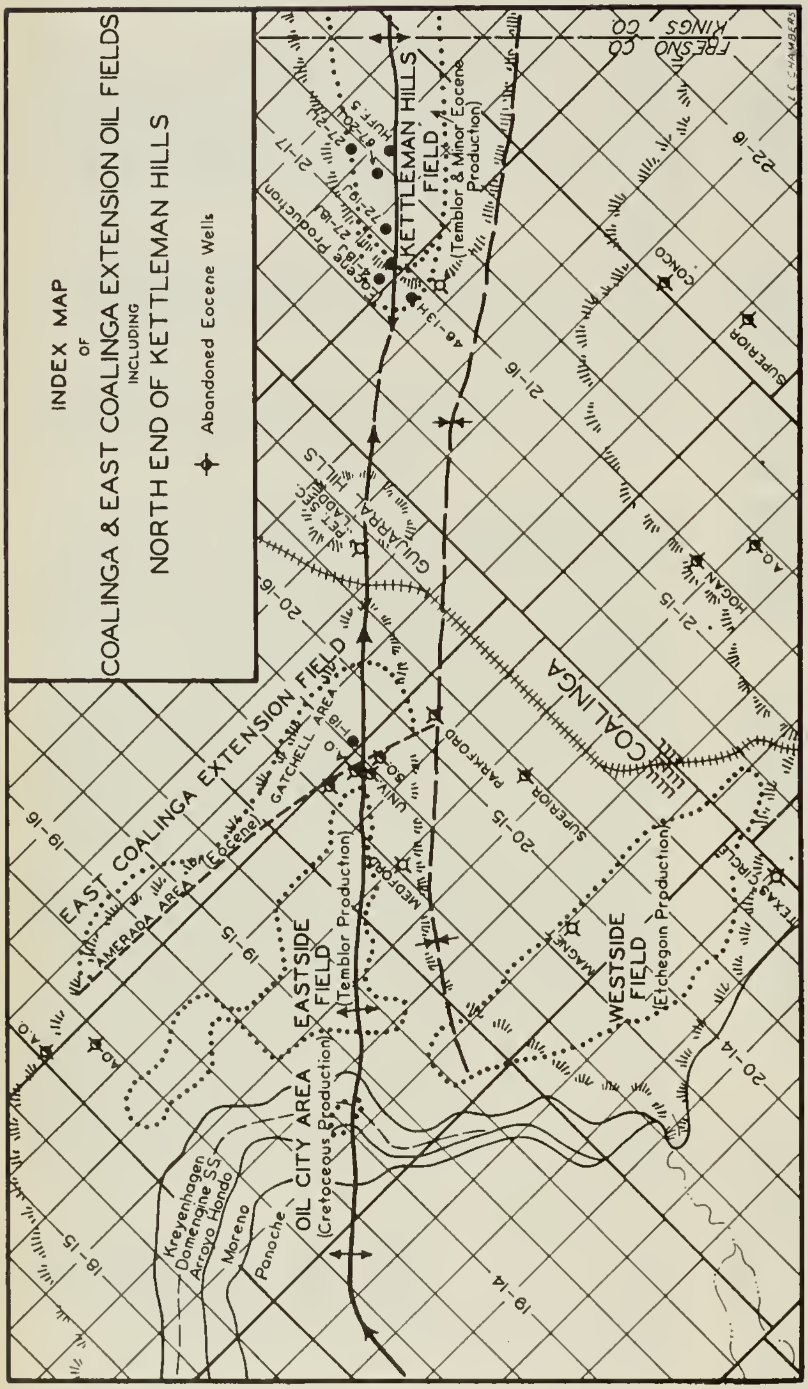


Fig. 205. Coalinga and East Coalinga Extension oil fields: map.

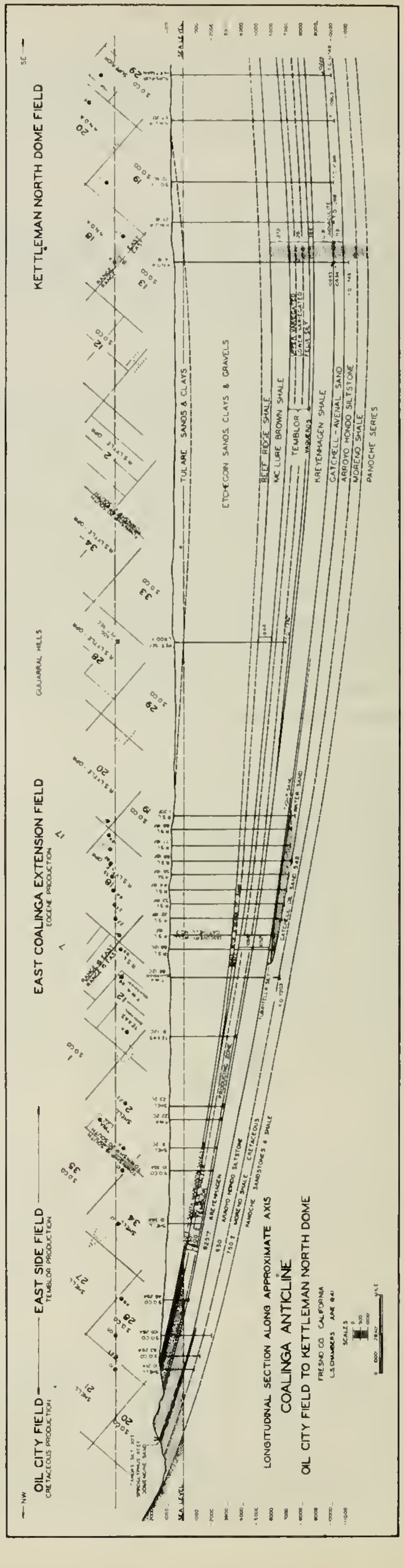


Fig. 206. Coalinga anticline: longitudinal section.

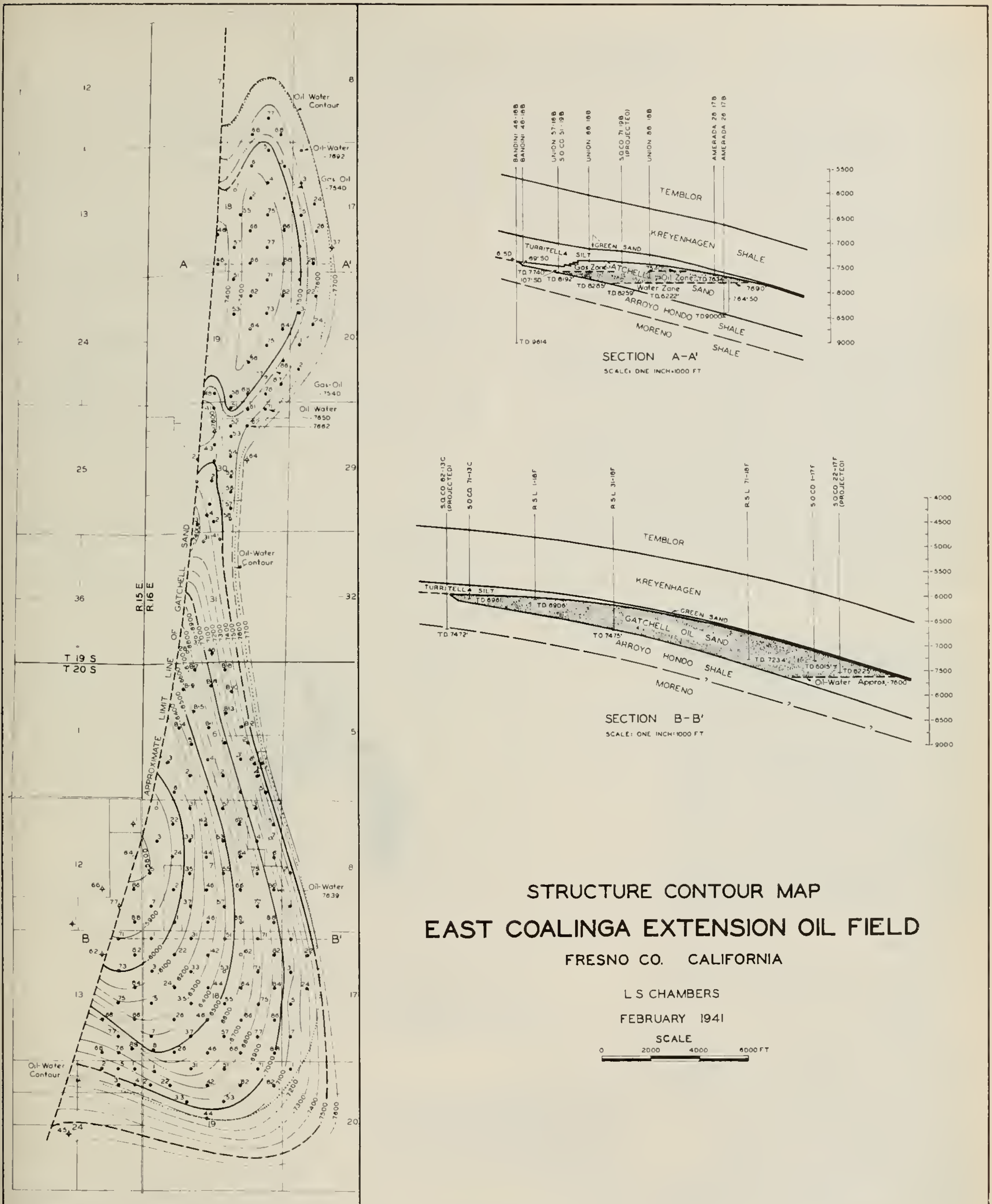


Fig. 207. East Coalinga Extension oil field: structure map; sections.

STRUCTURE

The structural picture is relatively simple. The East Side Coalinga field is a southeast-plunging anticlinal fold with relatively continuous plunge to a point just north of Kettleman Hills, where it rises again to form the Kettleman Hills field. This fold has a relatively steep west flank and a pronounced but more gentle east flank. The Amerada area is a secondary east-west fold on the east flank of the main Coalinga anticline, which results in a broad bowing of the contours. Reference is made to the accompanying cross-section (A-A′) to explain the configuration of the top of the Gatchell sand in the Amerada area.

Both the Kettleman Hills and East Side fields have Temblor production. At Kettleman, this production is primarily controlled by structural closure. In the old East Side field accumulation seems to have resulted from a combination of overlap and tar seal. Apparently a considerable portion of the producing horizon is exposed in outcrop, although this field has produced large volumes of oil.

Two wells had been drilled into the Eocene at Kettleman Hills, and some had penetrated the Eocene in East Coalinga prior to the Gatchell discovery. The old Eocene wells on the East Side were drilled close to outcrop and did not encounter the Gatchell sand although they were credited with small production. Those drilled at Kettleman for the most part had a very tight sand section, although at present 23 wells are producing from the Eocene of that field.

To account for the presence of the gas cap in the structurally low Amerada area and its absence in the structurally high Gatchell area, as well as the tilted water table which gives a low oil-water contact on the east side and north end of this field and a relatively high table on the south end, the author submits that there were two distinct periods of folding during accumulation.

The older Cretaceous folds in this area have an eastward trend, and it is thought that perhaps in Miocene time or earlier, the East Coalinga field was a broad eastward-plunging nose that permitted accumulation of oil and gas and the formation of a gas cap in or near the present Amerada area.

The late Pliocene and Pleistocene folding which completed the present structural picture allowed the Amerada area to arch sufficiently to trap the gas cap before the main Coalinga anticline was elevated high enough for the gas to migrate southward. Then the oil from the surrounding area largely moved southward and westward into the Gatchell area when the latter was completely elevated. Thus, the oil invaded the structure from the north and east. Because of resistance to flow and relatively recent folding, it has not reached a state of equilibrium that would result in a horizontal water table.

CITATIONS TO SELECTED REFERENCES—Continued

COALINGA OIL FIELD

Anderson, F. M. 05; Arnold, R. 09; 15; Arnold and Anderson 08b; Barnes, R. M. 22a; Blackwelder, Thelen, and Folsom 17; Bradley, W. W. 16a; Burkhart, H. W. 10; Carlson, A. J. 31; Church, C. C. 31; Clapp, F. G. 17; Clark, B. L. 35; Cunningham and Kleinpell 34; Cushman and Hanna 27a; Dodd, H. V. 30; 39; Dumble, E. T. 12; Eldridge, G. H. 03; Emmons, W. H. 21; Engineering and Mining Journal 10; Forstner, W. 09; 09a; Henny, G. 30; 38; 38a; Jones, E. C. 97; Keyes, R. L. 27; Lombardi, M. E. 16, McCollough, E. H. 34; Merriam, J. C. 15a; Mining and Scientific Press 00c; 00d; 09; 09a; 10; 10c; 10e; 10h; 11; 11c, Musser, E. H. 29b; Nomland, J. O. 16; Pack and English 14; Parsons, H. G. 00a; Petroleum Engineer 35; Petroleum World 36a; Prutzman, P. W. 04; 10; Rickard, T. A. 12; Stockman, L. P. 39b; 411; U. S. Geological Survey 34; Vander Leck, L. 21; Van Tuyl and Parker 41; Watts, W. L. 00; Wilhelm, V. H. 25; 27; Woodward, W. T. 40; Young, W. G. 01a.

Alcalde Area

Watts, W. L. 00.

Coalinga East Extension (East Coalinga Extension)

Hoots, H. W. 39a; Menken, F. A. 40a; Wilhelm, V. H. 40.

Coalinga East Side

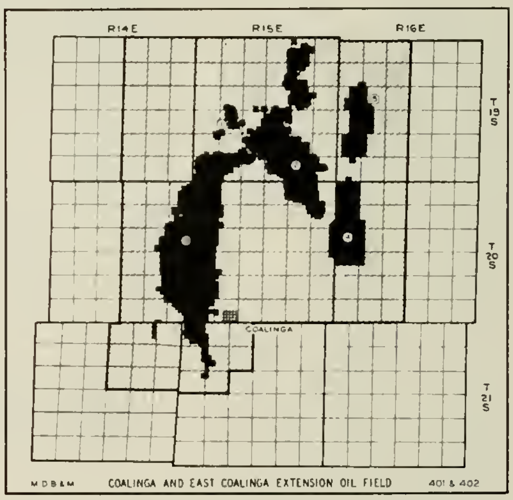
Anderson and Pack 15; Arnold and Anderson 08b; 10; Arnold, Darnell, et al. 20; Barnes, R. M. 21; Case, J. B. 19; Kirwan, M. J. 17; McLaughlin and Waring 14; Rogers, G. S. 17; Taff, J. A. 34.

Coalinga Nose (East Coalinga Extension)

California Oil World 42b; Wilhelm, V. H. 40.

Coalinga West Side

Anderson and Pack 15; Arnold and Anderson 08b; 10; Arnold, Darnell, et al. 20; Barnes, R. M. 21; Case, J. B. 19; Kirwan, M. J. 17; McLaughlin and Waring 14; Rogers, G. S. 17; Taff, J. A. 34.



Coalinga oil field. Areas in Coalinga oil field proper: (1) Oil City; (2) East Side; (3) West Side. Areas in East Coalinga Extension: (4) Gatchell; (5) Amerada.

Curry Mountain Area

Arnold, R. 10; Petroleum World 36a.

East Coalinga (East Coalinga Extension)

Wilhelm, V. H. 39a.

East Coalinga Eocene (East Coalinga Extension)

Hoots, H. W. 39; 39a; Porter, W. W. II 39b.

East Coalinga Extension

Dodd, H. V. 39; Stockman, L. P. 39b.

North Coalinga Nose

Porter, W. W. II 39b.

Northeast Coalinga (East Coalinga Extension)

Atwill, E. R. 40; California Oil World 42b.

Oil City Area

Arnold and Anderson 08b; 10; Eldridge, G. H. 03; McLaughlin and Waring 14; Mining and Scientific Press 11c; Taff, J. A. 34; U. S. Geological Survey 34; Watts, W. L. 00.

KETTLEMAN HILLS OIL FIELDS

By John Galloway *

OUTLINE OF REPORT

INTRODUCTION

The Kettleman Hills constitute a range some 30 miles long and 5 to 6 miles wide, located along the west side of the San Joaquin Valley in Fresno, Kings, and Kern Counties, California.

The hills reach an elevation of less than 1,400 feet, but rise some 700 feet above the synclinal plains which border them on the northeast and southwest. Their drainage and topography are typical of the semi-arid late Tertiary areas of California.

STRATIGRAPHY

Surface beds at Kettleman Hills are Pliocene, and possibly Pleistocene, in age. Certain strata, which are post-Tulare and probably Pleistocene in age, rest in some instances upon pre-Tulare strata within the heart of North Dome. Careful study of these beds and of the data related to the topography of Kettleman Hills (and North Dome in particular) suggests a stage of peneplanation which was arrived at after the anticline was folded almost into its present shape. After peneplanation, there was a resumption of folding and uplifting. This was accompanied by tilting and followed by a more rapid rate of erosion.

* Geologist, Standard Oil Company of California. Manuscript submitted for publication July 8, 1938.

Comparatively little coring has been done at Kettleman Hills above the lower portion of the McLure (brown) shale, so that much of the knowledge of the formations penetrated by the drill is derived from a study of nearby localities. Sufficient coring has been done, however, to indicate that the sequence of formations as determined on the outcrop is regular as far down as, and including, the Temblor formation.

STRUCTURE

Kettleman Hills contain three anticlines which have an en echelon relationship, and which are commonly referred to as North, Middle, and South Domes. South Dome is the highest structurally; Middle Dome is the lowest, as well as the smallest in areal extent.

These domes can be easily mapped, and because of the persistence of horizons they form an area suitable for structural contouring. However, only the northwest end of South Dome is exposed. The rest is covered by a mantle of alluvium which makes uncertain the location of the buried portion of the dome. The trend of the exposed axis of South Dome is towards Lost Hills, a producing area 12 miles or more to the southeast. Therefore, the structure at Lost Hills is assumed to be a continuation of South Dome.

Surface and subsurface closure can be determined at North Dome and Middle Dome. Closure, as used here, refers to the vertical distance between the apex of the dome, on any horizon, and the horizontal plane below which spilling would occur if that horizon were filled completely with a volatile substance. Surface closure at North Dome is computed to be 3,100 feet. At Middle Dome it is approximately 1,000 feet.

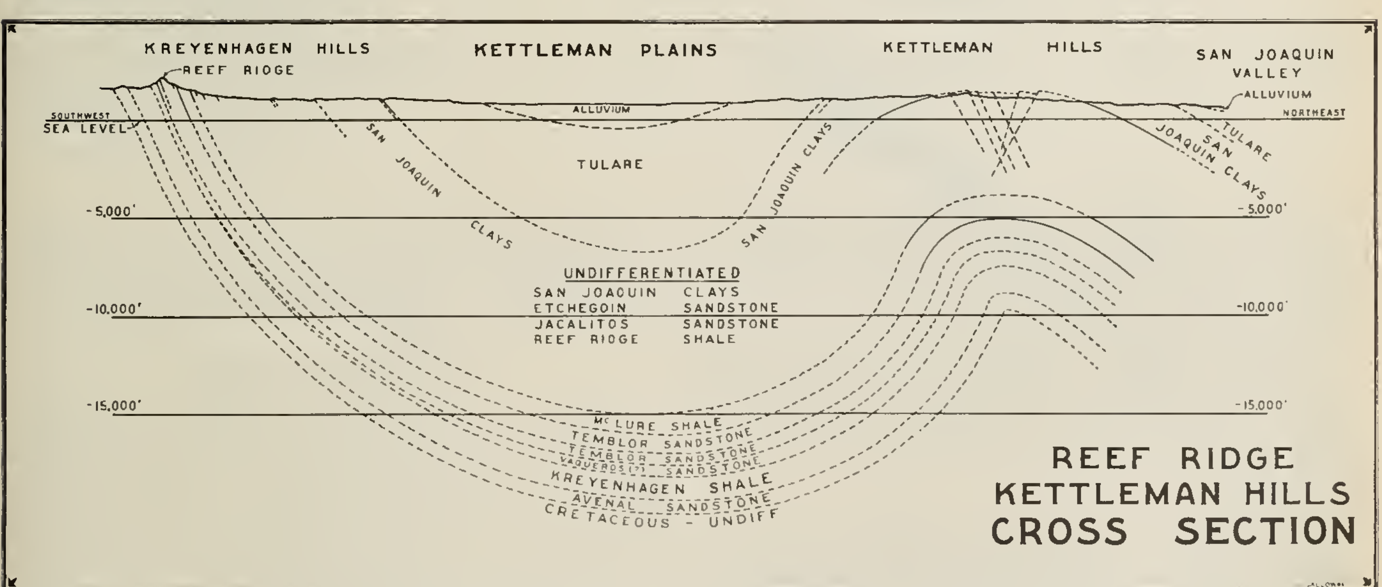


Fig. 208. Kettleman Hills: cross-section from Kreyenhagen Hills to San Joaquin Valley.

STRATIGRAPHY OF KETTLEMAN HILLS

Age	Formation	Description	Thickness (feet)	Markers	Producing zones	Remarks
Pleisto-Pliocene	Tulare	Fossiliferous fluviatile sands, clays, conglomerates	500 to 3,325			Tulare is eroded from crest of Kettleman Hills Deposits laid down mainly under fresh water conditions
Pliocene	San Joaquin clay	Fossiliferous sands, clays, conglomerates	1,700 (min.) to 2,635 (max.)			San Joaquin clay is eroded from crest of Kettleman Hills Environment during deposition varied from fresh to marine
Pliocene	Etchegoin (or Jacalitos)	Fossiliferous sands, clays, conglomerates	5,000 ±			Marine strata. Upper 540 feet of Etchegoin eroded at North Dome; upper 425 feet eroded at Middle Dome
Miocene	Reef Ridge	Blue clays and fine sands	600 to 800			Lower portion of formation contains rather abundant micro-fossil assemblage. Marine deposition
Miocene	McLure shale	Brown and dark gray shale	1,200 ± (min.) to 2,000 ± (max.)	Bentonite near base		Formation is mainly marine shale which is phosphatic in its lower portion. Several streaks of bentonite are found near the base of the formation. Except at the northwest end of Kettleman Hills, McLure shale contains a high head of water approximately 300 feet below top of the formation
Miocene	Temblor	Fossiliferous sandstone and shales with some conglomerate	1,200 (min.) to 1,900 + (max.)	Upper variegated shale, lower variegated shale, Felix silt	Zones I to V, inclusive	In general, shale markers are used to separate zones. Markers other than those given are "600-ft." shale and "800-ft." shale. Felix silt is at the base of the Temblor. There is a slight erosional unconformity between the Temblor and the underlying Vaqueros (?). Strata are largely marine
Miocene	Vaqueros (?)	Sandstone, shale, conglomerate, sparingly fossiliferous	470 at northwest end; 650 in discovery area of North Dome. Unknown farther southeast	Whepley shale over most of area	Zone VI	Vaqueros (?) has been penetrated only at North Dome. It is probably present at Middle Dome but at greater depths than present development. Due to unconformity, Whepley shale, which contains a distinctive fauna, is not present at northwest end of Kettleman Hills. Marine deposition
Oligocene and Eocene	Kreyenhagen shale	Mainly brown shale	1,200 at northwest end. Probably thicker farther southeast	*Uvigerina cocoaensis* zone		The Kreyenhagen shale to date has been penetrated only in the northwest end of the Hills because of deeper drilling there. Strata contain a distinctive and rather abundant fauna. Marine deposition
Eocene	Avenal	Sandstone, shale, with some novaculite near top	1,000 +		Zone VII	Thus far Avenal development has been only at northwest end of Hills because of deeper drilling there. The Avenal has not been completely penetrated. Its thickness therefore is unknown
Cretaceous	Moreno	Probably brown fossil shale				No well in Kettleman Hills has been drilled deep enough to reach the Cretaceous. These strata probably will be found at Kettleman Hills in wells deeper than present development

Subsurface closure can be determined quite accurately at North Dome where considerable drilling has been done. Using the top of the Miocene Temblor as datum, closure is about 2,200 feet. On top of the Eocene Avenal formation, it is about 1,500 feet.

Subsurface closure at Middle Dome is less than half of the surface closure because of the fact that the subsurface strata thicken in a southeasterly direction. Subsurface strata are thicker in the central portion of Middle Dome than they are at the southeast end of North Dome.

On the surface, the crests of North and Middle Domes are faulted. These faults are mainly keystone faults, but there are also transverse faults which probably were caused by torsional stresses. All faults apparently die out downward as no faulting has been observed within the producing measures.

Both North Dome and Middle Dome are asymmetric. Subsurface dips at North Dome are 65 to 70 degrees on the southwest flank, and 35 to 40 degrees on the northeast flank. The flanks of Middle Dome are probably steeper.

PRODUCTIVE HORIZONS

Productive horizons have been found in the Temblor, Vaqueros (?), and Avenal formations. Of these, the Temblor is the most important, and the Vaqueros (?) the least. The first five productive zones at North Dome, the principal producing area, are in the Temblor. The sixth zone is in the Vaqueros (?). The seventh and most recently developed zone is in the Avenal.

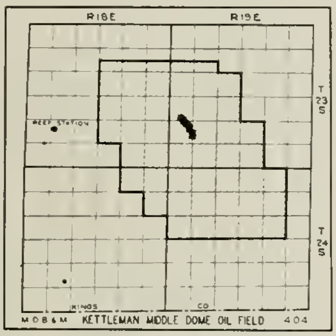
Within the Temblor formation, gas was originally present in the crestal portion of the field. It may have been present as free gas in all five zones, but probably was in greater abundance and under higher pressures in the first three zones. Within the apical area of North Dome, wells produced 60 degrees A. P. I. oil at ratios as high as 80,000 cubic feet of gas per barrel of oil. Outside the gas cap, in the so-called black oil belt, wells originally produced 33 to 37 degrees A. P. I. oil with a gas-oil ratio of approximately 1,000 cubic feet per barrel.

At Middle Dome, production has been obtained from horizons between the top of the Temblor and the top of the 600-foot shale. This is equivalent in position to the first and second zones of North Dome. The wells produce 58 degrees A. P. I. oil at ratios of approximately 30,000 cubic feet of gas per barrel of oil. Wells here have penetrated as deep as the Felix silt horizon, which is the basal member of the Temblor at the northwest end of North Dome, but thus far production has been obtained from only the upper portion of the Temblor.

At North Dome, neither Vaqueros (?) nor Avenal has been extensively developed. The former is not considered to be a prolific producer because of data obtained by Kettleman North Dome Association well No. 38, Sec. 34 J, in late 1933, when this formation was tested separately. The well, though located near the apex of the structure on top of the Vaqueros (?) flowed 1,003 barrels per day of 37.2 degrees oil at a ratio of approximately 1,100 cubic feet of gas per barrel of oil. Its flowing pressure was comparatively low.

Kettleman North Dome Association well No. 4, Sec. 18 J, located in the extreme northwest end of the field, discovered production in the Avenal. The well tested separately two sands in the upper portion of the formation. Production from the first sand was 1,172 barrels per day of 45.7 degrees oil with 20,967 M. c. f. of gas and 110 barrels of water. Flowing pressure was high. The second, and lower, sand produced 1,431 barrels of 28.0 degrees oil with 1,737 M. c. f. of gas and 1,266 barrels of water. Flowing pressure was low.

CITATIONS TO SELECTED REFERENCES—Continued



Kettleman Middle Dome oil field.

JACALITOS DOME

Barnes, R. M. 22a; no. 9, pp. 36-38; California Oil World 42; 42a; Stockman, L. P. 40, no. 12, p. 63; Wilhelm, V. H. 25.

KREYENHAGEN (KREYENHAGEN HILLS) REGION

Arnold and Anderson 08b; 10; McLaughlin and Waring 14; Mining and Scientific Press 09; 09a; 11c; Vander Leck, L. 21; Watts, W. L. 00.

REEF RIDGE AREA

Barbat and Johnson 34a; Crume, R. W. 40; Kleinpell, R. M. 38.

PYRAMID HILLS REGION

Oil Weekly 37a; Vallat, H. E. 41, p. 1164.

KETTLEMAN HILLS OIL FIELDS

Anderson, N. H. 32; Arnold, R. 09; Arnold and Anderson 08b; 10; Arnold, Mead, and Soyster 30; Barbat, W. F. 32; Barbat and Galloway 34; Barnes, R. M. 22a; Beal and Heller 29; Beebe, J. W. 32; Bignell, L. G. E. 30; Bramlette, M. N. 34; Brown, C. C. 30; 31; 32; Collom and Watson 37; Cooper, J. G. 94; Cunningham and Barbat 32; Dodd, H. V. 30; 31; 39; Dodd and Kaplow 32; 33; Franke, H. A. 30a; Galliher, E. W. 31; Gaylord, E. G. 32; Gester and Galloway 33; Goudkoff, P. P. 31; 34; Heller, A. H. 31; Henny, G. 30a; Herold, S. C. 30; 31; 31a; 33; Hodges, F. C. 38; Hoots, H. W. 38; Hoots and Herold 35; Keyes, R. L. 27; Kleinpell and Cunningham 34; Lohman, K. E. 38; Lynton, E. D. 31; Maxson, J. H. 40; McAllister, E. W. 40; 41; McCollough, E. H. 29; 34; McLaughlin and Waring 14; Mead, R. G. Jr. 31; Menken, F. A. 40a; Mills, B. 29b; 31; 31a; 32a; 32b; 35a; 38b; Mining and Scientific Press 11c; Musser, E. H. 28; 29; 29b; Oil and Gas Journal 32; Oil Weekly 38; Petroleum Times 30b; Petroleum World 29; Pilsbry, H. A. 34; 35; Reed, R. D. 26; 33, pp. 217-220; Russell, S. 30a; 31a; Snider, L. C. 33; Stockman, L. P. 30; 35i; 41l; Swigart, T. E. 30; Taff, J. A. 34; U. S. Geological Survey 34; Uren, L. C. 37; Vander Leck, L. 21; Van Tuyl and Parker 41; Watts, W. L. 00, pp. 54-55, 67; Wilhelm, V. H. 25; 38; Winterburn, R. 38; Woodring, Stewart, and Richards 34; 40; Woodward, W. T. 40.

Kettleman Middle Dome Oil Field

Dodd, H. V. 31; Dodd and Kaplow 32; 33; Gaylord, E. G. 32; Jensen, J. 34a.

Kettleman North Dome Oil Field

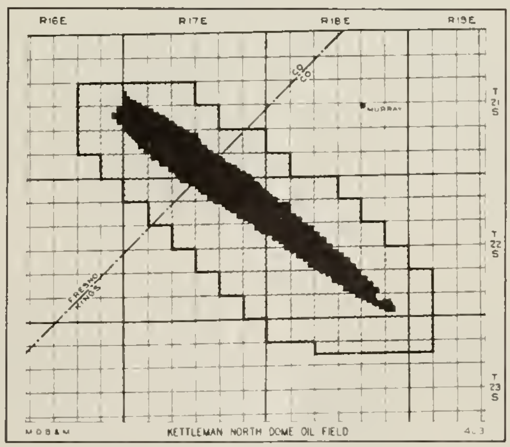
Barnes and Bell 32; Dodd, H. V. 31; Dodd and Kaplow 32; 33; Gaylord, E. G. 32; Lahee, F. H. 34a; Oil and Gas Journal 41a; Sawdon, W. A. 36; Silent and Rousselot 33; Stockman, L. P. 34a; 35i; 35j; 36f; 39a; Uren, L. C. 37.

Kettleman South Dome

Dodd, H. V. 31.

AVENAL AREA

Watts, W. L. 00, p. 133, fig. M.



Kettleman North Dome oil field

LOST HILLS OIL FIELD

By G. S. Follansbee, Jr.*

OUTLINE OF REPORT

HISTORY

The Lost Hills oil field is located in Kern County, approximately 45 miles northwest of the city of Bakersfield. The proven area extends from the west quarter-corner of Sec. 2, T. 26 S., R. 20 E., M. D., southeasterly to the east quarter-corner of Sec. 9, T. 27 S., R. 21 E., M. D. The discovery well was drilled in 1910 near the north quarter-corner of Sec. 30, T. 26 S., R. 21 E., M. D., and was completed from a depth of 530 feet. Because of the shallow depth of the producing horizon and the desirability of the oil, the main portion of the field was rapidly developed. After the discovery of a deeper horizon in Kettleman Hills in 1928, seven unsuccessful wells were drilled to test the equivalent Temblor zone. In 1936 the so-called Williamson area of shallow-zone production, centering around Sec. 2, T. 26 S., R. 20 E., M. D., was discovered. It is now fully developed.

STRATIGRAPHY

The stratigraphy of the area is dissimilar to that of Kettleman Hills in that large portions of the Pliocene sediments are absent along the axis of the fold. The surface formation consists of from 0 to 500 feet of alluvium of Recent age. This is underlain unconformably by from 200 to 1,100 feet of Tulare sands, silts, and clays of Pleistocene age which rest upon the San Joaquin clays of lower Pleistocene and upper Pliocene age. The contact is unconformable as the upper members of the San Joaquin clays are absent along the axis and there is a divergence of 5 to 10 degrees in dips on the east flank. The San Joaquin clays are from 0 to 725 feet in thickness and are composed chiefly of clays and sandy clays with a few interbedded sands. The contact between this formation and the Etchegoin sands and shales is also unconformable. Along the axis the upper Etchegoin has not been recognized and on the east flank there is a discordance in the dips of the two formations. The Etchegoin ranges from 1,200 to more than 3,500 feet in thickness.

Information relative to the upper Miocene is fragmentary. In the northern part of the field, the Reef Ridge punky and diatomaceous shales have a thickness of about 900 feet and the McLure brown shales vary from 1,200 to 1,400 feet. In the south-central portion these intervals are not well established, but the total shale thickness is between 3,300 and 3,500 feet. This difference in thickness, plus a discordance in dips between the Etchegoin and Reef Ridge, noted in one of the wells to the north, strongly suggests an unconformity at that point. The McLure shale is underlain by more than 2,900 feet of Temblor and Vaqueros (?) sands and shales. The upper portion of this sandy interval is probably McLure in age but is grouped with the Temblor because it marks the top of the sand section which is readily recognized in cores or electrical logs. The Temblor represents the lower middle portion and the Vaqueros the lower portion of the Miocene. The deepest stratigraphic depth penetrated is thought to be correlative with the "Belridge 64" sand of the North Belridge field and to be of Vaqueros age.

STRUCTURE

The Lost Hills anticline is very definitely suggested by a long narrow ridge running in a southeast direction and rising over a hundred feet above the surrounding valley. The slopes on either side are gentle and the ridge is traversed in several places by rather steep gullies, one of which is apparently the surface expression of a small normal cross-fault. A belt of gypsum running along the westerly flank has suggested further faulting but the well spacing has been such that this can not be confirmed. The surface of the hills is covered with alluvium and terrace deposits with the possible exception of an exposure of Tulare (?) beds in the northern portion of the main producing area.

The structure of the area consists of a narrow, elongated anticline. Present production is limited to the southeasterly plunging nose and to a small area on the eastern flank approximately opposite the apex. The only known fault is the small normal cross-fault in the northern part of Sec. 30, T. 26 S., R. 21 E., M. D., which apparently has no great effect upon production. The presence of the narrow zone of gypsum along the westerly flank may, as before stated, be related to further faulting, but there is insufficient evidence at the present time to either establish or refute its existence. Seismograph and well data indicate that the fold is slightly asymmetrical, the axis hading to the west.

The northerly closure of the oil sands along the plunging nose seems to be affected by: (1) overlapping of the Etchegoin by the San Joaquin clays and the latter by the Tulare and Recent deposits; (2) the lenticularity and thinning of sands toward the north; and (3) an asphaltum seal within the sands. The closure of the producing zones in the Williamson area is caused by a thinning of the sands up structure.

PRODUCTIVE HORIZONS

The production from the nose comes from two general zones, the lower of which extends throughout the field; the upper is confined between the north line of Sec. 24, T. 26 S., R. 20 E., M. D., and the south line of Sec. 32, T. 26 S., R. 21 E., M. D. The upper zone ranges in thickness from 15 to 240 feet; its top is encountered between the interval 250 feet above sea level and 600 feet below sea level. The zone is composed of approximately 60 percent sand and the oil ranges from 14 to 20 degrees A. P. I. gravity, the lower gravity oil coming from the structurally high wells.

The lower producing zone lies from 250 to 350 feet below the top of the upper zone and varies from a few stringers of oil sand to a maximum zone of 400 feet containing approximately 60 percent sand. The oil from this zone ranges from 14 degrees to slightly over 40 degrees A. P. I. gravity, and, as is the case in the upper

* Universal Consolidated Oil Company. Manuscript submitted for publication April 29, 1941.

zone, the lower gravity oil is produced from the higher wells. Both of the productive horizons are in the Etchegoin and probably are not higher than the *Pecten oweni* zone of the middle Etchegoin.

In the Williamson area there are three producing zones which occur in the interval between the *Pecten oweni* sand and the top of the Reef Ridge shale. The two upper zones have maximum thicknesses of 150 feet and are separated by 250 feet of shale. The lower zone is likewise about 250 feet below the middle zone but is only from 30 to 50 feet in thickness. The gravities of the oil from these zones range from 11 to 14 degrees A. P. I.

To date seven wells have been drilled into the Temblor zone, but none has been productive. It is interesting to note that all of these deep tests encountered varying amounts of oil-stained sands in the Temblor even though there is a maximum structural difference of 2,200 feet between them. Some of the Temblor sands contain a very high head hot salt water very difficult to control. In several instances drilling wells have flowed salt water out of control at rates estimated in excess of 50,000 barrels per day. The failure of any of these wells to find productive oil sands in the Temblor presents a problem that cannot be definitely answered. Several theories have been advanced, the most likely of which appears to be that the structure is so tightly folded that fractures or faults have permitted the escape of the oil to the overlying sand bodies in the Etchegoin. This theory has some substantiating evidence in the abnormally high gravity of the oil produced in the southern portion of the field, which is more generally characteristic of the oil produced from the Temblor zones at Kettleman Hills and North Belridge. If the oil has escaped along faults or fault zones it is quite possible that there may be untested fault blocks in which an effectual seal has retained the oil within the zone. The total thickness of sediments at Lost Hills is unknown, but is thought to be very great. Undoubtedly wells will be drilled to test various zones in the underlying Eocene, some of which are now productive in Kettleman Hills and East Coalinga Extension, and also to the Cretaceous. Until such time as the suggested faulting has been established or disproven, and until such wells have been drilled into the Cretaceous, the value of the deep zone possibilities will remain conjectural.

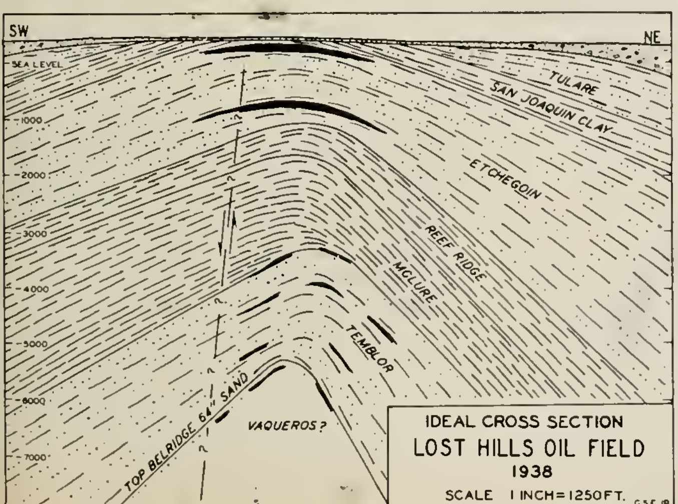


FIG. 209. Lost Hills oil field: ideal cross-section.

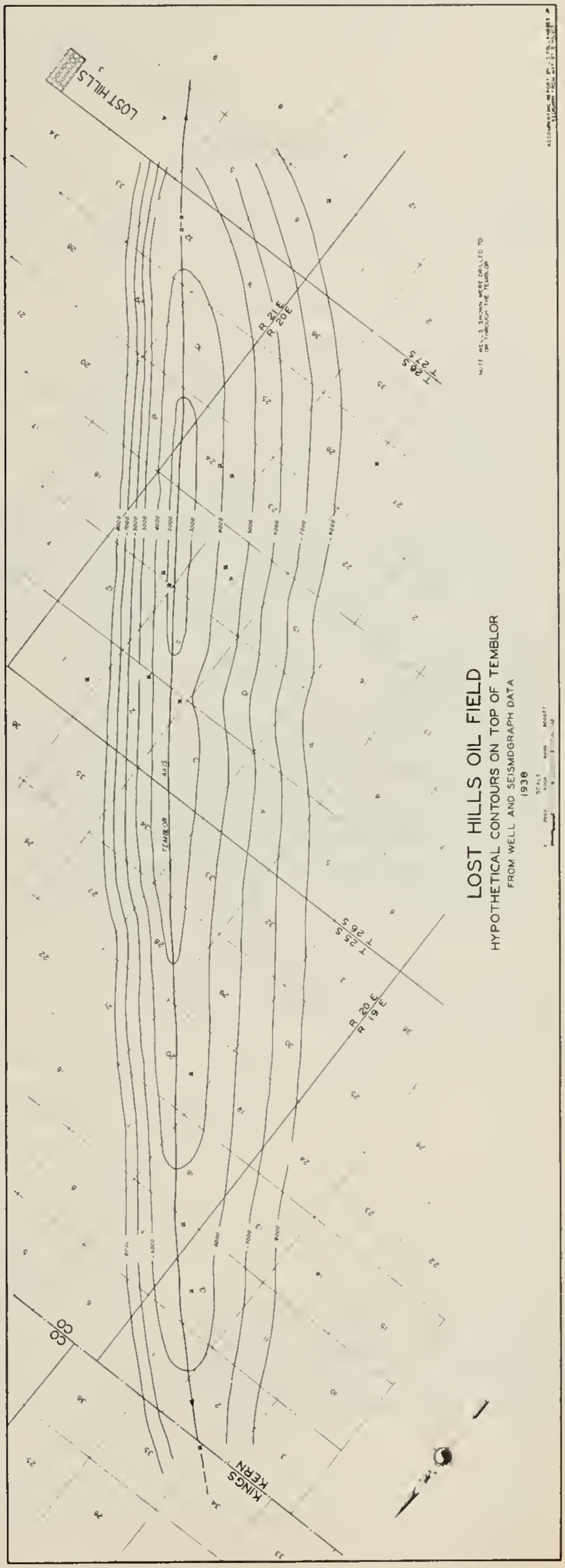


FIG. 210. Lost Hills oil field: structure map.

DEVILS DEN OIL FIELD

By Martin Van Couvering * and H. B. Allen **

OUTLINE OF REPORT

LOCATION

The Devils Den district lies in northwestern Kern County, adjacent to the Kings County line, about 40 miles in an easterly direction from Paso Robles, about 35 miles southeast of Coalinga and about 60 miles northwest of Bakersfield. These are air-line distances; by road the distance from each of the places mentioned is about 10 miles more. A highway running along the west side of San Joaquin Valley, through Taft and McKittrick to Coalinga, passes through the Devils Den district, and a highway from Bakersfield to the coast, through Wasco, Lost Hills, and Paso Robles, passes just south of it. These two highways cross at Blackwell's Corner and, a few miles farther northwest, are joined by a short connecting highway, which passes through the middle of the Devils Den district.

The Devils Den oil field is not a compact unit with all of the producing wells assembled in one well-defined area, although there is a focal point along the common boundary of Secs. 25 and 26 of T. 25 S., R. 18 E., M. D. Most of the wells in the district have been drilled in the NW¼ Sec. 25 and the NE¼ Sec. 26, as shown on the map accompanying this report. However, production has also been obtained near the center of Sec. 26, in the southeast corner of Sec. 23, in the southwest corner of Sec. 24, near the center of Sec. 14, and near the west quarter-corner of Sec. 11, all in T. 25 S., R. 18 E., M. D.

* Geologist and Petroleum Engineer, Los Angeles.
** Geologist, Bankline Oil Company. Manuscript submitted for publication September 4, 1941.

STRATIGRAPHY [1]

The exposed rocks are all sedimentary and nearly all of marine origin, outside of the alluviated area. Cretaceous, and probably Paleocene, rocks are present but have not been differentiated or given formational names in this report.

The middle Eocene is represented by the Mabury formation, which is a sandstone containing *Spiroglyphi*. Three formations are embraced in the upper Eocene: the Gredal, a variegated claystone; the massive Point of Rocks sandstone, which is the thickest formation exposed in the entire district; and the Welcome formation, composed of siltstone and claystone. An unconformity separates the first two.

The Oligocene is represented by the Wagonwheel formation, which consists of a fossiliferous sandstone and an overlying siltstone.

The lower Miocene is separated, by an unconformity, from the Oligocene. It is represented by the Hannah formation, which is divisible into three shaly members, separated by two sandstones. The three lower members have been assigned to Kleinpell's Zemorrian stage and the two upper ones to the Saucesian.

Unconformably overlying the Hannah formation is the Escudo, a very fossiliferous sandstone of middle Miocene age, and this is, in turn, overlain by the silty Alferitz formation, also of middle Miocene age. The Escudo is considered Relizian and the Alferitz Luisian.

Between the middle and upper Miocene there is another unconformity, above which is the McLure shale (Mohnian).

[1] The new stratigraphic names that appear in the succeeding paragraphs were invented by the authors and applied to units whose correlation with similar units in adjacent areas is uncertain. Although this procedure adds to the number of stratigraphic names, the authors believe it will avoid adding to the confusion that already exists in the matter of correlations between similar units in different places. The detailed descriptions of the newly named formations appear in a thesis that is yet to be published.

CITATIONS TO SELECTED REFERENCES—Continued

NORTH LOST HILLS

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LOST HILLS OIL FIELD

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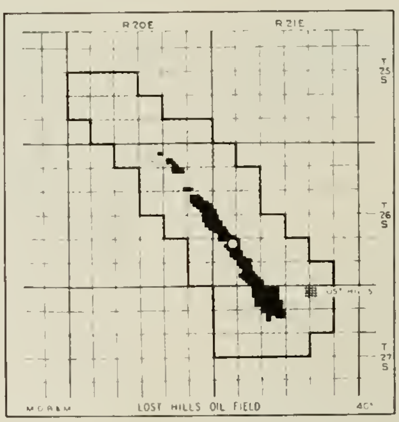
Hopkins—Lost Hills Group

Ferguson, R. N. 18a.

Williamson Area (Lost Hills Extension)

Ayars, R. N. 39.



Lost Hills oil field Areas: (1) Lost Hills; (2) Williamson.

COLUMNAR SECTION OF DEVILS DEN DISTRICT

EPOCH	STAGE	FORMATION	MAXIMUM THICKNESS	DESCRIPTION
PLIOCENE		JACALITOS	2200	Alternating strata of sand and shale, too soft to leave conspicuous outcrops
UPPER MIOCENE	MOHNIAN	McLURE SHALE	1660	Gray to tan, siliceous, platy shale, weathering to white chips, dark gray-brown on fresh fracture, plainly bedded numerous fish scales
MIDDLE MIOCENE	LUISIAN	ALFERITZ	700	Whitish to yellowish siltstone, containing orange-colored concretionary layers and occasional thin poorly sorted sands; less resistant to erosion than the beds above and below
	RELIZIAN	ESCUDO	150	Poorly sorted, buff, calcareous SS containing *Echinarachnius merriami*, *Pecten andersoni* etc
LOWER MIOCENE	SAUCESIAN	HANNAH 1	410	Tawny, sandy siltstone with yellow limy bed near center containing fish and whale vertebrae *Anadara osmonti* and *Lucina acutilineata* in sand at base
		2	555	Medium-coarse, platy sandstone, gray when fresh, black chert pebble bed near top
	ZEMORRIAN	3	325	Purple-brown siltstone with fish scales and clastic dikes white, friable sandstone near top containing *Anadara osmonti* and shark teeth
		4	360	Medium-grained, white, quartzose sandstone containing biotite and phlogopite, weathers to rusty color
		5	530	Lavender-buff siltstone interbedded with claystone abundant foraminifera locally
OLIGOCENE	REFUGIAN	WAGONWHEEL 1	550	Lavender-buff siltstone with occasional foraminifera, three limestone beds at top, the upper containing glauconite
		2	210	Tan, massive, medium-coarse grained sandstone with limestone beds, contains *Thyasira folgeri* and *Lucina inflata*
UPPER EOCENE		WELCOME	1020	Lavender-brown, siliceous, splintery siltstone and claystone, occasional foraminifera
		POINT OF ROCKS	3005	Tawny, massive, cavernous, crossbedded, medium to coarse, quartzose sandstone, contains large, chocolate-brown concretions in lower part; Silty, claystone beds
		GREDAL	1000	Variegated, green-red claystone containing occasional sandstone beds and considerable glauconite
MIDDLE EOCENE		MABURY	315	Coarse, tan sandstone with black chert pebble beds containing *Spiroglyphus tejonensis*
PALEOCENE AND CRETACEOUS	UNDIFFERENTIATED			Variegated, green-red, glauconitic claystone above, chocolate-brown sandstones and limestones below

Vancouvering and Allen

FIG. 211. Devils Den district: columnar section.

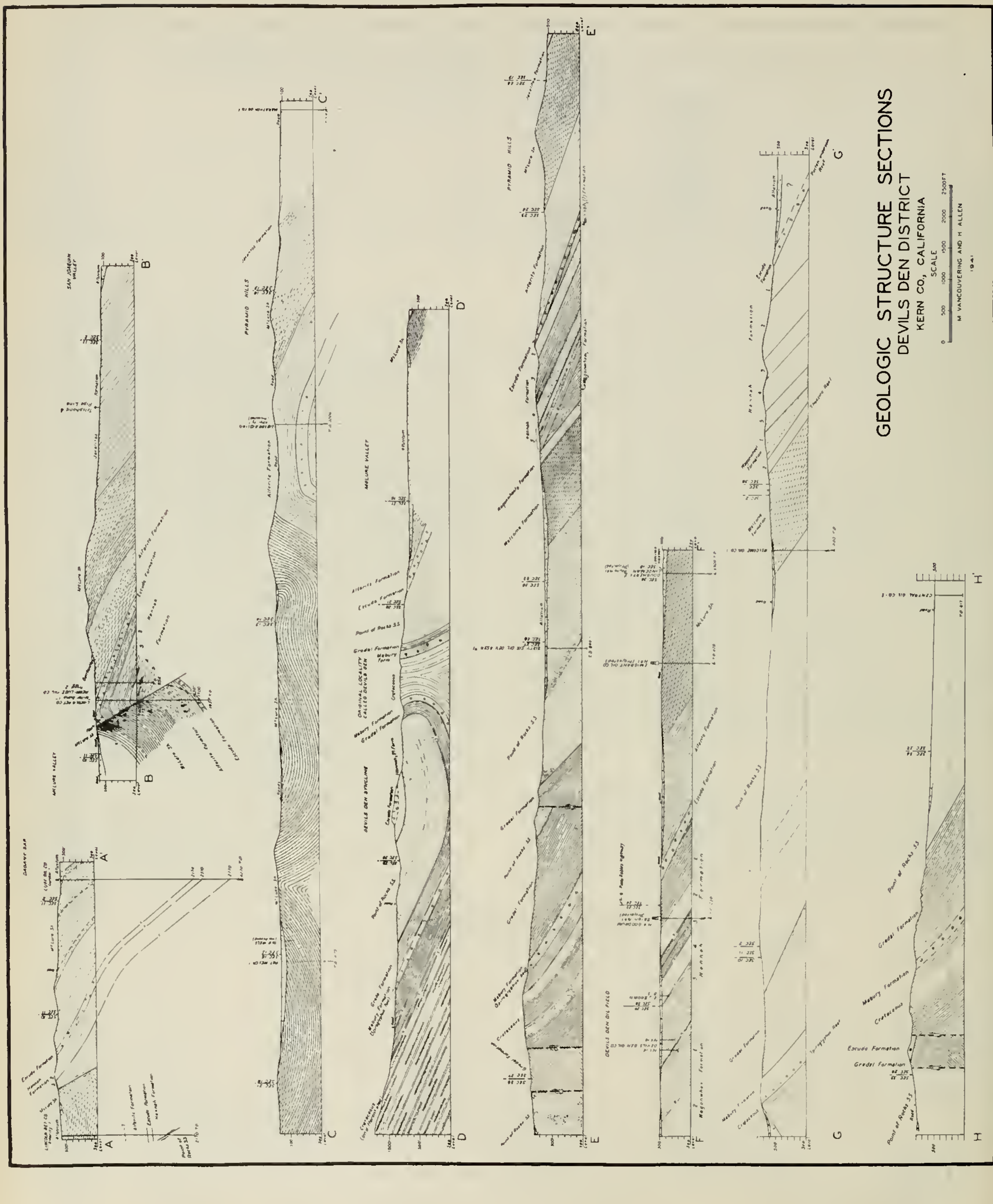


Fig. 212. Devils Den district: geologic structure sections.

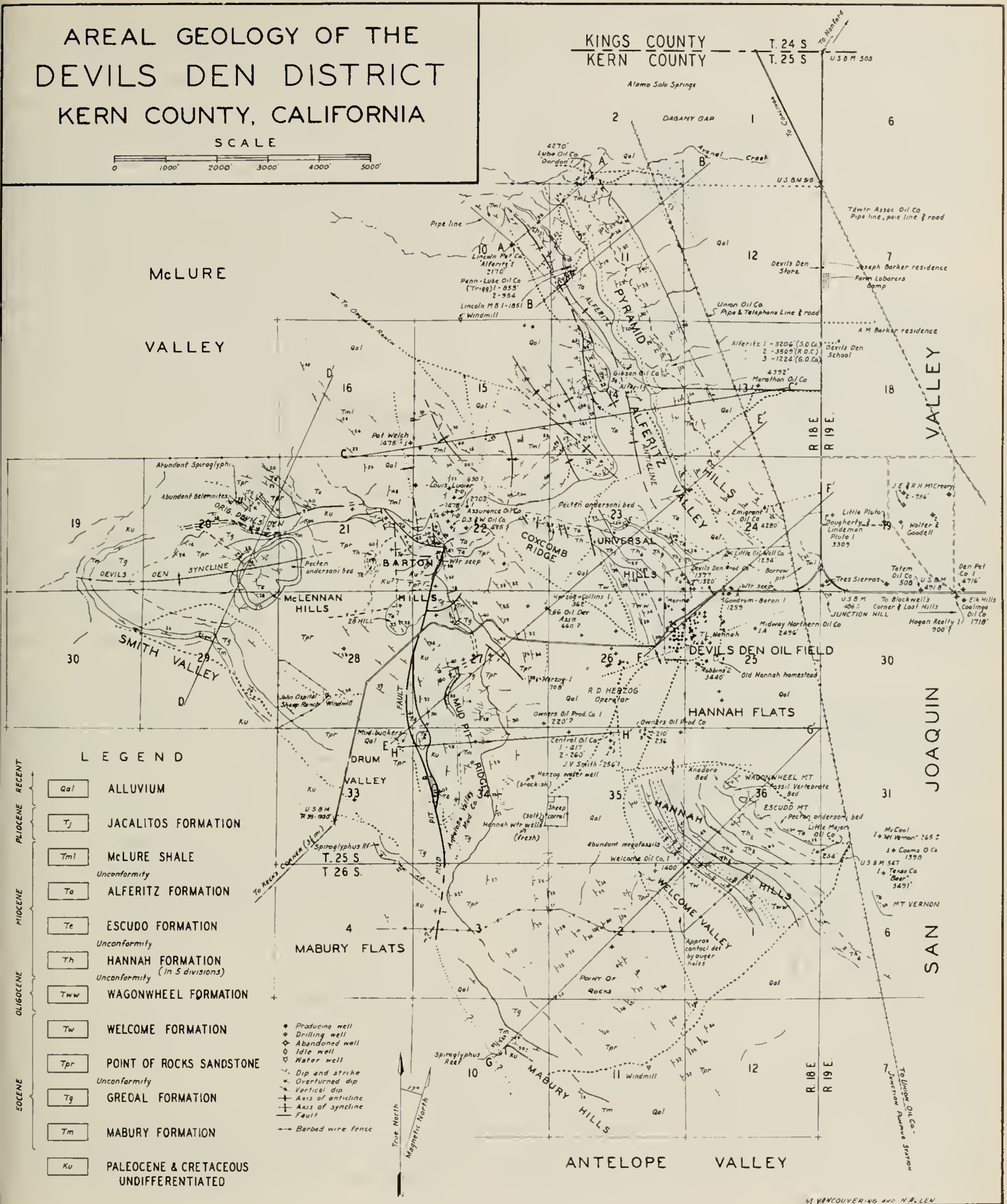


FIG. 213. Devils Den district: areal geologic map.

The Jacalitos formation of Pliocene age is apparently conformable upon the McLure shale. It consists of alternating strata of sand and shale, inconspicuous in outcrop.

The thicknesses of the formations are as follows: Mabury 315 feet; Gredal 1,000 feet; Point of Rocks 3,005 feet; Welcome 1,020 feet; Wagonwheel sand 210 feet; Wagonwheel shale 550 feet; $Hannah_5$ 530 feet; $Hannah_4$ 360 feet; $Hannah_3$ 325 feet; $Hannah_2$ 555 feet; $Hannah_1$ 410 feet; Escudo 150 feet; Alferitz 700 feet; McLure shale 1,660 feet; Jacalitos 2,200 feet.

STRUCTURE

The main structural features of the Devils Den district are as follows: (a) an eastward-plunging syncline in the southwest quarter of T. 25 S., R. 18 E., M. D., terminated by a major north-trending fault; (b) an eastward-plunging anticline through the southeast quarter of the same township, truncated, on the west, by the same fault; (c) a syncline parallel to and about three-quarters of a mile south of the aforesaid anticline; (d) a northeastward-dipping homocline adjoining the aforesaid syncline at the south; (e) a major synclinal basin under McLure Valley; and (f) an anticline through Alferitz Valley, with the Pyramid Hills on the northeast flank.

Much of the deformation seems to have occurred after middle Miocene time, but important faults had developed and a tremendous thickness of sediments had been removed by erosion before the Escudo formation was laid down, especially in the western part of the area.

ECONOMIC GEOLOGY

The oil of the Devil's Den district has accumulated in beds of the Oligocene Wagonwheel formation and the lower Miocene Hannah formation. In the main field these formations dip homoclinally, but oil is also produced from the Alferitz anticline. The productivity of the wells is so small as to be of minor importance.

Within the area shown on the geological map, more than 50 wells have been drilled, exclusive of the ones drilled in Secs. 25 and 26, T. 25 S., R. 18 E., M. D. In each of the latter two sections, evidences of about 50 wells are to be found. Many of these were drilled to very shallow depths with antiquated equipment. In a number of cases there could be no certainty that the evidences really represented the existence of wells, although in most cases there was no doubt. It may be, too, that numerous other wells once existed, of which there is now no evidence.

The records of the wells in the productive area in Secs. 25 and 26 are very meager, for the most part, and attempts to correlate the wells have not been very successful. They are usually less than 500 feet deep, though a few, around the northwest corner of Sec. 25, produced from a depth greater than 1,000 feet. A large part of this drilling was done about 1921 and the production obtained was small, rarely exceeding 20 barrels per day. Recently attempts have been made to revive these old wells and several are now pumping small amounts of oil.

The productive area in Sec. 14 was discovered by Standard Oil Company in 1931. Well No. "Alferitz" 1 was spudded October 4, 1930 and drilled to 3,206 feet. A test of the interval 2,739 to 2,950 feet failed to develop production, but the well was completed June 19, 1931 at 1,650 to 2,037 feet. It had an initial production of 90 barrels of 19.5 degrees gravity oil in 12 hours, and a cut of 35 barrels per day of water. The average production from June 20 to July 12, was 66 barrels of oil and 26 barrels of water. By May 1934 the well had been taken over by Richfield Oil Company, and it produced about 15,000 barrels under their ownership. In April 1938 the well was in the hands of Gibson Oil Company, and was producing 10 to 15 barrels per day.

Well No. "Alferitz" 2 was spudded by Richfield Oil Company December 7, 1934, and drilled to a depth of 2,500 feet. It was completed March 17, 1935, producing from the interval 1,695 to 2,500 feet. On March 18, 1935 it produced 64 barrels of 18.2 degrees gravity oil and 85 barrels of water, in 17 hours. A total of about 8,000 barrels of oil was obtained by Richfield Oil Company. During 1936, the well was deepened to 3,509 feet, bridged to 1,665 feet, and abandoned in June. After the property had been taken over by the Gibson Oil Company, the well was recompleted at 1,695 to 2,554 feet, and on July 26, 1940 was producing 10 barrels per day.

Well No. "Alferitz" 3 was spudded by Gibson Oil Company January 31, 1938, and drilled to a depth of 1,224 feet. It produced only about 5 barrels a day of 17 degrees gravity oil and 100 barrels of water from the interval 1,100 feet to 1,187 feet. It is now idle.

In the most northerly producing area, the Penn-Lube Oil Company well No. "Trigg" 1 was drilled many years ago as a water well, and was deepened, beginning in February 1940, from 375 to 693 feet. On September 7, 1940, the well was reported to have produced 20 barrels of 13 degrees gravity oil with a cut of 20 percent; and on November 12, 1940 it was reported to have pumped between 90 and 100 barrels of oil having a gravity of 19 to 20 degrees and a cut of 10 percent. A fault was reported at 652 feet; the bottom of the "button bed" at 110 feet; shales between 110 and 488 feet; and oil sands below 488 feet. This well is reported to have no casing except a short conductor string.

Well No. "Trigg" 2 was spudded August 19, 1940 and drilled to 954 feet. It was put on the pump in October of the same year.

A number of the more significant wells drilled for oil are shown on the cross-sections accompanying this report. Notable exceptions are Den Petroleum Company well No. 1 in Sec. 20, T. 25 S., R. 19 E., M. D., and The Texas Company well No. "Beer" 1 in Sec. 6, T. 26 S., R. 19 E., M. D. The former, with a total depth of 4,716 feet, is the deepest well in the entire Devils Den district, and both wells are among those most recently drilled. The "Beer" well, with a depth of 3,491 feet, is by far the deepest well drilled around Hannah Hills.

TABLE I—DEEP WELLS IN THE DEVILS DEN FIELD*

Company	Well No.	Location Sec.	Location T. (S.)	Location R. (E.)	Depth Ft.	Remarks
Den Petroleum Co.	1	20	25	19	4,716	Suspended 10/37
Marathon Oil Co.	1	13	25	18	4,392	Abandoned 3/10/32
Emigrant Oil Co.	1	24	25	18	4,280	Suspended 7/39
Lube Oil Co.	1	2	25	18	4,270	Suspended 4/37
Gibson Oil Co.	Alferitz 2	14	25	18	3,509	Producing
The Texas Co.	Beer 1	6	26	19	3,491	Abandoned 11/8/39
T. L. Hannah	21	25	25	18	3,440	Suspended 11/32
Dougherty & Lindeman	Pluto 1	19	25	19	3,309	Abandoned 1919
Gibson Oil Co.	Alferitz 1	14	25	18	3,206	Producing
Assurance Oil Co.	1	22	25	18	2,702	Abandoned 12/22
Lincoln Petroleum Co.	Alferitz 1	10	25	18	2,170	Abandoned 9/23/35
Lincoln Petroleum Co.	Miller-Bump 1	11	25	18	1,851	Abandoned 5/24/34
Hogan Realty Co. (Elk Hills-Coalinga Oil Company 1)	A	29	25	19	1,718	Abandoned 11/23
Luis Lucier	1-D	22	25	18	1,495	Suspended 1/27
Pat Welch	1	16	25	18	1,475	Abandoned 3/23
Welcome Oil Co.	1	2	26	18	1,400	Abandoned; no record
Cosmo Oil Co.	1	31	25	19	1,398	Probably drilled about 1910; now abandoned
Devils Den Products Co.	5	23	25	18	1,377	Produced some oil; abandoned 4/3/31

* In the sense in which the term is now used in California, no deep drilling has been done in the district covered by this report, no well having attained a depth of 5,000 feet.

Den Petroleum Company well No. 1 was spudded June 23, 1936. The well was not successful and was abandoned in October 1937. Some oil was reported bailed from the well in September 1936, after it had been redrilled to 752 feet, and later, at a depth of 4,114 feet, a showing of oil on the ditch was reported. According to the records of the State Division of Oil and Gas, the following geological interpretation was made by Luis Z. Johnson:

Alluvium and Tulare	0′– 300′
Jacalitos	300′– 800′
Transition zone (Reef Ridge)	800′–1190′
Monterey series, McLure shale	1190′–2830′
Variegated shale	2830′–3355′
Temblor	3355′–4109′
Middle Miocene, upper Vaqueros	4109′–4275′

The Texas Company well No. "Beer" 1 was spudded September 25, 1939, and was abandoned November 8, 1939. It also was an unproductive well. The following geological interpretation is by James Dorrance of The Texas Company:

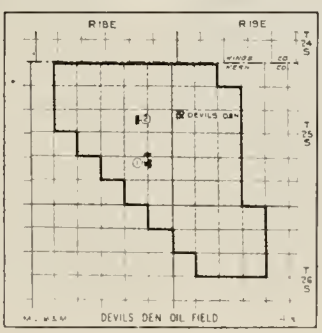
	Depth (feet)
Top of Brown shale	72
Top of first sand (reef beds)	360
Base of button-bed reef	452
Top of Main shale body (*Nonion-Nonionella*)	810
Base of Main shale	1280
Top of ashy sand	1550±
Base of ashy sand	2078±
Top of *Sipho. transversa* flood	2266
Top of Main white sand	2280–2285
Base of Main white sand	2321
Top of glauconitic gritty sand	2375
Base of Temblor (unconformity)	2383
Top of Salt Creek shale (?)	2427
First mud *Pecten lillisi*	2526
First *Glandulina*	2529
First *Plectofrondicularia*	2626
First *Gyroidina*	2634
Common mud pectens	2740–2750
Top equivalent glauconitic limestone of outcrop	2953
Top *Uvigerina gallowayi*	2954
Top second limestone reef of outcrop	2975
First *Uvigerina cocoaensis*	2981

Aside from petroleum products, the only mineral products that have been sold from the Devils Den district, so far as the authors are aware, are rotary drilling mud, which was mined in Sec. 34, T. 25 S., R. 18 E., M. D., and gypsum.

CITATIONS TO SELECTED REFERENCES—Continued

DEVILS DEN OIL FIELD

Arnold and Johnson 10a; Burkhart, H. W. 10; Godde, H. A. 26b; Howard, P. J. 39; Huguenin, E. 23; McLaughlin and Waring 14; Mining and Scientific Press 10; 11; Musser, E. H. 39; Oil Weekly 37b; Vander Leck, L. 21; Watts, W. L. 00.



Devils Den oil field. Areas: (1) Devils Den; (2) Alferitz

BELRIDGE OIL FIELD

By J. B. WHARTON*

OUTLINE OF REPORT

NORTH BELRIDGE AREA

History

The first commercial production in the North Belridge area of the Belridge field, Kern County, was obtained in Sec. 35, T. 27 S., R. 20 E., M. D., by the Manel-Minor Petroleum Company well No. "M-M" 1, which was spudded in June 1912. The completion data and initial production are not known, but in December 1915 the well was producing 18 barrels of 30.8 degrees gravity oil per day from a depth of 3,025 feet. Between 10 and 15 producers were drilled shortly thereafter, along or close to the axis of the structure, with initial yields of 40 to 800 barrels of oil ranging in gravity from 20 to 40 degrees A. P. I. at depths from 2,000 to 4,950 feet. The producing horizons were sandy or fractured zones within the Maricopa shale. A few small wells were completed on the southeast flank in Etchegoin sands carrying heavy oil.

In the spring of 1928 the Belridge Oil Company started deepening well No. 15 (then 3,168 feet in depth) in search of deeper production. The top of the upper Temblor sands was penetrated at 5,026 feet, and the well was completed at a depth of 5,457 feet. It produced 2,600 barrels of 46 degrees A. P. I. oil and an estimated flow of 50 to 60 million cubic feet of gas which increased steadily to 4,800 barrels per day of oil 6 months later. Active development of the Temblor pool followed, and in July 1931 the Belridge Oil Company decided to carry well 64-27 down in search of still deeper production. It was cored continuously to 8,062 feet, after passing through a sandstone member from 7,470 feet to 7,997 feet, which gave evidence of being productive. On a flow test started June 16, 1932, the well flowed gas at an estimated rate of 80 to 100 million cubic feet a day, and 2,092 barrels of 50.2 degrees A. P. I. white oil. Active development of this deep zone is continuing at this time.

* Geologist, Belridge Oil Company. Manuscript submitted for publication June 28, 1938.

Significance

The discovery of oil in large quantities in the Temblor sands in this area indicated the possibility of the presence of these measures in other structures in the southern end of the San Joaquin Valley, and gave stimulus to prospecting, which led to the discovery of several prolific fields.

As the North Belridge area is controlled entirely by a few strong companies, it has at no time threatened to upset marketing and price conditions, and will undoubtedly constitute an important reserve of oil and gas for the industry.

Distinguishing Features

Probably the most distinctive feature of the North Belridge area is the relatively small percentage of the total volume of the pool that is occupied by the oil. In fact, the area is really a gas bubble with a fringe of oil.

Stratigraphy

All wells start in Tulare sands and clays. Etchegoin sands and shales, absent over the top of the structure because of an unconformity, lie beneath the Tulare on the flanks. No other unconformities between or within formations have been demonstrated down to the base of the Miocene.

Below the Tulare, which is about 600 feet thick, punky diatomaceous Reef Ridge shale extends to about 1,600 feet where the first hard siliceous brown shale is encountered. This is locally referred to as the brown shale, and has a thickness of 3,400 feet, and includes the equivalent of the McLure shale of upper Miocene and Gould shale of middle Miocene age. There is little change in lithology throughout these measures, except for occasional beds of impure bentonite in the lower 1,000 feet. About 170 feet above the base of the Gould shale a very important faunal assemblage occurs, which contains *Pecten peckhami* and *Valvulineria californica*, which serve as excellent markers for the top of the Temblor sands. The upper Temblor measures commonly referred to as the Temblor sand, consist of 500 to 600 feet of alternate strata of fine to medium-grained, fairly well-indurated light-gray sandstone and gray shale, sandstone accounting for about 60 percent of the total thickness. Within the sand members are hard limy reefs carrying *Pecten andersoni* and a few *Turritella ocoyana* in addition to other molluscan fossils. Between the base of the Temblor sand and the top of the Bloemer sand 2,200 feet to 2,400 feet of lower Miocene sediments (hard dark-gray to black shale, and hard, well-cemented gray sandstone) occur. A stratum of gray bentonite resting upon a thin bed of glauconitic sandstone about 30 feet above the Bloemer sand serves as a reliable key bed for the latter. The Bloemer sand is the lowest member of the Temblor series and consists of from 40 to 100 feet of fine gray, somewhat friable sandstone that carries oil or gas over most of the field. The Salt Creek shale and the underlying 64-zone sand comprise the Vaqueros formation of lowermost Miocene age. It consists of about 100 feet of dark-gray siliceous shale with considerable sporbo and pyrite replacement of diatoms. The 64-zone sand takes its name from well 64-27 where it was first cored and produced. For some time it was considered to be of Eocene age and was called the Wagonwheel sand; but later evidence indicated that it should be included in the Vaqueros. It is non-fossiliferous, but contains numerous casts of molluscan borings. This is the main producing member of the deep sands, and ranges in thickness from 400 to 600 feet.

Structure

The North Belridge structure consists of one of the en echelon folds along the west side of the San Joaquin Valley roughly parallel to the Coast Ranges. It is a long, narrow asymmetrical anticline, with the steep limb toward the southwest, the general trend of the axis being northwest. Faulting has had little if any influence on oil accumulation in the region with the possible exception of the northwest end of the field, where unsatisfactory correlations between wells might be accounted for by thrust faulting.

Productive Horizons

Early production was obtained from fractured zones in the Maricopa shale at depths ranging from 2,500 to 4,500 feet, initial productions ranging up to 800 barrels per day. The Temblor sand is productive only over a small area at the top of the structure, but all wells had a large initial production, ranging from 2,000 barrels to more than 8,000 barrels per day. The Bloemer sand in the southeastern part of the field is productive lower on the structure than the deeper 64-zone, but at the northwest end the Bloemer carries water at locations where the 64-zone is productive. Some of the highest subsurface pressures ever recorded have been observed in both the Bloemer and 64-zone sands—more than 4,000 pounds having been recorded, with surface pressures up to 3,400 pounds.

Kinds of Oil and Gas

Following are typical analyses of North Belridge oil and gas:

OIL ANALYSIS

	Temblor	*64-zone*
Specific gravity (A. P. I.)	45.1°	42.3°
Asphalt	6.54%	0.41%
Paraffin	0.66%	1.66%
Sulphur	0.18%	0.15%
Commercial Products		
Gasoline 437° end point	61.93%	55.68%
Kerosene stock (37.8° A. P. I.)	12.40%	(42° A. P. I.) 8.32%
Gas oil (35.5° A. P. I.)	------	4.85%
Residuum (28.7° A. P. I.)	25.67%	31.15%

GAS ANALYSIS

	Temblor Per cent by volume	*Temblor* G. P. M.	*Wagonwheel* Per cent by volume	*Wagonwheel* G. P. M.
CO_2	0.40	----	0.20	----
Methane	89.04	----	91.83	----
Ethane	4.88	----	3.79	----
Propane	2.54	----	1.93	----
Iso-butane	0.53	0.17	0.32	0.103
N-butane	0.84	0.26	0.73	0.230
Pentanes and heavier	1.77	0.73	1.20	0.492
	100.00	1.16	100.00	0.825

SOUTH BELRIDGE AREA

History

An outcropping of dry oil sand in Sec. 33, T. 27 S., R. 20 E., M. D., led to the drilling of the discovery well of the South Belridge area of the Belridge field by the Belridge Oil Company, a short distance from the outcrop. This was well No. 101, completed on April 21, 1911, at a depth of 782 feet, with an initial production of 100 barrels of 25.3 degrees gravity oil. The initial success of this well led to the rapid development of the field by the Belridge Oil Company and the General Petroleum Corporation, who controlled most of the property within the productive limits of the shallow zone.

In June of 1934 the General Petroleum Corporation suspended a very interesting test on Sec. 30, T. 28 S., R. 21 E., M. D., in the South Belridge area, at the world's record depth, at that time 11,377 feet. The hole was probably in Carneros sandstone of lower Miocene age. An interesting oil showing had been obtained when mechanical difficulties prevented a satisfactory production test, and finally forced suspension of drilling. The test indicated an accumulation of oil within the Temblor members, which will probably be of economic importance over part of the field, at least.

Significance and Distinguishing Features

Probably the most distinctive features of this area are (1) the shallow depth of the productive formation, and (2) the relatively high productivity and ease of drilling, the usual time necessary to complete a well being from 2 to 3 weeks; initial productions range up to 1,200 and 1,500 barrels per day.

Stratigraphy

In the main part of the area there are 700 to 800 feet of Tulare and Etchegoin sand and clay formations of Pleistocene and Pliocene age above the Miocene Reef Ridge shale, locally known as Belridge diatomite, which consist almost entirely of punky blue-gray diatomaceous shale. It varies in thickness from 800 to 1,300 feet over the field, and rests conformably upon the McLure shale, locally called the brown shale, or Maricopa shale, and contains a considerable assemblage of Foraminifera. Only one well in the field, the No. "Berry" 1 of the General Petroleum Corporation, has completely penetrated this formation. It encountered about 660 feet of McLure shale. The middle Miocene is represented by 500 feet of Devilwater silt and 900 feet of Gould shale, both hard, brown, and siliceous, the former containing a *Valvulineria californica* assemblage. Below the Gould shale there are approximately 1,100 feet of Media shale—alternating dark-gray shale and fine gray sandstone containing a little oil. The equivalent of the Carneros sandstone was thought to be represented by 200 feet of alternate shale and gray sandstone.

Structure

The structure is a rather narrow anticlinal fold with a northwest trend, approximately parallel to the Temblor Range, and plunging to the southeast. What knowledge we have of structural conditions has been gained from drilling some 250 shallow wells which have not penetrated beyond the Etchegoin, plus a few wells in a limited area that have gone some distance into the Maricopa shale. The deep test of the General Petroleum Corporation, No. "Berry" 1, did pass through much older formations, but added little to the structural picture because of its location and the uncertainty regarding the deviation of the bore hole, as the unusually high subsurface temperatures encountered made a survey to bottom impossible.

Productive Horizons

The main producing formation is a sand member or members of varying thickness at or near the contact of the Etchegoin and the Reef Ridge shale, although some sand lenses within the Etchegoin are productive at some localities. The oil ranges from 16 to 30 degrees A. P. I. Fractured zones within the McLure shale yield small but consistent production of 30 to 33 degrees A. P. I. oil.

CITATIONS TO SELECTED REFERENCES—Continued

ANTELOPE VALLEY

Prutzman, P. W. 04, map op. p. 14.

BELRIDGE OIL FIELD

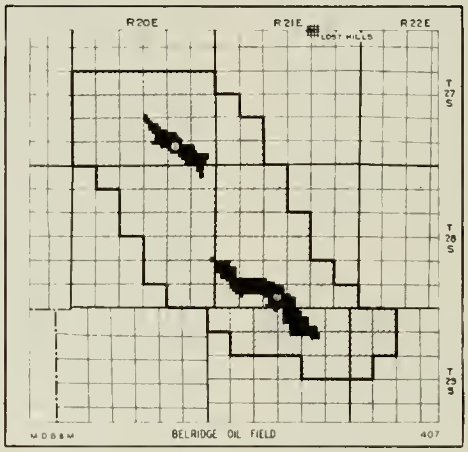
Arnold, R. 15; Arnold, Darnell, et al. 20; Blackwelder, Thelen, and Folsom 17; Boezinger, H. 24; Case, J. B. 19; Chappuis, L. C. 30a; Ferguson, R. N. 18; 18a; Godde, H. A. 26b; McCollough, E. H. 34; McLaughlin and Waring 14; Musser, E. H. 30; 39; Thoms, C. C. 22a; Uren, L. C. 37; Vander Leck, L. 21.

Belridge Oil Field (South Belridge Area)

Boezinger, H. 24; English, W. A. 21a; Kirwan, M. J. 17; McLaughlin and Waring 14.

Manel Minor (North Belridge) Area

Boezinger, H. 24; English, W. A. 21a.



Belridge oil field. Areas: (1) North Belridge; (2) South Belridge.

North Belridge Area

Bailey, W. C. 39a; Boezinger, H. 24; California Oil World 42b; English, W. A. 21a; Hoots, H. W. 38; Hoots and Herold 35; Howard, P. J. 39; Kirwan, M. J. 17; Kleinpell and Cunningham 34; Oil Weekly 37b; Petroleum World 36a; Preston, H. M. 32; Stockman, L. P. 30c; 33; 35i; 41l; Taff, J. A. 34; Wilhelm, V. H. 38; Williams, R. N. Jr. 36.

Shale Hills Area

Stockman, L. P. 40, no. 12, p. 63; 40, no. 13, p. 87.

South Belridge Area

California Oil World 34; English, W. A. 21a; Howard, P. J. 39; Kirwan, M. J. 17; Kleinpell and Cunningham 34.

TEMBLOR OIL FIELD

By R. R. Simonson*

OUTLINE OF REPORT

HISTORY

The Temblor Ranch oil springs and tar seeps were known for a good many years before the discovery of the Temblor oil field (Sec. 36, T. 29 S., R. 20 E., M. D., Kern County). During the fifties and for several decades thereafter the Temblor seepages were visited by overland travelers to obtain tarry oil which was used to grease the wheels of their wagons. It is reported by English (21a, p. 36) that shallow wells were drilled near the seepages in the early sixties, making this one of the first oil areas prospected in California.

The discovery of the present producing zone was made in May 1900 by the Dillon No. 1 well (now Wesco No. 7), which came in for about 10 barrels of clean oil a day. When W. L. Watts (00, p. 129) visited the field in August 1900, he reported three wells on production and six prospect wells drilling. Some of the wells are said to have produced initially as much as 200 barrels of oil a day before water broke in. However, in most cases production soon dropped to 10 barrels or less per day. Wells have been drilled intermittently to 1938 when the Santa Ynez Oil Company suspended their "deep test" at 1,610 feet.

Maps of the State Division of Oil and Gas show that about 26 wells have been drilled in the field, and some 10 dry holes drilled on adjacent leases. At present there are 16 producers.

SIGNIFICANCE

Probably the most significant feature of this field is the slow decline of the wells. Wells that had an initial production of 10 or 15 barrels are still, after 40 years, producing 1 to 3 barrels of oil a day. This field is an outstanding example of the long life and slow decline characteristic of some California fields. During the 40 years that this field has been operating it is estimated that it has produced approximately 500,000 barrels of oil, or about 50,000 barrels per acre. With such a slow decline in production any estimate as to ultimate recovery is impossible.

This field is also unique because of the large amount of water which accompanies the oil. The daily production at present is about 1,100 barrels of water and 22 barrels of oil, or an average of 50 barrels of water for each barrel of oil, which is some kind of a record. A series of settling basins reduce the water content to about 6 percent; heating is then used to bring the water content down to shipping specifications. In spite of the tremendous amount of water pumped for each barrel of oil a few of the wells make very little water.

STRATIGRAPHY

The age of the producing sand is not definitely known because cores are not available. However, it seems evident that the producing horizon is closely related to the "Vaqueros sand" which outcrops a short distance north of the old Temblor ranch house. The Santa Ynez No. 1 is the deepest well of this field; it penetrated about 1,300 feet of sand with occasional hard shell and silt breaks below the overlying brown shale. It is thought that this well must have reached the massive Eocene sandstones mapped in the Temblor Range as "Tejon (?)" by Arnold and Johnson (10a, pl. 1). This well is now abandoned after testing wet between 525 and 610 feet, where the best oil showings were encountered.

STRUCTURE

The structure of this field is shown on the accompanying contour map to be a faulted anticline. Production is generally not found below the 1,300-foot contour. Exact correlations are difficult because of the antiquity of the available well logs.

PRODUCTIVE HORIZON

The producing zone consists of the upper 20 to 100 feet of the "Vaqueros sand." Oil showings have been noted above and below the producing zone but no commercial production has been found. The saline water in the oil sand has an obnoxious sulphurous odor.

KINDS OF OIL AND GAS

The oil that is produced at present ranges from 15.5 to 16.5 degrees gravity Baume. When the field was new, gravities as high as 20 degrees Baume were recorded. The Wesco No. 11 well produces sulphurous gas which is used on the Wesco lease for household purposes.

* Union Oil Company of California. Manuscript submitted for publication January 15, 1940.

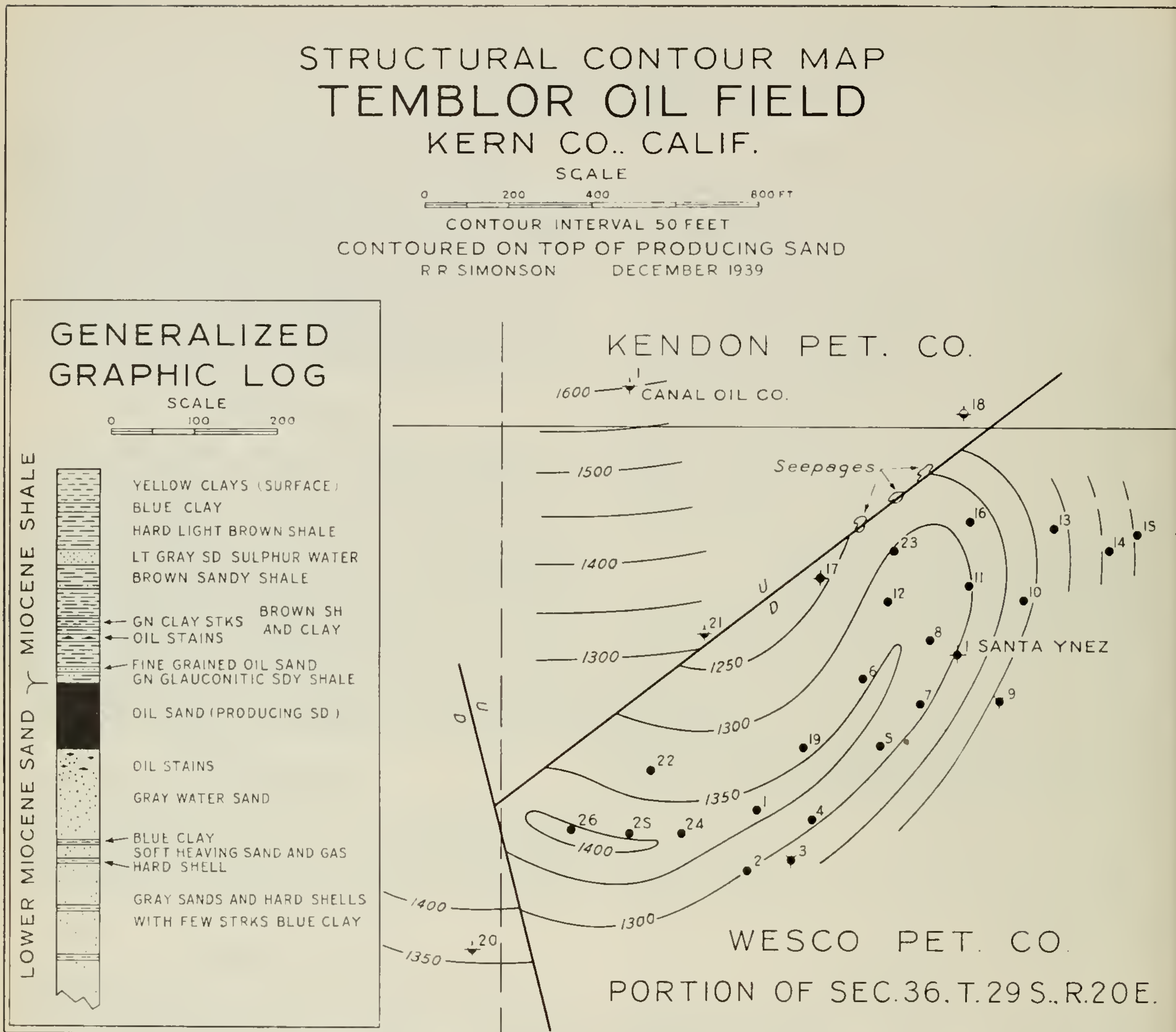
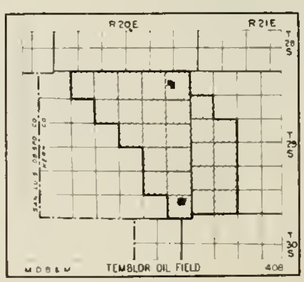


FIG. 214. Temblor oil field: generalized graphic log; structure section.

CITATIONS TO SELECTED REFERENCES—Continued



Temblor oil field.

TEMBLOR OIL FIELD

Arnold and Johnson 10a; English, W. A. 21a; Godde, H. A. 26b; Musser, E. H. 30; 39; Watts, W. L. 00.

McKITTRICK FRONT AND CYMRIC AREAS OF THE McKITTRICK OIL FIELD

By E. R. Atwill.*

OUTLINE OF REPORT

HISTORY AND SIGNIFICANCE

The McKittrick Front and Cymric areas of the McKittrick oil field are in the southwestern part of Kern County, a few miles north of the town of McKittrick.

McKittrick Front Area

The McKittrick Front area is confined mainly to a low range of foothills which form a connecting link between Elk Hills and the eastern edge of the Temblor Range proper, and which are bounded by the McKittrick Valley on the southwest and the San Joaquin Valley on the northeast. The hills occupy a strip some 6 miles in length with an average width of 1 mile.

There are two small producing districts in the McKittrick Front area which are about a mile apart; these will be discussed separately. The northerly district is located principally in Sec. 6, T. 30 S., R. 22 E., M. D. The Standard Oil Company of California, the Nevada County Oil Company, and the Pittsburg Oil and Gas Company were all drilling wells here in 1916; but, from the available data, it would seem that credit for discovery should go to the Standard Oil Company.

The various producing properties have changed hands many times since they were first developed, and some of the original minor operators are now defunct. Approximately 32 wells have been drilled to date, and some 150 acres have proved productive. The present active operators are the Barnsdall Oil Company with four producing wells, and G. E. Gamble with six producing wells.

The initial production of the wells, which are all completed with pumping units, ranges from 35 barrels per day to 75 barrels per day of 13 degrees gravity oil. Completion depths range from 870 to 1,615 feet. The economic life of the best of these wells appears to be from 12 to 18 years, during which they may produce a total of from 20,000 to 115,000 barrels of oil.

The largest portion of the southern producing district is in the NW¼ Sec. 8, T. 30 S., R. 22 E., M. D. The Standard Oil Company, however, has recently extended the productive limits into the NE¼ Sec. 7 by the completion of a line of offset wells.

The oil in this district comes from a zone lower stratigraphically than that in the northern district. Locally it is called the "Franco-Western" sand, and occurs at depths ranging from 2,173 to 2,548 feet. The Standard Oil Company, in 1917, was the first operator to complete a well (now called Franco-Western No. 1) from this sand. Since 1923, the property originally held immediately around the well in Sec. 8 by Standard has changed owners several times. Finally, in 1928, it was purchased by the Franco-Western Oil Company, the present operator. There are 15 producing wells here at present, and they have proven some 115 acres.

The initial yields of the wells range from 145 to 335 barrels per day of oil that ranges in gravity from 12.2 to 19.1 degrees, the gravity apparently increasing as the wells are located higher structurally.

Two wells on the apex of the structure flowed for a few weeks after completion, but the majority of the wells are brought in on the pump. Over a period of 10 years a few of the present producing wells have yielded in excess of 280,000 barrels of oil, although the average is nearer 200,000 barrels. A remarkably slow decline is indicated for most of the wells. The total production from this portion of the field for 1938 was 166,601 barrels.

Cymric Area

The Cymric area is in a comparatively flat district about half a mile north of the northwest extremity of the McKittrick Front Hills. It was discovered in 1916 by H. S. Williams, whose well was located in the SE¼ Sec. 26, T. 29 S., R. 21 E., M. D. A depth of 1,375± feet was reached and the well had an initial production of approximately 150 barrels per day. There were subsequent changes of property control to various operators until 1930, at which time the Cymric Oil Company became the Welport Oil Company, the present sole operator in the area. To date, a total of 33 wells have been drilled —30 producers and 3 dry holes—and about 100 acres proven. The completion depths of the wells range between 1,080 and 1,400 feet.

Initial production varies between 60 barrels per day and 300 barrels per day of 12.5 degrees gravity oil. The average initial production, however, is approximately 115 barrels per day, and after several months most of the wells settle to about 35 barrels per day cutting 50 percent water. Many of the wells have produced as much as 18,000 M.c.f. of gas per day for a short time after completion. One early well blew out, and according to an estimate, yielded from 70,000 to 100,000 M.c.f. per day through the casing. The field is now capable of producing 105,000 barrels of oil per year, although production for 1938 was only 90,135 barrels. At the present time, there are 12 producing wells and 5 others capable of production, that are shut in.

STRATIGRAPHY

The exposed formations in the area are limited to the fresh-water beds of Tulare (Pleistocene) age, and the younger bench gravels and stream deposits of Recent origin. No well drilled to date in the vicinity of either the McKittrick Front or Cymric areas has penetrated through the Miocene.

* Research Geologist, Union Oil Company of California. Manuscript submitted for publication May 8, 1939.

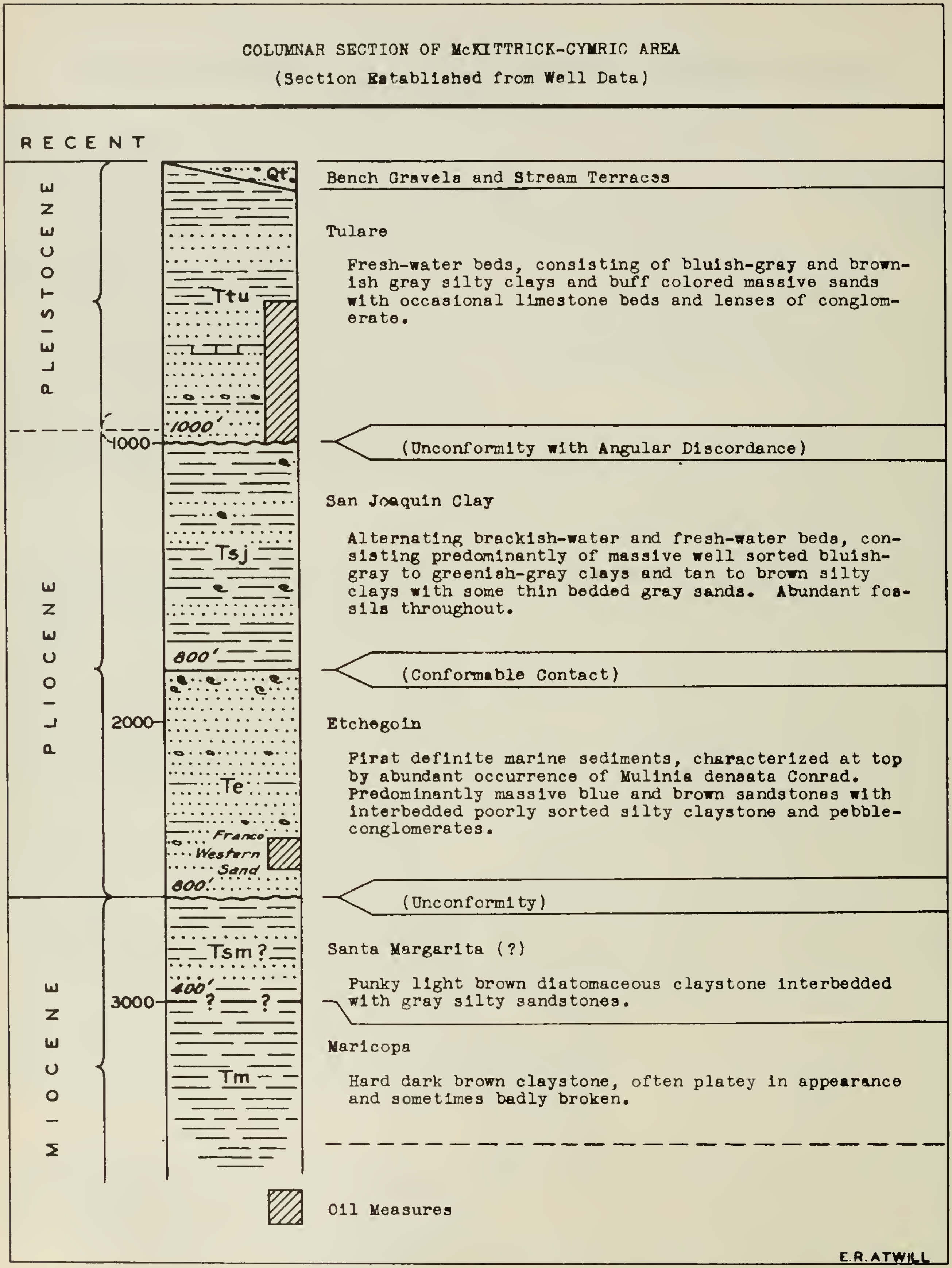


FIG. 215. McKittrick-Cymric area of the McKittrick oil field: columnar section.

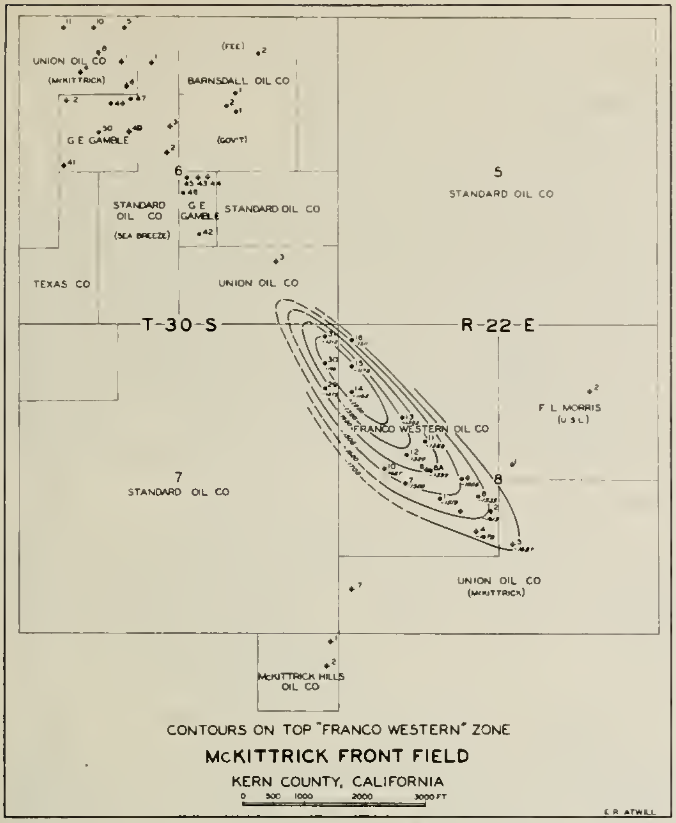


Fig. 216. McKittrick Front area of the McKittrick oil field: structure map.

The production in the northern district of the McKittrick Front area comes from a 500-foot oil zone near the base of the Tulare. In the southern district, oil is obtained from a sand in the lower part of the Etchegoin (Pliocene). The thickness of this sand averages 100 feet, and, judging from the greatly varying production of wells at equal structural elevation but in different parts of the field, permeability is an important factor.

The producing horizons in the Cymric area also occur near the base of the Tulare formation. The oil zone here consists of about 300 feet of interbedded oil sands and clays. Some 135 feet of this zone is generally oil sand.

STRUCTURE

Accumulation in the southern district of the McKittrick Front area is apparently caused by a small closed anticline (locally called the "Franco-Western" anticline) which is the highest structurally of many similar folds that appear as shallow crenulations on the arch of a larger anticlinal feature that probably gives expression to the McKittrick Hills. Production in the northern district may be caused by a buttressing of lower Tulare beds against the unconformable Etchegoin up the north plunge of the Franco-Western anticline, or even by a separate small closed dome on the same line of folding.

Sufficient data are not available at the present time to determine the exact reason for accumulation in the Cymric area. The presence here of commercial quantities of oil could result from either a westward thinning or overlap in the basal beds of the Tulare on a small eastward-plunging anticlinal nose, or from closure against a fault.

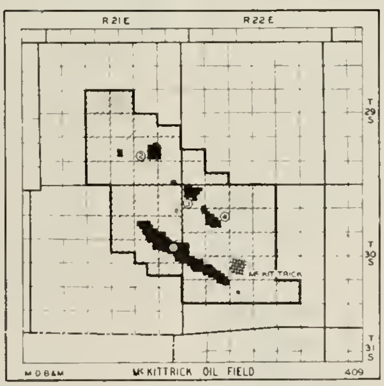
CITATIONS TO SELECTED REFERENCES—Continued

McKITTRICK OIL FIELD

Arnold, R. 15; Arnold, Darnell, et al. 20; Arnold and Johnson 10a; Blackwelder, Thelen, and Folsom 17; Case, J. B. 19; Clapp, F. G. 17; Edwards, M. G. 37; Eldridge, G. H. 03; Emmons, W. H. 21; Engineering and Mining Journal 10; English, W. A. 27; Ferguson, R. N. 18a; Gester, G. C. 17; Godde, H. A. 26b; Howard, P. J. 39; Jensen and Stevens 30a; 31a; Johnson, H. R. 09; McCollough, E. H. 34; McLaughlin and Waring 14; Mining and Scientific Press 00b; 00c; 10; 10e; 11; Musser, E. H. 30; 39; Naramore, C. 17; Petroleum Engineer 35; Prutzman, P. W. 04; 10; Rogers, G. S. 17; Stalder, W. 41; Stevens and Jensen 30; Taff, J. A. 33; Thoms, C. C. 22a; U. S. Geological Survey 34; Vander Leck, L. 21; Watts, W. L. 00.

Buena Vista (Buena Vista Oil and Asphaltum) District

Mining and Scientific Press 92d; 92e; 10d; Stalder, W. 41, p. 53; Watts, W. L. 94.



McKittrick oil field. Areas: (1) McKittrick; (2) McKittrick Front; (3) Franco-Western; (4) Cymric.

McKittrick Area

Taff, J. A. 34.

McKittrick District

Arnold and Johnson 10a; Eldridge, G. H. 03; Watts, W. L. 00.

McKittrick Front Area

McLaughlin and Waring 14; Petroleum Engineer 35; Taff, J. A. 34; Vander Leck, L. 21.

McKittrick-Sunset District

Arnold and Johnson 10a; Johnson, H. R. 09; Mining and Scientific Press 10e; Prutzman, P. W. 10.

McKittrick-Temblor Field

Arnold and Kemnitzer 31.

North McKittrick Front (Cymric) Area

English, W. A. 21a.

McKITTRICK AREA OF THE McKITTRICK OIL FIELD

By John B. Stevens*

OUTLINE OF REPORT

HISTORY

The McKittrick area of the McKittrick oil field is situated in the foothills of the Temblor Range along the southwest border of the San Joaquin Valley, Kern County. The trend of the area is northwest. Its length is approximately four miles, its average width less than half a mile. It is probably the oldest worked area in the San Joaquin Valley. Very early in the seventies the asphalt beds were opened and the product freighted by team to Bakersfield. On April 23, 1872, J. O. Lovejoy deeded 640 acres, now the heart of the McKittrick area, to the Buena Vista Petroleum Company. The first shallow development was to obtain oil to flux with the brittle surface asphalt in order to more satisfactorily meet trade requirements.

The building of the Southern Pacific branch line in 1893 to Asphalto, 2 miles out of the present town of McKittrick, kept the asphalt business alive through the depression of 1893, and later greatly stimulated the drilling of wells, as the advantage of fuel oil over coal in the development of power was quickly realized.

Extensive development of the McKittrick area did not take place until after 1900, and covered a period of some 15 years. Total productive acreage as given by the California State Division of Oil and Gas, is 1,545 acres. Approximately 500 wells were drilled in the area, of which 100 are now abandoned, 150 idle, and 250 still active producers. The cumulative production of the area is estimated to be in excess of 100,000,000 barrels of 12.0 to 19.0 degrees gravity oil. The present potential of the area is rated at 4,150 barrels per day. Drilling depths of the wells range from 800 to 1,400 feet, and the producing measures vary in thickness from 100 to 500 feet.

Early in the productive life of the area a considerable region became badly watered. Compressors were installed, and for several years more than 1,000,000 barrels of water per month were blown from the wells. Later the compressors were taken out and heavy pumping resorted to, and certain wells could be slowed down. The water table was definitely lowered, and apparently the source of water was in part depleted. Records show slow but steady improvement in the water situation during late years.

STRATIGRAPHY AND STRUCTURE

Production in the McKittrick area is obtained from sand beds in the Pliocene which unconformably overlie the organic shales of the Monterey formation. The reservoir measures are of post-Miocene age. A part of the oil is produced from the Tulare formation, but the bulk is from the basal Etchegoin. Fault movements, chiefly of down-grade gravity type, from the front of the Temblor Range adjacent on the southwest, are of such extent that over a considerable portion of the area Monterey shales heavily mantle the Pliocene strata, and wells are drilled through several hundred feet of the older shales before entering the younger measures beneath. Cross-sections through the area consistently show a monoclinal structure in the producing measures dipping 15 to 20 degrees northeast.

There has not been unanimity of opinion concerning the structure of the McKittrick area. All, however, agree that faulting played an important part in the accumulation or retention, or both accumulation and retention of the oil. From the most recent geological report that has been published regarding this area (Taff 33) the following quotation is made:

"The McKittrick field has two distinct stages of structural development.

"*The first stage* was developed in middle or late Pleistocene. At that stage, the 'structures' of the Temblor Range were developed essentially as at present and the McKittrick oil pool was in all essential respects like that of the North Midway field. The formations in monoclinal structure at the base of the Temblor Range were exposed and dipped toward the east: Miocene organic shales, the oil-source strata, 4,000-5,000 feet thick, lay at the base, with Etchegoin sand, oil saturated, resting unconformably on them. Tulare sands and shales rested unconformably on the Etchegoin and overlapped on the Monterey shale at the north end of the developed field. * * *"

"*The second structural stage* of the McKittrick field developed in late Pleistocene or Recent time when segments of the Monterey shale in the northeastern front of the Temblor Range across the central part of T. 30 S., R. 21 E., were broken down and moved in successive stages 2,000-3,000 feet vertically, and a maximum of 2 miles laterally over the exposed edges of the oil-bearing strata of the McKittrick field."

This interpretation, the report shows, is supported by the following facts:

1. Distinct physiographic features along the northeastern slope of the Temblor Range from which the faulted mass moved.
2. General slump or slide topography of the area involved.
3. Character and content of the fresh-water Santa Maria basin lying in the faulted mass and parallel with the range.
4. Crushed and broken character of the over-riding Monterey shales.
5. The low angle monoclinal attitude of these shales over the Pliocene oil-bearing measures.
6. Secondary character of the water permeating the overlying faulted mass of Monterey shale.

All familiar with the geology of the McKittrick district and the results of drilling in this area will appreciate the strength of the above interpretation in which the regional high-angle thrust faulting and intense folding in the range are taken into consideration and evaluated as contributing factors to existing structural conditions. Arnold and Johnson (10a), who made surveys of the region before the McKittrick area was completely developed, considered major low-angle overthrust faulting eastward from the Temblor Range to be the direct cause of the Miocene overlap of the McKittrick oil pool; they admitted, however, that the evidence available was not conclusive.

* Petroleum Engineer, Tide Water Associated Oil Company.
Manuscript submitted for publication August 30, 1939.

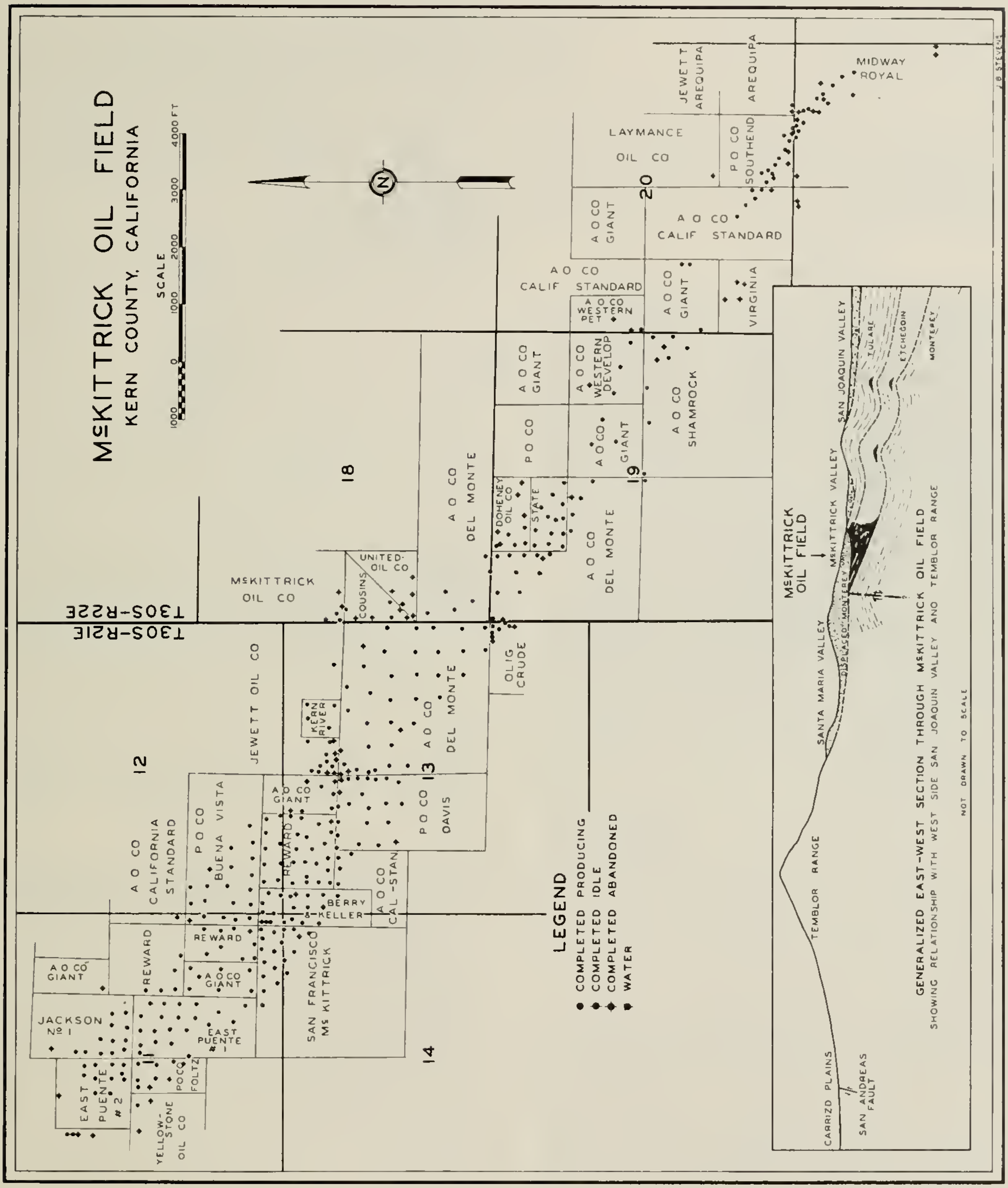


Fig. 217. McKittrick area of the McKittrick oil field: map; generalized section.

ELK HILLS OIL FIELD (U. S. NAVAL PETROLEUM RESERVE NO. 1)*

By LAWRENCE E. PORTER **

OUTLINE OF REPORT

HISTORY

In 1910, the west side of Kern County witnessed a feverish exploration and exploitation of lands on the eastern flanks of the Temblor Range in the area now known as the Midway-Sunset field. The flush of discovery caused the more venturesome to leave the shallow producing horizons along the eastern base of the Temblor range and migrate eastward in their prospecting work into the little-known areas of the Buena Vista and Elk Hills. The Elk Hills themselves, the site of the present Elk Hills field, are situated in a long range of low hills about 9 miles northeast of the town of Taft and are confined largely to the common boundary of Townships 30 and 31 South, between Ranges 22 and 25 East, M. D.

Although the ever-widening circle of development spread into the hills, the Elk Hills field was more or less dormant between 1909 and January, 1919, because of complications arising over title to lands, between the United States Government on the one hand, and oil operators and prospectors on the other. This followed the withdrawal, in September, 1909, of all Government lands in the area from tenancy.

According to Pack (20), only 35 prospect wells had been drilled by 1918 and, of these, only 3 were deep enough to give their respective areas an adequate test. The wells considered deep enough to be classed as test wells were all drilled by the Associated Oil Company. None obtained consistent commercial production, apparently because of improper mechanical condition and the lack of adequate geological information for determining proper shutoff points.

Commercial production was first obtained in January 1919 in the central part of Elk Hills (school section, Sec. 36, T. 30 S., R. 23 E., M. D.) by the Standard Oil Company when it completed its No. "Hay" 1 at a depth of 2,532 feet, for 225 barrels per day of 37.2 degrees gravity oil. Following this discovery, the Standard Oil Company, in February, 1920, completed the initial well in the extreme eastern portion of the field (Sec. 36, T. 30 S., R. 24 E., M. D.) at a depth of 2,828 feet for an initial production of 5,200 barrels per day of 25.4 degrees gravity oil. This latter well was the first producer to be completed outside the Naval Petroleum Reserve, and definitely showed the productive area to be quite extensive outside of it.

The discovery of prolific production in the eastern area of the field was followed by intense development, as typified by the following statistics:

Year	*Production (Barrels of Oil)*	*Percent California Total Production*
1919	281,019	0.2
1920	7,275,000	6.9
1921	18,085,000	15.8

The discovery of fields elsewhere in the State in rapid succession, contemporaneous with certain labor difficulties within the industry, caused producing operations here, as in other older fields, to be suspended during 1922 and most of 1923. To December 31, 1940, Elk Hills had produced 154,305,486 barrels of oil, representing about 2.9 percent of the accumulated production of the State of California as of the same date. During the month of December, 1940, the Elk Hills had a daily average production of 12,058 barrels from 197 producing wells, or a daily average production of 61 barrels per well. The total acreage involved in the Elk Hills field is 42,552, of which 89.5 percent or 38,069 acres is within the Naval Petroleum Reserve. About 5,300 acres or 13.9 percent of the lands within the Reserve are privately controlled.

Past production in the eastern area has been from 34,000 barrels to 140,000 barrels per acre. That this will be a measure for the entire 18,690 acres (Woodring, Roundy, and Farnsworth 32) thought to bear oil, is doubtful. Estimates have placed the future reserves of the proven developed areas slightly in excess of 41,000,000 barrels, and with a possibility of 400,000,000 barrels in the event the entire probable oil-bearing area is found commercially productive.

Exploration for deeper zones and further exploitation of existing ones will depend on the future policy of the Federal Government. The successful development of oil in the Miocene formations in the nearby Ten Section, Greeley, and other fields to the north and east suggests a fair possibility of additional oil reserves being obtained in zones of equivalent age in the Elk Hills structure. The deepest drilling below the *Scalez* oil zone so far has been limited to the fringe of the field, the deepest well being drilled by the Standard Oil Company (No. "K C.L." 27, depth 8,404 feet) in Sec. 31, T. 30 S., R. 25 E., M. D.

* This paper represents a digest of previous published reports, as well as unpublished material in the files of the Richfield Oil Corporation and its former subsidiary, the Pan American Petroleum Company. Factual memoranda, accumulated by the writer during the past 14 years of repeated contact with operations and problems of this field, have also been used.

** Assistant Manager, Exploitation Department, Richfield Oil Corporation. Manuscript submitted for publication July 1, 1938. Revised February 7, 1941.

Legislative and Legal History (Ball, M. W. 26)

A brief reference to the legislative and legal history of the Reserve is herewith included because of the influence it has had upon the development and production of the field.

February 24, 1908. The Director of the Geological Survey called the United States Government's attention to the policy of the British Government in conserving liquid fuels for its Navy; and recommended the establishment of a possible oil reserve in California and the suspension of further claims to oil lands. On September 17, 1909, the Director of the Geological Survey again called the Federal Government's attention to the possibility of using Federal lands in California to establish a Naval Petroleum Reserve.

September 27, 1909. Government lands in California and Wyoming were withdrawn for the purpose of holding them in status quo until the formulation of adequate legislation.

June 26, 1912. The General Navy Board requested the Interior Department to make the necessary reservation of lands. On August 8, 1912, the Director of the United States Geological Survey recommended for submission to the President a withdrawal order involving 38,069 acres in the Elk Hills which were to constitute Naval Petroleum Reserve No. 1. This was followed on September 2, 1912, by an executive order of President Taft creating the first Naval Petroleum Reserve, which was followed in quick succession by the formation of Naval Petroleum Reserve No. 2, of 29,541 acres, in the nearby Buena Vista Hills.

March 5, 1920. The Secretary of the Navy asked for legal authority to protect the Reserves from drainage by operators on private lands adjacent to them. By the Act of June 4, 1920, Congress gave the Secretary of the Navy the right to develop the lands within the Naval Reserve to prevent drainage. These steps by the Federal Government were necessary because in the creation of Naval Petroleum Reserve No. 1, all potential oil lands had not been included, as their potentiality had not been ascertained until private interests made discovery.

June 16, 1938. Senate Bill No. 1131 authorized the Secretary of the Navy to negotiate on an exchange basis Government lands in Naval Petroleum Reserve No. 2 for private lands in Naval Petroleum Reserve No. 1. At this writing, the Secretary of the Navy is attempting to carry out the provisions of this Act.

STRATIGRAPHY

The exposed formations in the Elk Hills field are nonmarine in character, consisting of unconsolidated gravels, sands, clays, and marls of Pleistocene or late Pliocene age (Tulare), equivalent to the uppermost part of the McKittrick group (Pemberton, J. R. 29). The surface configuration is typical "semi-desert topography."

Quaternary

The Quarternary alluvium around the boundary of the Elk Hills consists of unsorted sands, gravels, and silts, which conceal the underlying Tulare formation.

Pliocene

The Tulare formation (uppermost Pliocene) consists chiefly of non-marine deposits (Woodring, Roundy, and Farnsworth 32) 2,900 feet thick in the vicinity of Sec. 14, T. 31 S., R. 24 E., M. D.; in the central portion of Sec. 1, T. 31 S., R. 23 E., M. D., 875 feet thick; and on the north edge of the eastern portion of the field in the vicinity of Sec. 22. T. 30 S., R. 24 E., M. D., 2,370 feet thick. The Tulare is separated into three parts: (1) upper zone, 250 to 300 feet thick, consisting of tawny gray shales derived from the weathering of nearby formations in the Temblor Range, fragments of Maricopa (Miocene) shale making up a large portion of this particular phase; (2) middle, or second zone, grayish to buff colored, more or less banded shales and sandy shales, slightly in excess of 200 feet in thickness; and (3) third, or lower tawny group, 215 feet in thickness, seen in a few of the more deeply eroded gulches.

The exact contact between the Etchegoin formation and the overlying Tulare is not known because of the lack of information from well logs. The *Scalez* bed, a definite marker found in cored logs, occurs about 2,000 feet below the top of the Etchegoin.

The Etchegoin-Jacalitos (Pliocene) has been found about 8,300 feet below the surface in the extreme easterly portion of the field. Core records from this deep test, however, have not been made available for general use.

Miocene

In most instances the Maricopa formation underlies the Etchegoin unconformably. In the Temblor Range to the west, it ranges from 2,000 to 7,000 feet in thickness. Pemberton (29) believes the diatomaceous shales of the Maricopa to be the probable source of the Elk Hills oil.

STRUCTURE

The structure of the Elk Hills field is anticlinal, the reflection of which is well shown in the erosional exposures. The elevation of the center of the dome varies from 1,500 to 1,550 feet, tapering to 300 feet at the eastern limit and to about 900 feet (above sea level) at the western border near the town of McKittrick. Approximately 700 feet (Pemberton 29) of the Tulare nonmarine sediments have been exposed. These beds gradually dip valleyward away from the flanks of the anticlines, and are buried in the surrounding valley alluvium. The anticline is elongated about three times its width, and the dome or apex occurs in the south half of T. 30 S., R. 23 E., M. D., or about two-thirds of the distance west from the easterly limits of the topographic elevation. An outstanding correlative guide in interpreting the subsurface structure has been a fish-scale-like fossil, *Scalez petrolia*, which is the operculum of a soft, shell-like gastropod. This marker exists in a fairly hard, compact, bluish-gray shale ranging in thickness from 5 to 10 feet. Minute gastropods known as Amnicolas (Roberts, D. C. 26) usually accompany the *Scalez* bed in a similar shale some 15 to 20 feet above the *Scalez* marker. The *Scalez* bed generally is found from 10 to 25 feet above the main producing oil zone in the eastern area of the field.

Development has shown a closed dome in the eastern area, one in the middle-western or Hay Carmen area, and one in the extreme west, known as the Hillcrest area. Subsurface correlations from well logs indicate subsurface strata are conformable somewhat to the surface features overlying them, except that the deeper beds increase in their dip away from the axis. The eastern area is marked by four northeast-trending faults, having displacements ranging from 50 to 200 feet. These faults have been determined largely from subsurface data from the wells drilled. The wells drilled into the zone of faulting generally have obtained little or no production. These faults have had a marked influence on the production of the several fault-blocks; oil gravity differences between wells of one fault block and another have also been marked. Undoubtedly faults having considerable subsurface influence will be found in the undeveloped portions of the field to the west.

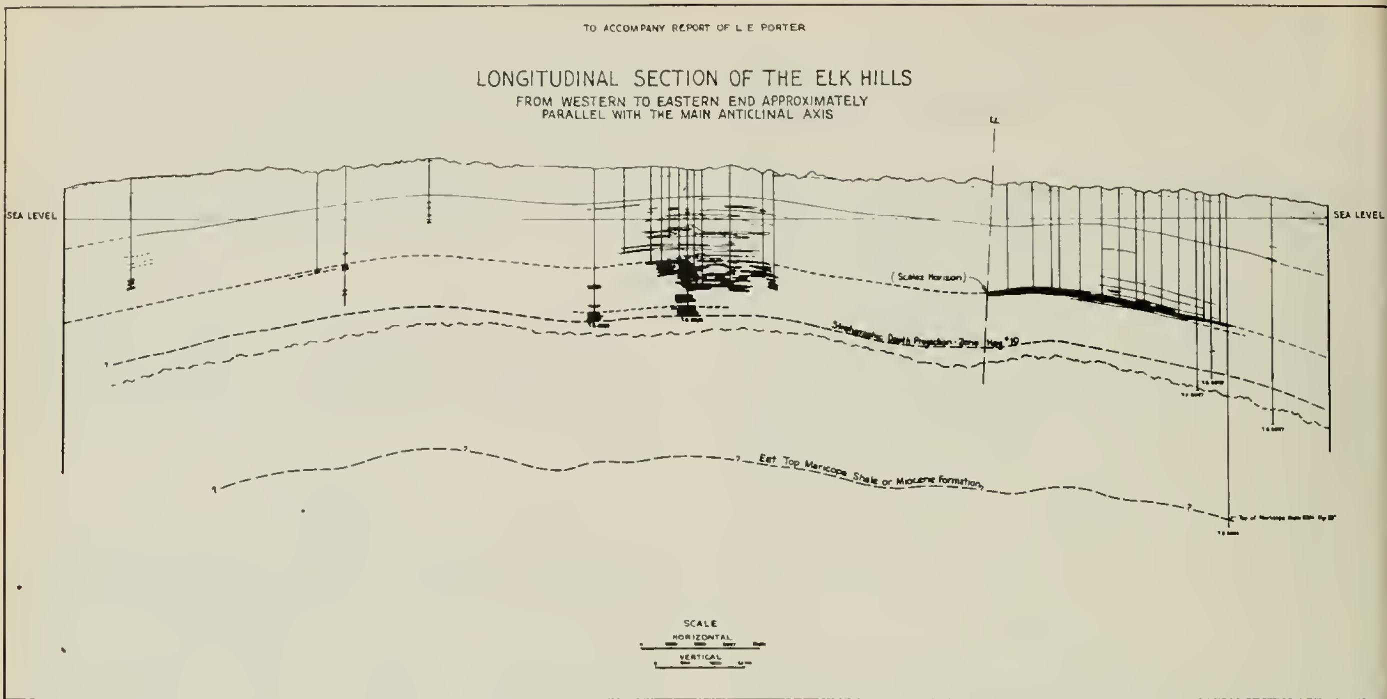


FIG. 218. Elk Hills oil field: longitudinal section.

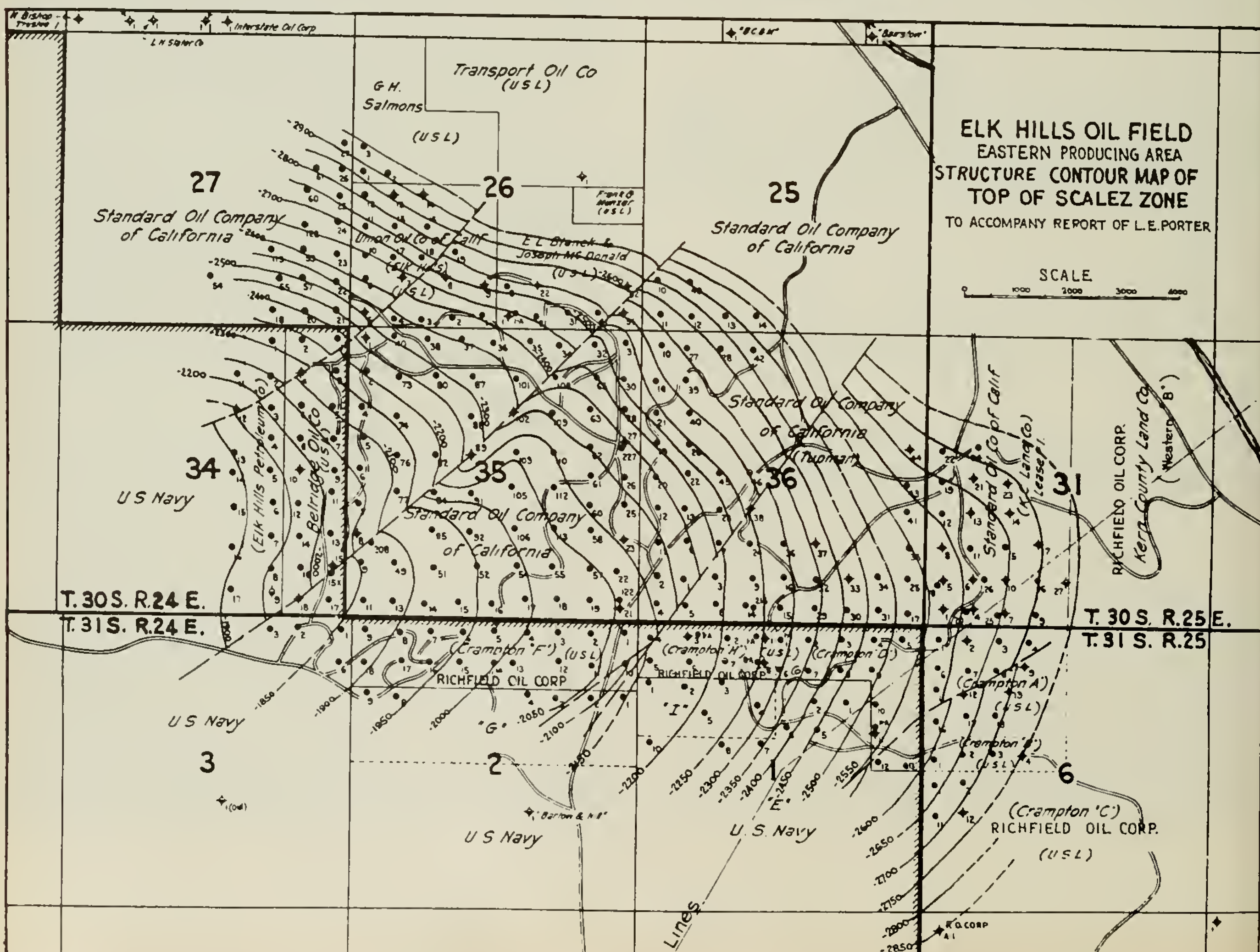


FIG. 219. Elk Hills oil field: structure map, eastern producing area.

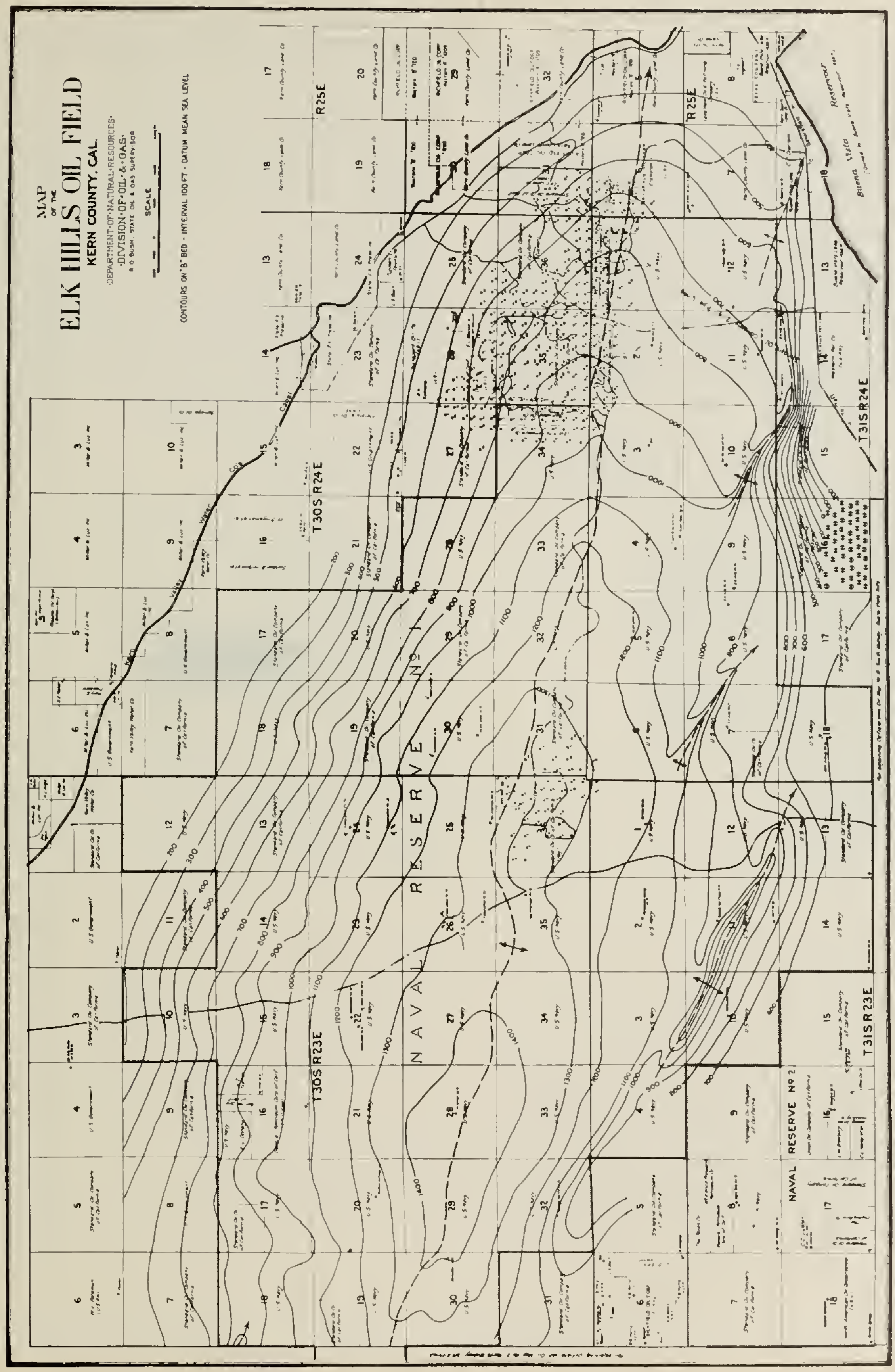


FIG. 220. Elk Hills oil field: map.

PRODUCTIVE HORIZONS AND KIND OF OIL AND GAS

Eastern Area

In this area oil gravity ranges from 14 to 26 degrees, and at least 75 percent of the oil produced is over 21 degrees gravity. The higher gravities usually are found in the higher structural positions. The productive zone ranges from 100 to 200 feet in thickness and consists of about 35 to 40 feet of solid sand; the balance of the zone is composed of interbedded sands and shales. The main producing zone occurs immediately beneath the *Scalez* horizon at depths ranging from 2,750 to 3,500 feet. The oil has an asphaltic base and is similar in most respects to oil of equivalent gravity found in the nearby Midway-Sunset field. Sufficient production history has now been accumulated to give a very clear picture of progressive water encroachment within the oil zone to the extent that it typifies a model field for the study of mechanics of water encroachment. Only a few clean-oil areas remain.

Western Area (Hay Carmen)

The absence of coring and the existence of only meager records have resulted in little information being available as regards the oil zones in this area. The gravity of the oil produced ranges from 21 to 53 degrees and averages about 35 degrees. While initial well-completion data are also incomplete, it is known that large gas wells and wells of gas condensate were completed in this portion of the field at depths ranging from 1,800 to 3,500 feet. The oil zones apparently consist of interbedded shales and sands. Recorded gas pressures at the surface have been as high as 1,500 pounds. Several outstanding gas wells were completed on the Hay Carmen leases of the Standard Oil Company in Sec. 36, T. 30 S., R. 23 E., M. D., and Sec. 31, T. 30 S., R. 24 E., M. D. Observable natural repressuring has been noted in several depleted gas wells which have been shut in for a protracted period; this repressuring was doubtless caused by fluid encroachment up the structure to the low-pressure or depleted areas.

CITATIONS TO SELECTED REFERENCES—Continued

ELK HILLS OIL FIELD

Arnold and Johnson 10a; Ball, M. W. 26; Brown, C. C. 26; 30; Collom, R. E. 21a; Doyle, F. F. 27; Godde, H. A. 26b; Hight, W 33; Hoots and Herold 35; Howard, P. J. 39; Kleinpell and Cunningham 34; Lahee, F. H. 34a; Masser, H. L. 22; 23; McCollough, E. H. 34; McLaughlin, R. P. 20; McLaughlin and Waring 14; Musser, E. H 30; 39; Pack, R. W. 20; Pemberton, J. R. 29; Petroleum Engineer 35; Petroleum Times 32; Porter, W. W. II 39b; Roberts, D. C. 26; 28; Sanders, T. P. 41; Saunders, L. W. 25; Stockman, L. P. 35i; 38a; 39; Taff, J. A. 34; Thoms, C. C. 22a; Thoms and Smith 21; U. S. Geological Survey 34; Uren, L. C. 37; Vander Leck, L. 21, pp. 169-171; Wagner, P. 23; Woodring, Roundy, and Farnsworth 32.

Hay Carmen (Carman) Area

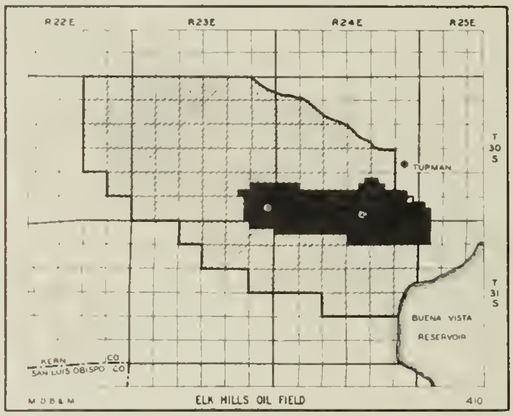
Petroleum Engineer 35.

Topman Area (East Elk Hills)

Petroleum Engineer 35.

U. S. Naval Petroleum Reserve No. 1

Arnold, R. 15; Ball, M. W. 26.



Elk Hills oil field (U. S. Naval Petroleum Reserve No. 1). Areas. (1) Elk Hills Central; (2) East Elk Hills.

BUENA VISTA HILLS AREA OF THE MIDWAY-SUNSET OIL FIELD

By J. H. McMasters*

Among the several anticlinal ridges and stratigraphic traps making up the large Midway-Sunset oil field on the southwestern border of the San Joaquin Valley, the Buena Vista Hills are the low hills lying immediately east and north of the town of Taft, in Kern County. A structural and topographic low point about midway in the 12-mile extent of the Buena Vista Hills divides them into the United anticline on the northwest and the Honolulu anticline on the southeast. Although the United States Naval Reserve No. 2 is located on Buena Vista Hills, more than half of the land is owned in fee.

The Buena Vista Hills, being obviously anticlinal in structure, were the scene of early development. In 1909 Honolulu Consolidated Oil Company drilled well No. 1 in Sec. 10, T. 32 S., R. 24 E., M. D. This well blew in out of control as a gas well from 1,608 feet, but was later deepened to the oil sand at 2,540 feet and completed as the discovery well of the field. Initial production was about 2,500 barrels of oil per day; no other producing data are available. Practically all oil and gas production of the field comes from sands of Pliocene-Pleistocene age, but a very slight amount is obtained from sand streaks in upper Miocene siltstone. Wells have an average depth of 2,500 to 4,500 feet and the oil a gravity of 24 to 33 degrees A.P.I., with an average of about 25 degrees.

As of January 1, 1942, about 1,367 wells had been drilled in the field, of which 398 have been abandoned. In December 1940, the average oil production was 15,154 barrels per day, produced under curtailment by about 650 wells. Estimated capacity of all producible wells (896 in December 1940) was 25,541 barrels per day. At the end of 1940, a total of 297,116,866 barrels of oil had been produced from this field. Based on an estimate of 14,500 productive acres, oil recovery per acre to that date was 20,490 barrels.

Development of the field has been continuous since the discovery and has not yet been completed; drilling still continues on inside locations and most recent completions yield satisfactory returns. Low points in drilling activity are noted for the period 1919-1921 and following 1929, and several high points mark the discovery and initial development of the several productive areas making up the total field.

Many difficulties were encountered in the early development, principally because of the very high gas pressures encountered at shallow depths. Knowledge and equipment were inadequate to handle the gas and many wells intended as oil producers blew in as wild gas wells before reaching the oil measures. At the present time, with formation pressures greatly depleted, drilling of inside locations by light portable equipment is carried on safely. Completion to a depth of 2,800 feet requires 10 to 12 days.

Accumulation of oil and gas has been controlled by anticlinal structure in connection with stratigraphic variations and some faulting, so that all parts of the field are not equally productive and several areas of good structural position are barren. Considering the field in its entirety, water-drive seems a negligible force in the production of oil and in one area at least, heavy oil withdrawals down-structure depleted a large adjacent up-structure area. A generalized stratigraphic column is included herewith to show the formations encountered and locations of the oil and gas zones.

Irregularly occurring but more or less interconnected sands are found within the San Joaquin clays. At high structural positions some of these sands carry gas, first shows being encountered near the base of the Tulare. Heavy withdrawals and water flooding due to poor drilling practice have at this date largely depleted these sands. Gas also has occurred in the oil measures at structurally high points, and, having been rapidly dissipated and not replaced by oil, has left several of these sands barren.

Oil occurs in the basal portion of the San Joaquin clays, usually in two closely adjacent sands immediately below a marker fossil called *Scalez* (designated as lower or type *Scalez* to distinguish it from upper occurrences), but may be found in sand streaks as much as 200 feet above type *Scalez*. The two lower sands, separated by a thin shale break, are referred to as the *Scalez* sands. They occur as a halo around the anticlinal fold of the Buena Vista Hills, due either to non-deposition on top of the fold or to later erosion, and therefore are usually productive farther out on the flanks of the fold than are the underlying more blanket-type sands. They disappear on the north end of the southwest flank but are productive to the south and on the southeast nose, where higher streaks also carry oil, and are the sole productive zone of the very large area comprising the northeast flank or Buena Vista Front. Here they have their greatest combined thickness of 30 to 45 feet.

Immediately below the top of the Etchegoin formation, marked by the first occurrence of *Mulinia densata* Conrad, occurs the *Mulinia* sand. Near the top of the structure, where type *Scalez* is absent but the basal sands of the San Joaquin clay immediately above *Mulinia* are oil or gas saturated, they have also been included in the *Mulinia* zone. The *Mulinia* sand is productive on top of the structure and on the southwest flank, but

* Geologist, Honolulu Oil Corporation. Manuscript submitted for publication March 5, 1942.

thins in crossing the crest, is gassy along parts of the crest, and is not productive on the northeast flank or the lower part of the southeast nose.

Below *Mulinia* a distance of 75 to 230 feet (and 40 to 50 feet below a fossil gastropod *Bittium*) lies a thick series of silty sands making up the Sub-*Mulinia* or Sub-*Bittium* oil zone. This zone is more extensive than the *Mulinia* zone, being productive on the southwest flank and including the northwestern end where *Scalez* and *Mulinia* zones are absent, and on the southeastern nose, where faulting has caused oil to be trapped in beds once considered too low structurally to be productive. In this area also, due to thickening of the sediments, a lower portion of this zone which is integral on the southwest flank becomes separated from the upper part of the zone by barren silts and is referred to as the *Pecten oweni* zone. Like the *Mulinia* zone, the Sub-*Bittium* zone is not productive on the northeast flank.

In addition to these three zones which have yielded practically all the oil produced from the field, there is a limited occurrence of oil in the upper 400 feet of the "Santa Margarita" or Reef Ridge shale and silt of upper Miocene age and this interval has been opened to production by several wells of high structural position on the southwest flank.

Until 1940 the field's deepest well stratigraphically had only penetrated the top of the McLure shale, encountering a few thin gassy sand laminations approximately equivalent to the upper part of the Stevens zone of the Ten Section field to the east. Much speculation on the possibility of deeper production in the Buena Vista Hills was laid to rest by the drilling of Honolulu Oil Corporation's well No. 10-25P in 1940-1941 on the same section as the field's discovery well. Drilled to a total depth of 14,622 feet, the well penetrated a great thickness of Miocene rocks as shown on the graphic section, and was bottomed in silty hard sand probably of Vaqueros (lower Miocene) age.

The lithology below 5,900 feet was mostly silt and sand with irregular bedding and very low permeabilities throughout. Silty sands from 5,900 to 6,500 feet, equivalent to some portion of the Stevens zone of fields to the east, were fairly well saturated with oil and gas but were too impermeable to produce when tested. Other oil and gas showings occurred from 6,750 to 7,550 feet and from 8,700 to 11,000 feet in upper Miocene beds, while gas and salt water under high pressure were encountered in middle-lower Miocene beds from 13,750 feet to bottom.

Worthy of a short note in a description of the Buena Vista Hills field is the active fault whose surface trace occurs along the crest of the Honolulu anticline near the middle of the southwest flank. This is a thrust-type fault with the plane dipping at an angle of about 25 degrees to the northeast and striking northwest parallel to the axis of folding. Several near-surface casing failures occurred before discovery of the surface trace, which was emphasized by arched pipe lines and slack power lines across the trace. Movement has averaged about 1 inch per year since 1933 when measurements were initiated in several shallow shafts sunk to relieve pressure on casing.

Much additional material on the Buena Vista Hills field may be had from the report by Paul J. Howard (35) which was consulted frequently in the preparation of these notes.

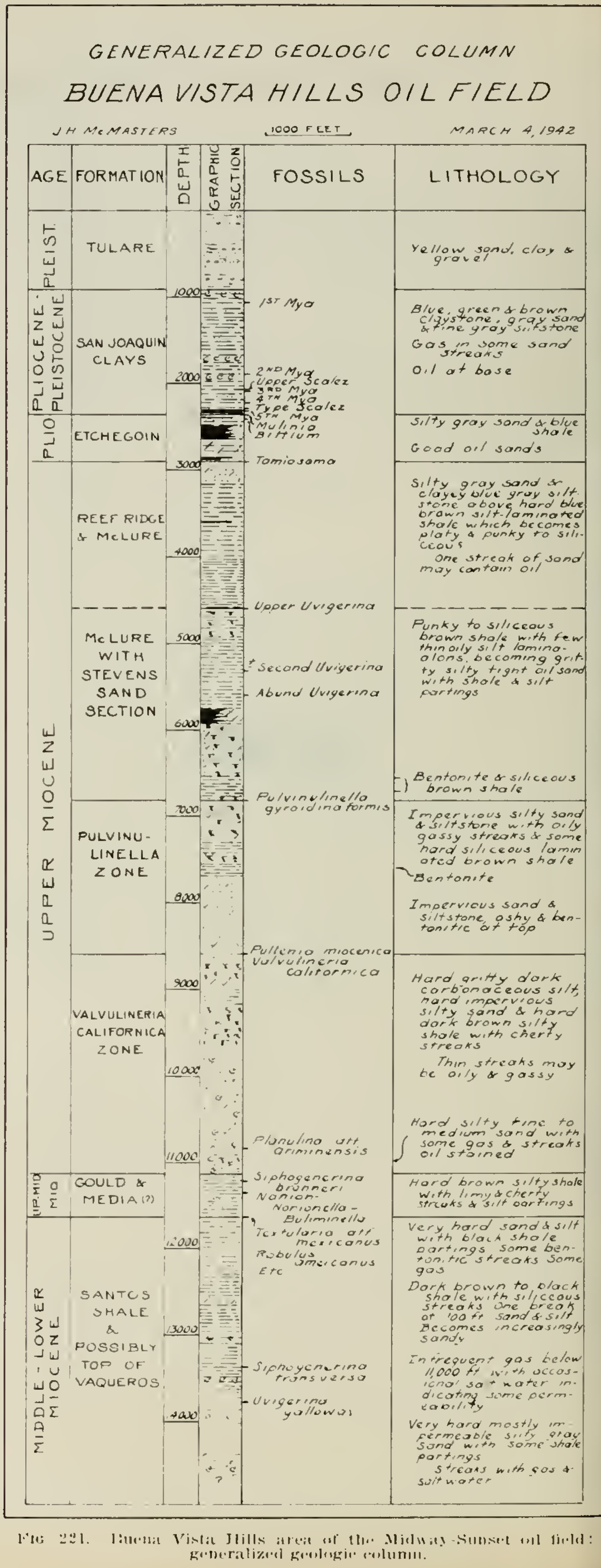


FIG. 221. Buena Vista Hills area of the Midway-Sunset oil field: generalized geologic column.

NORTH MIDWAY AREA OF THE MIDWAY-SUNSET OIL FIELD

By W. T. Woodward *

OUTLINE OF REPORT

HISTORY

Development of the North Midway area of the Midway-Sunset oil field was just getting under way as Arnold and Johnson (10a) sent their report on the McKittrick-Sunset oil region to press. This report, which has since become a standard reference work, contained brief mention (pp. 146-147) of development in the North Midway area. By the time R. W. Pack (20) published his paper on the Sunset-Midway oil field, roughly 75 percent of the present development in the North Midway area had been achieved. This latter publication treats the area in great detail, and has likewise become a standard reference work.

Many of the wells in the southeastern part of the North Midway area originally flowed several thousand barrels per day, one as much as 10,000 barrels per day. However, wells along the southwest and northwest edges of present development yielded as little as 5 barrels per day.

The area represents one of the major oil deposits of the great Midway-Sunset oil field, and probably is the most underdeveloped portion of that field. Development of present proven lands and extensions of productive boundaries, coupled with the slow drainage characteristic, should assure a long productive life for the area.

* Consulting Petroleum Engineer, Geologist, Taft, California. Manuscript submitted for publication August 23, 1941.

STRATIGRAPHY

Most of the area is covered by Recent alluvium and stream terraces. Occasionally the underlying Tulare fresh-water beds (Pleistocene) are exposed in the intermittent stream cuts. The Tulare beds lie in unconformable contact with the outcropping Reef Ridge formation (Miocene) along the southwest edge of present development.

Well data indicate a very thin section of San Joaquin clay (Pliocene) underlying the Tulare beds in the northeast portion of the area. The San Joaquin clay beds are more numerous in the southeast portion. The underlying Etchegoin formation is likewise present under the northeast and southeast portions of the area, and is underlain by the "Reef Ridge" formation, presumably unconformably.

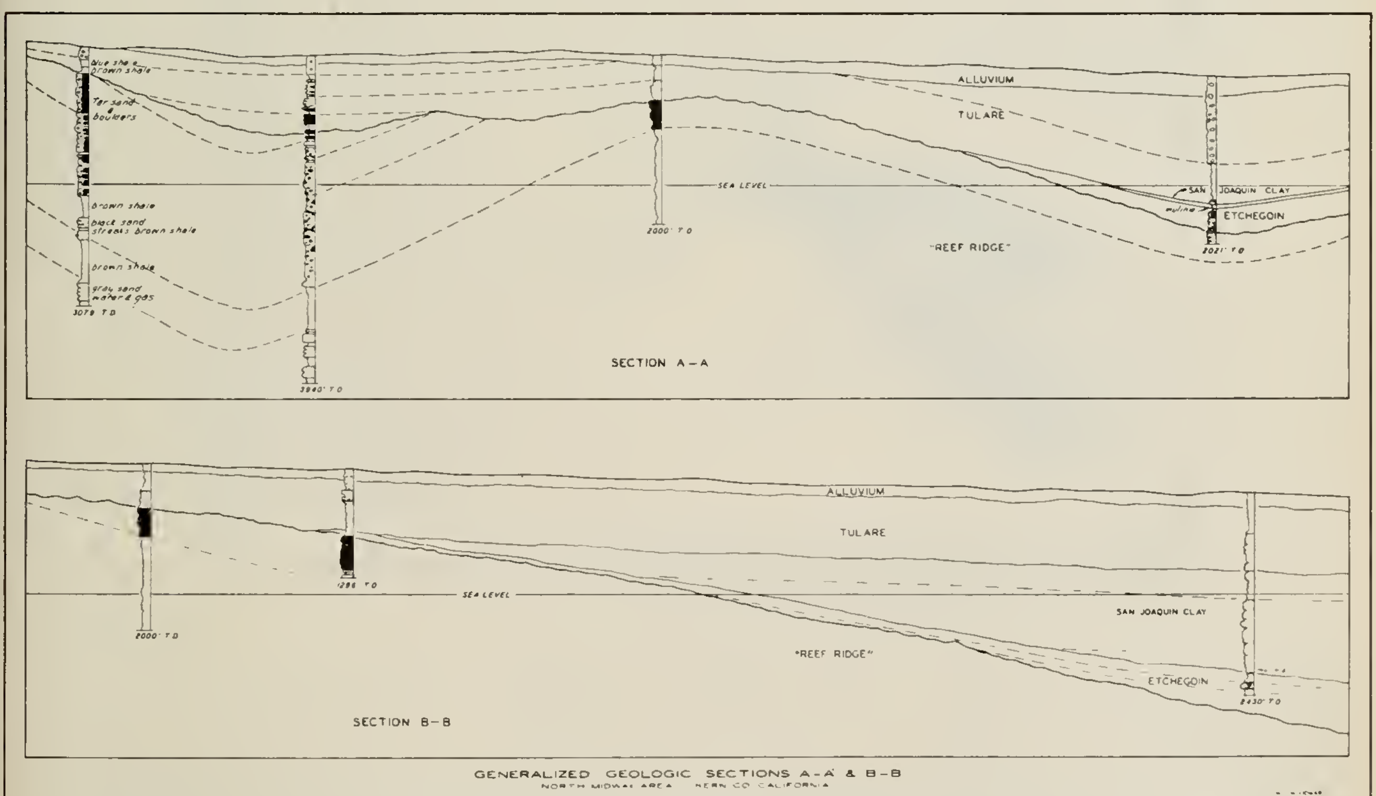


Fig. 222. North Midway area of the Midway-Sunset oil field: generalized geologic sections.

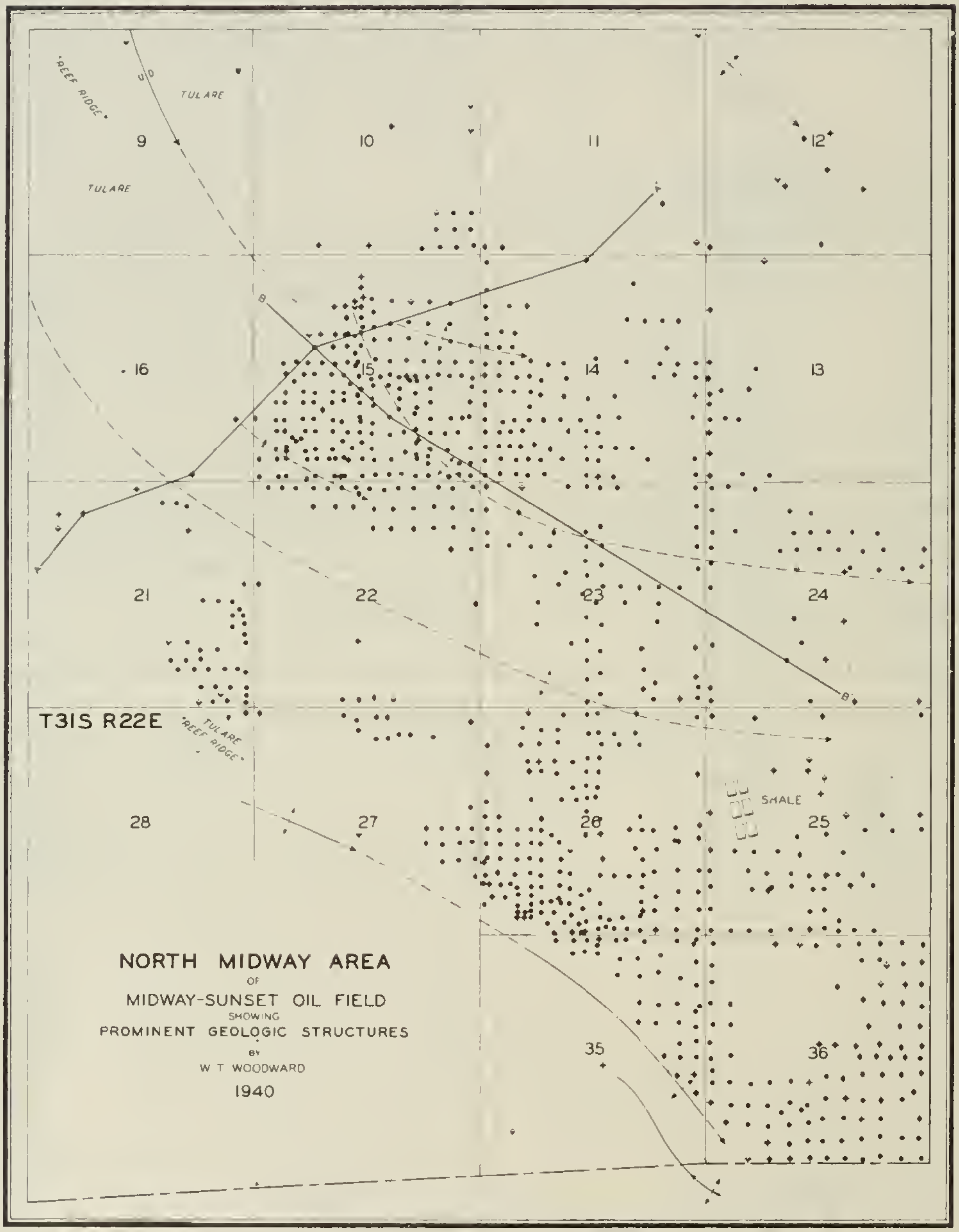


Fig. 223. North Midway area of the Midway-Sunset oil field: map.

The alluvium and terrace material consists for the most part of a buff-colored sandy clay matrix enclosing siliceous shale, chert, granite, and quartzite granules, pebbles, cobbles, and boulders.

The Tulare beds are buff to tan or green clays interbedded with material similar to the terrace deposits.

Blue and green-gray clays, and gray, fairly well sorted quartz sands carrying marine fossils make up the San Joaquin clay.

The Etchegoin formation is composed of green sandy clays and gray well-sorted quartz sands containing marine fossils.

Soft, diatomaceous, brown-gray shale and granitic, poorly sorted sand and gravel characterize the "Reef Ridge" formation.

STRUCTURE

The accompanying map and geologic sections illustrate the major structural features of the North Midway area. The accumulations are almost invariably the result of overlaps with oil trapped in Etchegoin, San Joaquin clay, and Tulare sands, generally buttressed against the "Reef Ridge" formation. Sands of the "Reef Ridge" probably constitute the chief reservoir along the western and southwestern edges of the area, being in turn overlapped by the younger formations.

The North Midway area is situated at the foot of the northeast flank of the Temblor Range, adjacent to the very complex McKittrick disturbance. The otherwise normal southeast-plunging tributary folds are somewhat faulted.

Most of the wells were drilled before the days of coring, and it is impossible to make detailed correlations or draft a satisfactory contour map from the old cable-tool-drilled well logs. However, recently drilled, cored wells allow reasonable interpretation of the various horizons.

PRODUCTION

Oil production is obtained from the "Reef Ridge," Etchegoin, San Joaquin clay, and Tulare formations. It is only natural that the gravity of the product has a wide range, from 11 to 27 degrees. The estimated average daily oil production per well is 15 barrels, and the average gravity about 16 degrees.

Gas is very often present in quantities sufficient to provide fuel for pumping equipment.

Considerable water accompanies the oil—salt water from the Etchegoin and San Joaquin clay horizons, and sulphur water from the Reef Ridge and Tulare formations.

Sand in great quantities has been brought to the surface by wells in the western and southwestern portions of the area, and has caused numerous mechanical failures.

CITATIONS TO SELECTED REFERENCES—Continued

MIDWAY-SUNSET OIL FIELD

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Buena Vista Hills (U. S. Naval Petroleum Reserve No. 2)

Arnold, Darnell, et al. 20; Arnold and Johnson 10a; Ball, M. W. 26; Brown, C. C. 26; 30; Forsberg, C. F. 41; Godde and Keyes 26; Honolulu Oil Corporation, Geology Department 41; Hoots and Herold 35; Howard, P. J. 35; Kleinpell and Cunningham 34; Kock, T. W. 33; Mining and Scientific Press 92d; 92e; 10d; McMasters, J. H. 41; Musser, E. H. 30; Nickerson, C. M. 36; Oil Weekly 41a; Roberts, D. C. 26; Sanders, T. P. 37e; 41a; Stockman, L. P. 41j; Taff, J. A. 34; Thoms, C. C. 22; Uren, L. C. 37; Wilson, G. M. 41.

Calidon Area

Roberts, D. C. 26.

Calivada Area

Roberts, D. C. 26.

Fellows Region

Arnold, Darnell, et al. 20; Pack, R. W. 20.

Gibson Area

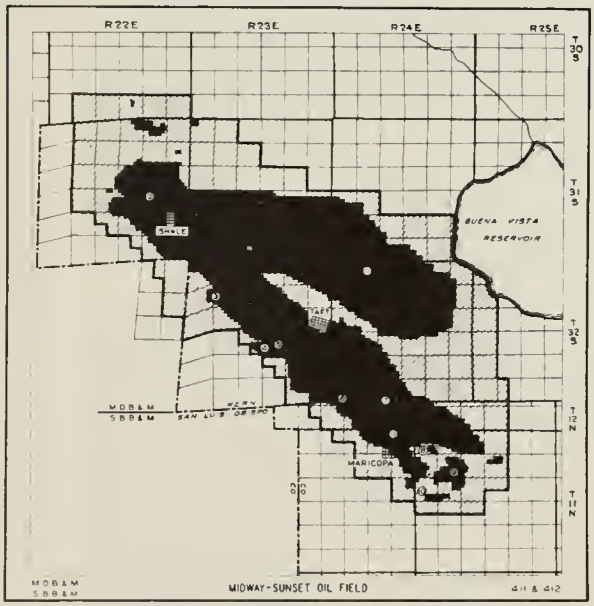
Woodward, W. T. 41a.

Gibson-Hoyt Area

Musser, E. H. 36.

Hovey Hills Area

Saunders, L. W. 23; Wallace, K. C. 24.



Midway Sunset oil field. Areas: (1) Buena Vista Hills (U. S. Naval Petroleum Reserve No. 2); (2) North Midway; (3) Republic; (4) Williams; (5) Twenty-Five Hill; (6) Hovey Hills; (7) Lake View; (8) Gibson; (9) Signal; (10) Sunset Extension; (11) Maricopa Flat.

Lake View Area

Musser, E. H. 36; Mining and Scientific Press 10e; 10f; Van Tuyl and Parker 41.

Little Signal Hill (Williams) Area

Hillis, D. 37; 37a.

Maricopa Flat (Maricopa Flats) Area

Arnold, Darnell, et al. 20; Atwill, E. R. 31; Clute, W. S. 23; Dana and Morgan 30; Musser, E. H. 30; 36; Pack, R. W. 20; Petroleum World 36a; Roberts, D. C. 26.

Midway Field

Arnold, Darnell, et al. 20; Arnold and Johnson 10a; Blackwelder, Thelen, and Folsom 17; Brown, C. C. 30; Burkhart, H. W. 10; Case, J. B. 19; Eldridge, G. H. 03; Emmons, W. H. 21; Engineering and Mining Journal 10; Ferguson, R. N. 18a; 19; 19b; Masser, H. L. 22; 23; McLaughlin, R. P. 14a; Mining and Scientific Press 10; 10e; 10j; 11; Musser, E. H. 30; Pack, R. W. 20; Prutzman, P. W. 04; Taff, J. A. 34; U. S. Geological Survey 34.

(Continued on page 525)

REPUBLIC AREA OF THE MIDWAY-SUNSET OIL FIELD*

By Umberto Young **

OUTLINE OF REPORT

HISTORY

The Republic area consists of approximately 10 square miles of territory situated immediately south of and adjacent to the town of Fellows, Kern County, in a belt 2½ miles wide (east and west) and 4 miles long (north and south). Locally the term "Republic area" is used to designate that particular small area in Secs. 7 and 8, T. 32 S., R. 23 E., M. D., which includes the only Republic zone development of importance to date. As used in this article, the term comprises the following territory: Secs. 5, 6, 7, 8, 17, 18, 19, 20, T. 32 S., R. 23 E., M. D.; and E½ Secs. 1, 12, 13, T. 32 S., R. 22 E., M. D. The area takes its name from the Republic zone, which was named for the company making the discovery.

The history of this region is identified with some of the most interesting phases of development of the Midway-Sunset field, pioneering of which commenced in the early nineteen hundreds. On the accompanying map is shown an area designated "belt of wells producing from shallow oil zones." This is part of the "buttress sand" area of the early Midway development. Most of these wells are pumpers, but there were occasional wells of spectacular proportions that flowed from the "gusher sand."

The peak of development of this buttress sand area was reached from 1911 to 1914, and there was another very lively drilling campaign in 1920 and 1921. During the years of intensive development, this region passed through some interesting geographical changes. The large number of employees required by the operators brought oil workers and their families from different parts of the country, and a large population lived in small settlements and towns strung along the west side fields in a belt many miles long. These people were dependent for transportation and supplies entirely on the Sunset Railroad, a Santa Fe and Southern Pacific joint project. With the changes in transportation and the steady decline of the oil fields, this population has gradually moved away and the towns have disappeared. Fellows, once a prosperous camp, has shrunk to a fraction of its former size, and the Sunset Railroad has been abandoned from Taft to its northern terminal, Shale.

* The writer acknowledges the use of U. S. Geological Survey Professional Paper 116 (Pack, R. W. 20) and U. S. Geological Survey Bulletin 406 (Arnold and Johnson 10a) in the preparation of this report.

** Geologist and Petroleum Engineer, Republic Petroleum Company. Manuscript submitted for publication July 1, 1941.

Some of the many hundreds of wells drilled during the early days of development of the shallow pools ("buttress sands") made notable production records. Because reliable records are lacking, it is difficult to give a connected narrative of development, but a few of the more interesting wells are noted.

Chanslor-Canfield Midway Oil Company well No. 1 was one of the early wells, and was drilled in 1907. It was located in Sec. 18, T. 32 S., R. 23 E., M. D. Its total depth was 2,554 feet—fairly deep for those days. It penetrated the Republic sand equivalent from 2,420 to 2,525 feet. No production was developed. The sand was logged as water sand.

Combined Oil Company well No. 1, Sec. 18, T. 32 S., R. 23 E., M. D., was drilled in 1920 to a depth of 1,512 feet, and was completed in the tar sands at the base of the Belridge diatomite as a small producer. The well developed water trouble and was abandoned in 1923.

Combined Oil Company well No. 2, in the northeast corner of the same section (18), was drilled in 1921 to a total depth of 1,142 feet. It developed a little heavy production, too small to be of commercial value, and was abandoned in 1923. After this date, apparently, no outpost wells were attempted for several years.

Republic Petroleum Company well No. 25 discovered the Republic zone on March 3, 1928, as the result of a deepening job. This well, in Sec. 8, originally producing from the base of the Tulare at a depth of 870 feet, was deepened by cable tools. It topped the Republic sand at 2,655 feet, and was completed at a total depth of 2,704 feet. From the 49 feet of penetration an initial production of 1,200 barrels of 23 degrees Baume oil per day, and 350 thousand cubic feet of gas testing 1.6 gallons per thousand was obtained. Although the drilling was carried on with some improvised equipment (the liner was actually made from 3-inch boiler tubes), the well was nevertheless completed in good shape and brought in under control. Mechanical troubles forced the completion of the well when only a fraction of the producing sand had been penetrated. A drilling campaign proceeded steadily during the ensuing 3 years, under a well-ordered spacing program, all the productive acreage being under the control of two companies, Chanslor-Canfield Midway Oil Co. and Republic. The resulting development was surprisingly small in extent, there being a final total of 20 producing wells covering an area of barely 80 acres; but the oil zone has been prolific and recoveries unusually large. A total of 23 wells was drilled, of which two were abandoned as being situated unfavorably on the steep north flank of the structure. These were the Republic well No. 32 in Sec. 8, and Republic well No. 35 in Sec. 7. The discovery well, Republic No. 25, produced a total of 425,000 barrels of oil to May 1931, when casing trouble and mechanical difficulties caused its abandonment. As of June 1, 1941, there are producing 12 wells for Chanslor-Canfield Midway, and 8 wells for Republic.

The discovery of the Republic zone stimulated immediate exploration of the upper Miocene and a number of outpost wells were drilled.

Knudsen No. 1, located near the center of Sec. 12, T. 32 S., R. 22 E., M. D., was drilled to a depth of 1,486 feet. The geological record is not definite, but the log indicates that part of the Republic zone was penetrated. No production was obtained.

Purman No. 1 well, located in the SE¼ Sec. 12, T. 32 S., R. 22 E., M. D., reached a depth of 3,648 feet. It was drilled in 1929, starting in McLure shale at the surface, and penetrating the top of the Republic sand at approximately 800 feet. Some poorly saturated tar sands were found at the top of the zone. The hole passed into hard, chocolate-brown siliceous shales at 2,200 feet, and continued in that formation to bottom. No important oil showings were encountered and the well was abandoned.

Phelps No. 1 (Keefe and Morrison No. 1) well in the NE¼ Sec. 13, T. 32 S., R. 22 E., M. D., was also drilled in 1929. The location, on an outcrop of the Republic sand, was structurally poor. Total depth was approximately 2,000 feet, and the well was bottomed in the hard brown siliceous shales. No oil showings were encountered.

Southern Exploration Company No. 1 well, located near the northeast corner of Sec. 13, T. 32 S., R. 22 E., M. D., was drilled to 890 feet in 1929, and penetrated the Republic sand at a depth of 200 feet. The location was poor structurally, and no showings were encountered.

Lincoln Drilling Company well No. 1, in Sec. 18, T. 32 S., R. 23 E., M. D., was drilled in 1929 to a depth of 1,028 feet. Tar sands of the diatomite were penetrated, the casing was cemented, and a production test was made. The hole was bailed dry, and the well abandoned. The location was poor structurally.

Republic well No. 39 in Sec. 8, T. 32 S., R. 23 E., M. D., was drilled in 1935 to a depth of 4,551 feet. The location was intended to test the possibility of a structural trap against the steep flexure on the northeast flank of the Midway anticline. At a depth of 2,020 feet dips of 75 degrees were encountered in the Miocene shales, and these were found to continue to bottom. The Republic sands were not penetrated and the well was abandoned as being unfavorable structurally.

Valley Oil Company well No. 1, in Sec. 18, T. 32 S., R. 23 E., M. D., was drilled in 1937 to a depth of 3,175 feet. It penetrated oil-stained Republic sand between 2,615 and 2,786 feet, but no saturated sands were cored. A drill-stem test indicated that the formation was barren, and the well was abandoned. The location appears to be on the upper end of an eastward-plunging syncline.

Baker, Leyce, and Sonne well No. 1, in Sec. 20, T. 32 S., R. 23 E., M. D., was drilled in 1939 to a depth of 2,730 feet. No production was encountered, though several showings of heavy oil were reported. Lack of a definite coring program seems to have left the geologic position of the well in some doubt. It is probable that part of the Republic zone was penetrated, and that it was largely shale.

Republic well No. 40, in Sec. 18, T. 32 S., R. 23 E., M. D., was drilled in 1940 to a depth of 2,466 feet, and was plugged back to 1,890 feet. Initial production was 200 barrels per day of 17 degrees Baume oil from 120 feet of the Republic zone.

Republic well No. 41, located in Sec. 18, T. 32 S., R. 23 E., M. D., was also drilled in 1940, to a depth of 2,050 feet. It was plugged back to 1,895 feet and completed for 75 barrels per day of 15 degrees Baume oil initial production, from 50 feet of the Republic zone.

The two wells last mentioned are located on a small, sinuous fold that trends southeastward through the NE¼ Sec. 18, T. 32 S., R. 23 E., M. D. The initial productions in each case, though small, are sufficient to encourage further exploration, which will be necessary to properly delineate the extent of the productive area.

Of the 20 wells now producing from the Republic zone in Secs. 7 and 8, initial productions ranged from 600 barrels to 2,500 barrels per day. For the first few months the wells were produced without curtailment, and while large flows were permitted, the operators at all times maintained proper control with flow beans and back pressure. To June 1, 1941, the field had produced approximately 11,000,000 barrels of oil, approximately 137,000 barrels per acre. The oil is propelled by a combined gas and water drive.

As of June 1, 1941, the allotment for the pool was 528 barrels per day, based on a potential of 1,041 barrels per day.

No particular difficulties are experienced with either drilling or production technique. On the earlier wells the water string was set 400 to 600 feet above the top of the oil zone, on the theory that some of the thin sand lenses of the McLure shale were productive. This practice has been discontinued in the later wells.

STRATIGRAPHY

In describing the stratigraphy, the writer has combined records from several wells where careful coring was done and foraminiferal determinations were made, such as the Chanslor-Canfield Midway well No. 29 in Sec. 8, T. 32 S., R. 23 E., M. D. Regionally there is a wide variation in thickness of formations. They pinch out on the flank of the Temblor Range, and thicken to great depths towards the valley. The following descriptions give the approximate thicknesses encountered in the vicinity of the Chanslor-Canfield Midway well No. 29 in Sec. 8, which, on account of the careful coring, has been used as a key by the paleontologists.

Surface Alluvium

The surface alluvium ranges from 50 to probably 150 feet of sands, gravel, boulders, and yellow clay. This formation carries considerable fresh water and contributes to the local ground-water supplies.

Tulare

The Tulare (formerly "Paso Robles") of upper Pliocene age, is approximately 700 feet thick, and consists of fine to coarse sands and gravels buff to blue in color. The formation carries fresh water, and is interbedded with fine sandy clays and silts. There are occasional boulders and conglomerate at the base. Outcrops show thin streaks of limonite and sulphur. Streaks of tar sand are found at various depths, and in this region a heavy oil sand is usually found near the base.

Etchegoin

The Etchegoin (lower Pliocene) appears to be absent in wells of the Republic pool, as it thins out toward the Temblor Range and is overlapped by the Tulare against the upper Miocene. It definitely appears near the center of Sec. 8, T. 32 S., R. 23 E., M. D. It consists largely of blue clays, silts, fine sandy clays, "sticky" blue clays, and sands and gravels, interbedded. It carries abundant marine fossils near the base. The lower half contains several distinct oil sands arranged in an overlapping progression to the southwest, marking the successive shore lines of the transgressive Etchegoin sea. These sands appear to join into one solid body as they approach the overlap, and "buttress" against the underlying upper Miocene. They are the oil zones of the "buttress sand" areas which extend in a long belt along the west side of the San Joaquin Valley, and have been such prolific producers during the past years of intensive development. They still produce a very substantial amount of the oil in the west side fields.

Belridge Diatomite

The Belridge diatomite (upper Miocene—also referred to as Reef Ridge equivalent) is situated unconformably below the Etchegoin; its thickness is approximately 1,200 feet. It consists largely of both massive and bedded white punky diatomaceous shale which weathers to a yellowish-gray color, and is interbedded with thin lenses of white quartz sand, stained or partially saturated over a large part of this area with heavy black oil. There are also occasional interbeds of dark grayish-brown siltstone, and some sandstone and conglomerate reefs that may contain large boulders, the latter being the "boulder beds" familiar to drillers.

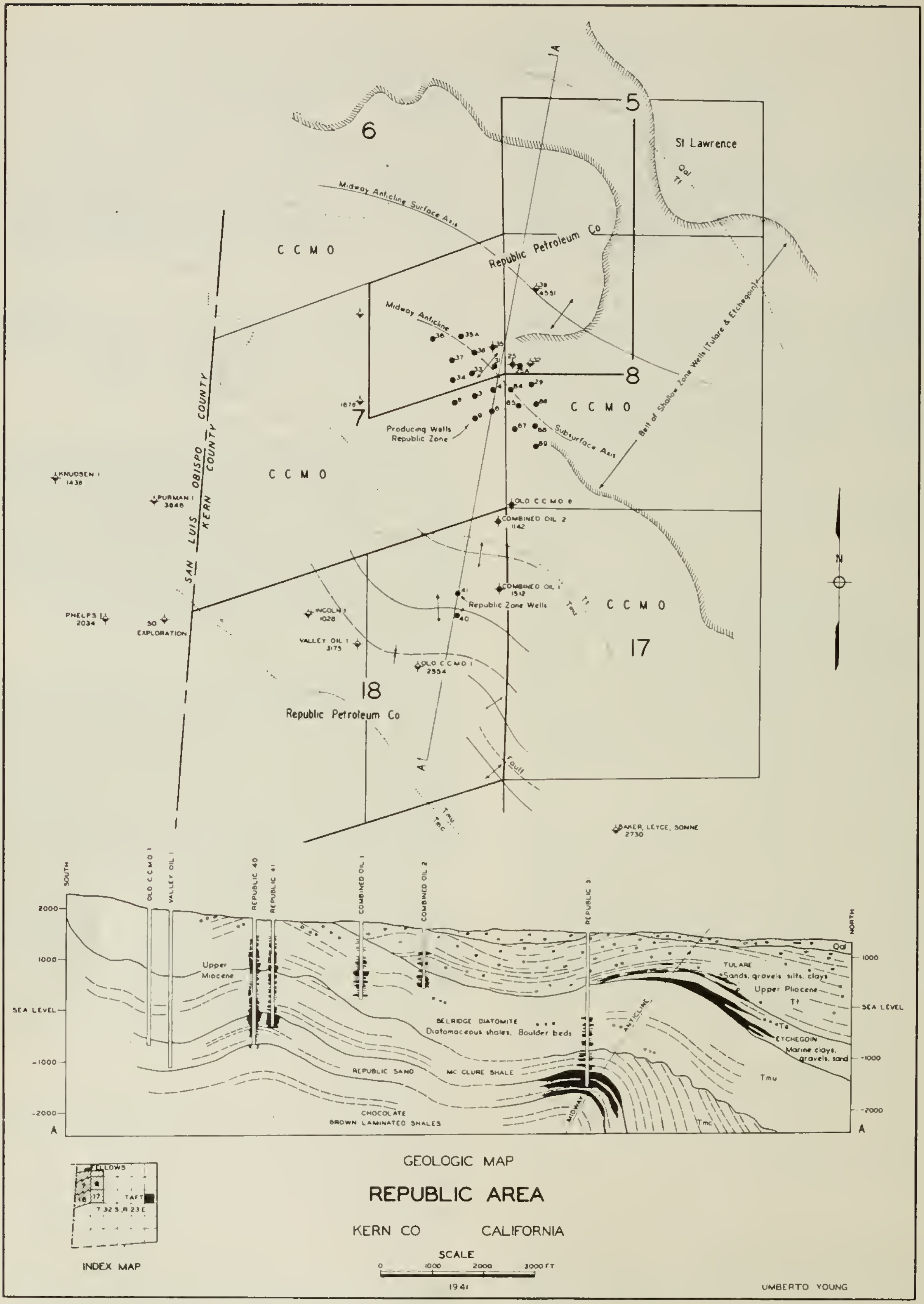


FIG 224. Republic area of the Midway-Sunset oil field: geologic map; section.

Outcrops of the diatomite are generally a yellowish-white color, but fresh samples from the core barrel grade from light grayish-brown to an oil-stained dark brown, as the depth increases. The formation carries at the base a well-defined tar-sand zone of variable thickness, which is not permeable because of its high lime content. A few of the shallow wells of the "buttress sands" area have been carried into the diatomite beds (logged usually as "brown shale" or "Maricopa shales"), and completed for small production.

McLure Shale

The term "McLure shale" is used to designate that part of the upper Miocene which here lies below the tar sand at the base of the diatomite, and above the Republic oil sand. It consists of hard brown shales, often laminated, with occasional fracture zones, and contains many thin lenses of very fine oil sand. It attains a thickness of approximately 800 feet in this area, and appears to be conformable with the overlying diatomite. This shale contains the *Bolivina* zone which is useful as a marker throughout the area. Many of the early wells logged this formation as "brown shale," "Maricopa shale," or "hard brown," there being general confusion of this formation with the overlying diatomite, and even with the brown siltstone streaks of the Etchegoin, prior to the introduction of coring and foraminiferal classification.

Republic Sand

The Republic sand is composed of medium-fine to medium-coarse, subangular to rounded oil sand, usually well sorted, ranging from very compact beds to loose, friable, and poorly consolidated beds. It contains considerable micaceous silt. Total thickness is approximately 600 feet, but this includes a very large percentage of shale beds which occur chiefly in the lower half of the zone, where the oil sands appear to be split up into many small beds by them. This feature is well illustrated in prominent outcrops of the formation in Sec. 12, T. 32 S., R. 22 E., M. D. In developing the oil zones the operators have generally followed the practice of taking the upper 250 to 300 feet of formation; two or three wells which took greater penetration developed water trouble and were plugged back.

Middle Miocene

Below the Republic zone are middle Miocene beds (probably the equivalent of the Antelope shale) of hard, dark-chocolate-brown laminated shales. These shales have not been prospected in this immediate area, and may possibly contain some productive sand lenses at favorable structural locations.

STRUCTURE

The most prominent structural feature of the area is the Midway anticline, which can be traced on the surface in Sec. 6, and, less prominently, in Sec. 8, T. 32 S., R. 23 E., M. D. It is strikingly asymmetric in the Miocene, the axis having an average inclination to the vertical of 26 degrees. On the northeast flank, dips of 75 degrees to 80 degrees were obtained from cores. The southwest flank dips gently (maximum 20 degrees) into a generally synclinal area that trends southeastward through the center of Sec. 7. The accompanying subsurface structure map of the Republic zone in Secs. 7 and 8 was developed entirely from core information. The fold is clearly reflected in the Pliocene beds on the surface but the angles are gentle, and there is a pronounced angular unconformity at the Pliocene-Miocene contact.

To the southwest the structural features become bolder as the formations are exposed prominently on the shoulder of the Temblor Range uplift. These features appear as a series of small folds. On one of these, in the NE¼ Sec. 18, the Republic sand has been found approximately 1,000 feet higher structurally than in Sec. 7, and two wells have been completed on this structure as small pumpers in the uppermost part of the Republic zone. The small folds to the southwest of the Midway anticline appear to be somewhat more symmetric. There is no prominent surface evidence of either faulting or asymmetry in the immediate area.

KIND OF OIL

Refinery analyses of samples from some of the wells showed the following approximate determinations:

Gravity	22.72°	Baume
Gasoline	18.0	percent
Residuum	68.0	percent
Sulphur	1.03	percent

CITATIONS TO SELECTED REFERENCES—Continued

Midway-Sunset Oil Field

(Continued from page 521)

North Midway Area

Arnold and Johnson 10a, pp. 146-147; Pack, R. W. 20; Roberts, D. C. 26; Ziegler, F. W. 22.

Republic Area

Musser, E. H. 30; 36.

South Midway Area

Forstner, W. 10; 11.

Sunset Field

Arnold and Johnson 10a; Blackwelder, Thelen, and Folsom 17; Burkhart, H. W. 10; Case, J. B. 19; Clute, W. S. 23; Copp and Godde 23; Eldridge, G. H. 03; Emmons, W. H. 21; Engineering and Mining Journal 10; Farnsworth, H. R. 17; 28; Ferguson, R. N. 18; 18a; Godde, H. A. 26a; Henny, G. 38b; McLaughlin and Waring 14; Mining and Scientific Press 92d; 92e; 00b; 00c; 10; 10d; 10e; 10j; 11; Musser, E. H. 30; Prutzman, P. W. 04; Roberts, D. C. 26; Taff, J. A. 34; U. S. Geological Survey 34; Vander Leck, L. 21; Watts, W. L. 00.

Sunset Extension Area

Rogers, R. G. 23.

Thirty-five Anticline

Copp and Godde 23; Farnsworth, H. R. 17; Godde and Musser 26a; Musser, E. H. 36; Roberts, D. C. 26.

Twenty-five Hill Region

Arnold, Darnell, et al. 20; Ferguson, R. N. 19b, pl. II.

United Anticline

Roberts, D. C. 26.

Williams Area

Musser, E. H. 36; Woodward, W. T. 41.

WILLIAMS AND TWENTY-FIVE HILL AREAS OF THE MIDWAY-SUNSET OIL FIELD

By Donuil Hillis* and W. T. Woodward**

OUTLINE OF REPORT

LOCATION AND HISTORY

The Spellacy anticline, which is the principal structural feature associated with the area herein described, is 1 mile southwest of Taft in the Midway-Sunset oil field. Early development was in beds of Pliocene age which erosion had removed along the highest axial part of the fold but which furnished production due to overlap along the northeastern flank, the southeastern plunge of the axis and to a lesser degree on the southwest flank. The part of this production in Sec. 25, T. 32 S., R. 23 E., M. D., on the southeast axial plunge came to be known as Twenty-Five Hill. The latest development has been in beds of Miocene age on the apex of the anticline in the Williams area. These two areas and the production on the northeast and southwest flanks are herein collectively referred to as the Spellacy area.

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** Consulting Petroleum Engineer and Geologist, Taft, California. Manuscript submitted for publication November 22, 1941.

The first production of oil in the Midway district is reported to have been in 1901, from a well drilled in Sec. 4, T. 32 S., R. 23 E., M. D., which is said to have yielded "250 barrels per day, though it was pumping but 12 hours a day." Discovery of oil in the area herein described probably occurred in the same year, since it was among the first to be drilled but intensive development was delayed until about 1907.

Initial productions were usually small, ranging from 10 barrels per day on the southwest flank to 500 barrels along the axis and northeast flank. Wells in Sec. 30, T. 32 S., R. 24 E., M. D., are reported to have flowed as much as 10,000 barrels per day. The gravity of the oil ranged from 12 to 26 Baume. By 1917 some 600 wells had been drilled in the Spellacy area, 400 of which were producing an aggregate of 4,000 to 5,000 barrels of oil and 10,000 barrels of water per day. This early production on the flanks and axial plunge was obtained from oil-sand members of the Tulare (Pleistocene), San Joaquin clay (Pliocene), Etchegoin (Pliocene), and to a smaller extent from the Reef Ridge (upper Miocene) formations.

In 1929 the Union Oil Company discovered oil at a structurally higher location in sands of the McLure (upper Miocene) formation, some 1,200 feet stratigraphically deeper than any previously known producing horizon in the Spellacy area. The discovery well was "Williams" No. 1, Sec. 22, T. 32 S., R. 23 E., M. D.,

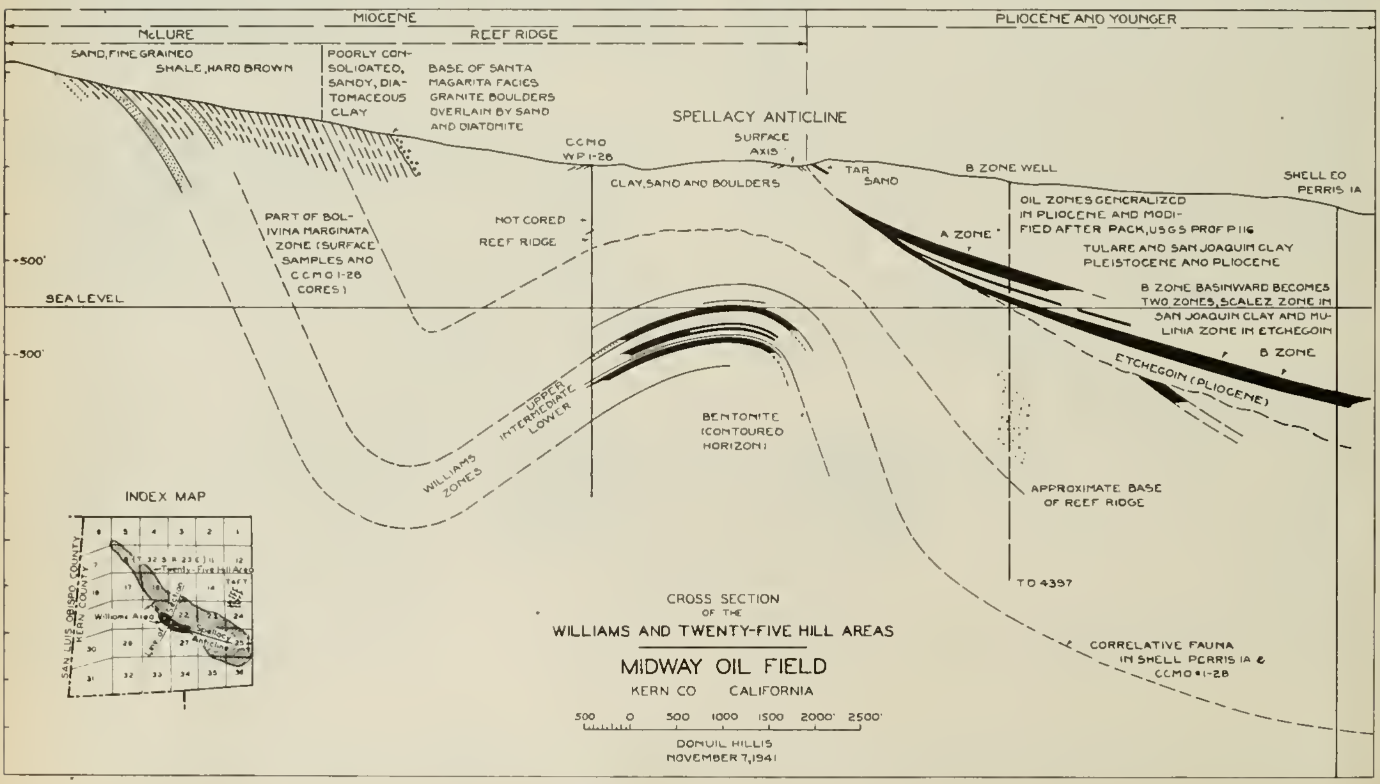


Fig. 225. Williams and Twenty-Five Hill areas of the Midway-Sunset oil field: cross-section; index map.

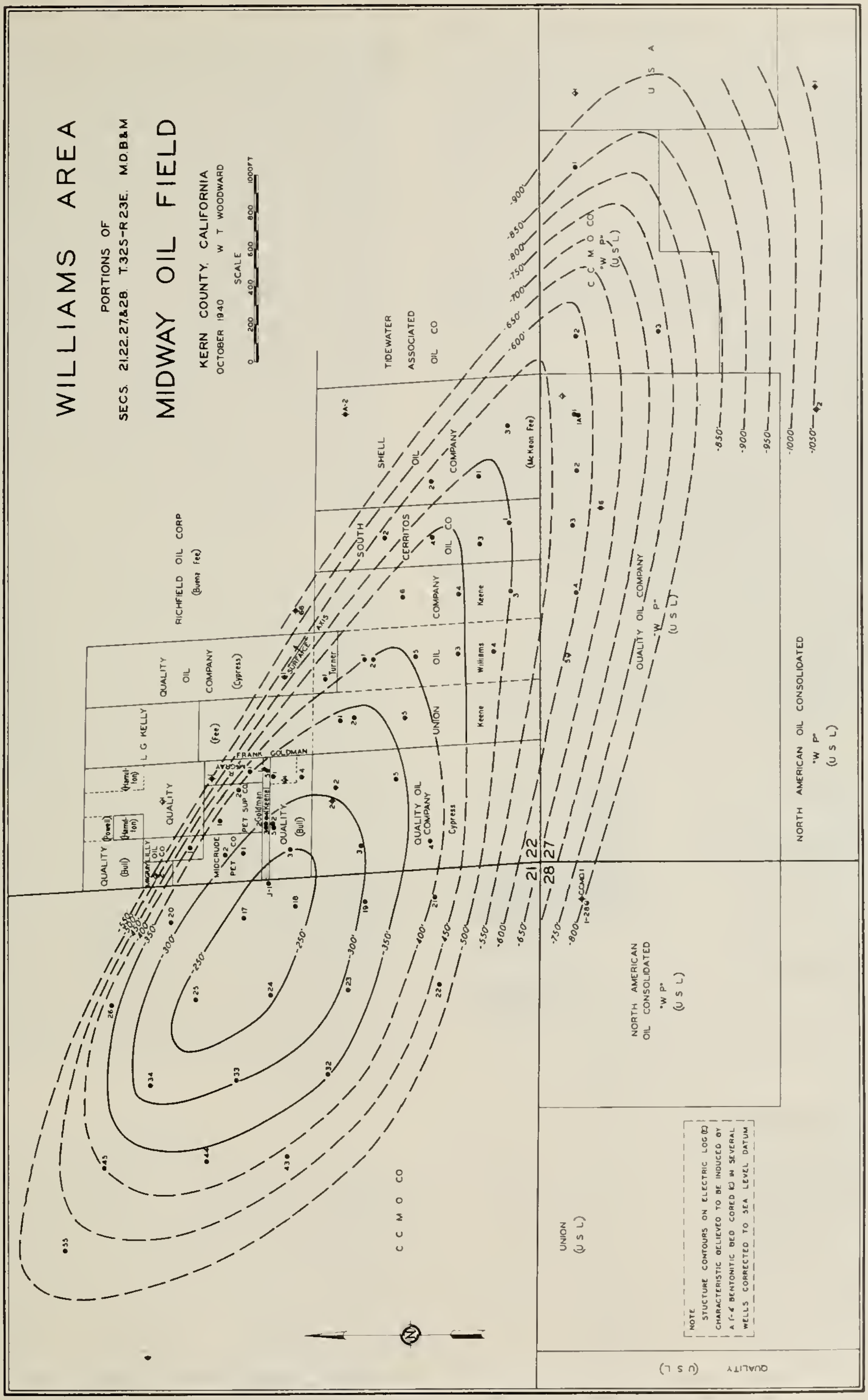


FIG. 226. Williams area of the Midway-Sunset oil field: structure map.

drilled to 2,888 feet, and plugged back to 1,494 feet, leaving open to production 289 feet of formation which yielded a settled production of 250 barrels per day of 13.8 A.P.I. gravity practically clean oil. Development of the "Williams" area was slow until 1936, when the Chanslor-Canfield Midway Oil Company completed its initial test well No. 17 in Sec. 21, T. 32 S., R. 23 E., M. D., pumping from the upper zone open to "Williams" No. 1 plus additional zones which have been termed the intermediate and lower "Williams." The well yielded an average of 770 barrels per day of 18.3 gravity clean oil during the first 30 days, between the depths of 1,425 to 2,105 feet. Production on the peak day was 1,800 barrels. Rapid development followed, leading to highly competitive drilling on small parcels in the southeastern half, so that the area was given the name "Little Signal Hill."

The productive limits of the Williams area are confined to the SE¼ Sec. 21, SW¼ Sec. 22, and the north-central portions of Sec. 27, T. 32 S., R. 23 E., M. D. A quarter-mile strip of barren acreage separates it from the older and stratigraphically shallower productive area on the northeast flank of the Spellacy anticline. This strip is structurally too low for Miocene production and the Pliocene beds that yield production farther down the flank are missing. There are 67 productive wells in the Williams area to date (1940) and 12 dry holes, 5 of which were drilled prior to discovery. Most of the wells had 300 to 600 barrels per day initial production, but by December 1940 the daily average per well had declined to 64 barrels of oil, representing about 30 percent of the gross. At this time one 10-acre parcel with four producing wells had a cumulative production of 40,000 barrels per acre.

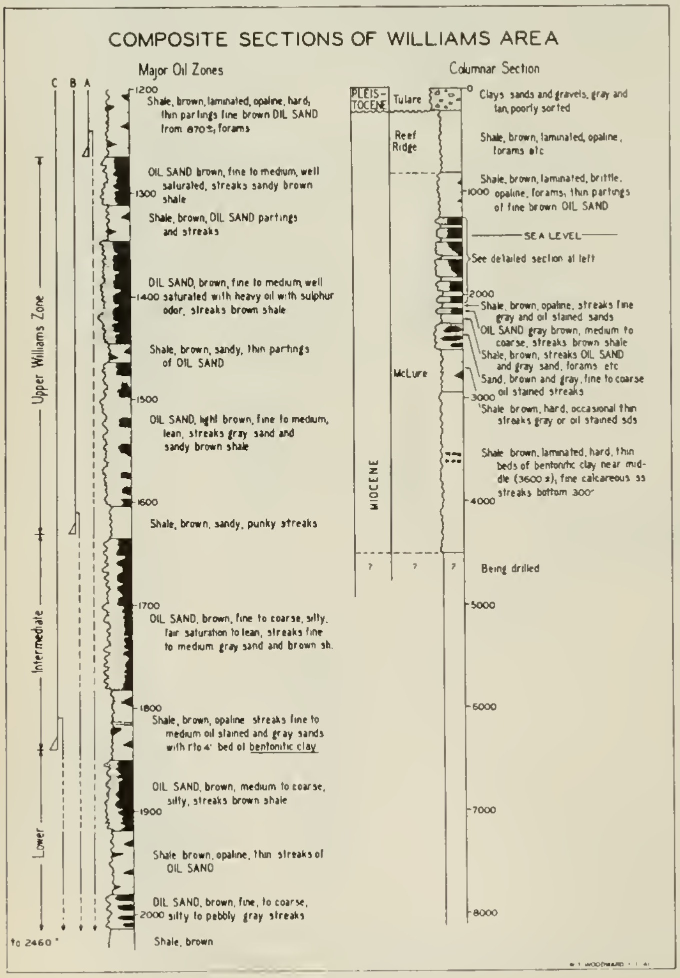


Fig. 227. Williams area of the Midway-Sunset oil field: columnar sections.

Following the discovery of the "Williams" horizon of upper Miocene age, an attempt was made to develop production from middle and lower Miocene formations underlying the Spellacy anticline. Standard Oil Company drilled "Mascot" No. 1 to a depth of 9,750 feet in the SW¼ NE¼ Sec. 26, T. 32 S., R. 23 E., M. D. Although near the surface axis, this well was situated on the northeast flank of the structure at the total depth and was considerably down the southeast plunge. There was a fair showing in Vaqueros sands even though the well was 1,000 feet structurally lower than the North American Consolidated Oil Company well now drilling in the northeast corner of Sec. 28, T. 32 S., R. 23 E., M. D. The latter is far enough southwest of the surface axis of the asymmetric structure to encounter middle and lower Miocene formations at a structurally favorable position for an adequate test of the oil possibilities.

DISTINGUISHING FEATURES

Notable features of the Spellacy area are the accumulation of oil due to overlap and the anticlinal accumulation of oil in the Williams area in highly fractured shale, which because of its siliceous nature, was too brittle to bend 75 degrees along the axis. As a result of the shattering and tension fractures, the shale developed voids that made it an oil reservoir comparable to the interbedded sands. The high permeability developed in this manner is shown by the fact that after a drilling well lost circulation, only 30 minutes were required for its mud to stop the flow of oil from a neighboring producer with a bottom-hole location 600 feet away. It might be assumed that the fractures in the siliceous McLure shale responsible for such high permeability would have permitted the oil to migrate vertically upward into the sands and gravels of the Reef Ridge, leaving the Williams sands barren. But interbedded with the siliceous shales are others pliable enough to participate in the folding without fracturing and thus prevent a vertical migration of any magnitude. The more prolific production and higher gravity of the lower Williams sand is doubtless related to the unusually good seal provided by a 2-foot bentonite bed overlying it.

STRATIGRAPHY

The drilled portion of the stratigraphic section of the Spellacy area represents approximately 10,000 feet of sediments. The Vaqueros, at the nearest measurable outcrop, in the northern part of T. 10 N., R. 23 W., S. B., near Maricopa, exposes 4,000 feet of predominantly hard sandstones. The Standard Oil Company "Mascot" No. 1 drilled in Sec. 26, T. 32 S., R. 23 E., M. D., is believed to have entered the Vaqueros at 9,629 feet and penetrated it to 9,753 feet. Overlying the Vaqueros, as indicated by the "Mascot" test, are some 6,700 feet of lithologically inseparable lower, middle, and upper Miocene beds which are predominantly shale. However, foraminiferal evidence indicates the separation shown in the stratigraphic column. The Williams zone in the southeast end of the Williams area contains approximately 500 feet of rather fine, poorly consolidated sand, interbedded with brown shale in the second thousand feet of this series. Along the strike some of the sands grade to sandy shales and others diminish in thickness until at the northwest end of the field there are no sands in the well cores and at an equivalent point on the outcrop, projected at right angles to the strike, they also disappear. This change of thickness of the Williams sand from 500 feet to 0 along the strike between two points 1½ miles apart, is explained by its origin as a delta of a stream flowing northeasterly. Its position in the section as the first sand below the top of the McLure shale and its relationship to the *Bolivina marginata* zone of the McLure, both suggest it is the equivalent of the Stevens sand which has yielded the production of several fields to the east in the more central part of the San Joaquin Valley, such as Ten Sections and Coles Levee.

On top of the McLure shale with its interbedded Williams sands lie, probably unconformably, lighter brown shales with some diatomite and sand which can be correlated with the Reef Ridge formation. This previously mentioned Santa Margarita fanglomerate facies within the Reef Ridge is a wedge which disappears to the northeast and eventually is gradually replaced by diatomite to the northwest toward McKittrick. The uppermost, overlapped sand members of the Reef Ridge are productive on the flanks of the Spellacy anticline.

Unconformably overlying the Reef Ridge formation is the lower Pliocene Etchegoin formation which is mainly sand and which has contributed the principal production of the Spellacy area. The blue-gray color and numerous littoral zone mega-fossils distinguish the Etchegoin and the overlying upper Pliocene San Joaquin clay from the gray brown Reef Ridge shale in which mega-fossils are almost absent.

With *Mulinia densata* at the top of the Etchegoin and *Scalez petrolia*, an abundant fossil, at the base of the San Joaquin clay, a separation of these two formations can be made. Oil sands within the San Joaquin clay also yield production.

The Tulare progressively overlaps the more steeply tilted San Joaquin clay, Etchegoin, and Reef Ridge beds, not entirely covering the latter, as they are exposed at the apex of the axis near the center of the SW¼ Sec. 22, T. 32 S., R. 23 E., M. D. Some oil is believed to be obtained from the Tulare in the old wells northeast of the surface axis.

STRUCTURE

The Spellacy anticline is an asymmetric fold which branches out from the east flank of the Temblor Range, coursing southeast through Sec. 17, rising gently through Sec. 21, plunging through Secs. 22, 26, and 25, T. 32 S., R. 23 E., M. D., turning east near the southeast corner of Sec. 25, and eventually plunging under the alluvium.

Dips as steep as 70 degrees have been recorded from Miocene beds in wells drilled on the northeast flank, while 40-degree dips are about the steepest recorded from equivalent beds on the southwest flank. A similar asymmetry exists in axial exposures of Miocene beds near the center of the SW¼ Sec. 22, T. 32 S., R. 23 E., M. D. Surface exposures of Pleistocene beds show less tilting, with the steeper-dipping beds on the northeast flank.

PRODUCTIVE HORIZONS

The positions of the oil sands on the northeast flank of the Spellacy anticline are shown by R. W. Pack to be overlapped, and are called by him zones "A" and "B." In the Williams area, these sands have been removed by erosion, and production is drawn from the stratigraphically deeper "Williams" zones.

KIND OF OIL

Oil from all zones of the Spellacy anticline area is of asphalt base, and sulfur compounds are dissolved in the oil-zone fluids. Most of the oil is heavy, ranging from 12 to 17 degrees A.P.I. However, oil from some of the overlapped Pliocene sands was 26 degrees gravity.

STRATIGRAPHIC SECTION OF SPELLACY ANTICLINE AREA

AGE	THICKNESS	STANDARD COLUMN	DESCRIPTION
PLEISTOCENE	0-1000'	Tulare	Gray and tan, poorly sorted gravels, sands and clays; fresh-water megafossils; TAR and OIL.
PLIOCENE	0-300'	San Joaquin clay	Blue-gray and gray clay; some gray sand and brown clay; marine fossils; OIL.
	0-300'	Etchegoin	Green-gray and gray sands, silty, fine to coarse; streaks of green-gray clay; marine fossils; OIL.
UPPER MIOCENE	200'-2000'	Reef Ridge shale Santa Margarita facies	Gray-brown diatomaceous, sandy, micro-micaceous, thin-bedded shale; beds of poorly sorted granitic sandstone and conglomerate in Santa Margarita facies; fossils; OIL.
	4560'	McLure shale	Brown, porcelaneous, thin-bedded, platy shale; fossils; sandstone lenses; OIL in Williams area only.
MIDDLE MIOCENE	854'	Gould shale Button bed	Brown, siliceous shale and calcareous sandstones; fossils; OIL SHOWINGS.
LOWER MIOCENE	4000' (outcrop)	Media shale Carneros sandstone Santos shale Vaqueros sandstone	Brown siliceous shale and calcareous sandstones; fossils; OIL SHOWINGS.

D. Hillis and W. T. Woodward

Fig. 228. Spellacy anticline, Midway-Sunset oil field: stratigraphic column.

GIBSON AREA OF THE MIDWAY-SUNSET OIL FIELD

By W. T. Woodward *

The Gibson area lies in the SE¼ Sec. 6, T. 11 N., R. 23 W., M. D., about 1½ miles east of Maricopa, Kern County. The discovery well, Gibson Oil Company, Inc. No. "Francis" 1, was completed in December, 1935, initially pumping about 150 barrels of oil and 35 to 50 barrels of water. This fluid came from sand streaks and lenses in the uppermost portion of the Reef Ridge (Miocene) formation (Barbat and Johnson 34a); being induced through knife-perforated casing, which had been cemented solidly down in the oil-sand zone at a redrilled depth of 3,040 feet. The casing was subsequently gun perforated in January of 1936, from 3,040 to 2,925 feet, and the well recompleted, pumping about 190 barrels per day of 20.4 degrees oil along with about 30 barrels per day of water and considerable gas.

The original hole was drilled in the Spring of 1935 by Michigan Oil Company to a depth of 3,500 feet; this company, after conducting discouraging open-hole formation tests of lower Etchegoin (Pliocene) and Reef Ridge sands, bridged the hole with cement from 3,100 to 2,800 feet and suspended operations. The project was idle from May until December, 1935.

On March 4, 1936, the second project for the area, Gibson Oil Company, Inc. No. "O'Brien" 1, was completed flowing at the rate of 1,250 barrels per day of 23 degrees oil, cutting 0.1 percent basic sediment and water, through a ⅜-inch tubing bean with flow-pressure ranging from 75 to 100 pounds and casing pressure of 500 pounds, along with 250 thousand cubic feet of gas. The total depth of the well was 2,816 feet, and water shut-off was effected at 2,775 feet. This completion stimulated development which resulted in the rapid delineation of apparent productive limits of the pool.

On the south, Shell's No. "Dorsey-Flack" 1 found the "Gibson" oil-sand horizon only sparingly sandy. The well produced only a negligible quantity of oil along with considerable water.

General Petroleum's No. "Main Line" 1 proved to be the area's most prolific producer when it established a potential of over 2,000 barrels per day of clean oil, along with 750 thousand cubic feet per day of gas through a 38/64-inch bean. However, No. "Main Line" 2, a west offset, was completed flowing only 100 barrels per day of clean oil along with 5,000 thousand cubic feet per day of gas, suggesting the upper limits of the accumulation.

To the northwest, Gibson's No. "Blanck" 1 was deepened to a horizon considerably below the "Gibson" sand without encountering oil-saturated sands. Bankline Oil Company deepened what is now Morrison's No. "Gordon" 8 into the Reef Ridge brown shale without encountering the "Gibson" sand.

To the northeast, Chief Oil Company drilled what is now R. & W.'s No. "Francis" 1 to a depth of 4,468 feet, penetrating some 1,400 feet of Miocene beds, and finding the "Gibson" sand unfavorably represented and structurally low.

Standard Oil Company of California drilled the second deepest well in the area and established the fact that the "Gibson" sand did not extend as far east as their No. 9 in Sec. 5, T. 11 N., R. 23 W., M. D. This well penetrated Miocene brown shales some 738 feet, to a depth of 3,913 feet, encountering only minor sand streaks.

Gibson's No. "Westside Lumber Company" 1 found only laminae and small lenses of oil sand interbedded with brown shale in the "Gibson" sand horizon, and so established the southeast limits of the pool.

The "Gibson" sand apparently is a lens in the Reef Ridge shale formation. However, the possibility of a condition analogous to that proposed by Atwill (31) for the Signal area to the southeast, must be considered. The "Gibson" sand approximates 100 feet at its greatest thickness and is stratified, containing numerous partings of sandy, micaceous, diatomaceous (often punky) laminated brown siltstones which are sometimes calcareous. These and subjacent siltstones carry a poorly preserved foraminiferal fauna. The sand is loose, medium to coarse textured, micaceous, and saturated with dark-brown oil, at the point of greatest concentration; and grades to very fine sand and sandy shale near its extremities.

The accompanying contour map shows an unconformity between Etchegoin (Pliocene) beds and those of the Reef Ridge (upper Maricopa of Pack). The Etchegoin beds dip to the northeast at about 15 degrees, whereas the underlying beds dip about 25 degrees presumably in a similar direction. The accumulation is apparently due to buttressing Etchegoin beds (deposited in a transgressive Pliocene sea) overlapping truncated Reef Ridge beds. The sharp syncline to the north probably has no bearing on the accumulation of oil in the "Gibson" sand.

The formations penetrated in the area are shown on the accompanying composite sections. Because of lack of coring in the shallow beds, definite contacts can not be established between the alluvium and Tulare, and the Tulare and San Joaquin clays. The alluvium-Tulare contact is based on the top of a fairly consistently logged yellow sandy clay. A tar sand, also consistently logged, sometimes as a conglomerate, is believed to be the basal bed of the Tulare formation.

* Consulting Petroleum Engineer and Geologist, Taft, California.
Manuscript submitted for publication December 20, 1940.

The bottom 100 feet of the San Joaquin clays contain beds of oil sands, some of which are being produced in two wells. This horizon is variously known as the "Top Oil," *Pecten-Mytilus*, or *Scalez* zone; it is characterized by the rare occurrence of significant megafossils in its upper portion. The wells are small producers.

The Etchegoin formation contains oil-stained sands which are not productive in the area.

The usual procedure in development was to drill approximately 100 feet of 22-inch hole and cement 16-inch casing to prevent surface caving; drill 12¼-inch hole to estimated top of oil zone and rat-hole ahead with the core barrel. After all hole had been made and electrically logged, 8⅝-inch casing was cemented near the top of the "Gibson" sand. After obtaining water shut-off, the rat-hole was usually scraped to a larger diameter before running 6⅝-inch liner, usually with 120-mesh perforations. In some wells a portion of the hole had to be plugged off. The best wells have approximately 75 feet of formation open to production, although some have as much as 150 feet.

Following discovery, 16 other holes were drilled to the "Gibson" sand horizon in the immediate area, 10 of which were completed producing from it. Of the 11 "Gibson" sand producers, 8 are considered commercial wells.

Search for extension of the pool led to the discovery of the Hoyt area, three-quarters of a mile southwest, where oil sands likewise were found immediately below the Pliocene-Miocene unconformity. Also, search for "Gibson" sand production near the east quarter corner of the NE¼ Sec. 6, north of the syncline indicated by the contour map, led to considerable development of "Kinsey" sand production in that vicinity.

The Gibson area had produced more than 1,300,000 barrels of oil to July 1, 1940, of which 98 percent came from the "Gibson" sand, a recovery of approximately 30,000 barrels per acre to date. Gravity of the crude oil ranges from 21 to 23 degrees A. P. I. From an early analysis the oil was found to contain about 18 percent of 48.5 gravity gasoline at a 430-degree end point distillation; 81 percent of 18 degree fuel oil; and 1 percent nonrecoverables. Decline in production has been rapid, and about the middle of 1940 more than 50 percent of the area's production was salt water. At the same time, gas production approximated 2,200,000 cubic feet per month. This gas yields about 1.25 gallons of casinghead gasoline per 1,000 cubic feet. It has a specific gravity of 0.77 and contains about 15 percent carbon dioxide.

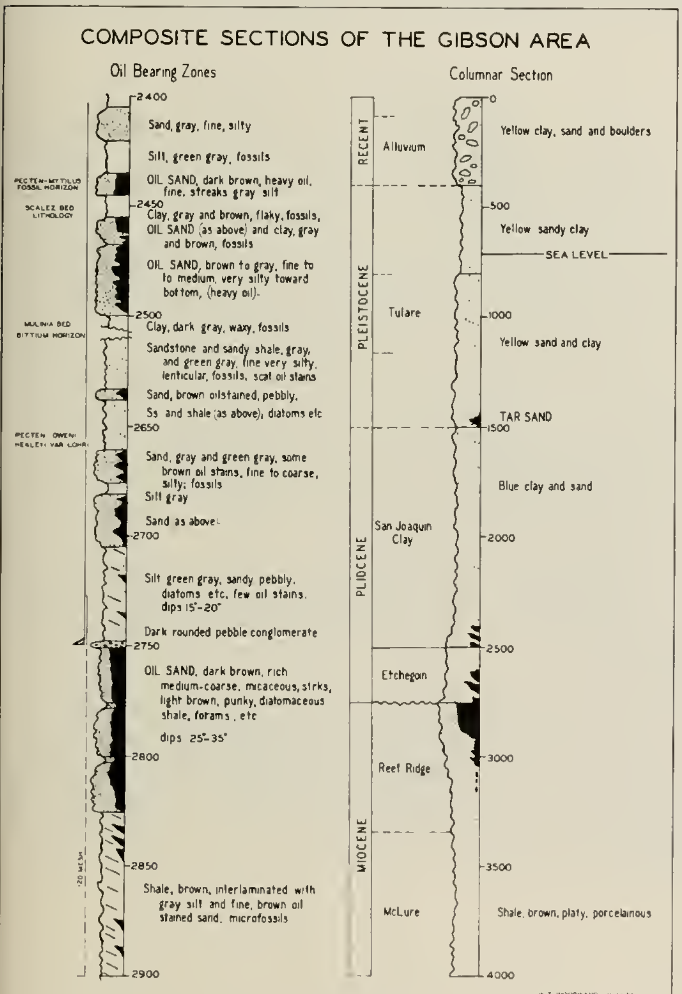


FIG. 229. Gibson area of the Midway-Sunset oil field: columnar sections.

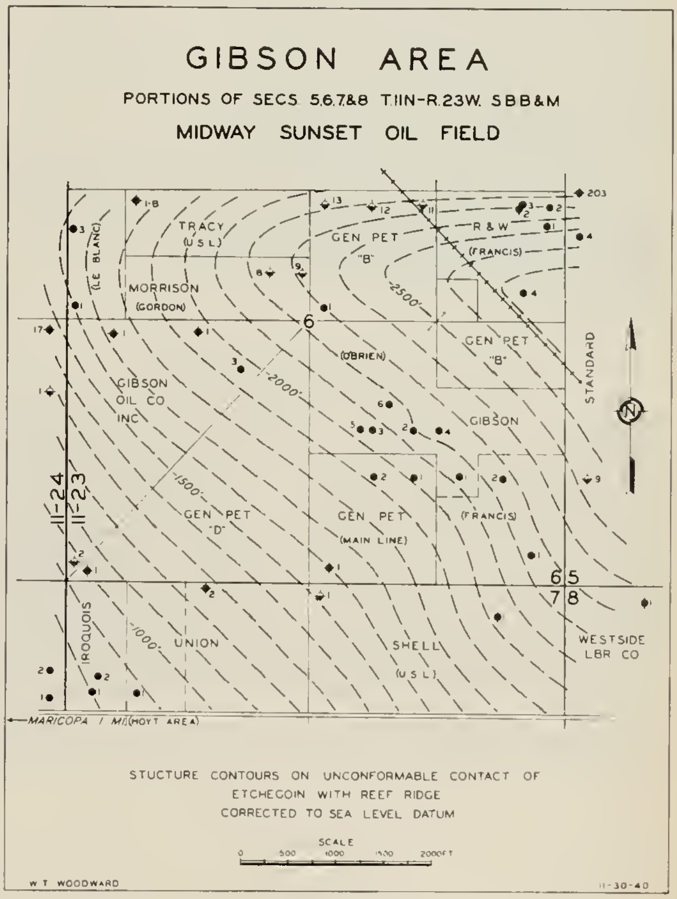


FIG. 230. Gibson area of the Midway-Sunset oil field: structure map.

WHEELER RIDGE OIL FIELD

By S. H. Gester *

OUTLINE OF REPORT

HISTORY

On the southern border of the San Joaquin Valley, some 25 miles south of Bakersfield, in Kern County, Wheeler Ridge rises abruptly to an elevation of 2,000 feet, or about 1,500 feet above the valley floor. The ridge is an east-west elevation along the north flank of the Tehachapi Mountains, and was recognized as an anticlinal fold early in the geological exploration of California.

Several wells were drilled around the edges of this structural feature in the years 1914 and 1921, but discovery of the field was made by the Standard Oil Company of California in the drilling of well No. 1 Kern County Land Company Lease No. 2, in the NE¼ Sec. 28, T. 11 N., R. 20 W., M. D. This well was completed in January 1923, making 323 barrels a day of 26 degree gravity oil from a depth of 2,185 feet. Production from this field to September, 1941, has been 3,887,437 barrels of oil attributable to some 34 wells spread over an area of about 222 acres. The Standard Oil Company of California has produced practically all of the oil taken from the Wheeler Ridge field. The General Petroleum drilled four wells, three of which were productive, on the west plunge of the structure, and the Richfield Oil Company drilled one well, which had a small production, on the south flank.

STRUCTURE AND STRATIGRAPHY

Wheeler Ridge anticline is in general a structural reflection of a topographic elevation. It is an asymmetric anticline that trends in an eastward direction, the axial plane dipping southward. Formational dips on the north flank average about 50 degrees, although they become as steep as 70 to 80 degrees along the north edge of the hills. On the south flank the dips average about 20 degrees. There is pronounced plunge of the anticline both to the east and the west, and a closure of approximately 2,000 feet in the upper beds of the structure.

Poorly consolidated coarse gravel, sand, and boulders with occasional beds of buff-colored silty clay, compose both flanks and plunging ends of Wheeler Ridge anticline. These beds are nonmarine and have been assigned to the Tulare (Pliocene) formation. Lower beds exposed on the crest of the structure become finer grained and contain more grayish-colored silts and clays. These also are nonmarine and unfossiliferous and may be either a lower member of the Tulare or the upper part of the Etchegoin. H. W. Hoots (30) ascribes these beds to the Etchegoin on the basis of lithology. Beneath the formations exposed on the crest of the structure drilled wells in the Wheeler Ridge area have logged an additional thickness of Tulare (?) or Etchegoin (Pliocene), Santa Margarita, Maricopa brown shale (Miocene), Vaqueros (lower Miocene), San Lorenzo, and Tejon (Eocene). For a detailed description of these formations as they outcrop in the vicinity of Wheeler Ridge, see U. S. Geological Survey Bulletin 812-D (Hoots, H. W. 30).

PRODUCTIVE HORIZONS

Oil is produced from two zones within the Miocene. The upper, or Main zone, includes portions of the lower Santa Margarita and upper Maricopa, and is encountered on the crest of the structure between depths of 2,000 and 2,500 feet. The lower zone in the Maricopa occurs between depths of 3,200 and 4,000 feet. This zone is apparently conformable to the Main zone. These two zones have been respectively correlated with the Fruitvale shale and Round Mountain silt of the Kern River area. The gravity of the oil produced ranges from 21 to 31 degrees, the lighter oil occurring in the higher axial positions on the structure. In general, the sands within the producing horizon are disconnected and lenticular and can be correlated only with uncertainty between drilled wells in the field. Standard Oil Company Kern County Land Company 2 well No. 36 was drilled to 7,154 feet in a structurally high portion of the field, penetrating and testing sands of the Vaqueros formation (lower Miocene). Commercial production was not obtained in this portion of the lower Miocene.

In the years from 1938 to 1940, Richfield Oil Company drilled two deep wells in the SE¼ Sec. 28, T. 11 N., R. 20 W., M. D., on the south flank of the structure in an attempt to develop lower productive horizons at a favorable axial location. Both of these wells found salt water in the Eocene formation and were abandoned.

* Geologist, Standard Oil Company of California. Manuscript submitted for publication December 3, 1941.

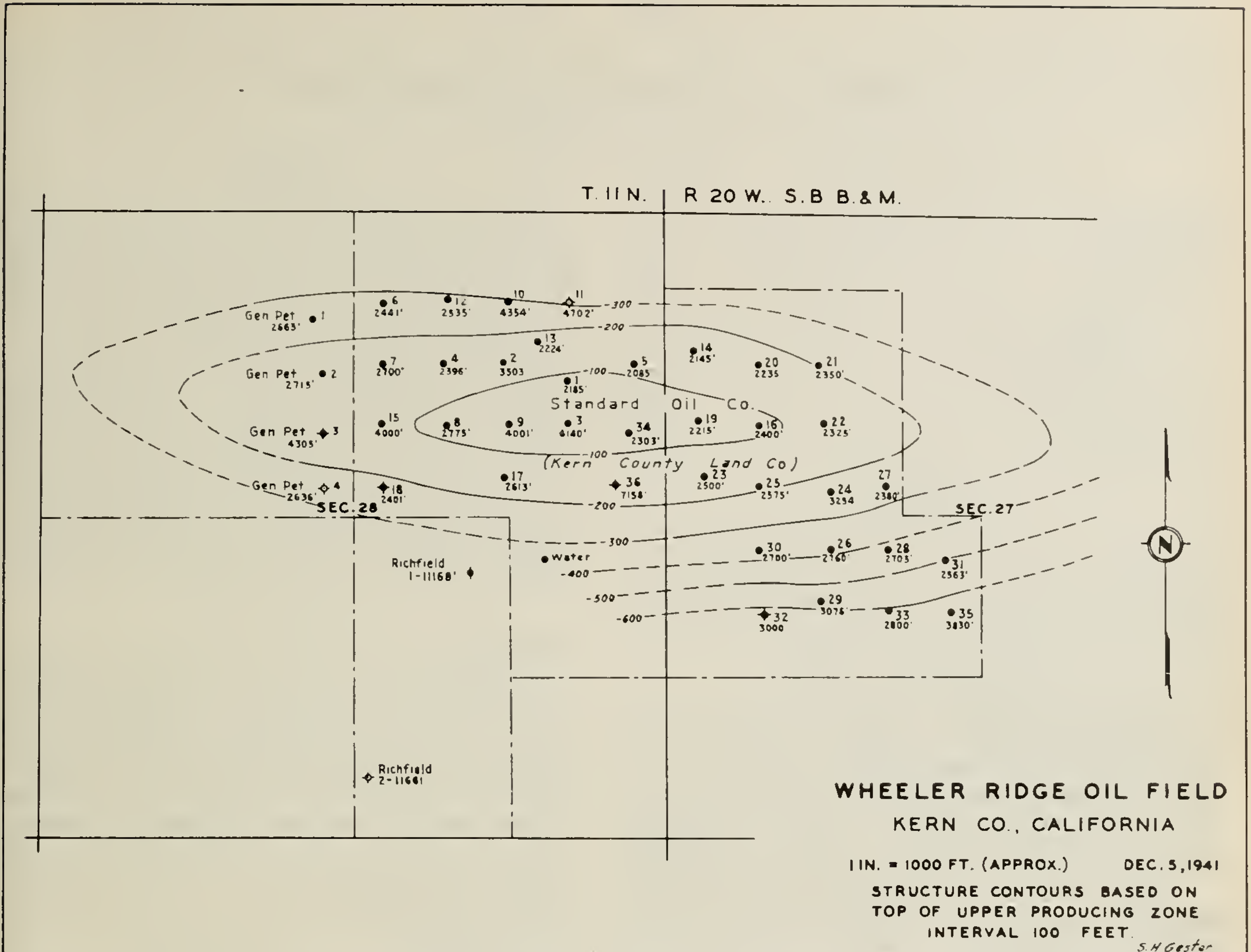


FIG. 231. Wheeler Ridge oil field: structure map.

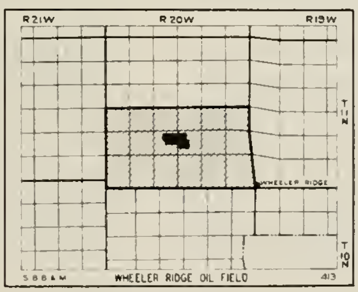
CITATIONS TO SELECTED REFERENCES—Continued

SAN EMIGDIO (SAN EMIDIO) REGION

Anderson, R. 12; Henny, G. 38b; Prutzman, P. W. 04; Stockman, L. P. 40, no. 17, p. 92.

WHEELER RIDGE OIL FIELD

Anderson, R. 12; Clute, W. S. 36; Copp, W. W. 24; Cunningham, G. M. 26; 26b; Godde, H. A. 28a; Hoots, H. W. 29; 30; Howard, P. J. 39; Huguenin, E. 25; Kaiser, C. L. 23; McCullough, E. H. 34; Mining and Oil Bulletin 23a; Musser, E. H. 39; Perry, S. S. 24; Standard Oil Bulletin 23; Taff, J. A. 34; Thoms, C. C. 22a; Van Tuyl and Parker 41.



Wheeler Ridge oil field.

TYPE LOCALITY OF THE TEJON FORMATION

By Jay Glenn Marks *

OUTLINE OF REPORT

INTRODUCTION

The type area of the Tejon formation is located in Kern County, California, at the extreme southern end of the San Joaquin Valley, approximately 32 miles south of the town of Bakersfield; it extends about 5 miles to the east and 3 miles to the west of the point where U. S. Highway 99 enters the Tehachapi Mountains.

HISTORICAL REVIEW

The recorded history of the Tejon strata began in 1853, when W. P. Blake, geologist for the Pacific Railroad Survey, made a brief excursion up Grapevine Canyon. He picked up a single rock from which T. A. Conrad of the United States National Museum described 13 species of mollusks. Conrad (55) declared that the beds from which the fossils came were unequivocally Eocene.

Within a few years, several persons, including W. M. Gabb, had made collections of the shells from the strata which were called Tejon. Gabb concluded that these fossils were late Cretaceous in age, and termed the strata from which they came "Cretaceous B" (Gabb, *in* Whitney, J. D., 68). While Conrad and Gabb were disagreeing, the name Tejon was applied to more and more strata in various parts of the State. Conrad's contention that the Tejon fossils were Eocene finally prevailed.

R. E. Dickerson (15) published a paper in which the molluscan fauna from the type Tejon was listed, with figures of many species. A similar paper by Anderson and Hanna (25) reconsidered the fauna and stratigraphy. A geologic map by Hoots (30) shows the distribution of the formations in this region.

* Graduate student, Stanford University. Report prepared under the direction of Professor Hubert G. Schenck. Manuscript submitted for publication March 6, 1942.

STRUCTURE

The Tertiary strata, in the type area, normally form a homocline, dipping at an angle of 55 degrees northward from the granitic basement; but locally the sediments are folded, faulted, and overturned. East of Pastoria Creek the normal structure pattern is preserved. To the west, structural complexities begin. Local overturning in the Tejon beds is evident on the first ridge west of Pastoria Creek canyon. In Liveoak Canyon 1,450 feet of the Tejon strata dip regularly from the basement rock; the superjacent strata then overturn, dipping southward at an angle of 65 degrees. On both sides of the canyon structural complexities and landslide debris make interpretation of the structure difficult. To the west of Liveoak Canyon as far as Tecuya Creek, landslides, faults, and overturned strata are prevalent.

STRATIGRAPHY

Basement Rocks

Underlying and outcropping to the south of the Tertiary sediments is the granitic terrain which forms the core of the Tehachapi Mountains. Granodiorite and gneiss are the principal constituents; but quartzite, marble, schist, and mafic differentiates are not uncommon. No evidence was found for the geologic age of the basement complex, except that the thick basal conglomerate of the nonconformable Tejon formation suggests a period of long subaerial exposure before deposition began in Eocene time.

Tejon Formation

The type area of the Tejon formation is herein considered to be the elongate strip of land on the north flank of the Tehachapi Mountains between Tecuya Creek on the west, and Pastoria Creek on the east. This designation conforms with the implications of previous workers in the area, and to the definition of Anderson and Hanna (25; *see also* Wilmarth, M. G. 38).

The Tejon formation within this type area is a conformable sequence of sedimentary marine strata, overlying by nonconformity or fault contact the basement complex, and unconformably overlain by the Tecuya formation of varicolored silts, coarse sandstones, and conglomerates. The Tejon formation is divisible by lithologic criteria into four members.

Uvas Conglomerate Member. The type locality and total outcrop of the Uvas conglomerate occurs on the west side of Grapevine Canyon. The constituents of this basal unit are the residual material of the underlying crystalline complex, to which it bears a strong superficial resemblance, and upon which it is nonconformable. The appearance and texture are those of a weathered granitic outcrop; the distinction is made by observing obscure bedding and the paleontologic content. The boulders and sand grains are chiefly rounded to angular quartz, feldspar, and minor ferromagnesian minerals. The fossils, which comprise about 5 percent of the rock, were listed in a previous paper (Marks, J. G. 40).

This basal member is well exposed and aggregates 110 feet in thickness. It lies by unfaulted, clearly nonconformable contact upon the basement rock. Its faunule of large Foraminifera affords a valuable means of age determination. The member is correlated with the Crescent formation of Washington, of probable late middle Eocene age (Berthiaume 38).

Liveoak Member. Conformably overlying the Uvas conglomerate in Grapevine Canyon, and resting upon the granitic terrain in all other parts of the area by either unconformable or fault contact, is the Liveoak member of the Tejon formation. The type locality is Liveoak Canyon. Here the member is the only representative of the Tejon strata. The sediments rest, apparently nonconformably, upon the granitic basement rocks, and lie unconformably beneath the Tecuya formation conglomerates. Notwithstanding the fact that the adjacent members are absent at the type section, the Liveoak member is thought to be precisely defined because the lithology and fauna of the upper and lower strata are recognizable in Grapevine Canyon, where the underlying and overlying members are present.

In general, the Liveoak member consists of coarse-grained sediments in the lower half, and of alternating fine-grained sandstones, silts, and shales in the upper half. The molluscan fauna of the member has long been considered to constitute an indivisible paleontologic unit (Dickerson, R. E. 15; Anderson and Hanna, 25). However, the faunules from the strata at succeeding horizons vary in many respects. Most notable are the specific changes in the genera *Turritella* and *Ficopsis*.

Where it is exposed to the west of its type section, the Liveoak member retains the characteristics seen in Liveoak Canyon, varying only in the relative development of certain facies. The thickness (1,970 feet), decreases toward the east; and the member finally wedges out some miles east of Pastoria Creek. The sediments in that direction become coarser grained and have a limited, presumably shallow-water fauna.

The Liveoak member is assigned tentatively to the late middle Eocene. On the basis of the small Foraminifera, the lower fourth of the member is correlated provisionally with the upper part of the Llajas formation (Cushman and McMasters 36).

Metralla Sandstone Member. Reed Canyon is the type locality of the Metralla sandstone. Here it is conformable between the Liveoak member below and the Reed Canyon silt member above. The Metralla member consists of fine- to medium-grained sandstones which are uniformly gray in color, massive, and well-indurated by a calcareous cement. The most striking feature is the large number of spherical concretions which range up to 10 feet in diameter. These weather out of the massive sandstone matrix, and lie scattered upon the surface of the ground. The Metralla member is 1,300 feet thick in Reed Canyon.

The molluscan fauna of the Metralla member is distinct from those of the adjacent members. The majority of the species characteristic of the Liveoak member are absent. Foraminifera are abundant, and the nautiloid cephalopod *Cimonia* sp. occurs in these strata.

Landslide debris covers the outcrop of the Tejon sediments between Reed Canyon and Tecuya Canyon. Eastward, the Metralla sandstone is well exposed in Metralla Canyon and on the west side of Grapevine Canyon, where its conformable relation to the Liveoak member is evident. On the east side of Grapevine Canyon are isolated concretions and contorted fine sandstones which attest to the presence of the Metralla sandstone in that area of landslides. The Metralla strata do not appear in Liveoak Canyon.

Reed Canyon Silt Member. The uppermost member of the Tejon formation is the Reed Canyon silt. At its type locality in Reed Canyon are 160 feet of fine-grained sediments, grading from very fine sandstone at the base to silt which contains considerable glauconite 35 feet below the top. The upper 20 feet consist of buff-weathering, unfossiliferous shale. The distinguishing features of the member are its fine grain and dark-gray color.

The fauna of the Reed Canyon silt consists of many small foraminifers, *Discocyclina* sp., *Turritella schencki*, *Ectinochilus elongatus*, and other species.

The only outcrops of the Reed Canyon silt are those at the type locality, and one small exposure in the first canyon east of Reed Canyon.

Because it is the upper member of the Tejon formation, and because of its abundant fossils, the Reed Canyon silt is important for correlation. On the basis of a preliminary faunal study, the member is considered to be late, but not latest Eocene in age, and is probably synchronous with the upper part of the Cowlitz formation of Washington.

Tecuya Formation

Tecuya is used here as a formational name. Stock (*see* Wilmarth, M. G. 38) applied the term "Tecuya beds." The strata which Stock describes are traceable into and through the type Tejon area. Since the aggregate of strata comprises a disinct lithogenetic unit, it is herein treated as a formation.

The Tecuya formation is best developed in the Tecuya-Reed Canyon sector where the basal conglomerate overlies disconformably the Reed Canyon silt member of the Tejon formation. Toward the east, Tecuya strata overlap successively the Metralla sandstone and Liveoak members of the Tejon formation, resting upon these sediments in nearly accordant relationship. In every exposure of the uppermost Tecuya strata, the top is marked by volcanic rocks.

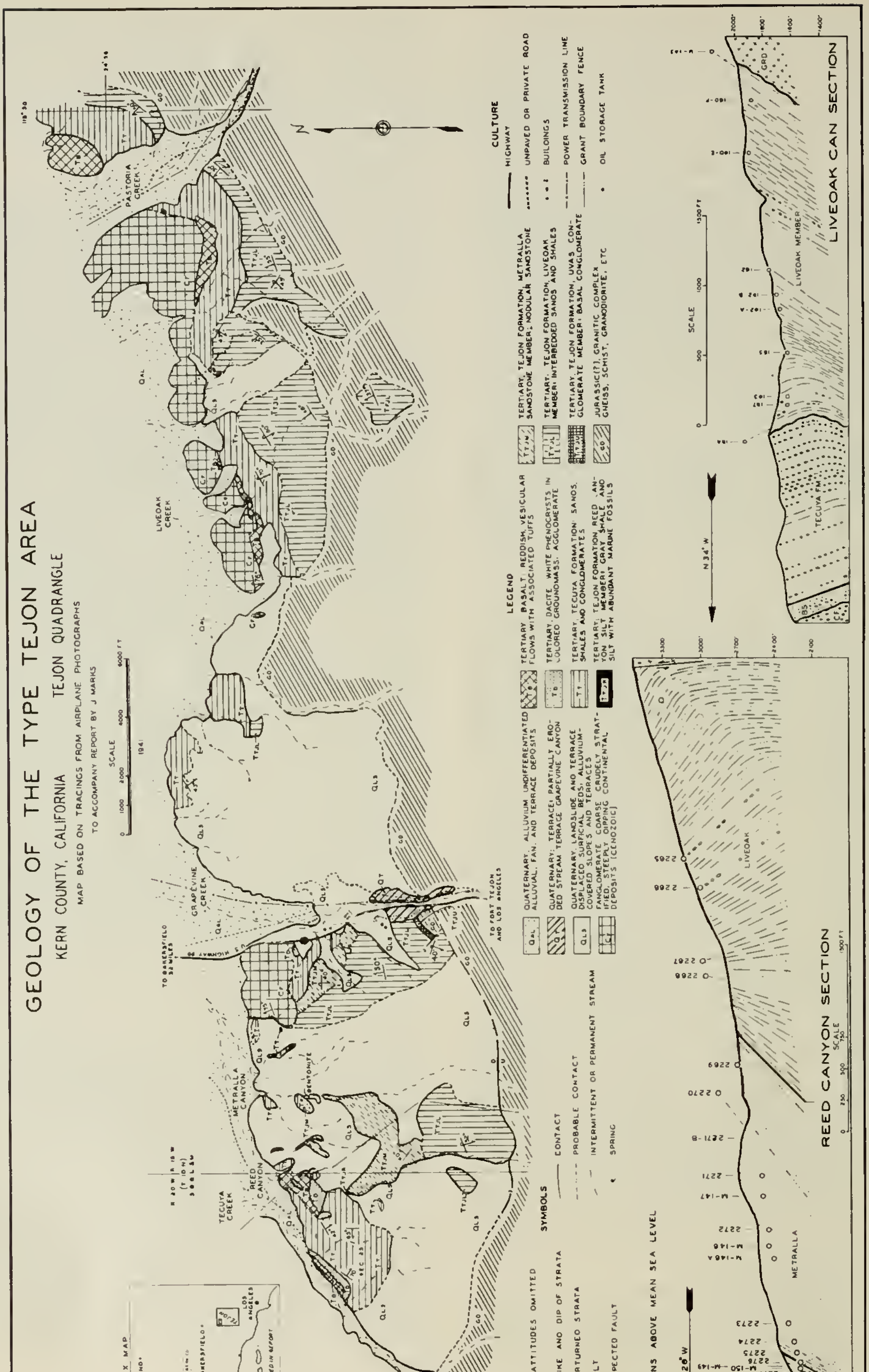


FIG. 232. Type locality of the Tejon formation: geologic map; index map; geologic sections.

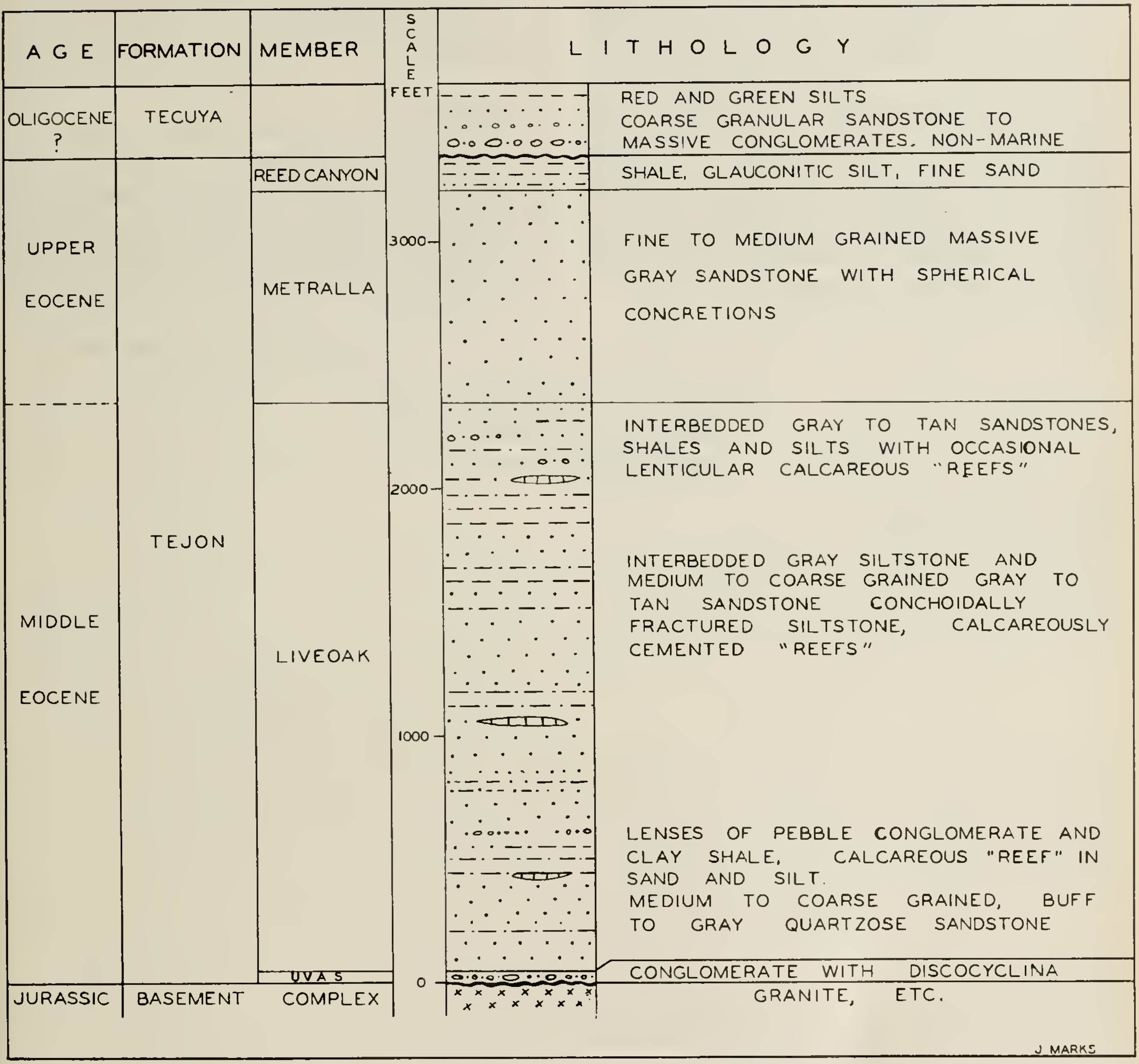


Fig. 233. Type locality of the Tejon formation: stratigraphic section.

The lower 100 feet of the Tecuya formation in Reed Canyon includes red and green silts of marine or brackish-water origin. The faunule of these strata includes *Potamides* sp. nov., *Crassatella* sp., and *Macoma* cf. *nasuta*. The majority of the Tecuya beds are well-stratified, coarsely granular, tan sandstones or massive conglomerates composed of rounded quartzose pebbles and boulders of a variety of crystalline constituents. The matrix is predominantly arkosic or quartzose sand.

The vertebrate fauna of the Tecuya beds has been described by Stock (20; 32b). On the basis of mammalian remains found near Salt Creek, 2½ miles west of Tecuya Creek, he refers the Tecuya to the "lower Miocene." B. L. Clark (21b) states that the Tecuya beds are intercalated in marine Vaqueros beds, and are more likely lower Miocene than upper Oligocene. One form from the beds in Reed Canyon resembles *Macoma nasuta,* which is "in the Vaqueros" according to Clark (letter, 1941).

The lithologic similarity to parts of the Sespe formation and similar superposition upon Eocene strata suggest a correlation of the Tecuya with a part of the Sespe formation. The recent tendency to raise the upper limits of the Oligocene to include the Vaqueros formation, and the Oligocene age of much of the Sespe formation, suggest that at least the lower part of the Tecuya formation may be Oligocene in age. In any event, a hiatus is represented by the unconformity at the top of the Tejon formation.

Superjacent Rocks

An agglomerate of angular volcanic fragments lies upon the Tecuya strata west of Grapevine Canyon. Overlying the dacite and also extending to the east are flows of andesite. These volcanics may belong to the same sequence of deposition as the underlying rocks. Unconformably superjacent over the entire area are lithologically heterogeneous, variably dipping fanglomerates, which are attributed to a post-Oligocene, pre-Recent diastrophism.

CITATIONS TO SELECTED REFERENCES—Continued

GRAPEVINE AND TEJON RANCH FIELDS

Hoots, H. W. 30; 36a; Howard, P. J. 39; Marks, J. G. 40; Musser, E. H. 30.

Grapeview (Grapevine) Field

Oil Weekly 37a.

DUDLEY RIDGE GAS FIELD

By Gerard Henny *

OUTLINE OF REPORT

HISTORY

The oldest well drilled in the neighborhood of Dudley Ridge was the Pacific Oil and Gas Company's well No. 1, in Sec. 18, T. 23 S., R. 21 E., M. D. It was drilled to a depth of 2,715 feet in 1920 and was mentioned in an early bulletin of the California State Mining Bureau (Barnes, R. M. 22). According to the article in the bulletin, this well had showings of a wet gas with 15 to 16 percent ethane and the gasoline content was 2.29 gallons per thousand cubic feet. The well was abandoned when the casing collapsed. In 1923 the same company drilled a second well to the west of No. 1, but this also had considerable mechanical difficulty, and was abandoned at a depth of 1,800 feet, when the casing collapsed. However, gas could be seen bubbling out of this well for a long time.

In 1923 the Tulare Basin Gas Company, Ltd., drilled a well in Sec. 2, T. 23 S., R. 19 E., M. D., to a depth of 1,192 feet. It produced gas for several months and had a shut-in pressure of 512 pounds. It is purported to have flowed 8,500 M.c.f. per day. The No. 2 well was completed in 1934. It was drilled to a depth of 1,198 feet, and blew the tubing out of the hole, blowing wild about 40,000 M.c.f. per day of gas until it sanded up.

The Dudley Ridge Syndicate well No. 1 was drilled to a depth of 1,286 (1,308?) feet into salt water. The well blew out 30 to 40 million cubic feet of gas, from a depth of 1,142 feet. After two weeks it was put under control, and for about two years it delivered gas to Kettleman City and to drilling wells. It is said that the well delivered 3 million cubic feet of gas per day to the pipe line for four months, while it still served Kettleman City and drilling wells. Then mud appeared. The bottom salt water found at 1,286 feet was never plugged off; the well is now abandoned.

The Valley Exploration Company (J. E. O'Donnell) well, offsetting this well to the east, was drilled to a depth of 4,310 feet during 1929 and 1930. It had a gas blowout at 1,175 feet and was abandoned when the drill pipe got stuck in cement.

The Kettleman-Lakeview Oil and Gas Company (Friend and Fiske) well No. 1, in Sec. 11, T. 23 S., R. 19 E., M. D., was drilled in 1930. It blew out of control at 1,285 feet and was abandoned. The No. 2 well was drilled to a depth of 1,200 feet. It delivered gas to the pipe line for several months.

The Irma Investment Company well No. "Watson" 1, in Sec. 7, T. 23 S., R. 20 E., M. D., was drilled to 1,334 feet. It was plugged back to 1,200 feet and produced gas for a few months. The No. 2 well had bottom water at 1,222 feet. There were attempts made to plug back, but the well was never completed.

The writer understands that the gas-producing wells in the district were abandoned when the gas was no more in demand. The pressure of the gas in the Dudley Ridge wells is much lower than that in the wells of the Kettleman Hills, and it did not pay to transport the Dudley Ridge gas in the same pipe line.

The Valley Exploration Company well No. "Brennan" 1, Sec. 20, T. 23 S., R. 20 E., M. D., was drilled to a depth of 3,711 feet. It is reported that the well had good gas showings.

The Eagle Oil and Gas Company drilled two wells in Sec. 15, T. 23 S., R. 20 E., M. D., in 1931 and 1932. The first one blew wild at 675 feet and the second was never completed.

More recently, in 1936, the Union Oil Company drilled a well in Sec. 28, T. 22 S., R. 20 E., M. D., to a depth of 5,338 feet. It had a big gas showing below 2,829 feet in the upper *Mya* zone.

The Dudley Development Company's well No. "Josephine" 1, Sec. 24, T. 23 S., R. 20 E., M. D., was drilled a depth of 6,498 feet; it is now idle. Nothing can be said 1,025 feet, and 1,300 feet. The No. 2 well was drilled to a depth of 6,498 feet; it is now idle. Nothing can be said about the well, as there were not sufficient coring data.

The last well drilled in the district was the Graphic Oil Corporation's well in Sec. 34, T. 23 S., R. 20 E., M. D. It was recently abandoned at a depth of 4,044 feet.

DISTINGUISHING FEATURES

Wells in the western part of the field (Secs. 2, 11, 12, T. 23 S., R. 19 E., and Sec. 7, T. 23 S., R. 20 E., M. D.) produced gas that is almost pure marsh gas. It came from a 6-foot horizontal sand at a depth of 1,200 feet. To the east, the gas comes from different levels—the Eagle Oil and Gas Company's well blew out at 675 feet, and the Pacific Oil and Gas Company's well had gas at depths of 1,610 and 2,085 feet. The gas from this last well had an important gasoline content.

STRATIGRAPHY

Formation	*Thickness (Feet)*
Alluvium (valley fill, etc.)	300- 400
Tulare (Pleistocene)	3,000-3,500
San Joaquin clay (Pleistocene and upper Pliocene) (approx.)	2,000
Etchegoin (Pliocene) (approx.)	4,500
Miocene	3,500-5,500

It is noteworthy that the alluvium is only a few hundred feet thick. One would expect a much greater thickness in the middle of the San Joaquin Valley. However, a sample taken at a depth of 550 feet in the Dudley Syndicate well was definitely of the Tulare formation.

The Valley Exploration Company's "Brennan" (see map) reached the San Joaquin clays at a depth of 3,680 feet. The Dudley Dome well was still in Tulare at 3,003

* Consulting Geologist, Los Angeles, California. Manuscript submitted for publication January 19, 1940.

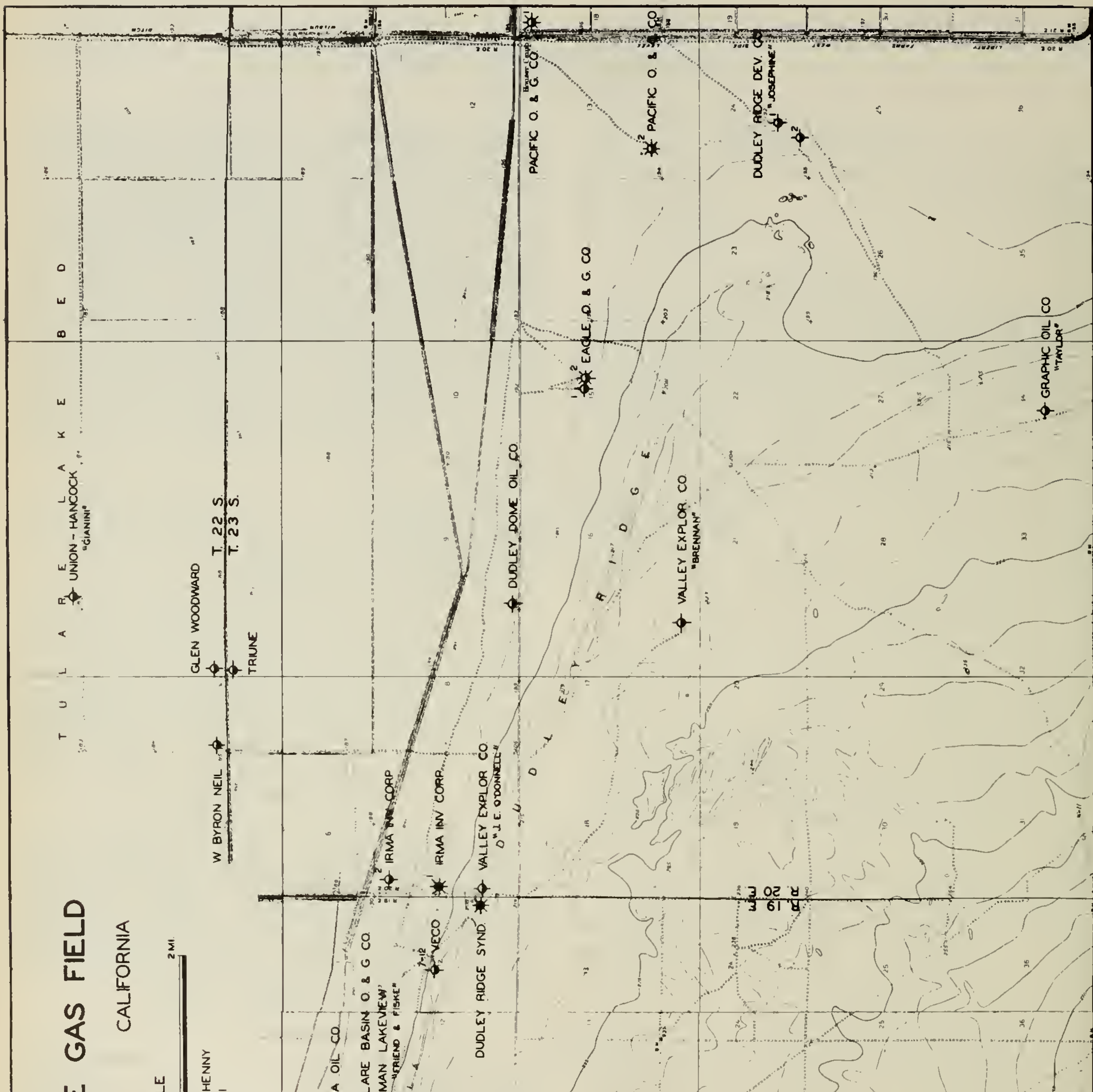


FIG. 234. Dudley Ridge gas field: map.

feet. The Valley Exploration Company (J. E. O'Donnell) well (near the Irma wells) reached the San Joaquin clay between 3,200 and 3,300 feet. The Union "Hancock" in the northern part of the district seems to be higher than all the other wells. It reached the first *Mya* zone (the top of the San Joaquin clay) at 2,829 feet.

This same well reached the *Mulinia* zone (top of the Etchegoin) at 4,861 feet. This would indicate that the San Joaquin clay has a thickness of approximately 2,000 feet.

None of the wells in the district ever reached the Miocene. The thickness given for the Etchegoin is the same thickness that is present in the Semitropic gas field. The writer feels that this thickness will prevail in the Dudley Ridge district.

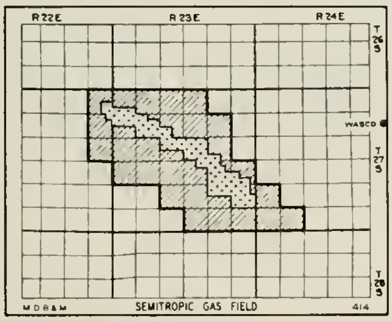
The thickness of 5,500 feet of Miocene, given in the above table, is taken from the deep Wasco wells. In the Kettleman Hills the total thickness of the Miocene is 3,500 feet. The true thickness of the Miocene in the Dudley Ridge district is probably between the two figures.

The deepest well drilled in the district is the Dudley Ridge Development Company's No. "Josephine" 2. It was drilled to a depth of 6,498 feet. The base of the Tulare formation was reached at approximately 3,280 feet in this well, and the top of the Etchegoin between 4,730 and 4,985 feet.

STRUCTURE

The first wells of the district were drilled in the vicinity of Dudley Ridge. Apparently it was surmised that this ridge was of structural origin. There is, however, no doubt that it consists of dunes bordering Tulare Lake. A very different topographic feature, however, exists near the northeast quarter of Sec. 19, T. 23 S., R. 20 E., M. D. The topography here indicates the possibility of the existence of a fault zone. The topographic map shows here little closed basins or depressions such as are frequently found near a recent fault. This probable fault zone has a northwest trend. The gas in the wells to the north of the fault could have come from a petroleum accumulation against the fault. The wet gas in the Pacific Oil and Gas well No. 1 and the gas in the Union "Hancock" well, on the contrary, could have come from an anticlinal structure to the east of these wells. The dips in the cores of the Union "Hancock" well seem to have been already rather flat. Supporting this view is a high in Tulare Lake, outside the eastern limits of the map, which is called "Pelican Island."

CITATIONS TO SELECTED REFERENCES—Continued



Semitropic gas field.

DUDLEY RIDGE GAS FIELD (*see also* **TULARE LAKE GAS FIELD**)

Beebe, J. W. 32; 35; Dodd, H. V. 30; Hoots and Herold 35; Rousselot, N. A. 35.

TULARE LAKE GAS FIELD (*see also* **DUDLEY RIDGE GAS FIELD**)

Barnes, R. M. 22; Bradley, W. W. 16b; Crawford, J. J. 96; Gibbs, C. D. 76; Laizure, C. McK. 22; McLaughlin, R. P. 19; Rousselot, N. A. 35; Vander Leck, L. 21; Blake, W. P. 64.

SEMITROPIC (SEMITROPIC RIDGE) GAS FIELD

Godde, H. A. 26b; Hoots, H. W. 36a; Howard, P. J. 39; Kaplow, E. J. 38; Musser, E. H. 30; 39; Petroleum World 35; Rousselot, N. A. 35; Soper, E. K. 32a.

SHAFTER FIELD

California Oil World 42.

SEMITROPIC GAS FIELD

By W. W. Valentine *

OUTLINE OF REPORT

HISTORY

The Semitropic gas field is located in Kern County about 30 miles northwest of Bakersfield on a slight topographic high known as Semitropic Ridge. The topography strongly suggests a structural origin in the form of a gently folded anticlinal nose breaking out of the regional monocline and plunging gently to the northwest.

Prospecting along this ridge was conducted by various companies from 1923 to 1934. In 1935, after detailed seismic work, the Standard Oil Company of California discovered the Semitropic gas field when their No. "Hill" 1, in Sec. 8. T. 27 S., R. 23 E., M. D., blew out, burned, and was subsequently completed as a gas well in the B zone of the San Joaquin Valley clays at a depth of 3,193 feet. The productive area of 4,480 acres has been developed by 22 wells, an average of one well to every 200 acres.

* Fullerton Oil Company. Manuscript submitted for publication December 30, 1937.

STRUCTURE

The structure, as mapped on the First *Mya-Elphidium* zone is a long, gently folded anticline, 8 miles long by 1¼ miles wide, slightly asymmetrical, with the west flank somewhat steeper than the east flank, and with a closure of 125+ ft.

PRODUCTIVE HORIZONS

Development has divided the Semitropic gas field into three producing areas: (1) Northwest *Mya* area, producing from a sand at the First *Mya-Elphidium* zone; (2) Hill area, in the central portion of the field, producing from lenticular sands in the B zone; and (3) the Southeast *Mya* area, producing from the same horizon as the Northwest *Mya* area. The First *Mya* sand pinches out in the central portion of the field, the interval normally occupied by sand changing to siltstone.

Only dry gas is produced, with a specific gravity of 0.56 and a heating value of 990 B.t.u.

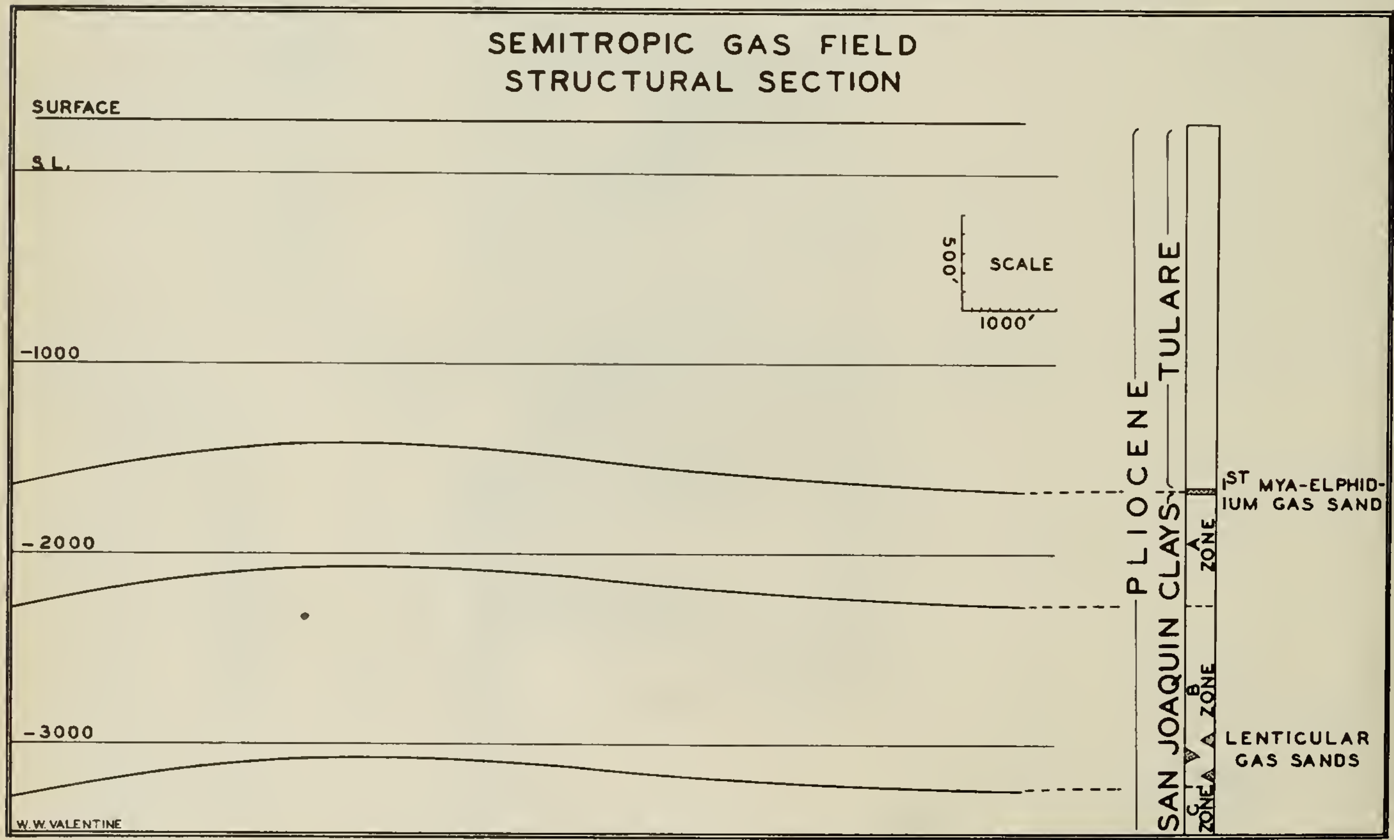


Fig. 235. Semitropic gas field: section.

BUTTONWILLOW GAS FIELD

By L. S. Chambers *

OUTLINE OF REPORT

HISTORY

The Buttonwillow gas field is located on the floor of the San Joaquin Valley about 30 miles west and 5 miles north of Bakersfield, Kern County. It is the oldest central valley floor field; it was discovered in 1926, prior to the development of successful geophysical exploration methods.

Although the region is almost flat, attention was first drawn to the area by a gentle topographic high. This feature is reflected by soil conditions; the higher portion is occupied by the sandy loams of the Panoche series,[1] and is completely surrounded by alkali-spotted clays of the Merced series.[1]

After a study of the data available from surrounding wells and from two core holes, Milham Exploration Company located and drilled its No. "Kern" 1 well upon the structure. This well blew out from a depth of 3,323 feet, on November 3, 1926, forming a crater and completely destroying the rig. No. "Kern" 1 was followed by "Kern" 1-A, which was located nearby, and started as a deep test. However, at a depth of 4,661 feet, mechanical troubles caused by heaving shales made it advisable to plug back in an attempt to make a gas well; thus "Kern" 1-A was completed August 4, 1927. At first a considerable amount of water was produced, but successive plugging has now eliminated this difficulty.

The Buttonwillow gas field now has 26 producing wells; four have gone to water after producing relatively small quantities of gas; four additional off-structure wells were unsuccessful; and No. "Kern" 1 and No. "Kern" 6 wells were not completed because of mechanical difficulties. Although the latter well, No. "Kern" 6, was started as a deep test, no well has been drilled below 4,946 feet on this structure. Recent deep wells in the area indicate an extreme depth for the now known oil-producing sands of the valley floor fields.

SIGNIFICANCE

The present productive area of the Buttonwillow gas field is 1,600 acres. Since January 1, 1930, gas production has totaled 10,115,064 M.c.f. The reserve is estimated by a modified pressure decline method as 18,000,000 M.c.f. This reserve is derived by using 300 pounds as the lowest producing pressure for wells on top of the structure. Edgewater is very active in the main zone (Zone 2), and, because of the gentle dip of the structure, all except the very highest wells probably will go to water before this pressure is reached.

Although field withdrawal seldom exceeds 10 to 15 million cubic feet per day, almost every individual well is capable of greater than this production against 600 pounds back pressure.

STRATIGRAPHY

Only Pleistocene and Pliocene sediments have thus far been penetrated on North Buttonwillow dome. They consist of the following:

Alluvial fill—Six hundred feet of surface sands—soft green and brown sands and clays.

Tulare (*Pleistocene*)—Consists of 2,000± feet of shales and sands. Soft, crumbly, blue-gray shale, containing abundant fresh-water fossils (principally *Anodonta, Amnicola*, and ostracod) makes up most of the formation. Streaks of sand are relatively common, and toward the base of the formation form the principal gas zone of the field. The base of the Tulare and the top of the San Joaquin clay series is marked by the First *Mya* zone. This zone is of variable thickness, but usually consists of 10 to 20 feet of shale and coarse sand containing abundant *Mya, Cryptomya, Elphidium,* and small oysters.

San Joaquin (*Upper Pliocene*)—The top of the San Joaquin clay is marked by the first occurrence of brackish-water fossils; the base is marked by the first definite marine forms. The formation has a thickness of approximately 2,400 feet and is composed of alternating brackish and fresh water beds similar in lithology to the overlying Tulare, except for a 300-foot bed of brown platy shale that occurs about 1,100 feet below the top of the formation. About 200 feet below the top of this brown shale, a thin zone of *Scalez petrolia* occurs. Below the First *Mya* and above the brown shale is a thick series of laminated shale and fine sands in which are found occasional sand lenses produced in the B zone wells.

Etchegoin formation has not been penetrated at Buttonwillow, but from the position of the second *Scalez* zone, it is believed to occur at a depth of approximately 5,000 feet. The San Joaquin clay-Etchegoin contact is marked by the *Mulinia* bed, the first occurrence of true marine fossils.

The Etchegoin apparently is entirely marine, and carries a good marine fauna. Lithologically, this formation consists of a thick series of gray sandy silt shales and massive clay silt shale believed to offer few gas or oil horizons.

The Etchegoin probably extends to a depth of about 9,800 feet, below which should be found the Reef Ridge shale, the McLure brown shale, the Olcese sand, and, at an estimated depth of 15,000 feet, the Vaqueros sandstone. This formation includes the Vedder or Rio Bravo zone, which is the only known producing sand that can reasonably be expected under the Buttonwillow structure, although upper sands, at present unknown, might prove productive.

* Geologist, Seaboard Oil Company of Delaware. Manuscript submitted September 14, 1938.

[1] These terms refer to soil types, not geologic formations.

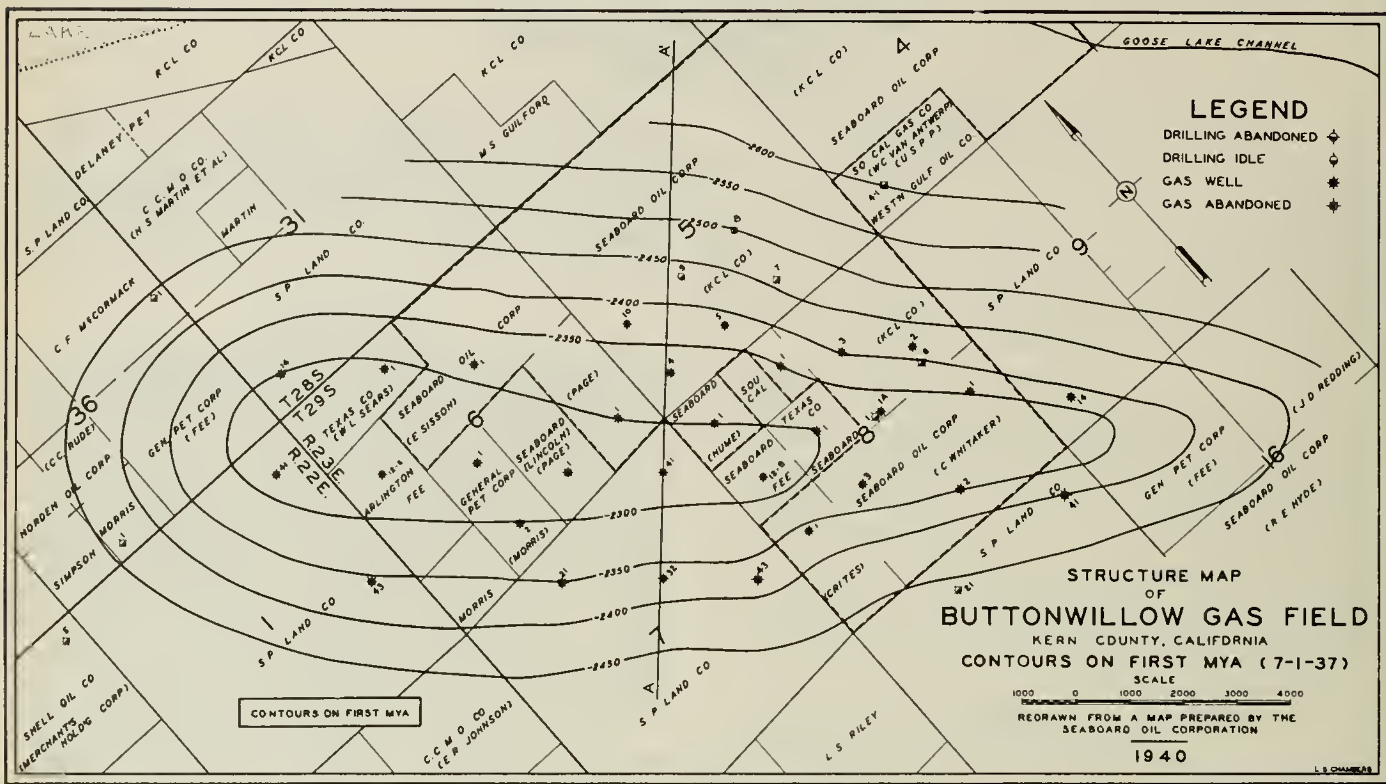


Fig. 236. Buttonwillow gas field: structure map.

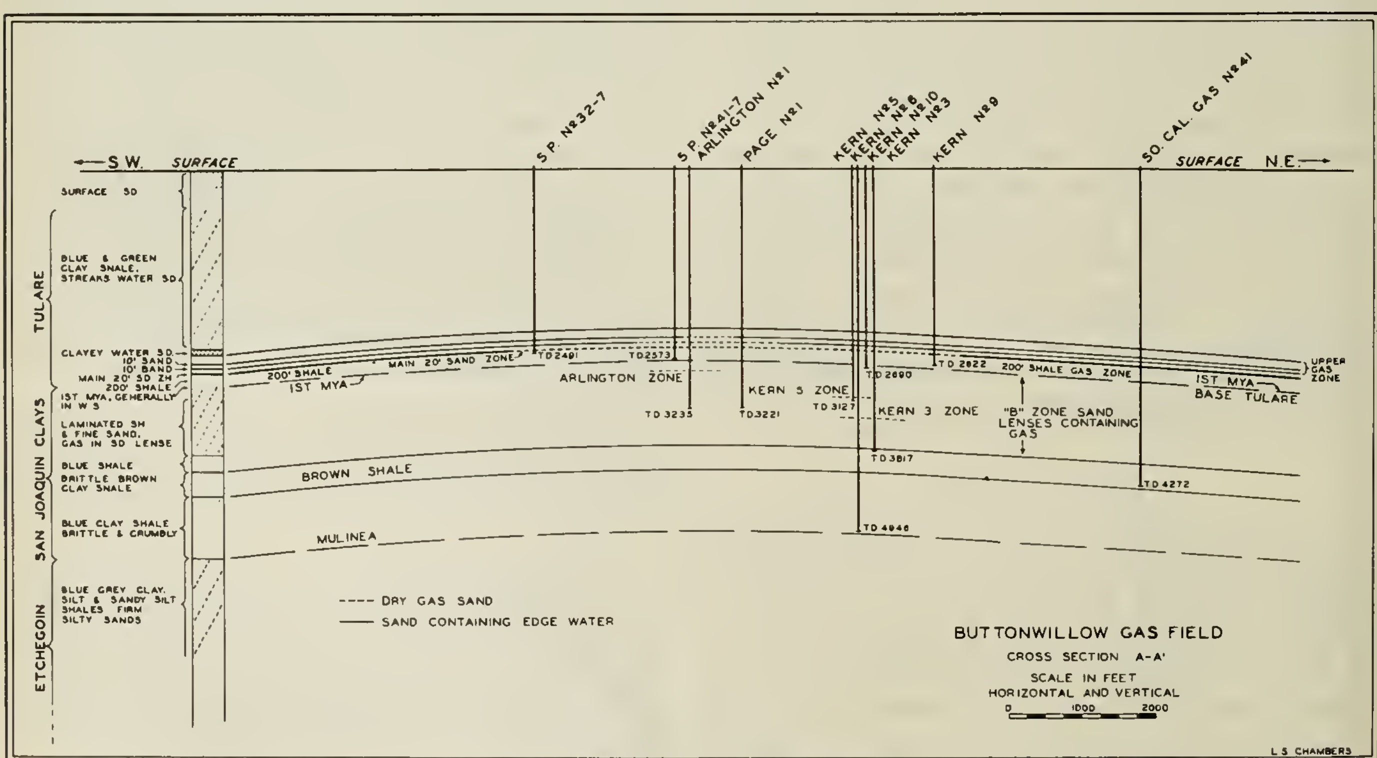


Fig. 237. Buttonwillow gas field: section.

STRUCTURE

The structure of the Buttonwillow field as shown on the accompanying map is a gentle anticlinal fold trending northwest. Drilling has demonstrated 200 feet of closure, although considerably more is probably present. The greater closure is around the west flank and north end; the minimum closure is around the south end and east flank.

PRODUCTIVE HORIZONS

Zone 1 includes the three sand zones above Zone 2. The G. P. No. "Morris" 2 well blew out from one of these sands; however, on test, all of the sands have proved to be wet.

Zone 2 (20-foot sand zone) consists of a soft, medium-grained, clean, gray, blanket sand 14 to 18 feet thick, that is present over the entire structure. This zone is the most satisfactory producing horizon of the field, but contains active edgewater.

Zone 3 (200-foot shale zone) is productive only in the central portion of the east flank of the field, where it either carries thin sand stringers, or where the crumbly nature of the shale offers fractures through which the gas travels into the well. In the remainder of the field the zone consists of fine silt shale and firm clay which was found to be nonproductive. The base of this zone is the First *Mya*.

Zone 4 (so-called B zone) consists of the strata which lie 100 feet below the First *Mya* and 200 feet above the Pliocene brown shale. They consist of laminated shale with paper-thin streaks of fine sand. At various places the sand concentration in one horizon increases to lenses that produce gas. These lenses are not continuous, however, and for the most part, satisfactory producing wells can not be completed in them.

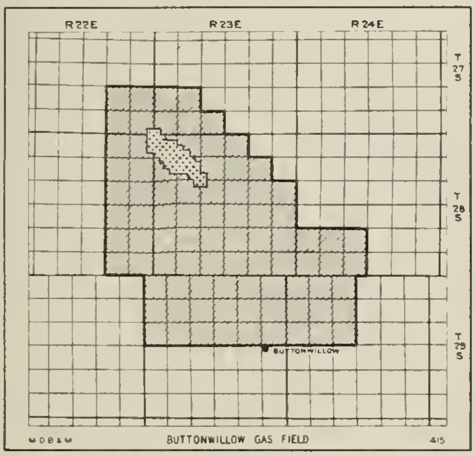
Numerous tests have been made in and below the brown shale of the Pliocene. None of these has been successful, however, and from the section inferred from other deep wells in the area, it is concluded that there is little possibility of additional paying gas zones within economic gas-drilling depth.

KIND OF GAS

Gas of the Buttonwillow field is almost pure methane with no trace of the heavier hydrocarbons, and has shown the same analysis for all zones developed to date:

CH_4	98.8%
CO_2	0.4%
N_2	0.8%
Specific gravity by balance	0.563
Calorimeter B.t.u.	985
Calculated B.t.u.	991

CITATIONS TO SELECTED REFERENCES—Continued



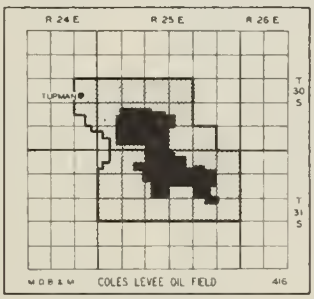
Buttonwillow gas field.

BUTTONWILLOW GAS FIELD

Ferguson, R. N. 21; Godde, H. A. 26b; Hoots and Herold 35; Howard, P. J. 39; Kaplow, E. J. 38; Musser, E. H. 29a; 30; 39; Oil and Gas Journal 41f; Rousselot, N. A. 35; Soper, E. K. 32a; Stockman, L. P. 35d; 36j; 36k; Vander Leck, L. 21; Wagy, E. W. 27.

BOWERBANK GAS FIELD

Stockman, L. P. 42a.



Coles Levee oil field.

COLES LEVEE OIL FIELD

Atwill, E. R. 40; Hoots, H. W. 39a; Howard, P. J. 39; McDermott, E. 40, p. 869, figs. 7, 8; Porter, W. W. II 39b; Stockman, L. P. 41l; Wilhelm, V. H. 39a.

Coles Levee Area

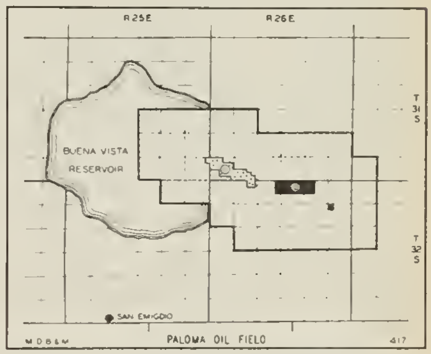
Hoots, H. W. 39; Wilhelm, V. H. 40; 41; 41a.

Richfield-Western Area

Hoots, H. W. 39; 39a; Porter, W. W. II 39b; Wilhelm, V. H. 39a; 40; 41; 41a.

Tupman (Richfield Western) Area

Howard, P. J. 39; Stockman, L. P. 38a; 39; 40, no. 12, p. 63; 40, no. 13, p. 87; 41l; Wilhelm, V. H. 40, p. 256.



Paloma oil and gas field. Areas: (1) Paloma gas (Buena Vista Lake gas); (2) Paloma oil.

PALOMA OIL AND GAS FIELD

Atwill, E. R. 40; California Oil World 41a; 41b; 41c; 42b; Clark, R. W. 40; Geis, W. H. 41; 42; Huggins, R. P. 41; Johnston, N. 41; Moeller, W. Jr. 41; Oil and Gas Journal 40; Paine, P. 41; Porter, W. W. II 39b; Stockman, L. P. 41b; 41g; 41l; Wilhelm, V. H. 40; 41; 41a; Wood, J. T. Jr. 41; 42.

Buena Vista Lake Gas (Paloma Gas) Area

Howard, P. J. 39; Kaplow, E. J. 38; Musser, E. H. 30; 39; Oil and Gas Journal 41f; Rousselot, N. A. 35; Stockman, L. P. 40e.

Panhandle Oil (Paloma Oil) Area

Stockman, L. P. 39c.

CANAL OIL FIELD

By R. N. Williams, Jr. *

The Canal oil field is located in T. 30 S., R. 25 E., M. D., southwest of the city of Bakersfield, Kern County, in the west central part of the San Joaquin Valley plain. The country is flat, brushy, grazing land, and the surface topography gives no indication of the subsurface structure. The field lies 2 miles northwest of the larger Ten Section field, and is similar in structure, being an elongate closed dome, with about 150 feet of closure, the longer axis trending east. The producing area covers about 760 acres, and the field has been completely developed, a 20-acre spacing and staggered offset pattern having been rigidly followed.

The first well in the area, the Shell Oil Company No. "Canal A" 21-14, in Sec. 14, T. 30 S., R. 25 E., M. D., was drilled as a result of a reflection seismograph survey. This well was spudded March 17, 1937, and was drilled to a depth of 8,613 feet. Stevens sand equivalent was found at 8,300 feet, and sufficient oil showings were found to warrant setting casing at 8,275 feet. Exhaustive tests of the sands, however, showed that they contained principally salt water, although in almost every test, some oil was recovered. The well was suspended in August 1937. Later development in the area has demonstrated that this well lay just outside the lowest producing contour. In September 1937, Ohio Oil Company spudded No. "KCL-E" 3 in the same section three-fourths of a mile southeast of the Shell well. This well was completed November 20, 1937 at a total depth of 8,175 feet, for an initial production of 2,267 barrels of 36.9 degrees oil per day through a 1-inch bean, and 1,700 thousand cubic feet of gas. The oil was clean, cutting only 0.8 percent, and it later cleaned to 0.1 percent. Tubing pressure was 420 pounds, casing pressure 1,525 pounds. The well produced from 80 feet of Stevens sand.

All acreage in the field is held by three companies, and development has been systematic and orderly. By the end of 1940 the field had been completely drilled, though some of the early wells were later deepened. There were 38 wells completed in the field, and all but two were flowing wells. The wells take in an average of 150 feet of zone, and most of the wells are completed at a depth of 8,340 feet.

Porosity of the sand ranges from 15 to 30 percent, and averages about 22 percent. Permeability is variable, ranging from about 60 to about 800 millidarcys, and averaging approximately 200 millidarcys. Production in the field has been under strict curtailment. Total cumulative production to December 31, 1940 was 4,769,184 barrels, or approximately 6,280 barrels per acre.

Wells were drilled in about 50 days with steam rotary equipment. An 11¾-inch surface string is generally set at 1,000 feet. The water string is 7 inches or 6⅝ inches, and is set about 15 feet above the top of the oil sand. A 4¾-inch liner or 5½-inch liner, either of steel or aluminum, with 100-mesh perforations, is used to complete the well. In the shales and cherts above the producing sand, excellent correlations are obtained by electric logs.

The maximum penetration was in Shell Oil Company well No. "KCL-A" 21-13,[1] an edge well, which was cored continuously from 8,239 feet to 8,980 feet. The top of the Stevens oil sand was found at 8,240 feet, and the first gray sand at 8,287 feet. Below 8,287 feet the formation was predominantly gray sand, minor amounts of siltstone, and occasional thin streaks of oil sand. The well was plugged and completed on gas lift from the intervals 8,245 to 8,280 feet and 8,350 to 8,355 feet for an initial production of 51 barrels per day, cutting 32.9 percent.

The Stevens sands are the only productive horizon in the field to date. The Vedder sand has not yet been reached in the field,[1] but from its known occurrence in a well 2 miles to the northwest, and in a well a mile to the northeast, it seems reasonable to assume that it may also underlie the Canal field. In both of these wells, however, the sand is tight and relatively impervious.

The majority of the Canal field wells had a potential production in excess of 1,500 barrels per day, but the edge locations were considerably lower than this. The gas-oil ratio is fairly low, ranging from 1,000 to 2,000 cubic feet per barrel of oil. The oil ranges from 34 to 38 degrees A. P. I. The sulphur content is low and the oil has a waxy base. Since the early part of June 1941, attempts to maintain the reservoir pressure have been made by injecting surplus gas into a well in the highest part of the field. As yet, it is too early to determine the effectiveness of this work.

* Geologist, Honolulu Oil Corporation. Manuscript submitted for publication July 25, 1941.

[1] In July 1941, Shell Oil Co. Inc. spudded its well No. KCL A-44-14 as a deep test. This well was located close to the crest of the structure and was drilled to a depth of 13,400 feet. The top of the Vedder sand (lower Miocene) was located at 12,616 feet and extended to 13,263 feet, although not all of this interval was sand. The maximum permeability of the gray sand was 5 millidarcies and a few oil-stained areas ran as high as 18 millidarcies. It appears that the Vedder sand in this area is too impermeable to have any appreciable fluid content. No tests were made in the Vedder sand, and the well was plugged back and completed in the lower Stevens zone.

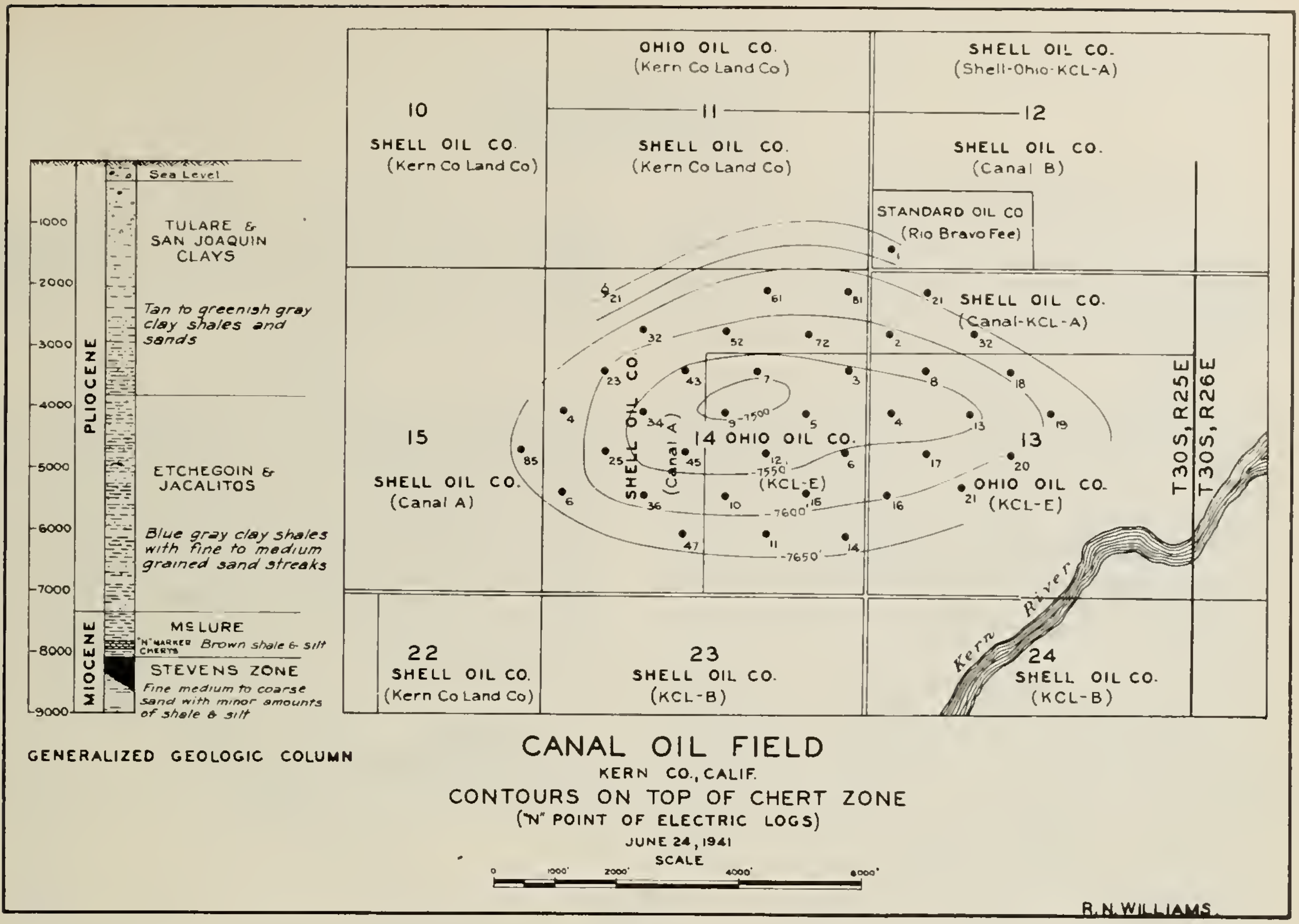
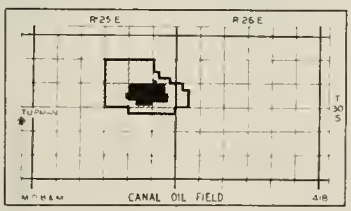


FIG. 238. Canal oil field: geologic column; structure map.

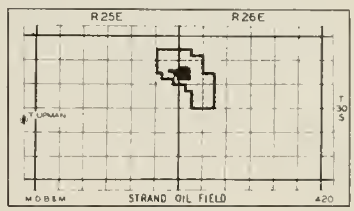
CITATIONS TO SELECTED REFERENCES—Continued

CANAL OIL FIELD

Hoots, H. W. 38; Howard, P. J. 39; McDermott, E. 40, p. 869, figs. 7, 8; Musser, E. H. 39; Oil and Gas Journal 38a; Petroleum World 37b; Porter, W. W. II 39b; Stockman, L. P. 411; Walling, R. W. 39a.



Canal oil field.



Strand oil field.

STRAND OIL FIELD

Atwill, E. R. 40; Menken, F. A. 40; Porter, W. W. II 39b; Walling, R. W. 39a; Wilhelm, V. H. 40.

STRAND OIL FIELD

By CHARLES M. CROSS *

OUTLINE OF REPORT

HISTORY

The Strand oil field is located 12 miles southwest of the town of Bakersfield, along the Kern River, 2 miles north of the Ten Section oil field. The Strand field was discovered in 1939 as a result of drilling on a structure mapped by detailed reflection seismograph surveys. The name "Strand" is taken from the railroad siding of the same designation in the southeast portion of Sec. 6, T. 30 S., R. 26 E., M. D.

The discovery well, Tide Water Associated-Continental well K. C. L. E-35-7, in Sec. 7, T. 30 S., R. 26 E., M. D., was spudded on April 1, 1939, and completed on June 12, 1939, at a depth of 8,364 feet. Initial production was 1,042 barrels daily of 34 degrees A. P. I. gravity oil, and two days later the well established a potential of 1,306 barrels of oil and 978,000 M.c.f. of gas. Development at the time of this writing includes five completed wells and two drilling wells. Initial production ranges from 1,400 to 3,600 barrels daily. No dry holes have been drilled, nor have edge conditions been encountered in any of the wells.

STRUCTURE

At the present time the governing factor of the accumulation is believed to be structure; there are, however, stratigraphic changes between the wells which may or may not influence accumulation to some extent.

The variable character of the sands precludes their use for structural studies, so correlations for this purpose are based on electrical logging. The marker most widely used is commonly referred to as the "N" marker, and is found approximately 235 feet above the first oil sand. Although, from geophysical surveys, the structure is known to be anticlinal, development has not yet progressed sufficiently to make possible the complete delineation of structure contours or the productive limits.

PRODUCTIVE HORIZONS

The producing zone of the Strand field is equivalent to the Stevens sand from which the neighboring fields produce. This sand zone is correlative with the upper Fruitvale shale and is Mohnian upper Miocene in age. In the Strand field the oil zone consists of two separate bodies of sand, separated by a silty shale body ranging in thickness from 20 to 60 feet in the various wells. The upper sand body is from 20 to 40 feet thick and has an average porosity of 21 percent. The lower sand, approximately 60 feet in thickness, is more irregular, being broken by occasional siltstone or shale members a few inches to a foot thick. This second sand has an average porosity of 26 percent. The average permeability of both sands is 345 millidarcys.

* Tide Water Associated Oil Company. Manuscript submitted for publication November 28, 1939.

KIND OF OIL

Wells in the Strand field are completed at an average depth of 8,350 feet in about 35 days. The present drilling program includes $13\frac{3}{8}$-inch surface casing set around 1,000 feet, 7-inch oil string cemented just above the oil sand, and 5-inch liner with 100-inch perforations opposite the oil sands. The oil produced is a typical California asphaltic base oil, averaging 34 degrees A. P. I. gravity. It flows from the wells under a natural reservoir pressure of about 3,600 pounds per square inch, with from 500 to 1,000 cubic feet of gas per barrel of oil.

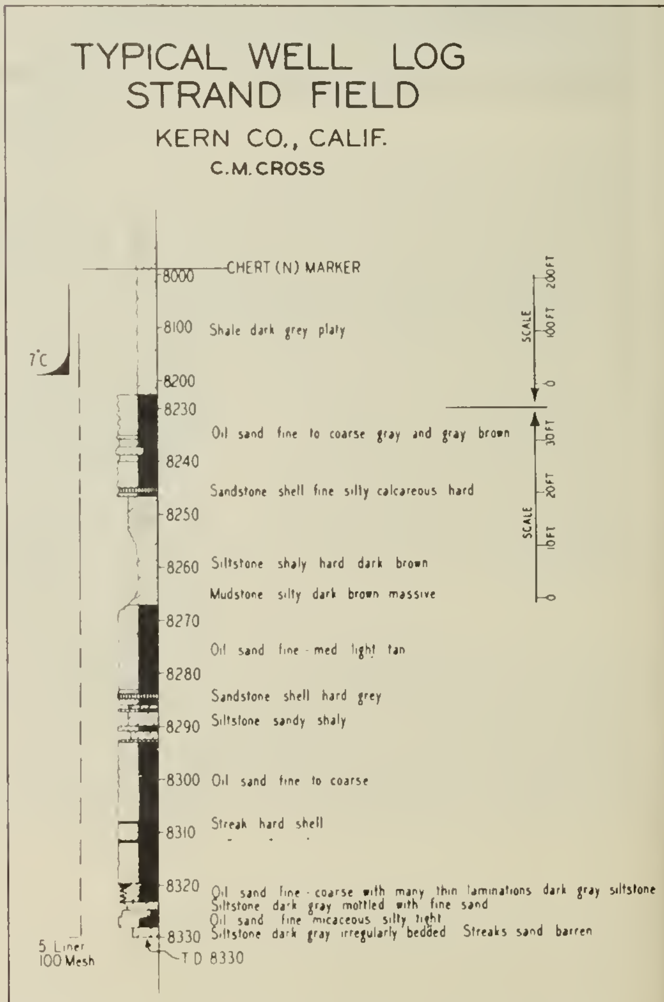


FIG. 239. Strand oil field typical well log.

TEN SECTION OIL FIELD

By A. W. Gentry *

OUTLINE OF REPORT

HISTORY

The Ten Section oil field is located approximately 10 miles southwest of Bakersfield, Kern County. Although there is no surface evidence to indicate the presence of a structure suitable for the accumulation of oil, reflection seismograph surveys indicated the presence of a structural high. Shell Stevens A-1, located at the apex of the structure as indicated by the geophysical work, was spudded January 22, 1936, and completed June 2, 1936, at a total depth of 7,888 feet, with 88 feet of formation open, flowing 827 barrels per day of 60.6 degrees A. P. I. gravity oil and 14,123 M.c.f. of gas through a $\frac{34}{64}$-inch and $\frac{32}{64}$-inch tubing orifice, tubing pressure 2,000 pounds, casing pressure, 2,300 pounds.

* Exploitation Engineer, Shell Oil Company, Incorporated. Manuscript submitted for publication November 24, 1939.

Following the completion of Shell Stevens A-1, Ohio Oil Company drilled well E-1 at a location $1\frac{1}{4}$ miles northwest of the discovery well, and the Standard Oil Company drilled well 10-1 at a location $1\frac{1}{10}$ miles north of the discovery well. These wells found no oil showings worth testing in the Stevens sand and were abandoned.

About $2\frac{1}{2}$ miles to the east of the discovery well, Standard Oil Company drilled three wells to test the Stevens zone. The first, KCL 9-1, was abandoned after testing oil showings at the top of the Stevens zone. The second well, KCL 15-1, was completed with 35 feet of the Stevens zone open flowing 243 barrels per day of 28.2 degrees A. P. I. gravity oil. It is not known at this time whether this well is an edge well in the Ten Section field or whether it is in a separate field, designated the Canfield Ranch field. In the third well, KCL 15-2, no showings worth testing were found and the well was abandoned.

The deepest well drilled to date is KCL A 6-29, which was drilled to a depth of 8,984 feet and plugged to 8,383 feet.

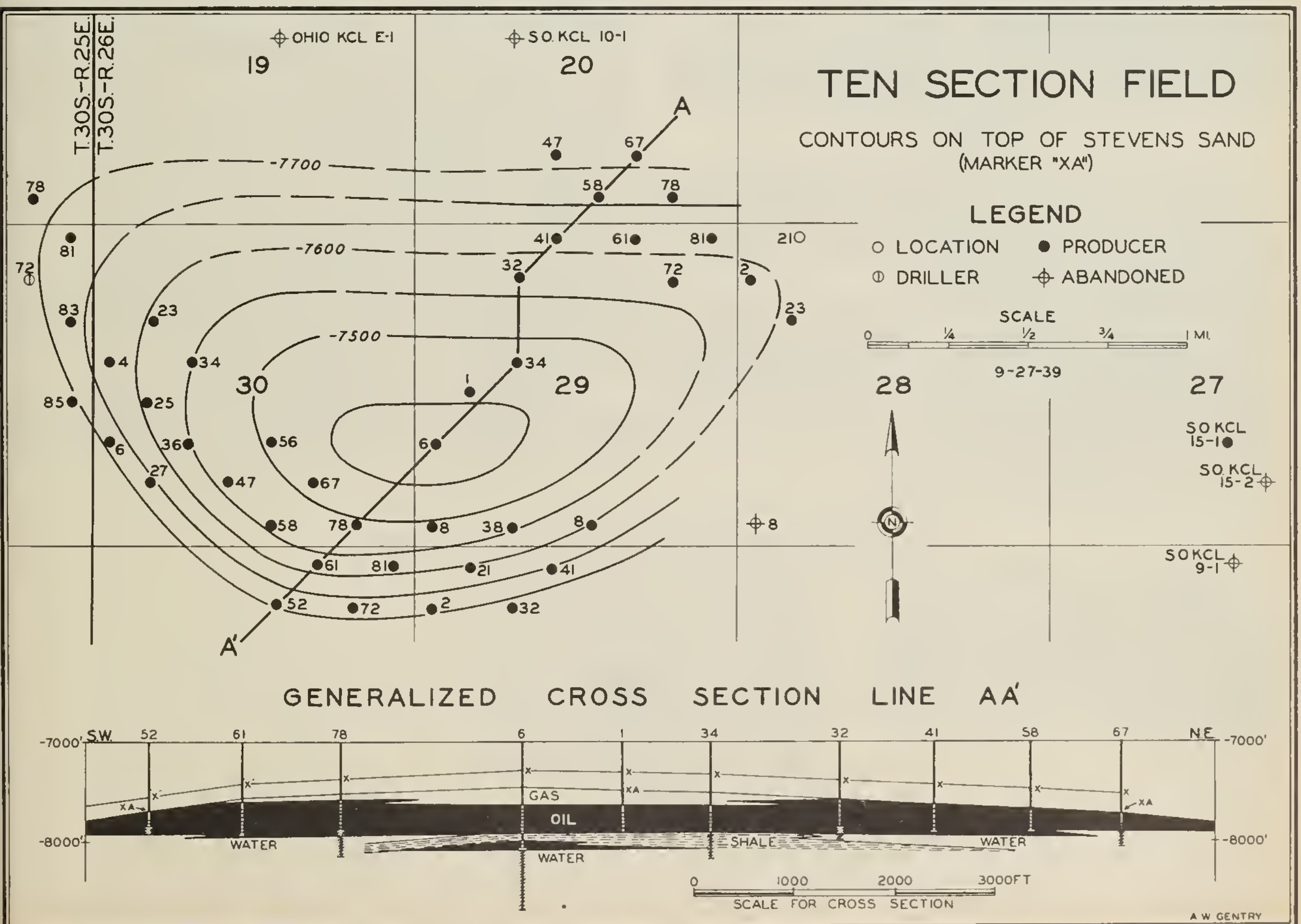


Fig. 240. Ten Section oil field: structure map; generalized cross-section.

During the 40 months since discovery, there have been 42 wells drilled by Shell on the Ten Section KCL "A" and "B" leases, all but one being completed as producers.

STRATIGRAPHY

Immediately beneath the surface alluvium there are loosely consolidated fresh-water-bearing sands with thin layers of clay and sandy silt. These beds probably represent the Tulare formation. Below them is approximately 6,000 feet of alternating claystone, siltstone, and friable sand which have not been classified. Ditch samples indicate that the top of the upper *Mulinia* zone occurs at a depth of approximately 4,000 feet.

The Pliocene-Miocene contact occurs at a depth of about 7,000 feet. The uppermost 200 feet of the Miocene is gray siltstone and brownish-gray shale, followed by 700 feet of hard, generally well-laminated, platy, dark-brown shale containing abundant resinous fish remains, together with some forams and pyritized diatoms. There are occasional dark-brown chert streaks.

The Stevens formation underlies the brown shale and is also of upper Miocene age. It is predominantly sand with interbedded shale streaks. There is rapid lateral variation in lithology within this formation, suggesting irregularity in depositional conditions.

The deepest well yet drilled in this field, KCL A 6-29, penetrated approximately 1,200 feet below the top of the Stevens formation and was still in this sandy series at its final depth of 8,984 feet.

The Stevens sand has an average porosity of about 22 percent and permeability ranging from 150 to 400 millidarcys.

STRUCTURE

Differences in lease terms made it necessary to concentrate most of the drilling along the boundary between the "A" and "B" leases and, although 42 wells have been drilled to date, the structure and limits of production have not yet been well defined.

The accumulation occurs in an anticline, the axis of which is arcuate. There are no faults known in this field.

Measured along the axis of the anticline the field is approximately 3½ miles long, with a width at the widest point of approximately 1½ miles. According to the present structural interpretation, the Stevens zone has a productive area of about 2,250 acres.

Good correlation by means of electrical logs exists down to a point 150 to 250 feet above the top of the Stevens sand. The structure as depicted by contours drawn on the top of the sand conforms fairly well with the structure as defined by contours drawn on higher stratigraphic markers.

PRODUCTIVE HORIZONS

The oil and gas occur in sand streaks in an interval about 400 feet thick at the crest of the structure. The percentage of sand varies greatly from one location to the next, but averages about 80 percent of the interval open to production.

In the crestal area the uppermost sand streaks contain gas and very high gravity oil. The first well drilled was completed in the upper 76 feet of the Stevens sand and produced 827 barrels per day of 60.6 degrees A. P. I. gravity oil and 14,000 M.c.f. per day of gas. Because of the high gas-oil ratio, this well was later deepened to exclude the gas-cap and to produce from lower sand streaks where the average gravity was about 35 degrees A. P. I. Later wells blanked off this upper high gas-oil ratio zone.

Bottom-hole pressure data are obtained during the water shut-off test and also after the completion of the well. When the potential test has been completed, the well is closed in for at least 24 hours and the bottom-hole pressure determined.

Early completions showed a bottom-hole pressure (7,800 feet subsea) of 3,600 pounds per square inch. This pressure has gradually declined and is now approximately 3,300 pounds per square inch. This decline in shut-in pressure applies both to new wells and wells which have produced a considerable quantity of oil. The temperature at this depth is 212 degrees Fahrenheit.

It appears likely that a horizontal water table occurs over most of the field at a subsea depth of approximately 7,900 feet (well depth approximately 8,230 feet).

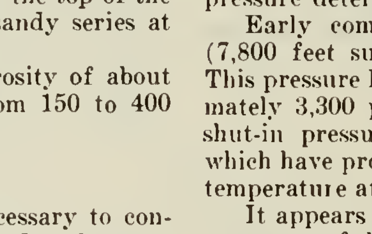
The present potential oil production rate of the 41 productive wells drilled to date is 67,850 barrels per day; the allotment for September, 1939, is 8,664 barrels per day. The cumulative production from discovery to September 1, 1939, is 5,782,000 barrels.

No well that can be termed a deep test has yet been drilled on the Ten Section structure. The deepest well, KCL A 6-29, was still in upper Miocene beds at its total depth of 8,984 feet.

CITATIONS TO SELECTED REFERENCES—Continued

TEN SECTION (TEN SECTIONS) OIL FIELD

Clute, W. S. 36; Eckis, R. 40; Edwards, M. G. 37; Fox, S. 41; Hoots, H. W. 38; Howard, P. J. 39; McDermott, E. 40, p. 869, figs. 7, 8; Musser, E. H. 30; 39; Oil and Gas Journal 37a; Oil Weekly 37; 37b; Petroleum World 36a; 37b; 37d; Porter, W. W. II 39b; Sanders, T. P. 37a; Stockman, L. P. 41a; 41e; 41l; Wilhelm, V. H. 38; Wyatt and Baptie 38; 38a.



Ten Section oil field.

TRICO GAS FIELD

By E. C. Doell *

The Trico gas field is located in northern Kern County and southwestern Tulare County, approximately 12 miles west of the town of Delano.

The field was discovered November 18, 1934, by the Trico Oil and Gas Company well No. 2, Sec. 3, T. 25 S., R. 23 E., M. D. The discovery climaxed a 2½-year search, led by Mr. Harry Magee. Mr. Magee was attracted to the area by the abundant showings of gas in water-wells throughout the Tulare Basin and also by the existence of a very low topographic ridge on an otherwise featureless plain. Early wells drilled on the ridge showed it to be structurally high, but the location of the discovery well resulted from data obtained with the reflection seismograph.

The Trico gas field is one of the minor dry gas fields in the San Joaquin Valley and is similar structurally and stratigraphically to the Buena Vista Lake, Buttonwillow, and Semitropic gas fields. Like these other fields, it produces nearly pure methane gas from a low dome and from thin sands in the San Joaquin clays formation. In the Trico field the upper and chief producing sand is in the First *Mya-Elphidium* zone (Barbat and Galloway 34) of the San Joaquin clays. The lower producing zone is in the Second *Mya-Elphidium*.

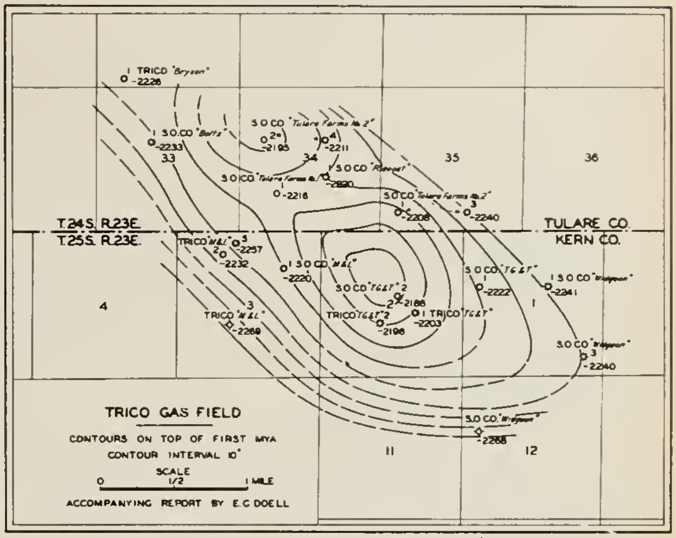
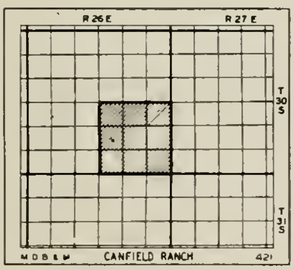


FIG. 241. Trico gas field: structure map.

To date 19 wells have been drilled in the field. Of these, 17 have obtained production. Only two of the wells produce from the Second *Mya-Elphidium* zone, the others all being productive in the upper zone. The field is approximately 4 miles long and 1½ miles wide, the long axis trending in a northwest direction.

* Assistant Geologist, Standard Oil Company of California. Manuscript submitted for publication July 14, 1939.

CITATIONS TO SELECTED REFERENCES—Continued

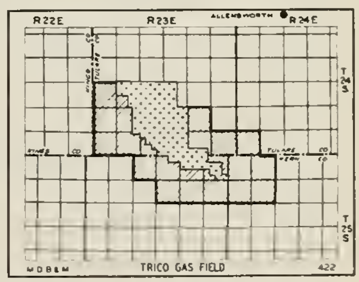


Canfield Ranch oil field.

CANFIELD RANCH OIL FIELD
Musser, E. H. 39.

TRICO (DELANO) GAS FIELD
Howard, P. J. 39; Kaplow, E. J. 38; Musser, E. H. 30; 39; Oil and Gas Journal 41f; Rousselot, N. A. 35; Stockman, L. P. 36a; 40e.

ALLENSWORTH AREA
Collom, R. E. 21d, p. 24.



Trico gas field.

STRATIGRAPHIC SECTION OF THE TRICO GAS FIELD.

E.C. DOELL

Geological Column.				Approx. Thickness in feet.
Recent	Alluvium.			1900 ± (Alluvium and Tulare Formation together)
PLEISTOCENE	Tulare Formation - Sandy clays, clays and water sand.			
PLEISTOCENE	SAN JOAQUIN CLAYS	A Zone	Tan clay.	550
PLEISTOCENE	SAN JOAQUIN CLAYS	1st Mya Zone	Blue clay with thin sands.	35
PLEISTOCENE	SAN JOAQUIN CLAYS	B Zone	Interlaminated green clay and gray silt with few thin beds of sand.	600
PLEISTOCENE	SAN JOAQUIN CLAYS	2nd Mya Zone	Sandy gray clay with thin sands.	100
PLEISTOCENE	SAN JOAQUIN CLAYS	C Zone	Brown clay.	215
PLIOCENE	SAN JOAQUIN CLAYS	3rd Mya Zone	Silty gray clay.	10
PLIOCENE	SAN JOAQUIN CLAYS	D Zone	Interlaminated green clay and gray silt.	205
PLIOCENE	SAN JOAQUIN CLAYS	E Zone	Green, blue and brown clays with zone of interlaminated gray clay and silt.	270
PLIOCENE	ETCHEGOIN	Siltstones, tight sandstones; mostly silty shale toward base.		3450 ±

Fig. 242. Trico gas field: stratigraphic section.

WASCO OIL FIELD*

By Roy M. Barnes **

OUTLINE OF REPORT

INTRODUCTION

Wasco oil field is located in southern San Joaquin Valley approximately 4 miles west of the town of Wasco in northern Kern County. The field was discovered April 11, 1938, by completion of Continental Oil Company well No. "K.C.L." A-2, in Sec. 8, T. 27 S., R. 24 E., M. D. The accompanying index map, stratigraphic column of the deepest well, and subsurface structure-contour map should be referred to during reading of the ensuing report.

Early exploratory interest in the Wasco-Semitropic area was localized along a low-lying northwest-trending topographic high known as Semitropic Ridge, which is 8 miles southwest of the town of Wasco. This topographic feature and certain soil changes were recognized as being the probable surface expressions of an anticlinal fold. Exploratory wells indicated that an anticlinal axis in Pleistocene and upper Pliocene sediments lay somewhat to the northeast of the topographic feature. This was later confirmed by reconnaissance seismograph data, which placed the axis of folding in Pleistocene and upper Pliocene 1 to 1½ miles northeast of Semitropic Ridge, but did not indicate any lower Pliocene and Miocene reversal until 3 miles farther to the northeast, in the vicinity of what is now the Wasco oil field.

After the discovery of Semitropic gas field in March, 1935, on the Pleistocene and upper Pliocene line of folding parallel to Semitropic Ridge, more detailed seismograph work was undertaken throughout the Wasco-Semitropic area. Results of this work showed that the deeper fold, above referred to, lies about 4 miles west of Wasco, and suggested a closed area surrounding the southwest corner of Sec. 8, T. 27 S., R. 24 E., M. D. Subsequent seismograph results indicated that this structure lies near the northwest end of a line of folding extending southeastward through what are now the Rio Bravo and Greeley oil fields. As a result of discovery of upper Miocene oil production at Ten Section in June, 1936, available land was leased on the Wasco structure and a drilling exploration program was undertaken by Continental Oil Company.

* The writer acknowledges helpful suggestions by E. H. Vallat and R. W. French of Continental Oil Company.

** Chief Geologist, Continental Oil Company in California. Manuscript submitted for publication July 1, 1941.

DRILLING EXPLORATION

Continental Oil Company well No. "K. C. L." A-1 was spudded November 7, 1936, for the purpose of testing upper Miocene which has proved productive in Ten Section oil field, and shortly thereafter in Greeley oil field. Oil showings in Pliocene fine sands and silts beginning at 7,108 feet were nonproductive. The well was bottomed at 9,591 feet for mechanical reasons and was completed under poor mechanical conditions April 26, 1937, flowing 35 barrels per day of 30 degrees gravity oil from a chert and shale horizon between approximately 9,540 and 9,591 feet. On July 1. 1941, this well was flowing 3 barrels of oil per day. This production is believed to be from the shale equivalent of the upper part of Stevens-Greeley sand zone of upper Miocene in Ten Section, Greeley, and other fields to the south.

Continental Oil Company well No. "K. C. L." A-2 was spudded June 21, 1937, for the purpose of deeper prospecting in upper Miocene, which showed evidence of oil in well No. "K. C. L." A-1. The drill disclosed that upper part of Miocene is entirely shale (yielding oil showings) to top of Olcese sand. By this time Olcese sand had shown evidence of oil (noncommercial) at Rio Bravo, and the Rio Bravo oil field had been discovered in the underlying Rio Bravo-Vedder zone. This made it advisable to prospect ahead in well No. "K. C. L." A-2. The Olcese sand member exhibited low permeability and only minor evidence of oil. A sand showing oil was encountered below 13,100 feet underlying a 400-foot shale body. Later electrical log showed top of this sand at 13,095 feet, indicated it to be about 35 feet thick, with favorable resistivity and permeability characteristics. This sand was later designated the A-2 sand for the reason that it lies stratigraphically higher than the Rio Bravo-Vedder sand zone of Rio Bravo oil field. Drilling and coring below the A-2 sand proceeded in Miocene, through hard tight sands and streaks of siltstone and shale with occasional evidences of oil, to approximately 14,000 feet where Oligocene shale showing oil was encountered. Prospecting for sands in this shale body was decided upon. Oligocene and upper Eocene shales showing oil were penetrated to depth of 14,967 feet and below this depth Eocene hard fine sandstone, siltstone, and altered bentonite were cored to the bottom of the hole at 15,004 feet. The well was plugged and a string of 4½-inch casing with perforations opposite the A-2 sand was cemented in two stages with cement pumped out below and above the sand. A test which started April 11, 1938, resulted in completion of well No. "K. C. L." A-2 for a demonstrated flow of 3,385 barrels of 37+ degrees gravity oil per day with accompanying gas giving the very low average gas-oil ratio of 320 cubic feet per barrel of oil.

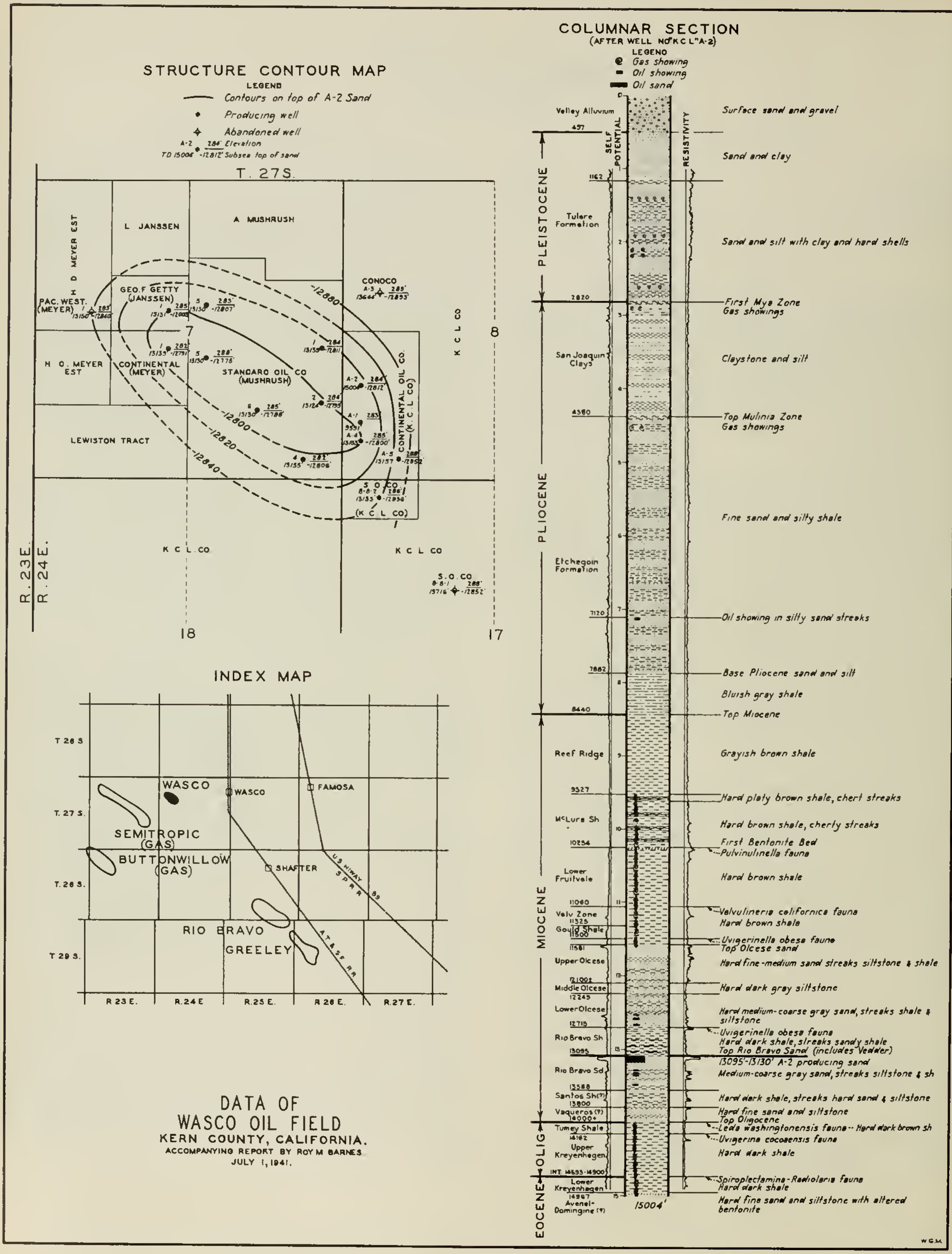


FIG. 243. Wasco oil field: structure map; columnar section; index map.

Two superlatives occur in this narrative: Continental Oil Company well No. "K. C. L." A-2 is the deepest well ever drilled; and it is producing *crude* oil from the greatest depth yet developed. Ordinary drilling equipment was used in accomplishing this feat, but minor changes were made to accommodate increasing depth and greater loads.

DEVELOPMENT DATA

As of July 1, 1941, Wasco oil field contains 12 wells producing the A-2 sand from average depth of more than 13,135 feet. Ownership division of the wells is as follows:

Standard Oil Company of California	7
Continental Oil Company	4
George F. Getty	1

Three nonproductive wells have been drilled into the A-2 sand on the edge of the field, one well by each of the above companies. These wells help delineate productive limits. Initial productions of wells have ranged from 2,500 to 6,500 barrels of 37 to 38 degrees gravity oil per day under varying mechanical conditions. Some wells near the edge of the field do not completely penetrate the A-2 sand. Completion gas-oil ratios have been low; they have averaged 300 cubic feet of gas per barrel of oil.

Present production of the field is approximately 1,740 barrels of 36 to 39 degrees gravity oil per day under proration with average gas-oil ratio of 270 cubic feet of gas per barrel of oil. Water cuts remain low even in edge wells. The field has produced approximately 1,384,000 barrels of oil to July 1, 1941.

Structure of the field at top of A-2 sand is that of an elongated dome of low relief with less than 100 feet productive closure. The productive area is approximately 385 acres. No commercially productive sand has been found in Wasco oil field other than the A-2 sand. Its thickness ranges from 25 to 40 feet. Permeabilities of this sand are much higher than those of other Miocene sands in the area and range as high as 2,200 millidarcys with a porosity range of 11 to 24 percent. Aside from a few tight streaks the average permeability is at least 300 millidarcys.

Original reservoir pressure at 13,134 feet well datum was determined as 5,675 pounds per square inch, which is normal value for hydrostatic gradient. After more than 3 years of productive life, average reservoir pressures have decreased only slightly. Productivity indices of individual wells have been calculated to be between 5 and 8 barrels of oil per pound drop in pressure. The oil is extremely undersaturated with gas. There is apparently no gas cap. An interesting aspect of solubility conditions in this field was the high ratio of initial reservoir pressure to the bubble-point pressure at reservoir temperature, namely, 3.8 to 1. This phenomenon was manifested in the discovery well by presence of fluid at the surface during both shut-in and flowing tests. High percentage recovery should result if production rates continue to be controlled within the limits imposed by water entry and pressure decrease. When productivity and pressure data are correlated with the evidence of flowing water in off-structure dry holes in the A-2 sand it becomes quite apparent that the oil accumulation is of the hydrostatic type and that the lifting force is that of an active water drive.

Temperature of the A-2 sand has been determined as 277 degrees Fahrenheit and the temperature at the bottom of the 15,004-foot well has been estimated as 297 degrees Fahrenheit. A study of subsurface temperature data from other areas in California indicates that Wasco is relatively cool.

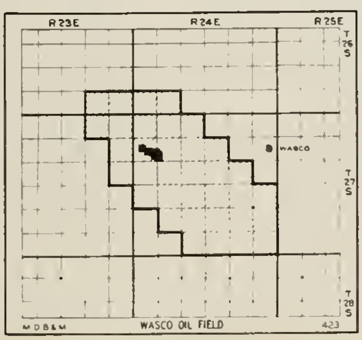
Well No. "K. C. L." A-2 penetrated the A-2 sand in 234 days and was completed in 284 days, including plugging back from 15,004 feet. The average time for completion of subsequent producing wells is 102 days and the minimum time is 73 days.

Considerable difficulty during drilling has been caused by flowing waters in Pliocene and upper Miocene. An intermediate string of conductor casing was found necessary except under achievement of delicate mud control. Casing programs have varied as follows:

Surface Pipe: 500 feet to 1,500 feet of 10$\frac{3}{4}$-inch to 16-inch casing
Protective string: 5,400 feet to 11,580 feet of 6$\frac{5}{8}$-inch to 9$\frac{5}{8}$-inch casing
Water string: 11,573 feet to 13,100 feet of 4$\frac{1}{2}$-inch to 7-inch casing
Oil string: liner of 2$\frac{7}{8}$-inch, reduced because of mechanical trouble, to 5-inch casing cemented through perforations when water string is high

The diminutives in this narrative are the small thickness of productive sand; low gas-oil ratios; low structural relief; small productive closure; and restricted area of production. Although oil production per acre-foot will be quite large because of high permeabilities and water drive, ultimate production of the field will be small, probably between 6,000,000 and 8,000,000 barrels of oil, because of limited thickness and areal extent of productive sand.

CITATIONS TO SELECTED REFERENCES—Continued



Wasco oil field.

WASCO OIL FIELD

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RIO BRAVO OIL FIELD*

By EARL B. NOBLE **

The Rio Bravo field, 15 miles northwest of Bakersfield, Kern County, was the third in a series of oil fields discovered as a result of reflection-seismograph work in the relatively flat, alluvium-covered part of the San Joaquin Valley. The discovery well, the Union Oil Company's No. "Kernco" 1-34 (now designated 85-34), was spudded March 29, 1937. The top of the Rio Bravo sand was encountered at 11,240 feet and the well completed November 4, 1937, at a total depth of 11,302 feet, flowing 38.7 degrees gravity oil at the rate of 2,400 barrels per day through a $^{40}/_{64}$-inch bean with a pressure of 1,500 pounds on the tubing and 1,700 pounds on the casing. The oil was clean, cutting less than 0.1 percent, and was accompanied by a flow of gas estimated at 2 million cubic feet.

The first few wells compelted in the field took only the limited penetration of the discovery well. The Superior Oil Company's No. "Ruhl" 1 was the first to drill through the grit zone into the lower sand. Since then, it has been general practice to complete the wells with both sands open.[1] Penetration into the oil sand has varied throughout the field from 21 feet in the Superior Oil Company's No. "Moody" 1 to 394 feet in the Superior's No. "Osborne" 1-1. The majority of the wells take about 200 feet of penetration, of which 70 to 80 percent is oil sand. Average porosity of the sand is 22 percent. The permeability ranges from 100 to 1,300 millidarcys, the average being 450 for the better part of the field. There are now 87 wells producing, 2 abandoned, and 3 drilling. Present production from the field is 12,000 barrels per day; the official potential for May was set at 333,606 barrels per day. Total production of the field to May 1, 1941, is 9,592,405 barrels.

Rio Bravo was the first field in the State to produce from sands below 11,000 feet, and for awhile the discovery well was the deepest commercially productive oil well in the world. The action of this well demonstrated conclusively that depth is not necessarily an unfavorable factor. All the wells are producing from below 11,000 feet, but owing to the ease and speed with which they can be drilled, their cost is not excessive. Most of the recent wells have been completed in 34 to 50 days. This speed was made possible by the use of heavier equipment, improvement in drilling technique, and careful control of the drilling fluid. Very few cores are taken, and most of the correlating is done with electric logs. Some operators drill into the oil sand before setting casing, while others prefer to drill to within a few feet of the estimated top of the sand, check their position by an electric log and then set casing before entering the sand.

Present development program is to drill 1,500 to 2,000 feet with $12\frac{1}{4}$-inch bit, ream hole to $15\frac{1}{2}$ or $17\frac{1}{2}$ inches, and set $12\frac{3}{4}$ or $13\frac{3}{8}$-inch surface casing, drill with 11-inch bit to the top of the Rio Bravo sand or drill with $11\frac{3}{4}$-inch bit to 6,100 feet and reduce to 11 inches until immediately above the sand, cementing a 7-inch or $5\frac{1}{2}$-inch water string; finish with 5-inch or $5\frac{1}{2}$-inch liner through the 7-inch or 4-inch flush liner through the $5\frac{1}{2}$-inch water string. Several wells have been completed satisfactorily without the use of a liner.

Accumulation is apparently controlled by a northwest-trending anticline having a closure in excess of 350 feet. Present productive area covers about 2,000 acres. The limits of the field are well defined in every direction but northwest. Correlation between Superior No. "Osborne" 1-1, the highest well in the field, and Superior No. "Riggs" 1, an unsuccessful attempt to extend the field northwesterly, indicated a steep northwest plunge which has been substantiated by recent drilling. Therefore, it seems certain that the northwest edge of production will be found shortly.

There is some evidence to suggest the presence of a fault along the northeast flank of the field (possibly of the rift type), but whether this flank is bounded by a fault or a relatively sharp syncline can not be determined until additional wells are drilled. Also, a small normal fault is indicated from well control, trending approximately north between Union Oil Company No. "Crites" 72 and Superior No. "Osborne" 1-2. This fault has a throw of approximately 150 feet (up to the west) at the north end of the field and dies out to the south. It apparently does not affect production.

The formations encountered in drilling are shown on the generalized stratigraphic column accompanying the contour map of the field. It is interesting to note that the Greeley sand, productive in the Greeley field to the southeast, is not present at Rio Bravo as a sand. The interval cored in the discovery well from 8,463 to 8,690 feet is probably the equivalent of the Greeley zone but, excepting $1\frac{1}{2}$ feet of silty oil sand, it is made up entirely of hard brown shale.

Only one well, the Superior Oil Company's No. "Helbling" 1, has been drilled below the present producing zone. This well encountered a fault at about 10,000 feet and apparently was in a fault zone for the next 2,000 to 3,000 feet, as many of the cores showed slickensiding, brecciation and erratic dips. The lower part of the hole was logged as hard, brown to gray shales and hard, medium to fine sandstones. The well was abandoned at 14,018 feet in what is generally believed to be basement rock.

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* Originally published under Geological Notes in Volume 24, Number 7 (July, 1940), Bulletin of the American Association of Petroleum Geologists, and now revised as of May 15, 1941.

** Union Oil Company.

[1] In the field, the part of the Rio Bravo zone above the grit is commonly referred to as the "Rio Bravo sand" and the part below as the "Vedder sand."

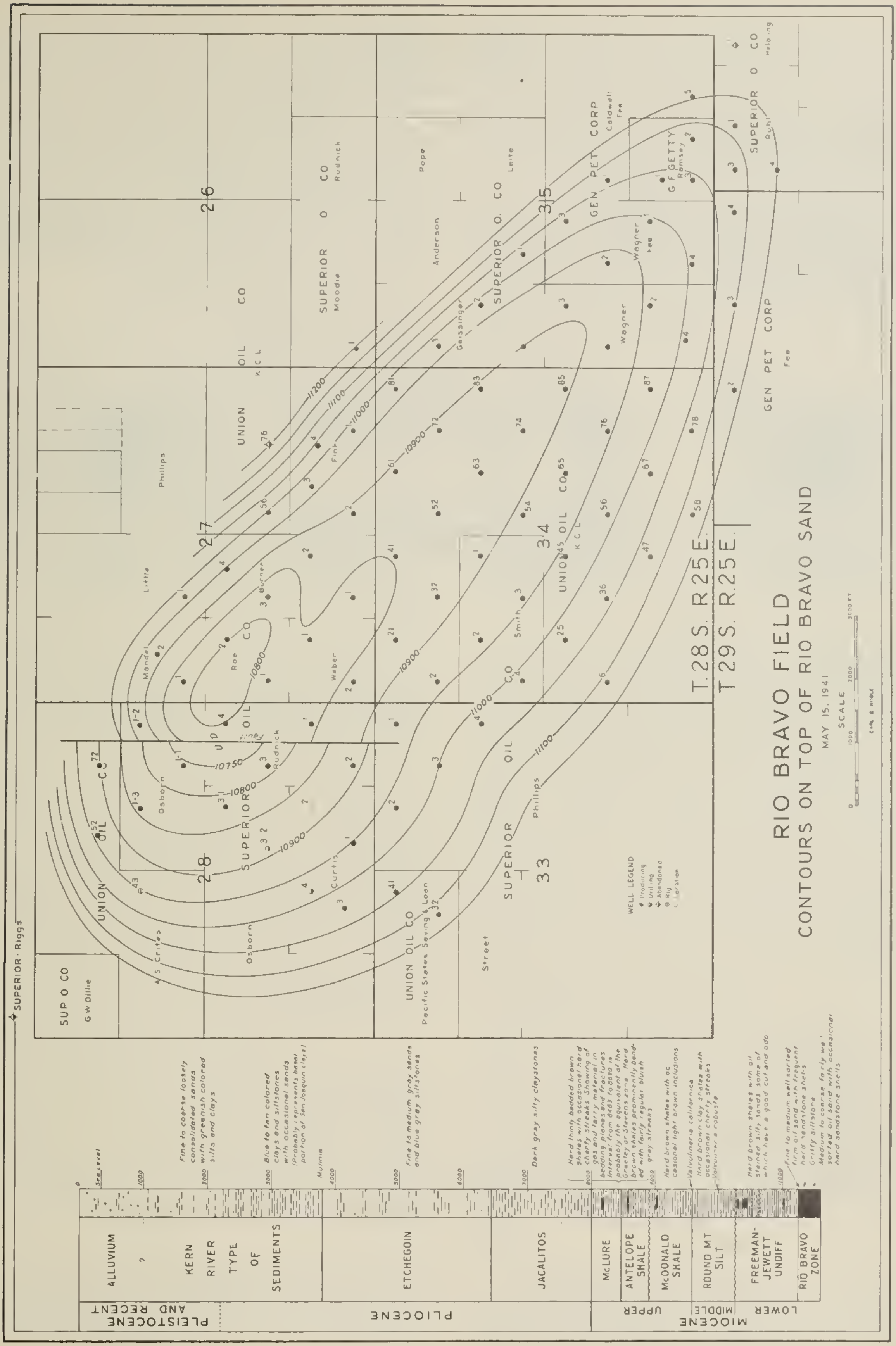

FIG. 244. Rio Bravo oil field: columnar section; structure map.

The field is characterized by having only one producing zone and this entirely below 11,000 feet. Many of the wells, if opened, could produce in excess of 10,000 barrels per day. No attempt has been made to establish individual potentials and each well as completed is immediately restricted to conform to the field allowable which at present is 142 barrels per day per well. Gas-oil ratio is relatively low, averaging about 1,200 cubic feet per barrel.

Only four wells have shown evidence of water and these are at the southeastern end of the field. In three, the water is attributed to edge conditions and in the fourth, to excessive penetration. To minimize paraffine trouble some of the wells are produced at rates of 400 to 900 barrels per day until their monthly allotment is made and then shut in for the remainder of the month.

Original bottom-hole pressure was 4,800 pounds per square inch and at the present rate of production, a decline of approximately 150 pounds per year is indicated. Bottom-hole temperature is approximately 250 degrees Fahrenheit. The oil ranges in gravity from 36 degrees to 41 degrees, has about 46 percent of 425 degrees end-point gasoline, 33 percent of 725 degrees end-point gas oil, and 20 percent residuum. The sulphur content ranges from 0.2 to 0.4 percent. Knock rating ranges from 56 to 61. The oil has the general characteristics of a waxy base crude similar to that in Kettleman Hills and the deep zones at Santa Fe Springs.

CITATIONS TO SELECTED REFERENCES—Continued

RIO BRAVO OIL FIELD

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GREELEY OIL FIELD

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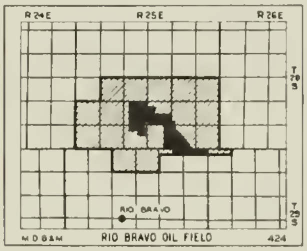
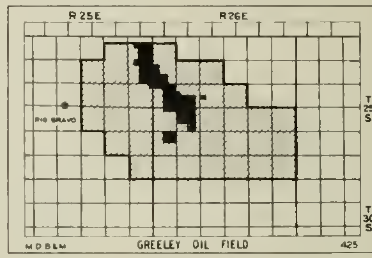


Rio Bravo oil field.



Greeley oil field.

GREELEY OIL FIELD

By W. P. Winham *

OUTLINE OF REPORT

HISTORY

The Greeley oil field is located on the floor of the San Joaquin Valley about 10 miles west and a little north of Bakersfield, in Kern County. As of October 1, 1940, the Greeley oil field had an estimated potential of better than 220,000 barrels of oil. 3,400 barrels from the upper or Stevens sand, and the balance from the Vedder sand.

There are no outcrops and little if any topographic evidence in the vicinity of the Greeley oil field to give a clue as to the presence of structures in this area. The discovery of the Greeley field was a direct result of extensive seismic work carried on by the Standard Oil Company in this general area during 1934 and 1935.

On December 22, 1936, the Standard Oil Company of California completed its K. C. L. 11 No. 1 well, located in the northeast corner of Sec. 19, T. 29 S., R. 26 E., M. D., for 2,600 barrels of 37 degrees gravity oil along with 2,500,000 cubic feet of gas. It flowed through one $^{96}/_{64}$-inch tubing bean under a tubing pressure of 230 pounds and a casing pressure of 1,105 pounds. Production was from the Stevens sand (upper Miocene) which was topped in this well at 7,740 feet and penetrated to 7,807 feet.

On October 20, 1937, Standard Oil Company completed well K. C. L. 12 No. 2 in Sec. 16, T. 29 S., R. 26 E., M. D., flowing 3,304 barrels per day of 30.5 degrees gravity oil, with 2,390,000 cubic feet of gas through two tubing beans, $^{48}/_{64}$-inch and $^{62}/_{64}$-inch, and one casing bean, $^{96}/_{64}$-inch, under 110 pounds tubing pressure and 145 pounds casing pressure. Subsequent development has shown that the accumulation in the K. C. L. 12 No. 2 well is not connected with the oil accumulation of the Greeley oil field. It is from 30 feet of satuarted oil sands of the Stevens sand, found below 7,600 feet. Cause for the accumulation in well K. C. L. 12 No. 2 is considered to be local lenticular conditions.

Later, Standard Oil Company well K. C. L. 11 No. 2, Sec. 20, T. 29 S., R. 26 E., M. D., which had failed as a Stevens sand producer, was deepened to the Vedder sand (lower Miocene) and completed as a 14,000-barrel well of 35.1 degrees gravity oil, along with 18,120,000 cubic feet of gas. It flowed under 1,190 pounds tubing pressure and 770 pounds casing pressure through one $^{16}/_{64}$-inch tubing bean and two casing beans of $^{64}/_{64}$-inch and $^{96}/_{64}$-inch.

The Stevens sand horizon has been completely drilled by some 15 wells with a proved area of 500 acres. The total production from the Stevens horizon to October 1, 1940, was 2,305,182 barrels of oil and 12,239,202,000 cubic feet of gas. Only about one-third of the wells producing from the Stevens sand are still flowing.

The development of the Vedder sand horizon is fairly well advanced with some 25 wells having been completed to October 1, 1940. A moderate initial estimate for Vedder sand producers would range from 5,000 to 15,000 barrels per day. Under proration no large flow tests are made. The areal extent of the Vedder sand is much greater than that of the Stevens sand, and it is estimated that the Vedder pool will include about 1,900 acres.

STRATIGRAPHY

The general stratigraphic section of the Greeley oil field is fairly well known from cores and from electric logs. It is graphically represented on the accompanying chart.

The total thickness of sediments above the basement complex is estimated to be 13,700 feet. The oldest rocks penetrated in the field to date were cored in Standard Oil Company well No. "Elrich Community" 1, in Sec. 20, T. 29 S., R. 26 E., M. D. This well was drilled to a depth of 13,538 feet and penetrated about 40 feet of sand of Eocene age.

The Pleistocene-Pliocene section, which includes the Kern River, Etchegoin, and Chanac formations, has a combined thickness of 6,900 feet. These formations for the most part in the Greeley area are composed of interbedded greenish-gray and bluish-gray shales and sands. The lowermost 600 feet is a somewhat more compact bluish-gray shale, which is clayey in places.

The upper Miocene, which is composed of the Reef Ridge formation, upper and lower Fruitvale shale (Stevens sand in the upper Fruitvale), Round Mountain silt, and Gould shale, has a thickness of 3,650 feet. With the exception of the Stevens sand, the section is made up of predominantly brown shales and brown siltstones. The middle Miocene, including Freeman silt (not recognized here), Olcese sand, and Jewett silt, is 750 feet thick with 5 to 25 feet of fine-grained sands of the Pyramid Hills sand at the base. The lower Miocene which includes the Vedder sand and lower Miocene shales is approximately 600 feet thick.

Oligocene and Eocene brown siltstones, sands, and shales have a thickness of 1,250 feet. Although no separation is possible because core data are incomplete, nevertheless the Eocene sands and shales are estimated to have a thickness of 500 feet. In all probability they lie upon the basement complex. The Eocene sand was topped in the off-structure Standard Oil Company well No. "Elrich" 1, Sec. 20, T. 29 S., R. 26 E., M. D., at a depth of 13,538 feet. It penetrated 43 feet of fine- to medium-grained, well-sorted quartz sand, calcareous in places.

STRUCTURE

The structure of the Greeley oil field is that of a northwest-trending anticline about 4 miles long and 5,000 feet wide, and is located on the general Wasco-Rio Bravo-Greeley trend. Developments to October 1, 1940, give a fairly good idea of the structure, and the effective

* District Geologist, Standard Oil Company of California, Northern District. Manuscript submitted for publication October 30, 1940.

closure for the anticline is about 300 feet. Other details on the structure show the presence of three small closures with the highest dome located in the central part of the SW¼ Sec. 7, T. 29 S., R. 26 E., M. D.

Inspection of the contour map will show that within the productive area of the Stevens sand the dip of the Stevens sand is to the northwest, whereas the dip of the Vedder sand within the same area is to the southeast. This condition can be explained by a two-stage folding—an earlier folding in lower Miocene time and a later folding which involved the uppermost Miocene beds but was not of sufficient magnitude to reverse the stronger dip of the lower Miocene beds.

PRODUCTIVE HORIZONS

Stevens Sand

The Stevens sand was first discovered in the Ten Section oil field, about 7 miles south of the Greeley oil field. Intervening well data give good evidence for the belief that the upper Miocene sands in the Greeley oil field have the same stratigraphic position in the geologic section as the Stevens sand at Ten Section field. Accordingly, the name Stevens sand has been applied to the sand at Greeley.

The age of the Stevens sand in the Greeley field has been the subject of much discussion, the general consensus now being that the sand is of upper Miocene age and that it probably occurs in the upper half of the Fruitvale shale.

The Stevens sand was deposited under near-shore conditions. It is a part of a great sand wedge which extended from the south and southeast part of the San Joaquin Valley and has a maximum thickness of 1,800 or 2,000 feet. In the Greeley area, the Stevens sand is on the north edge of this sand wedge where the greatest sand thickness is 600 feet in the NE¼ Sec. 20, T. 29 S., R. 26 E., M. D. The sand thins rapidly to the northwest and north of the Greeley field, only a few feet of the Stevens sand being present in the Rio Bravo oil field about 4 miles away. Within the productive area at Greeley there are local facies changes, the lithology varying from sand to silt and shale in an up-dip direction, which in conjunction with the west-plunging nose has brought about oil accumulation in the uppermost part of the Stevens sand. This change in lithology is the direct cause for the termination of production in the area just southeast of the center of Sec. 20, T. 29 S., R. 26 E., M. D.

Because of the irregular upper surface of the sand in the Greeley area, it has been necessary to choose a datum above the top of the Stevens sand to show correctly the structure on the accompanying map. Contours are drawn on a "sub-chert marker" of the electrical logs. The interval from this marker to the top of the Stevens sand varies from 20 to 150 feet.

The thickness of oil saturation in the Stevens sand varies from a few feet to a maximum of 175 feet. In general, the oil sands are medium grained to coarse, with considerable silt.

Vedder Sand

The Vedder oil sand, on the higher parts of the Greeley oil field, is found at a drilling depth of 11,260 feet, directly below a 5 to 10-foot impervious pebble zone. Over much of this area the pebble zone is overlain by 20 to 30 feet of fine-grained sand known as the Rio Bravo sand.

The Vedder sand is approximately 600 feet thick. It is predominantly sandy in the upper 350 feet, but in the lower 250 feet some sizable shale bodies and interbedded fine and coarse sands are present. No well located on the structurally high part of the Greeley field has penetrated a complete Vedder oil sand section. Greatest thickness of saturated oil sands to date is 250 feet. The porosity and permeability of the Vedder sand are much better than those of the Stevens sand, some streaks having a permeability rating between 4,000 and 5,000 millidarcys.

The accumulation of oil in the Vedder sand is the result of simple anticlinal folding, wherein a blanket porous sand (Vedder sand) is overlain by an impervious cover.

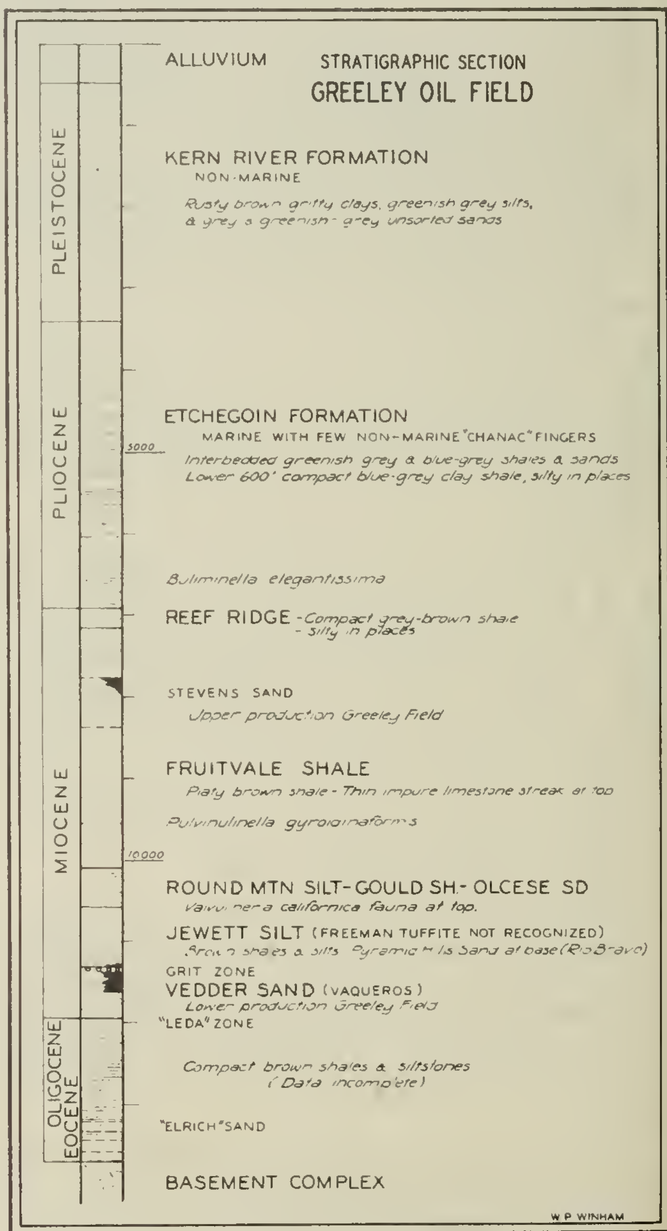


Fig. 245. Greeley oil field: stratigraphic section.

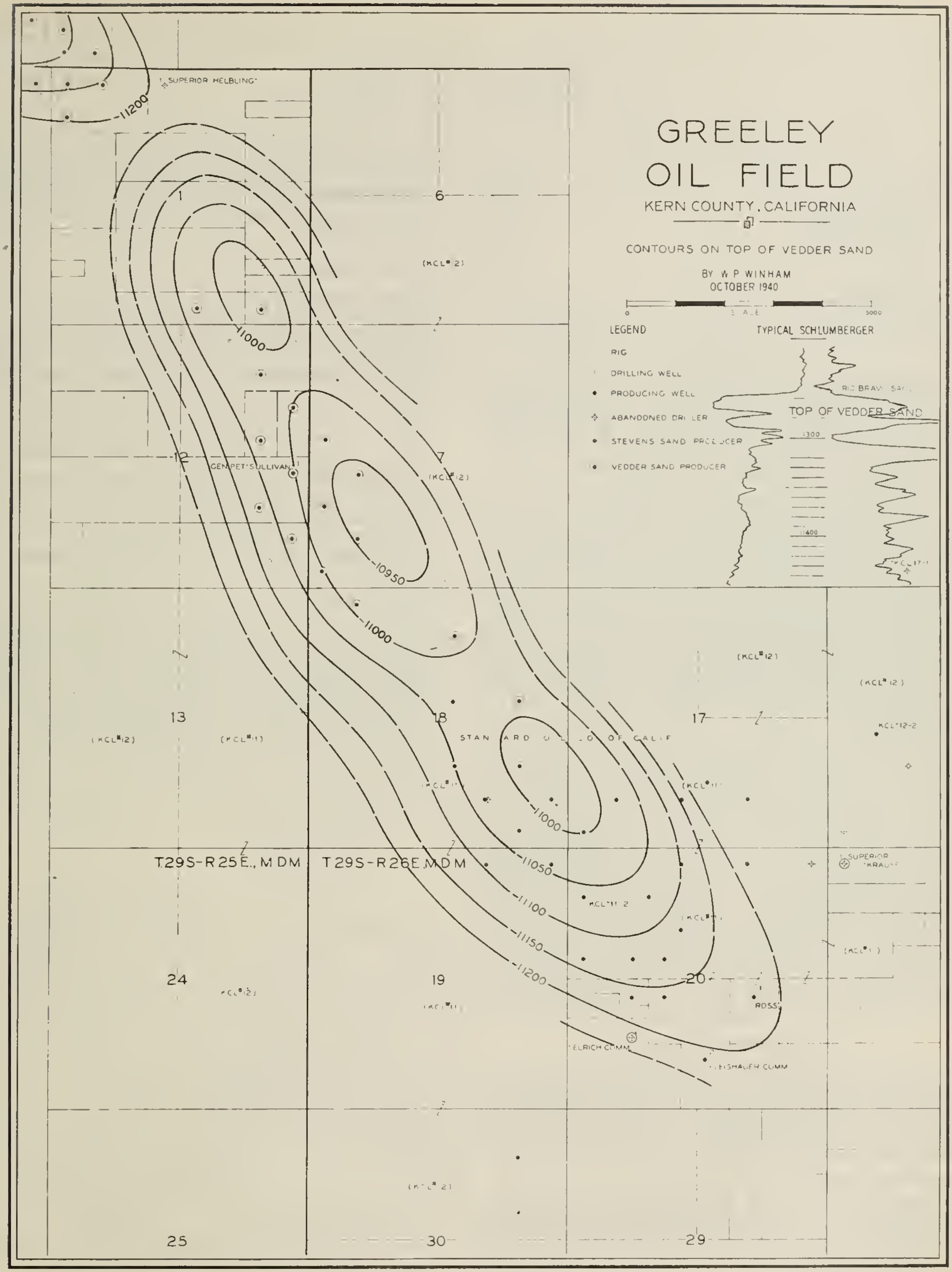


FIG. 246. Greeley oil field: structure map.

FRUITVALE OIL FIELD

By ROBERT H. MILLER* and GLEN W. LEDINGHAM*

OUTLINE OF REPORT

HISTORY

The Fruitvale oil field is located about 2 miles west of Bakersfield, Kern County, on the eastern side of the San Joaquin Valley. The production is mainly confined to Secs. 14, 21, 22, 23, and 27, T. 29 S., R. 27 E., M. D., although minor production is found in Secs. 15, 26, 28, and 29 of the same township and range.

The discovery well was the Western Gulf Oil Company No. "KCL-B" 1, located in the NE¼ Sec. 21. The area was drilled after a study of the topography. No. "KCL-B" 1 was spudded on October 10, 1927, and completed February 9, 1928. A 10¾-inch water string was cemented at 3,835 feet and the total depth of the well was 3,849 feet. Thirty days after completion the well produced 179 barrels per day of 23.2 degrees gravity oil, with a total cut of 0.2 percent. In June 1929, the well was deepened to 6,191 feet without finding further production, plugged back to 4,024 feet and recompleted in this zone.

Development work to the southeast followed slowly, being restricted by the lack of demand for the oil. The Mohawk Petroleum Company drilled on its leases in Secs. 21 and 27; offset wells were drilled, carrying the development work into the SE¼ Sec. 21 and the NW¼ Sec. 27. Concurrently the Seahawk Petroleum Company drilled well No. 1-C in Sec. 23, and development work in this area began. The development of Secs. 22 and 27 by the Western Gulf Oil Company continued as lease obligations became due. In October, 1935, the S. & G. Oil Company started a well in Sec. 26, which led to the development of this small isolated area, and in January, 1936, Dixie Lee Oil Company spudded its No. 2 well in Sec. 23, proving the Fairhaven sand of the Etchegoin; development followed rapidly to the northeast.

STRATIGRAPHY

From the surface down, the sequence of formations includes: Alluvium (Recent); Kern River (lower Pleistocene to middle Pliocene); Etchegoin (Pliocene); Chanac and "Santa Margarita" (probably upper Miocene), and older formations.

Kern River Formation

The Kern River formation consists of a series of continental sands and clays and gritty siltstones, ranging in texture from gravelly to fine, generally micaceous. The sands are gray and brown colored and the clays and silts are bluish-green to brown. The thickness is about 2,600 feet and the formation carries no oil or gas within the limits of the field.

Etchegoin Formation

The marine or brackish-water sediments of the Pliocene of Fruitvale are believed to be a sandy facies of the *Macoma* claystone member of the Kern Front and are referred to lower Etchegoin or possibly upper Jacalitos. This claystone member is characteristically recorded on the electric logs of the Kern Front area, and can be traced by electric logs around the west end of the Fruitvale field. Toward the east the claystone member becomes interbedded with sand bodies and gradually loses its identity, although electric log correlations can be carried through on marker beds within the member. The change is apparently a facies change and is not accompanied by any discernible unconformity; nor can unconformities be detected at the top or bottom of this formation.

Within the Fruitvale field, the formation is composed of gray micaceous sandy shales and medium- to fine-grained sands. Carbonaceous matter is abundant and occasional thin beds of lignite are also found. The basal beds of this formation have yielded a rather poorly preserved megascopic fauna, characterized by poorly preserved fossil casts of sea shells resembling *Macoma* and including *Siliqua lucida, Macoma kerica, Arca trili-*

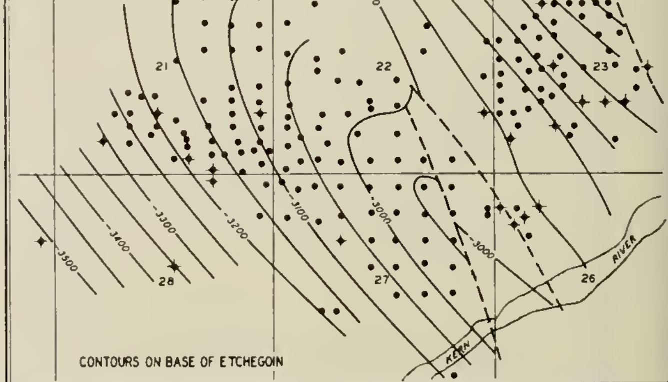


FIG. 247. Fruitvale oil field: structure map.

* Western Gulf Oil Company. Manuscript submitted for publication December 29, 1939.

neata, and *Vosella recta*. The lower contact of this formation is a rather abrupt change from marine to continental sediments, often difficult to distinguish within a short interval in well cores.

The lower contact of the Etchegoin has been taken from electric logs at a point which corresponds with the change of lithology in the cores in the main part of the field, when this change is definite. However, toward the west, the marine facies persists down into beds which are correlated as "Chanac" on electric logs; and in the southeast, the continental facies persists up into beds similarly correlated as Etchegoin. Where no electric log has been made, the point is chosen on the basis of lithology. In Secs. 14 and 23, many wells bottomed just before reaching the base of the Etchegoin, in which cases the base was estimated. The basal sands of the Etchegoin carry oil and tar in some parts of the field and produce oil in the higher parts of the Fairhaven district and in the higher part of the main field in Sec. 27. Within the field, the Etchegoin formation has a thickness of about 400 feet.

"Chanac" Formation

The sediments of the "Chanac" formation are similar to those of the Kern River formation. The sands are pebbly to fine grained, angular and micaceous, and are often highly feldspathic and of low porosity. The siltstones and claystones are usually poorly sorted, sandy, micaceous, and greenish gray. Toward the lower part of the "Chanac" the claystones and siltstones have a mottled reddish-brown and greenish-gray color, and are sometimes a deep reddish brown in color. Within the field, the "Chanac" formation has a thickness of about 1,100 feet. Toward the southwest, marine or brackish-water lenses appear within the "Chanac," and farther west the beds become entirely marine in character.

The lower contact of the "Chanac" is apparently gradational into Santa Margarita sands. The fauna of the "Chanac" is meager and not diagnostic; however, from general geological criteria it is now thought to be a continental facies of the lower part of the Jacalitos (Pliocene), Reef Ridge, and upper brown shale (Miocene).

"Santa Margarita" and Lower Formations

The upper 600 feet of the "Santa Margarita" is predominantly fine to medium gray sand with abundant fossil remains, including *Pecten discus*, *Venerupis staminea*, *Glycymeris septentrionalis*, and *Macoma wilsoni* and is underlain by fine sandy dark-gray shale, containing abundant carbonaceous material and fish scales, interbedded with soft, well-sorted micaceous gray sand.

With the exception of Standard Oil Company of California well No. "5-KCL" 2 in Sec. 24, which produced a small amount of oil from the "Santa Margarita," no oil or gas has been produced from this formation, although poor oil sands of probable "Santa Margarita" age have been cored in a few wells in the area. The "Santa Margarita" formation is sometimes locally subdivided into an upper Fruitvale carbonaceous sand division and a lower upper Fruitvale shale division.

Only a few wells have been drilled below the "Santa Margarita" formation. Western Gulf Oil Company well No. "KCL-B" 8, which was drilled to a depth of 7,725 feet, probably encountered the top of the lower Fruitvale shale at about 7,050 feet, and the top of the Round Mountain silt equivalent at about 7,340 feet. The Meridian Petroleum Corporation well No. "Fee" 2 was drilled to a depth of 8,534 feet. This well encountered the top of the lower Fruitvale shale at 5,122 feet; the Round Mountain silt equivalent at 5,632 feet; the Vedder sand at 7,740 feet; and the basement at 8,527 feet.

STRUCTURE

The Fruitvale field consists of a low-relief fold or terrace on the Kern River uplift. Accumulation of oil is probably due to a combination of folding or terracing and minor faults, some of which are shown on the structural map, and is influenced considerably by the porosity of the sand bodies. The field may be divided into three distinct areas: (1) the main field, occupying the southwest half of Sec. 22 and extending into Secs. 21, 27, and 28; (2) the Fairhaven district, in Secs. 14 and 23; and (3) a minor productive area in Sec. 26, that extends into Secs. 22 and 27.

The main area of the Fruitvale field is a very low-relief dome whose high point is in the NE¼ Sec. 27. The closure on the northeast is probably due to a series of small faults; however, the evidence is mostly inferential. One well, Western Gulf Oil Company No. "Red Ribbon" 5, passed through a fault just below the base of the Etchegoin, which cut out about 50 feet of beds. This is consistent with the assumption that the dome is closed on the northeast by a normal fault, downthrown on the northeast with a corresponding amount of displacement. Tracing the fault to the northwest and southeast is rather a matter of speculation; the fault can only be projected between wells in which the production characteristics are different, or where there is a sharp change in the direction of the structural contours.

Northeast of the main field, the formations are also productive in the same horizons, although the wells are generally smaller Here the formations rise fairly uniformly to the northeast at about 500 feet to the mile. This monocline is productive in the west half of Sec. 23 and in the SW¼ Sec. 14. The production in this area is bounded on the northeast by a sharp line, which for no other reason is assumed to be a small fault.

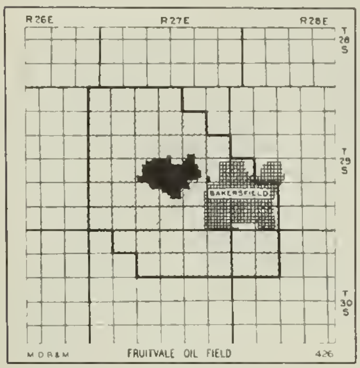
Between these two areas is a narrow strip, productive in its higher part, and bounded on the northeast by a small fault.

PRODUCTIVE HORIZONS

The shallowest producing horizon on the Fruitvale field is the basal sand of the so-called Etchegoin formation. The productive extent of this sand is very limited, being confined to the higher parts of the main field and to that part of the Fairhaven area adjacent to the fault. There is at the most about 40 to 50 feet of productive sand, with a fairly high permeability. Because of the relatively small thickness of sand and the close spacing of the wells in the Fairhaven area, water encroachment and the decline of the wells have been rapid. The sand is generally known as the Fairhaven sand from its prominent development in that area. The underlying Chanac oil zones are known by a multitude of names. None of the zones is adequately defined, and in all probability they overlap. Since deposition is lenticular, individual sand zones which have been specifically named can not be treated precisely from well to well; however, in the main part of the field, so-called Parker, Martin, and Kernco zones appear about 50, 200, and 400 feet respectively below the base of the "Etchegoin" formation. In general, the lower zones have the greater extent.

KIND OF OIL AND GAS

The oil of the Fruitvale field has a waxy asphaltic base and low gasoline content. Its gravity ranges from about 14 to 23 degrees, according to the producing horizon and location. In general, the gravity of the oil in any particular zone decreases to the east. The gravity of the oil in the Etchegoin sands ranges from about 14 to 17 degrees, and in the Chanac sands from about 17 to 23 degrees. The gas-oil ratio is low, and averages about 50 cubic feet to the barrel. The gasoline content of the gas is low. The naphtha content of the oil ranges from 4 percent to 8 percent, and the Etchegoin oil contains about 23 percent lube stock.



Fruitvale oil field

CITATIONS TO SELECTED REFERENCES—Continued

FRUITVALE OIL FIELD

Cadle, A. 28; Clark, R. W. 40a; Clements, T. 36; Clute, W. S. 36; Gale and Scofield 31; Godde, H. A. 26b; Howard, P. J. 39; Musser, E. H. 30; 39; Oil Weekly 37b; Petroleum World 29a; Preston, H. M. 31; Stockman, L. P. 35i; Taff, J. A. 34; Wagy, E. W. 27.

Fairhaven Area

Miller, R. H. 38.

Hensley Area

Preston, H. M. 31.

Lahore Area

Preston, H. M. 31.

Union Avenue Area

Cadle, A. 28; California Oil World 41b; 42; Petroleum World 29a; Stockman, L. P. 41b; 41d; 41i; Wagy, E. W. 27.

BAKERSFIELD REGION

Clark, A. 41; Keen, A. M. 39.

MOUNTAIN VIEW OIL FIELD

Atwill, E. R. 40; California Oil World 33a; Clements, T. 36; Clute, W. S. 36; Gow, K. 35; Hoots, H. W. 38; Howard, P. J. 39; Miller and Bloom 37; Musser, E. H. 30; 39; Oil Weekly 37b; Petroleum World 30; 33a; 35; Porter, W. W. II 38; Stockman, L. P. 35f; 35h; 35i; Uren, L. C. 37; Wilhelm, V. H. 38; 40.

Arvin Area

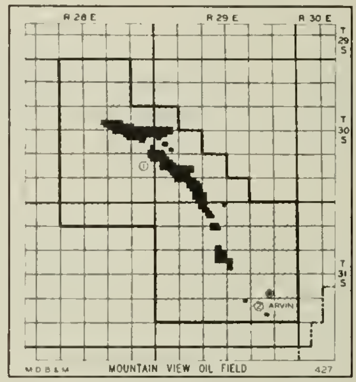
Hoots, H. W. 38; Kasline, F. E. 39; Stockman, L. P. 36k; Wilhelm, V. H. 38.

South Mountain View Area

Porter, W. W. II 39b.

Weed Patch (Mountain View) Oil Field

Petroleum World 30; 33a; Wilhelm, V. H. 32.



Mountain View oil field. Areas: (1) Mountain View; (2) Arvin.

MOUNTAIN VIEW OIL FIELD

By Robert H. Miller * and Glenn C. Ferguson **

OUTLINE OF REPORT

INTRODUCTION

The Mountain View oil field is located near the southeast end of the San Joaquin Valley, extending in a northwesterly direction from the Arvin area to a few miles southeast of Bakersfield. It traverses diagonally the area formerly known as the "Weed Patch." The field consists of four or possibly five separate producing areas, each being a separate structural feature. Some of the areas are separated by barren spaces which have been at least partially disproved by drilling. The divisions of the field are generally referred to as the Northwest area, the Central area, the Southeast area, the Southeast Extension and the Arvin area. Each of these divisions in this paper is considered separately in the discussion on structure; however, for convenience in the discussion on stratigraphy, only two divisions have been used, (1) "the Mountain View field proper" (which includes the Northwest area, the Central area, and possibly the Southeast area), and (2) the Mountain View Extension, which includes the Arvin area.

STRATIGRAPHY

The surface beds of the Mountain View oil field consist of sandy loam which, in an unbroken blanket, covers the whole of the Weed Patch area. This presumably grades downward into a series of continental deposits most of which are Pleistocene and Pliocene in age.

Pleistocene and Pliocene Beds

Within the Mountain View oil field proper all of the beds above the Wharton sand, as far as is known, are nonmarine deposits. In the Mountain View Extension field an Etchegoin finger is present between beds locally known as the Kern River above, and the Chanac formation below. With this exception, the Kern River beds grade into the underlying Chanac with no apparent break. Some workers have attempted to distinguish them by means of color, but at best this is an unsatisfactory method, for no two persons can agree on a common point. The Kern River beds, because of their position with respect to the Etchegoin (Pliocene marine finger), are thought to be entirely Pliocene or Pleistocene in age. The Chanac on the other hand grades downward into Santa Margarita sands, and thus it may be in part Miocene in age. The continental beds of the Mountain View field have often been referred to as the Kern River—Chanac series. For the most part this series consists of coarse detrital material which accumulated over a considerable area as an alluvial fan at the base of the Sierra Nevada. The beds consist of lenticular sand, coarse grits, and boulders, intercalated with beds of clay, often with false bedding. In the upper part of the series, the sands and clays are often buff colored; in the lower part the predominant color is greenish gray. The sands are commonly carbonized and the grains are generally angular. Pebbles of white quartz, granite, and schist are common, as also are granite boulders. In the Mountain View Extension field, as previously mentioned, this series is broken by a marine-Etchegoin finger. The general character of these sediments is similar to the nonmarine beds, except that numerous marine and brackish-water megafossils are present, indicating marine deposition.

The productive oil sands of the Chanac formation are in the lower 400 or 500 feet in the Mountain View field, but most of the production from the Mountain View Extension field comes from the marine Etchegoin. The productive portion of the Chanac formation in the Mountain View field is characterized by somewhat finer sediments and predominantly green coloring. The clays are generally bentonitic and light colored and usually gritty, often containing ashy fragments. Pholas, or possibly worm borings, are common, suggesting an approach to marine conditions. This type of sediment grades into and is interbedded with fine, gray, carbonaceous sands which were definitely deposited under marine conditions, as they contain numerous megafossils in different parts of the field.

Miocene

Although the Chanac may be in part Miocene, the Wharton sand is the first definite Miocene.

Wharton Sand. The Wharton sand consists of a fine, carbonaceous, silty sand containing numerous megafossils. The megafossil assemblage obtained from wells having cored this sand is similar to those occurring in the type Santa Margarita, and for this reason the Wharton is often referred to locally as the "Santa Margarita" sand. Judging by its position with respect to underlying beds, it is older than the restricted McLure shale on the west side of the valley, and for this reason it may not be the exact stratigraphic equivalent of the type Santa Margarita, although it is, in general, related to it.

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Upper Fruitvale "Shale." Underlying the Wharton sand is a relatively thin (especially in the east and southeast ends of the field) zone of sandy, carbonaceous siltstone which is here referred to the upper Fruitvale shale of the Fruitvale field, judging from its position with respect to the underlying lower Fruitvale shale.

Lower Fruitvale Shale. The lower Fruitvale shale consists of thinly laminated, silty shale containing numerous Foraminifera and some pearly gastropods. These shales are generaly identified with the appearance of *Pulvinulinella gyroidinaformis*, and associated species. This shale overlaps all older Miocene beds toward the southeast, and in the Mountain View Extension field is resting on the basement. In the Mountain View Extension a few beds of sand as much as 50 feet in thickness are present in the lower portion of this shale member. In the Mountain View field proper, about the only sand present, except at the extreme northern end, is an abundant series of thin sand partings.

Wicker Sand. The Wicker sand is a local term used for the sand separating the lower Fruitvale shale and the Round Mountain silt in the area north and northeast from the Mountain View field. The only well having penetrated this sand to date is Union Oil Company well No. "Wible" 4, located at the northwest end of the field. It is here a relatively tight, poorly sorted, pebbly sand with cobblestones, and containing an abundange of decomposed feldspar. This sand extends downward and replaces the upper part of the Round Mountain silt in this part of the field; however, it does not begin as high stratigraphically as it does farther north.

Round Mountain Silt. In the main part of the Mountain View field the upper Fruitvale shale rests directly upon the Round Mountain silt without any appreciable break in sedimentation. The Round Mountain silt in this area contains an abundance of *Valvulineria californica*, and associated species. *Valvulineria californica* s.s. is confined to the upper part of this member but other related species range to the base. The Round Mountain silt here is used in the sense that it includes all of the shale zone between the base of the lower Fruitvale shale and top of the Olcese sand. The Round Mountain silt in the Mountain View field is not, in the strictest sense, a silt, but it is rather a silty shale, a portion of which is actually platy in character.

Olcese Sand. The Olcese sand is largely a sandy zone within the limits of the middle Miocene. Although this sand may not be directly connected with the type Olcese in the Round Mountain area, it is very closely related to it, judging by stratigraphic position. Unlike the type Olcese, this sand appears to be entirely marine in origin and thus should perhaps be assigned a new name. It is medium to coarse in texture, but in places shale, containing middle Miocene Foraminifera, is interbedded with it. This sand may be remotely related to the "Nazu" sand of the Edison field, except that this latter sand comes immediately below the flood zone of *Valvulineria californica* s.s. while as much as 200 or 300 feet of shale separates the sand in the Mountain View field from the same flood zone, although they both rest on the Freeman-Jewett (undifferentiated) siltstone.

Freeman-Jewett (Undifferentiated). Immediately underlying the Olcese sand in the Mountain View field is a series of siltstones and sandy siltstones occasionally interbedded with sand. This member contains the same species of Foraminifera as those found in the type sections of the Freeman and Jewett silts in the Round Mountain oil field.

Vedder Sand. The Shell Oil Company, Inc. well No. "Porter-Day" 1 (now Hogan Petroleum Company No. "Porter Day" 1) is the only well of several drilled to the basement that had anything like a complete Miocene stratigraphic section. Below the Freeman-Jewett this well cored a medium to coarse sand containing some oil shows. This sand has been tentatively assigned to the Vedder. This has been done because foraminiferal zones, occurring in the lower portion of the Freeman-Jewett, can be compared to those occurring immediately above the Vedder sand in the Poso Creek and Round Mountain areas. This sand is resting on continental beds, which, on the basis of position, can be assigned to the Walker formation.

Walker Formation. The Walker formation in this area consists of the same type continental beds as those present in the Walker formation elsewhere on the east side of the San Joaquin Valley, especially directly east of Bakersfield. They consist essentially of green, gritty, somewhat bentonitic claystones and poorly sorted greenish-gray sands. The Walker formation rests directly upon the basement.

Basement

The basement rock of the Mountain View field is a green schist of undetermined age.

STRUCTURE

With reference to the so-called Santa Margarita of the Bakersfield area, the structure of the Mountain View field is part of the southern flank of the Kern River salient which has raised the eastern margin of the San Joaquin Valley in a broad westward-plunging anticlinal nose centering in the low hills north of the Kern River. The structure in the lower beds is related to the Edison fold, which is antecedent to the Kern River uplift, and plunges in a northwesterly direction from the vicinity of the Edison field. Since the top of the so-called Santa Margarita sand appears to grade laterally into continental Chanac toward the margin of the valley, the contours on the top of this sand may diverge somewhat from true structure.

Regional

The stresses generated by the Kern River uplift have been relieved by minor buckling of the strata and by faulting, and the combination of the two conditions has been favorable for the accumulation of oil in the area. Crenulations of the margin of this uplift resemble broad and gentle folds plunging from a central point to the floor of the valley. In the vicinity of the Mountain View field the beds strike aproximately N. 50° W., and dip about 1,200 feet to the mile, the strike and dip being modified on the flanks of a broad flat syncline which plunges in a southwesterly direction through the central part of the field. The system of faulting that forms the

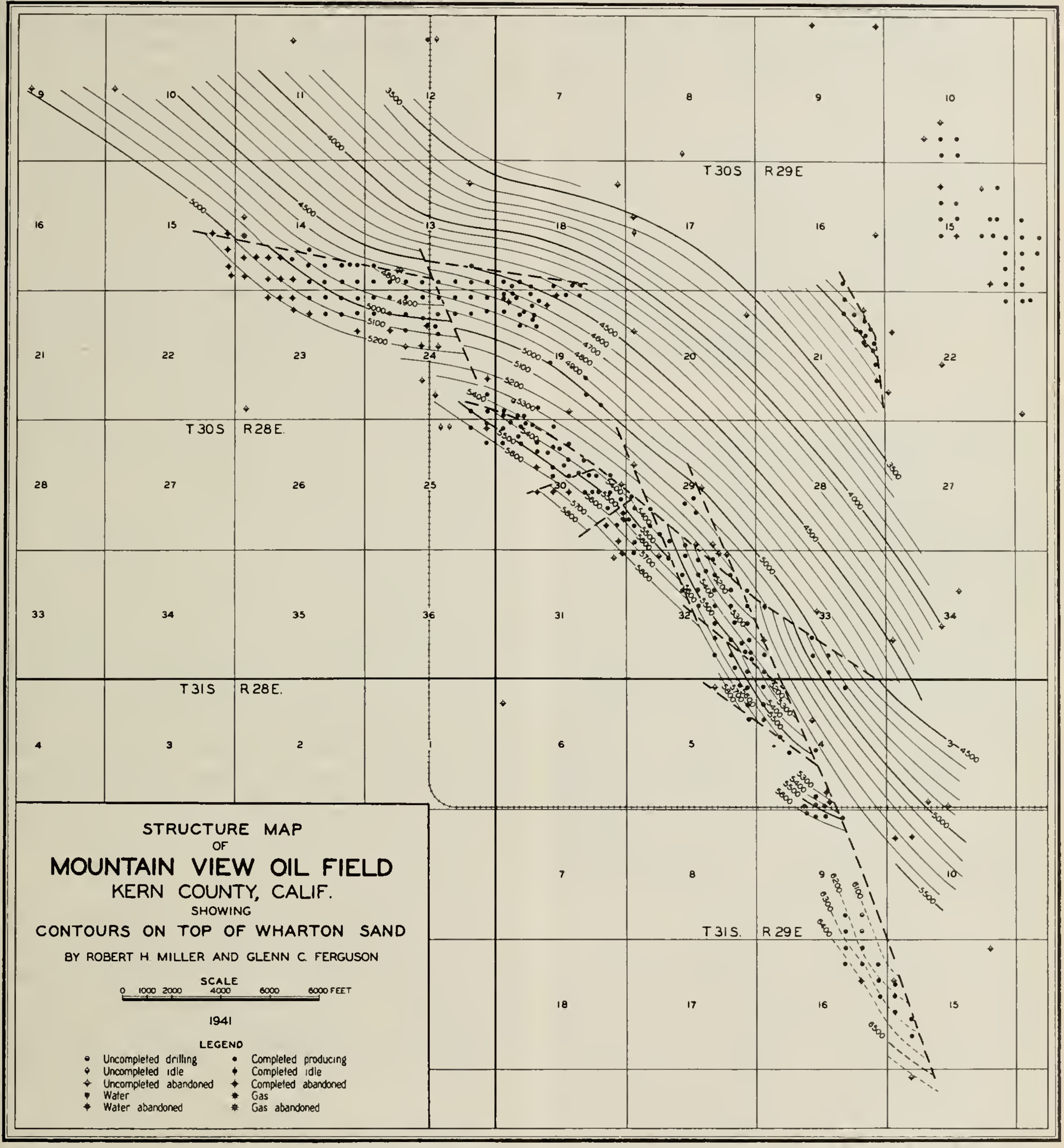

FIG. 248. Mountain View oil field: structure map.

barrier to the further migration of oil up dip is roughly symmetrical to the axis of this flat-bottomed syncline, and consists of relief faults occasioned by the settling of the basement which gave rise to the syncline.

The evidence of faulting is drawn entirely from subsurface data and is therefore meager. In very few cases have the fault planes actually been cored, and in most cases the presence and position of the faults is inferred from the limits of production and from discontinuity of stratigraphic surfaces.

Few of the faults have a displacement of more than 100 feet, and some have much less. The oil zones are generally predominantly sands, oil sand comprising from 60 to 70 percent of the zone thickness. It is therefore apparent that the sealing effect of the faults is not due to pervious strata being brought against impervious strata. The fault planes appear to have a very thin gouge, an inch or two in thickness, but it seems that on account of the generally high silt and clay content of the sands, a thin fault gouge of this material is sufficient to seal the beds against further migration of oil.

Northwest Area

The first development in the Northwest area occurred west of the Lamont branch of the Southern Pacific railroad. The producing horizon here is the Wharton sand, and some of the Transition zone sands are open to production in the wells located higher on the structure. Development to the north proved that production was limited in that direction by a fault, Tide Water Associated Oil Company well No. "Nunez" 1 being on the unproductive side, as were the original holes of Union Oil Company of California wells No. "Kernco A" 3 and No. "Kernco A" 4. These latter wells were redrilled and directed south on the "Kernco A" lease and were recompleted as satisfactory producers, thus defining the position of the fault within fairly narrow limits at this particular location. The Texas Company well No. "Schamblin" 1 was directed towards the south boundary of the Schamblin lease and encountered gas sands between 5,206 and 5,233 feet. The occurrence of gas sands is rather rare in the field, and probably represents a minor gas cap close to the fault. On a production test the well blew 8,000,000 cubic feet of gas through a 40/64-inch bean with 90 pounds per square inch tubing pressure. Shut in, the pressures on tubing and casing built up to 1,175 pounds per square inch.

The trend of the fault in an easterly direction has been fairly well defined across the remainder of Sec. 14 and the W½ Sec. 13 by several wells having been redrilled so that the original and redrilled holes straddle the fault. After the development of the main part of the Northwest area, Vesta Petroleum Company drilled well No. "Merritt" 8 in the northwest corner of Sec. 19, T. 30 S., R. 29 E., M. D., and found the Wharton sand barren, although the well was structurally higher than many wells to the west which produced heavily from the Wharton sand. This well was plugged back, and only the sand of the Transition zone was left open to production. The well demonstrated the presence of a fault separating it from the Wharton-sand wells to the west. Other wells drilled in the immediate vicinity found the same conditions in the Wharton sand, and the general practice of stopping the wells at the base of the Transition zone was soon adopted. As development continued, the position of the fault was finally determined as shown on the map, trending about S. 30° E. near the south quarter-corner of Sec. 13. The productive oil zones seem to be continuous across this fault, with the exception that the Wharton sand is productive only on the west side. In the area to the east of the fault, productive sands occur higher in the section than in the area to the west of the fault. It has been assumed that this fault, although acting as an effective barrier to the migration of oil in the Wharton sand, allowed the oil in the Chanac and Transition zones to migrate up dip with only slight impediment. Such selective action of the fault seems improbable, and a more likely hypothesis is that the accumulations are distinct but contiguous. The northern limit of production east of this fault has been established by Standard Oil Company of California well No. "Calif. Lands Inc." 3, Sec. 13, T. 30 S., R. 28 E., M. D. This well was found to be on the wrong side of a fault in the original hole and was redrilled to the south, where it found production. Although the trend of the fault is not definitely established, it is probably a continuation of the fault that limits this area in Sec. 14 and the W½ Sec. 13 offset to the north by the cross fault in Sec. 24. Development has extended eastward from the northwest corner of Sec. 19, but at present the east limit of the Northwest area remains undefined.

The fault that limits the area on the north has a displacement of about 100 feet and is downthrown to the south. The displacement seems to be fairly constant over the explored extent of the fault, and the fault continues in both directions outside the limits of the area. There are no complete data from which to determine the hade of the fault. However, from a study of the electric logs of the wells that passed through the fault, the points of intersection of the wells with the fault plane can be located, and it is probable that the hade is a fairly high angle. Less is known of the cross fault, since it crosses the structure where the contour lines are curved, and the dip of the strata is variable. That there has been lateral movement on this fault is indicated by the offset in the main fault at the point of intersection. The fault is probably downthrown to the west and the vertical movement probably increases to the south.

Central Area

The part of the field lying in Sec. 30, T. 30 S., R. 29 E., M. D., and extending northwest and southeast over the lines of the adjoining sections, comprises an individual producing unit. It is bounded on the northwest by the limits of production and on the southeast it is separated from the remainder of the field by faulting. The separation may be made along a line through Hogan Petroleum Company wells No. "Porter-Day" 9 and No. "Wharton" 2, which seem to belong to the Southeast area.

The Central area is limited on the northeast by a fault that passes just east of the northwest corner of the section and just south of the east quarter corner. The first well drilled in the area was Mohawk Petroleum Company well No. "Hood" 1, which apparently encountered the fault just above the Santa Margarita, and was abandoned after an unsuccessful attempt at production.

Succeeding wells were bottomed in the Chanac, and although Standard Oil Company of California well No. "Nichols Community" 1 was drilled to the Wharton sand, it also drilled through the fault and did not encounter production.

Later wells were drilled to the Wharton sand and several of the earlier Chanac wells were deepened. As in the Northwest area, several wells were first drilled on the northeast side of the fault and later redrilled and directed over to the productive side. The first producing well in the area, Mohawk Petroleum Company well No. "Hood" 2, was completed above the Transition zone, the stratigraphic point being at that time indeterminate. The second well, Mohawk Petroleum Company well No. "Clendenen" 1 at the other end of the area, was drilled into the Transition zone and stopped on a calcareous shell which became known as the "Clendenen lime." This was somewhat stratigraphically deeper than Mohawk Petroleum Company well No. "Hood" 2. The Clendenen lime was adopted as the finishing point of wells in this area until Hogan Petroleum Company well No. "Porter-Day" 5 established production in the Wharton. In the drilling and deepening campaign which followed, little regard was paid to the possibility of intermediate water between the Chanac oil zones and the Wharton sand. In the beginning there was little danger because the wells were located high on the structure and were completed with the Chanac and Transition zones and the Wharton sand all open to production. In one well flowing water was found in the Transition zone, and although it was satisfactorily shut off in this well with an intermediate cement job on the liner, it was not long before water encroached on the earlier wells. Bottom water also became evident after a time in wells which had gone a little too deep, so that many of the double-zone wells found it necessary to plug back to the Chanac sands in order to reduce the water content. Later drilling along the edges of the field successfully eliminated both intermediate and bottom waters. As production in the original zones became depleted, many wells were plugged and perforated in the higher Chanac or Nichols sand. The production from this sand has been minor compared with that from the lower zones.

The limits of production down dip have been fairly well established by Barnsdall Oil Company well No. "Mott" 1 in Sec. 31, T. 30 S., R. 29 E., M. D., and well No. "R. L. Noble" 1 in Sec. 30, T. 30 S., R. 29 E., M. D. In Sec. 25, T. 30 S., R. 28 E., M. D., the limit is established by Mountain View Oil Corporation well No. "Garner-Bristol" 1, which encountered oil sands in the Chanac, but due to poor core recovery the correlations with the rest of the field are unknown. The well was not a commercial producer. Barnsdall Oil Company well No. "Mott" 1 in Sec. 31, T. 30 S., R. 29 E., M. D., was one of the earlier wells drilled and was completed as a small producer in the lower part of the Transition zone and the Wharton sand. Production gradually diminished and the well was abandoned. Barnsdall Oil Company well No. "R. L. Noble" 1 adequately tested the Wharton sand and oil sands in the Chanac without obtaining commercial production.

Two minor cross-faults are shown at either end of the "Hood" lease of the Mohawk Petroleum Company. They are drawn mainly on the basis of the offset in the contours, and also on the basis of anomalies in the edge water line. Mohawk Petroleum Company well No. "Clendenen" 7 found a water sand within the Wharton sand, and although this particular sand streak was tested in Barnsdall Oil Company well No. "R. L. Noble" 1 farther down dip, it was not wet.

Two deep tests have been drilled in the area. Barnsdall Oil Company well No. "B. H. Young" 1, near the northeast corner of Sec. 31, T. 30 S., R. 29 E., M. D., was drilled to what is believed to be the Olcese sand without encountering showings of importance. Mohawk Petroleum Company well No. "Hood" 3, originally a Chanac well, was deepened to the Freeman silts when the casing parted. The well was backed up from a total depth of 8,689 feet without reaching the Vedder sand, which was the objective, and established the fact that, down to the depth reached, no further production occurs in this part of the field.

The fault that governs production in this part of the field appears to be a small, fairly high-angle thrust fault, and as elsewhere in the field the fault gouge seems to afford the seal. Cores of the fault gouge were recovered in two wells, Mohawk Petroleum Company well No. "Eisen Vineyards" 1 and Otis Hoyt well No. "Petrol" 1. In both of these wells there was a repetition of beds, indicating that the wells passed from the upthrown southern productive side to the downthrown northern barren side; hence the fault is a thrust fault of fairly high angle. The displacement across the fault at this locality is about 60 feet. Sheldon Oil Corporation well No. "Ross" 1, although north of the line of intersection of the fault and the top of the Wharton sand, is south of the fault in the upper part of the Nichols zone and was able to obtain small production from this horizon. Completion of this well led to the belief that production extended to the northeast across the fault without interruption. Two wells drilled on this hypothesis, Allied Petroleum Corporation well No. "Allied" 20 and Sheldon Oil Corporation well No. "Ross" 2, met with indifferent success. Small stringers of oil sand were found in both these wells and a little gas in the "Allied" well, and although they were completed as producers, the results were rather disappointing. The production obtained has been ascribed to seepage through the fault. This view is scarcely tenable since the time element is so vague. The assumption would seem unwarrantable that, at the present time, oil is seeping up dip in small quantities, and that the major accumulation remains in the leaky reservoir to the south of the fault. Further, the oil sands present in well No. "Ross" 2 are absent in well No. "Allied" 20 and vice versa. The more probable hypothesis is that this production is due to the occurrence of minor faults parallel to the main fault, or that the accumulation is merely the down-dip edge of the easterly extension of the Northwest area. Both of these wells are structurally higher than Gilmore Oil Company well No. "Dechent" 1 in Sec. 24, T. 30 S., R. 28 E., M. D., which produced some oil before it was finally abandoned. It is also possible that these wells merely picked up scattered productive lenses of oil sand.

Southeast Area

The Southeast area of the Mountain View field extends from the Central area southeast to Mohawk Petroleum Company well No. "Earl Fruit Co." 3. The main structural feature of the area is a fault trending about 30 degrees west of north. This fault limits production to the east. Possibly three secondary faults are known, meeting and perhaps intersecting this fault in a general northwesterly direction. That the structure is complicated, and inferred from insufficient data, is shown by the fact that no two geologists agree on the structural details. The accompanying map shows one interpretation of the structure, but still leaves some facts only partially explained.

Toward the south and east the stratigraphy of the area changes. The Chanac formation has an increasingly high clay content and in the extreme southeast portion of the area it consists of a series of green, coarse, unsorted, gritty claystones containing only a few streaks of sand porous enough to carry oil. Several marine fingers appear in the section at various horizons. The Santa Margarita—Transition zone becomes thinner and the marker beds of the other part of the field lose their identity. To the southeast also the Wharton sand loses its porosity due to a high feldspar content which has been kaolinized in place, and in several wells the Wharton has been found to have no fluid content. Thus, the accumulation may be in part stratigraphic rather than structural.

Most of the wells in the area are open to the lower part of the Chanac, the Transition zone, and the Wharton sand, and have been prolific producers.

The discovery well of the Mountain View field, Hogan Petroleum Company (formerly Shell Oil Company) well No. "Porter-Day" 1, is in the northern part of this area. This well is more or less surrounded by dry holes and the structure of the area still remains to be determined. The well made 1,201 barrels of oil per day for a short time, and after having been deepened was never satisfactorily recompleted. Neither was production of this order encountered in offset wells, so that the immediate area has been severely left alone. The fault that limits the Central area on the northeast is apparently continuous through the Southeast area and limits production in the same direction, and in the southwestward-dipping segments formed by the intersection of this fault with the main fault, the best production has been found. The development of the area was started on the Wharton lease by Hogan Petroleum Company, and the initial well was open only to the sand at the top of the "Santa Margarita," which was called the Wharton sand. The apex of this structure lies on the "Morris" lease of Barnsdall Oil Company, and on the higher parts of the structure some of the Chanac sands are open to production.

The Ohio Oil Company well No. "Derby" 3, although relatively low structurally when compared with wells to the northwest, was completed as a gas well at 5,804 feet, and the water string set at 5,538 feet. Hogan Petroleum Company well No. "Symons-C.C.M.O." 2, one location to the south, blew gas for several days before producing oil. This would indicate that these wells are near the apex of a separate fault block. A discontinuity of the contour lines indicates a probable northwestward-trending fault passing near the southeast corner of Sec. 32, T. 30 S., R. 29 E., M. D. Other parallel faults probably occur to the south and account for production and structural anomalies which are known to exist.

The Southeast area is probably separated from the Central area by a fault parallel to the main fault. It is otherwise difficult to account for the discordance of the contours on either side of the undrilled acreage between the two areas; and it is also difficult to explain why Hogan Petroleum Company well No. "Porter-Day" 9 was a poor well when it is structurally higher than well No. "Porter-Day" 7, which was a good well.

Southeast Extension

At the southeast intersection of the two main faults of this area, the beds are tilted in a southwestward-dipping monocline, and the Wharton sand is overlapped by the Chanac formation on the basement to the east. To the west, beds below the Wharton sand come into the section. The Chanac formation here consists of gritty claystone and occasional sand members, and the Wharton sand is decomposed and impervious. The first well drilled in this area was Bankline Oil Company well No. "Symons" 1, later Hogan Petroleum Company well No. "Symons-Bankline" 1, and although not a commercial well it made occasional flows of oil from the Chanac. Two wells were drilled by the Tide Water Associated Oil Company in Sec. 3, T. 31 S., R. 29 E., M. D. In the first of these wells sufficient sands were not encountered in the Chanac to make a well, while the second well started coring in the impervious Wharton sand and went from this sand into the basement. Mohawk Petroleum Company well No. "Earl Fruit Co." 1 found a zone below the Wharton sand which yielded abundant oil on a formation test, but could not be completed as a satisfactory producer; and well No. "Earl Fruit Co." 2 was abandoned for mechanical reasons after having failed to shut off water at the shoe. The Ohio Oil Company well No. "Derby" B-1 in Sec. 33, T. 30 S., R. 29 E., M. D., found oil sand in the Chanac and was completed for about 700 barrels per day.

The group of wells near the south quarter-corner Sec. 4, T. 30 S., R. 29 E., M. D., obtains production from the Chanac. It is believed that Hogan Petroleum Company well No. "Symons-Bankline" 2, about 2,000 feet northwest of the nearest producer in this group of wells, is in the same structural block.

Arvin Area

The existence of a separate small area of accumulation was demonstrated by the Standard Oil Company well No. "Jewett-Community" 2-1. This well was drilled to a depth of 6,270 feet and completed for about 1,300 barrels per day. The production in this area is from sands that occur within the marine Etchegoin beds. Subsequent drilling has shown that the accumulation is limited on the east by the extension of one of the main Mountain View faults. That the area itself is complicated by further minor faulting is shown by the characteristics of the wells. However, there are not sufficient wells definitely to determine the detailed structure. The generalized structure projected on top of the Wharton sand is shown on the accompanying map.

KERN FRONT AREA OF THE KERN RIVER OIL FIELD*

By Everett C. Edwards **

OUTLINE OF REPORT

HISTORY

The Kern Front area of the Kern River oil field is located in Kern County, on the east side of the San Joaquin Valley, 10 miles north of the city of Bakersfield.

History of the development, technology, and geology of the field has been described by A. B. Hendrickson (27). In recent years the field has been developed slowly, a small extension being found in Sec. 10 and more extensive developments occurring in the west portion of Sec. 24 and the NW¼ Sec. 25, T. 28 S., R. 27 E., M. D.

The local topography is that of gently rolling hills, separated by small valleys or gulleys. Maximum relief is approximately 500 feet.

The Kern Front area was discovered by the Standard Oil Company of California in its No. "Fee" 1 well in Sec. 27, T. 28 S., R. 27 E., M. D., completed at 2,500 feet in 1915 for 500 barrels per day initial production.

Present productive acreage lies in portions or all of the following sections: 2, 10, 11, 14, 15, 16, 21, 22, 23, 24, 25, 26, and 27, T. 28 S., R. 27 E., M. D. Proved productive acreage consists of approximately 3,165 acres, 80 percent developed; cumulative production to January, 1941, is 45,500,000 barrels of oil, 21 to 17 degrees A. P. I. gravity. Recovery to date has been approximately 15,000 barrels per acre. Depth of producing wells ranges from 1,600 feet at the north end to 2,500 feet at the south end of the area. They are all completed on the pump with small initial production, but have a long life.

Deep exploratory tests drilled on the east side of the San Joaquin Valley during the past few years have furnished additional information as to the genesis, lithology, thickness, and areal distribution of the underlying formations.

STRATIGRAPHY

The following description (see Table 1) of the sediments is based on well data. Wells in the area have not penetrated formations below the Fruitvale sand; so the description of the older sediments is based on data from wells of deeper stratigraphic penetration, outside the limits of the area.

STRUCTURE

The Kern Front area is located on the westerly flank of a very broad structural arch, known as the Kern River arch, which pitches gently toward the southwest. Other fields on this arch are the Kern River area, the Fruitvale field, and the Poso Creek (Premier) field.

The local structure is a southwest-dipping monocline which has been cut by faults of small displacement. The oil zones dip in the same direction at a rate of 400 to 500 feet per mile.

The eastern limit of the field is bounded by a north-trending normal fault of less than 100 feet displacement. A band of reddish oxidized soil which follows the course of a shallow topographic furrow is the surface evidence of its trace. Subsurface evidence is believed to have been found in the General Petroleum Corporation well No. "Young" 53, Sec. 13, T. 28 S., R. 27 E., M. D., a dry hole. At this location the interval between two marker

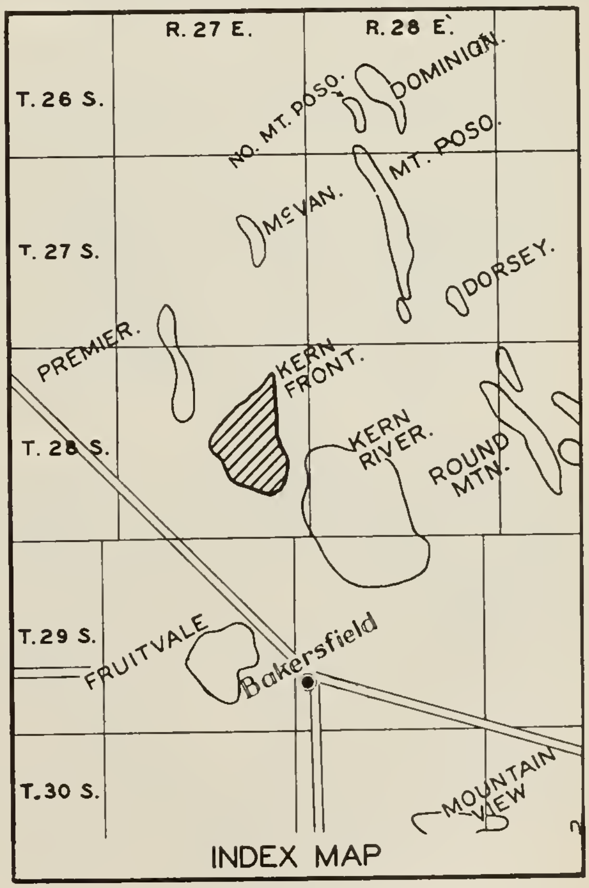

Fig. 249. Kern Front area of the Kern River oil field: index map.

* The writer wishes to express his gratitude to James C. Kimble, Frank B. Carter, D. J. Gribbin, Jr., and C. J. Dean, for suggestions and criticisms, and for the loan of maps and structure sections to illustrate this article.

This paper was originally written to form a part of a special volume on stratigraphic trap types of oil fields, prepared under the direction of Mr. A. I. Levorsen, to be published by the American Association of Petroleum Geologists. Permission for its publication by the State Division of Mines has been granted by the Editor of the Association.

** General Petroleum Corporation of California. Manuscript submitted for publication June 1, 1941.

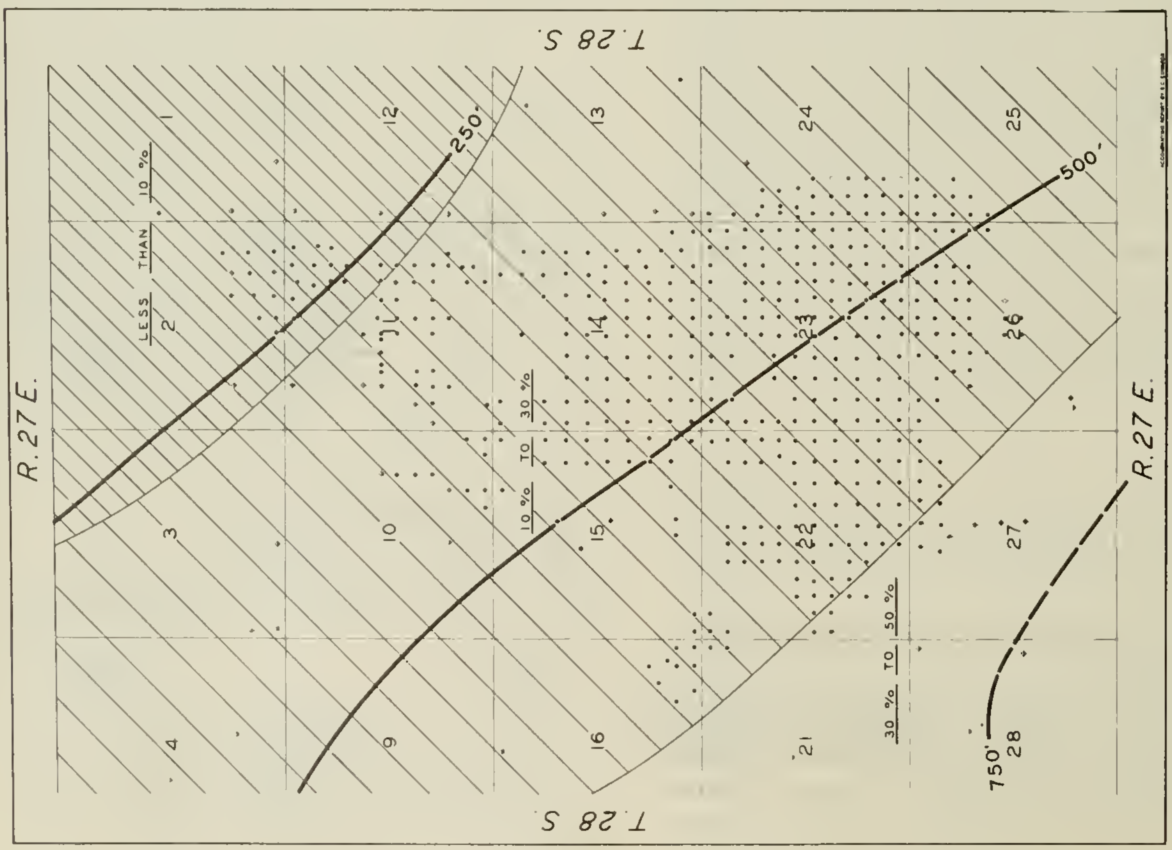

Fig. 250. Kern Front area of the Kern River oil field: Chanac formation. The plain and cross-hatched areas indicate the amount of sand present in the formation as shown in the percentage figures.

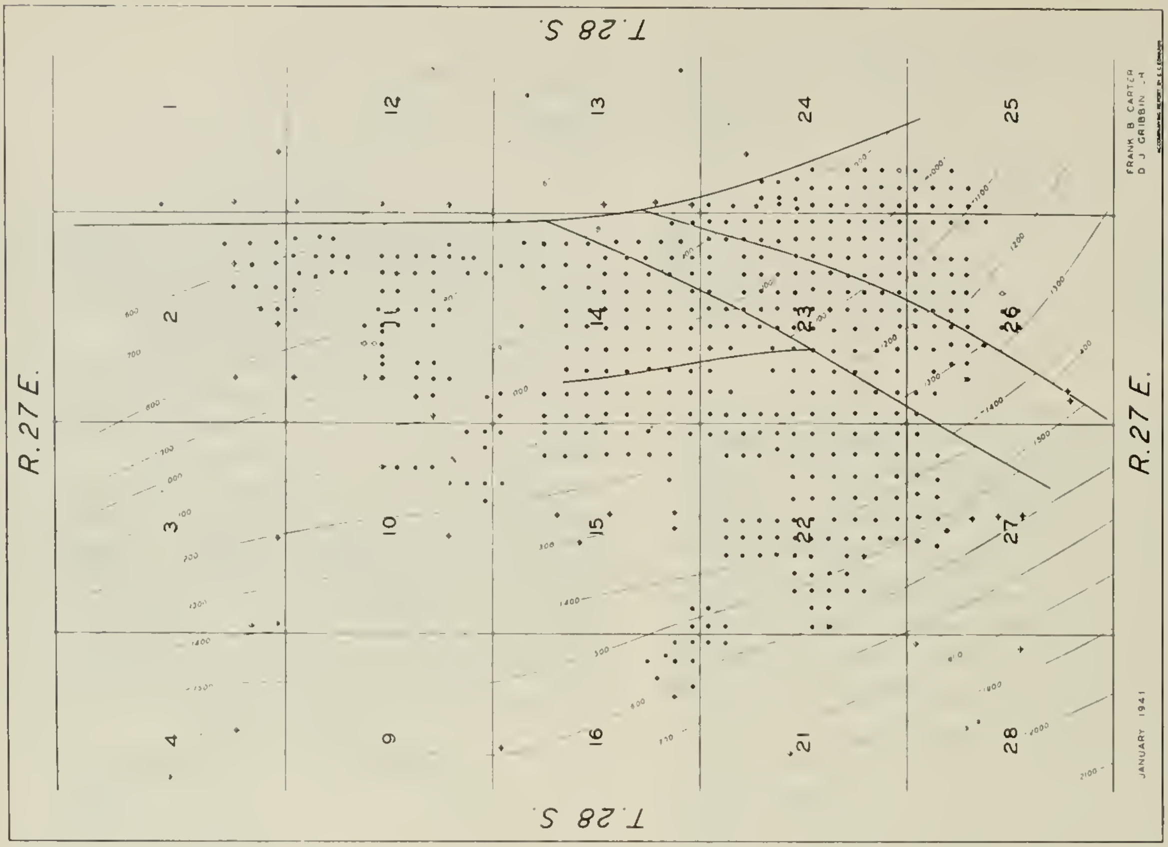

Fig. 251. Kern Front area of the Kern River oil field: structure map. Contours drawn on base of the Etchegoin marine claystone member.

TABLE 1

Formation	Age	Thickness (Feet)	Description
Kern River	Pleistocene, Pliocene	1,600 to 2,200	Non-marine sand, silt, clay, grit, and congomerate, mostly gray but with bluish, greenish, reddish, and yellowish bands; highly cross-bedded; largely of alluvial fan and alluvial plains origin, composed of the transported products of disintegrated and decomposed basement-complex rocks. Feldspars and ferromagnesian minerals highly decomposed. Forms surface formation of Kern Front area
Etchegoin claystone member	Pliocene	10 to 200, including transitional material	Marine claystone and siltstone with occasional sandy streaks at base. Cores of the claystone when dry break up with characteristic conchoidal or "hackly" fracture surfaces. Contains casts of *Macoma kerica*, *Cryptomya*, also black phosphatic pellets and nodules and charcoal fragments. Oil in basal sandy lenses at the north end of the field
"Chanac"	Upper Miocene (?)	200 to 700	Non-marine siltstone, sandstone, mudstone, occasional gravels of green, gray, buff, and maroon color. Contains appreciable amounts of biotite. Similar in composition and origin to the Kern River formation, but with more of the residual soil type of material. Main oil zones of the Kern Front area, as well as those of the Fruitvale and Poso Creek (Premier) fields in this formation
Fruitvale sand	Upper Miocene	400 to 500	Marine gray sand, fine to coarse, occasional gravels; sands predominantly well sorted, composed mostly of quartz with some feldspars and ferromagnesian minerals; rarely fossiliferous
The following formations, though not penetrated in the Kern Front area proper, are believed to occur below the Fruitvale sand:			
Lower Fruitvale shale	Upper middle Miocene	200 (estimated thickness)	Marine shale, brown to gray-brown, very platy ("pokerchip"). Contains the *Pulvinulinella gyroidinaformis* foraminiferal assemblage. Possible unconformity at top
Round Mountain silt	Middle Miocene	400 (estimated thickness)	Marine siltstone, mudstone, and shale, brown to gray-brown. Contains the *Valvulineria californica* assemblage in upper, and *Baggina robusta* assemblage in lower portion
Olcese sand	Lower Miocene	400 (estimated thickness)	Marine sandstone, gray to nearly white, hard to friable. Contains *Turritella ocoyana* fauna
Freeman silt	Lower Miocene	500 (estimated thickness)	Marine, ashy siltstone and claystone, gray and massive, may contain some sand in this area. Characterized by *Plectofrondicularia miocenica* foraminiferal assemblage
Jewett silt	Lower Miocene	500 (estimated thickness)	Marine siltstone and claystone, gray and massive; resembles the Freeman silt. Contains *Siphogenerina transversa* foraminiferal assemblage
Vedder sand	Lower Miocene	400 (estimated thickness)	Marine sand, fine to coarse, gray, hard to friable, fossiliferous
Vaqueros (?) and Kreyenhagen group	Lower Miocene Oligocene	750 (estimated combined thickness)	Shale with some sand. Upper part belongs to R. M. Kleinpell's (38) Zemorrian stage, and the lower part to the Refugian
"Famoso" sand	Eocene	600 (estimated thickness)	Sand and shale, marine and continental. Correlative of at least part of the Walker formation
Basement complex	Pre-Cretaceous		Granite, schist, or slate

beds in the pay zone was found to be less than normal, suggesting that the well had penetrated a fault and was bottomed on its barren east side. The operator was unable to exclude water from the oil zone and the well was abandoned. Minor cross faults within the field were suspected from numerous detailed structure sections, and their presence was substantiated by the difference in gravity of the oil on opposite sides of the faults.

The Kern Front area has no structural closure except that which might result locally from intersecting faults. The strata have a south component of dip throughout the field and beyond its limits of production.

PRODUCTIVE HORIZONS

Three oil zones have been recognized in the Kern Front area (Hendrickson, A. B. 27, pp. 15-17), although it is frequently difficult to distinguish them because they are irregular and lenticular. They are called the Tegeler, Lehnhardt, and Wonder zones, and occur in shingle arrangement, the Wonder zone being the uppermost and farthest north. The lowest or Tegeler zone is productive in the southwest part of the field, where it attains a thickness of 350 to 400 feet. This zone thins toward the northeast and is overlain by the Lehnhardt zone which is productive in the central part of the field. The Lehnhardt zone is 200 to 300 feet thick; possibly less, if a portion of the Tegeler zone has been included in this estimate. The Lehnhardt zone thins toward the northeast where it is overlain by the Wonder zone, which, in the northern part of the field, is producing from a zone less than 50 feet thick. Minor lenses of oil sand occur above the Wonder zone in the lower Etchegoin.

The oil sands range in grain size from very fine to gravelly and are appreciably silty.

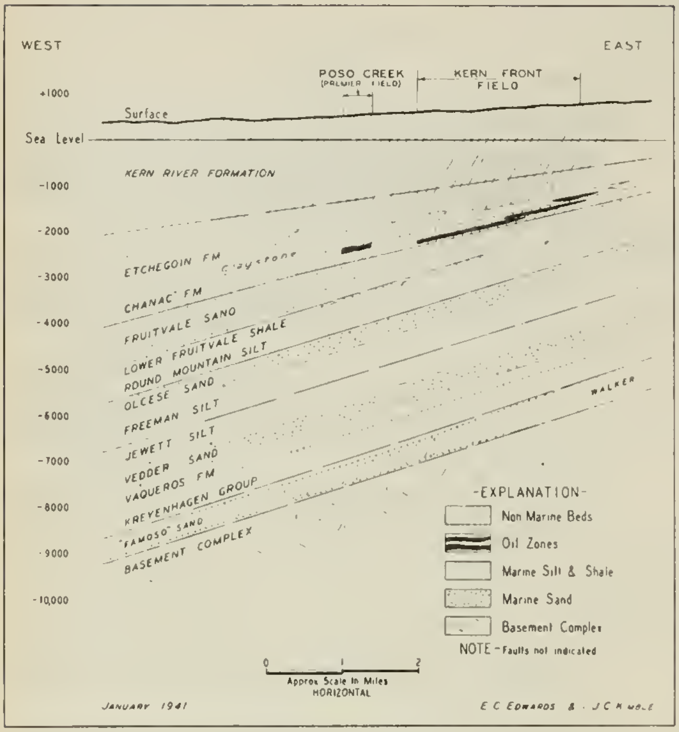

FIG. 252. Kern Front area of the Kern River oil field: diagrammatic structure section.

Fault Trap

The decomposed, kaolinized feldspars and other weathered minerals in the "Chanac" formation readily form gouge zones along fault planes even though the displacement is slight. The fault along the east side of Kern Front, therefore, is believed to be an effective seal for the oil in the "Chanac" measures, although its displacement is estimated to be much less than the thickness of the oil zones.

Stratigraphic Trap

The aggregate thickness of the continental beds is 700 feet at the south end of Kern Front and 200 feet at the north end. Porous sand members represent from 30 to 50 percent of the "Chanac" section at the south end of the field, and less than 10 percent at the northernmost end, exclusive of the discontinuous sands in the basal portion of the Etchegoin marine member.

The recognized zonal thinning, which is of more than local character, together with observed decrease in porosity and permeability toward the north, combined with fault seal on the east, in the opinion of the writer, account for the occurrence of oil in the area.

CITATIONS TO SELECTED REFERENCES—Continued

KERN RIVER OIL FIELD

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Kern Front Area

American Association of Petroleum Geologists 41a; Clements, T. 36; Clute, W. S. 36; Hendrickson, A. B. 27; Hight, W. 33; Howard, P. J. 39; Kleinpell and Cunningham 34; McCollough, E. H. 34; Taff, J. A. 34.

Kern River Area

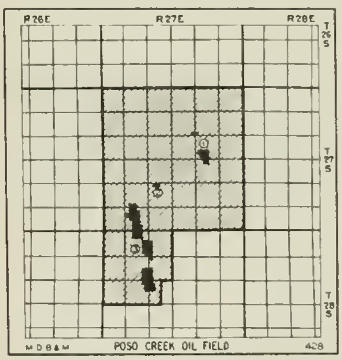
Clements, T. 36; Clute, W. S. 36; Howard, P. J. 39; Kleinpell and Cunningham 34; McCollough, E. H. 34; Stevens, J. B. 21; Taff, J. A. 34.

Lerdo Region

Oil Weekly 37b.

Poso Creek Field (Kern Front Area)

Kaiser, C. L. 24.



Poso Creek oil field. Areas: (1) McVan; (2) Agey; (3) Premier.

DYER CREEK FIELD

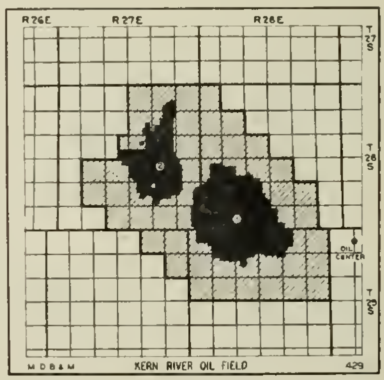
California Oil World 42.

POSO CREEK OIL FIELD

Howard, P. J. 39; Jensen, J. 27a; Kaiser, C. L. 24; Musser, E. H. 30; 39; Oil Weekly 37b.

Premier Area

Updike, F. H. 39.



Kern River oil field. Areas: (1) Kern River; (2) Kern Front.

KERN RIVER AREA OF THE KERN RIVER OIL FIELD

By John B. Stevens *

The Kern River area of the Kern River oil field is situated along the Kern River 5 miles north of the city of Bakersfield, Kern County. James Elwood and Jonathan Elwood, with pick and shovel, dug the discovery well in the spring of 1899. At a depth of less than 50 feet oil sand was encountered, and with the well curbed to that depth, bellows were installed for ventilation, and the hole continued for a short distance, when oil and gas entered to such an extent as to interfere with further work.

While the recorded details of the digging of this first well are somewhat sketchy, the results were evidently sufficiently clear to convince local oil men of the importance of the find. A scramble for land took place, and within a very short time several wells were completed; good oil was accumulating in sumps, and the discovery of a new oil field was proven beyond question. The newly discovered area lay almost within stone's throw of two transcontinental railroads, and at the very start of a long mountain and desert haul. The very nearness of the area to a consuming market and to transportation facilities, as well as a rapidly growing demand for fuel oil, accentuated development. In 1903 the area produced 16,800,000 barrels of oil.[1] The oil was of heavy asphaltic base, 13.0 to 16.0 degrees gravity, and fully met fuel requirements of the railroads and industry.

No gushers were ever drilled in the Kern River area. A few of the wells in the early days flowed 500 and 600 barrels a day for a short time. The area has always been a pumping area. The oil measures are of shallow depth and gas pressure negligible. The gas produced in the area has not for many years been sufficient to meet operating needs. From the discovery date in 1899 to July 1, 1938, the area has a credited production of 307,728,135 barrels. The present potential of the area is given as 9,130 barrels per day from 2,049 wells. The number of potential producers is listed by the State Division of Oil and Gas at 2,709. The proven acreage is held at 9,693. The area has a serious water problem which acts as a deterrent to full operation.

The oil horizon of the Kern River area consists of lenticular measures of sand and clay with a drilling depth varying from 350 feet along the eastern edge of the area to 2,000 feet along the southwestern edge. The producing horizon has a thickness of 600 feet in the center of the area, but thins appreciably at the producing margins. The shape of the area is roughly circular. The structure is monoclinal and dips about 6 degrees to the southwest.

The geological horizon is entirely of Kern River series, which, in accepted interpretation, is the continental equivalent of all measures above the Miocene. Some few wells of recent drilling seem to indicate a thin disappearing finger of marine Etchegoin at the base of the Kern River series at the very western edge of the Kern River area. The accumulation of oil in the Kern River area was not facilitated as in most fields by either faulting or folding, but apparently was caused solely by lateral or vertical, or both lateral and vertical, migration of oil into a lenticular, delta-like, sand trap which had been laid down on the eroded Miocene surface by some prehistoric equivalent of the Kern River.

* Petroleum Engineer, Tide Water Associated Oil Company. Manuscript submitted for publication September 6, 1938.

[1] California Oil World, Sept. 29, 1910, p. 43.

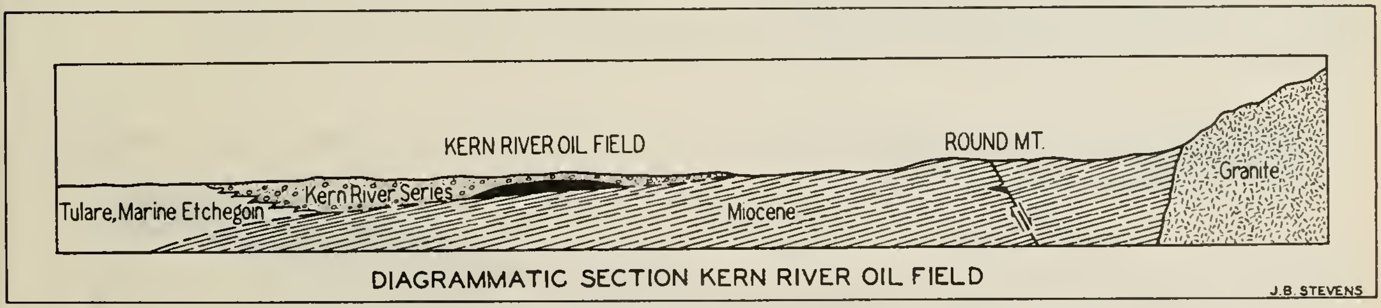


Fig. 253. Kern River area of the Kern River oil field: diagrammatic section.

EDISON OIL FIELD *

By Everett C. Edwards **

OUTLINE OF REPORT

HISTORY

The Edison oil field is located approximately 12 miles southeast of the town of Bakersfield, Kern County, in T. 30 S., R. 29 E., M. D., 4 miles west of the foothills of the Sierra Nevada. The field is situated on a gently sloping alluvial fan deposited by the Caliente River. It is an interesting oil field, in that its lower zone represents a stratigraphic trap type of accumulation.

In 1931 the Shell Oil Company and L. C. Osborn drilled the No. "Duff" 1 well, and commenced drilling the L. C. Osborn No. "Duff" 2, both located in Sec. 15, T. 30 S., R. 29 E., M. D. The No. "Duff" 1 penetrated oil sands at intervals between the depths of 3,450 and 3,504 feet, but the well was not commercial. In January, 1934, the No. "Duff" 2 was completed, having penetrated oil sands of questionable commercial value in what has become known as the "upper Duff" zone. The Monterey Exploration Company completed the No. "Duff" 3 in March, 1934, as the discovery well for the "lower Duff" zone. At the present time there are approximately 1,000 acres of proved production.

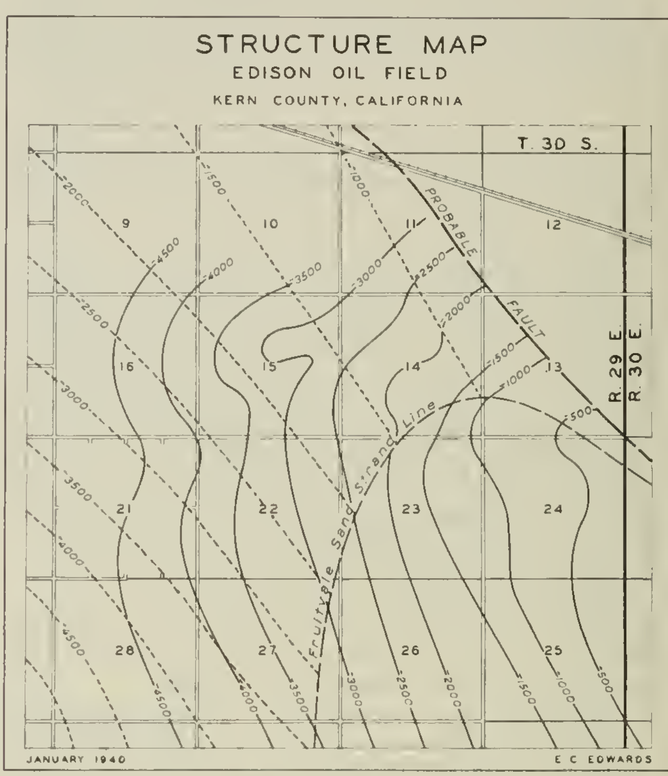


Fig. 254. Edison oil field: structure map.

* The writer wishes to express appreciation for helpful suggestions by Mr. Frank B. Carter, and for the use of his cross section. Foraminiferal determinations were by Dr. Paul P. Goudkoff.

** General Petroleum Corporation of California. Manuscript submitted for publication January 9, 1940.

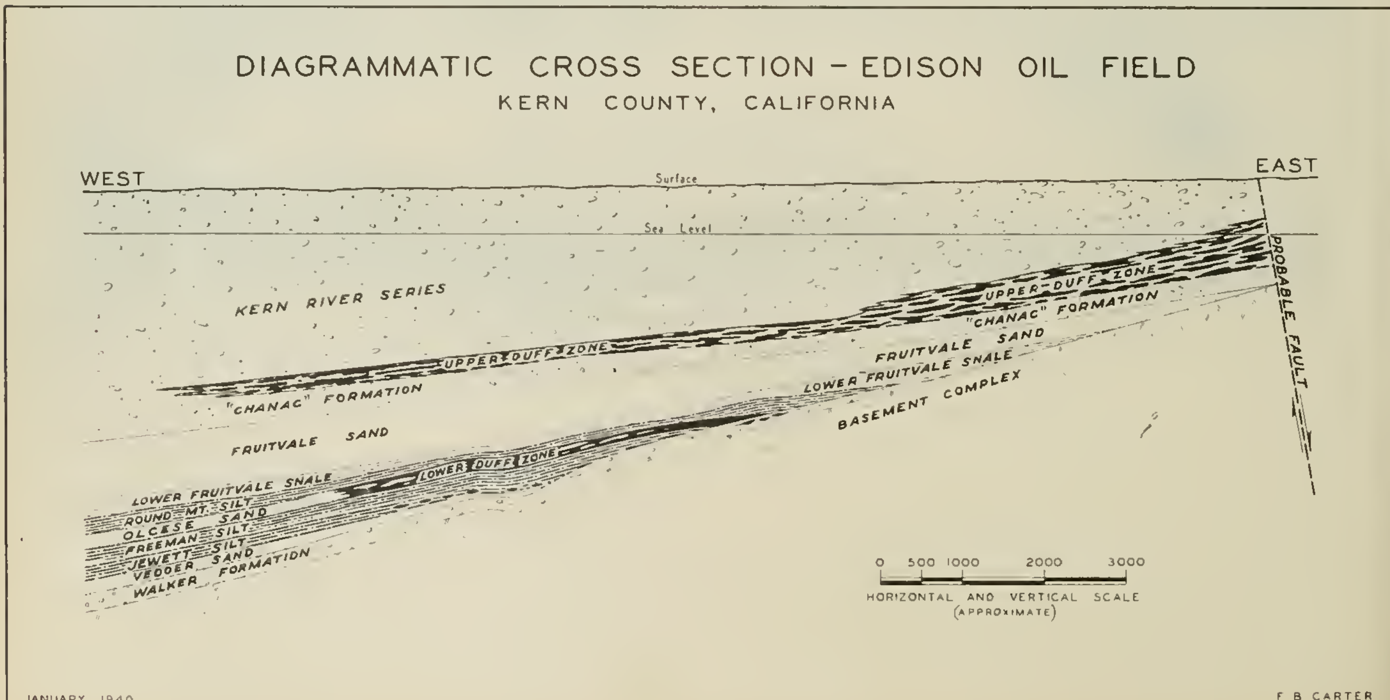


Fig. 255. Edison oil field: diagrammatic cross-section.

TABLE 1

Formation	Age	Thickness (Feet)	Description
Kern River	Pleistocene, Pliocene, uppermost Miocene (?)	1,200 to 2,500	Non-marine, largely alluvial fan type of deposit, composed of a mixture of basement complex material. Grain size ranges from clay to boulders. Feldspathic grits common, the feldspars usually being highly kaolinized. Color of strata green, blue, or tan, dark or light. Sands carrying fresh water present. Lower portion of series frequently contains ash beds. Upper Duff oil zone occurs 400 to 500 feet above base of Kern River series. It is 150 to 250 feet thick, 30 per cent of which is oil sand. Upper Duff wells capable of 50 to 150 barrels per day production of 15 to 16 degrees gravity oil. Porosity and permeability not uniform in this zone. In eastern part of field oil extends upward into younger strata, so the zone is thicker on the east side. Toward the south zone is barren of oil because of lack of porosity Continental strata immediately below upper Duff zone frequently termed "Chanac formation." Whether or not they correlate with the type Chanac section and are of latest Miocene or earliest Pliocene age is controversial
Fruitvale sand	Upper Miocene	0 to 500	Marine sandstone, gray, medium to coarse-grained, well sorted, but with some feldspars and femic minerals; rarely fossiliferous. Sand carries fresh water. Probably correlates with Wharton sand of Mountain View field, and Stevens sand of Ten Section field. Base of Fruitvale sand occasionally conglomeratic, containing pebbles and chips of the underlying lower Fruitvale shale
Lower Fruitvale shale	Upper middle Miocene	0 to 200	Marine brown to gray-brown shale, very platy. Contains the *Pulvinulinella gyroidinaformis* foraminiferal assemblage. Unconformity between this member and the overlying Fruitvale sand
Round Mountain silt	Middle Miocene	0 to 75	Marine brown to gray-brown shale, mudstone, and siltstone with occasional sandy streaks near base which carry some oil. Contains the *Valvulineria californica* assemblage
Olcese sand	Lower Miocene	0 to 100	Marine sand, fine to coarse grained, occasionally conglomeratic, gray except when oil saturated. The Olcese sand, combined with lower productive sands, constitutes the lower Duff zone from which single well-production as great as 500 barrels per day of 17 to 29 degrees gravity oil has been obtained
Freeman silt	Lower Miocene	0 to 300	Marine siltstone-claystone, gray and massive. Contains *Uvigerinella obesa* faunal assemblage
Jewett silt	Lower Miocene	0 to 250	Marine siltstone and claystone, gray and massive, resembles the Freeman silt. Contains lenticular sands which produce oil of 27 to 29 degrees gravity. *Siphogenerina transversa* zone
Vedder sand	Lower Miocene	0 to 150	Marine sandstone, hard, gray, fossiliferous. Attempt at precise correlation of this sand with the Vedder sand of Round Mountain and Mount Poso might present difficulties
Walker	Miocene (?) to Eocene (?)	0 to 200	The non-marine material between the Vedder sand and the basement complex is referred to the Walker formation on the basis of lithology rather than stratigraphy. The Walker formation consists of clay and sand, the clay in particular being of a very green color. Ash beds are common. The top and base of the formation are marked by unconformities. Some of the upper sands carry oil locally and are included with the lower Duff zone when produced
Basement complex	Pre-Cretaceous		Green chlorite and actinolite schist. Samples from different parts of field show varying degrees of hardness and schistosity. East and south of field, basement complex consists of quartz diorite and granite

STRATIGRAPHY

Several of the formations that underlie the Edison field are exposed in the hills 4 miles to the east. Lithologic changes are rapid in this area, however, and the summary description of the sediments given in Table 1 is, therefore, based on cores obtained from drilled wells. Thicknesses must be regarded as only approximate, because the entire section with the exception of the Kern River series overlaps and wedges out against a basement complex core. The formations are described from the surface downward.

STRUCTURE

The present subsurface structure of the Edison area is the result of many factors, including a core composed of basement complex rocks, overlap and truncation of sediments, structural warp, tilt, and faulting.

Structure of the Kern River series is that of a southwest-dipping monocline, the beds dipping at the rate of approximately 1,000 feet per mile. The older beds were warped or folded into a northwest-pitching anticline. The main period of this folding probably occurred at the end of lower Fruitvale shale deposition.

A fault bounds the northeast side of the field. The northeast side is downthrown with respect to the southwest, and the fault probably hades to the northeast. Total displacement along the fault plane probably varies for the different formations. The displacement of the basement complex may be as much as 2,000 feet, but the displacement of the shallow beds is very little.

Oil accumulation in the upper Duff zone is believed to have occurred as a result of fault seal on the northeast side and a lessening of porosity of the zone toward the southeast.

Oil accumulation in the lower Duff zone is caused by a concentration of oil along the structural nose in the porous sands, where it is sealed by impervious shales above and a wedging out of the sands against the older rock.

Depths of wells producing from the upper Duff zone range from approximately 1,200 feet on the east side of the field to 2,000 feet on the west side. The lower Duff zone is produced from wells whose depths range from 2,500 feet to 3,500 feet. The wells have a very limited flow life, most of them going on production as pumpers—particularly the upper Duff zone wells.

The field has been under curtailment since its discovery. Production to the end of 1940 was approximately 7,066,000 barrels. Well spacing is one well to 10 acres. Cost of drilling wells is approximately 10 dollars per foot. Production cost is 25 to 30 cents per barrel.

CITATIONS TO SELECTED REFERENCES—Continued

EDISON OIL FIELD

American Association of Petroleum Geologists 41a; Cadle, A. 28; California Oil World 42; Carter, F. B. 35; Clements, T. 36; Clute, W. S. 36; Godde, H. A. 28a; Howard, P. J. 39; Musser, E. H. 30; 39; Stockman, L. P. 35i; Van Tuyl and Parker 41; Wagy, E. W. 27.

JASMINE DISTRICT

Stockman, L. P. 40, no. 23, p. 84.

MOUNT POSO (POZO) OIL FIELD

Cadle, A. 28; California Oil World 42; Clements, T. 36; Diepenbrock, A. 33; Godde, H. A. 26b; 27; 28a; Hight, W. 33; Howard, P. J. 39; McCollough, E. H. 34; Musser, E. H. 30; 39; Stockman, L. P. 35l; Taff, J. A. 34; Wagy, E. W. 27; Wilhelm, V. H. 38; Wilhelm and Saunders 26a.

Dominion Area

Clute, W. S. 36; Diepenbrock, A. 33.

Dorsey Area

Clute, W. S. 36.

Glide Area

Stockman, L. P. 40, no. 18, p. 72; Vallat, H. E. 41a, p. 1164.

Lytle (Dorsey) Area

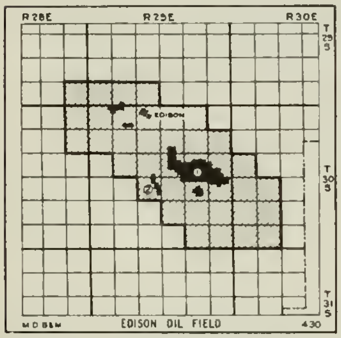
Clute, W. S. 36.

Mount Poso Area

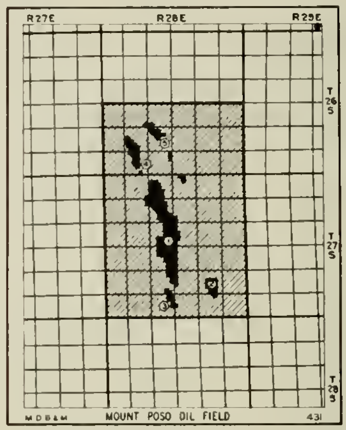
Clute, W. S. 36; Diepenbrock, A. 33.

Poso Creek (Mount Poso) Area

Jensen, J. 27a.



Edison oil field. Areas: (1) Edison; (2) 21-Community.



Mount Poso oil field. Areas: (1) Mount Poso; (2) Dorsey; (3) Vanguard; (4) Ring; (5) Dominion.

ROUND MOUNTAIN OIL FIELD

By R. G. Rogers *

OUTLINE OF REPORT

HISTORY

The Round Mountain oil field is located on the east side of the San Joaquin Valley 10 miles northeast of Bakersfield, in Kern County. The field is divided into the Main, Northwest, and Pyramid Hill pools. The Coffee Canyon area, lying immediately north of the Round Mountain field proper, is generally considered one of the Round Mountain group.

The combined productive area lies in Secs. 1, 12, 13, T. 28 S., R. 28 E., M. D., and Secs. 6, 7, 8, 16, 17, 18, 20, 29, T. 28 S., R. 29 E., M. D.

The main Round Mountain pool was discovered May 31, 1927, by Elbe Oil Land Development Company well No. 1, now Honolulu Oil Corporation well No. 2, in Sec. 20, T. 28 S., R. 29 E., M. D. This well was completed as a pumper in the Vedder zone with an initial settled production of 200 barrels per day. The well was drilled with rotary tools and cored from 607 feet to a total depth of 2,074 feet. Bailing tests were made on the interval 1,397 feet (shoe of 11¾-inch casing) to 1,653 feet, showing a rise of 22 feet of 29 degrees gravity oil and 44 feet of water while standing 13 hours after being bailed dry. After coring ahead to 1,851 feet the well was again bailed dry; and 123 feet of oil and 33 feet of water entered in 20 hours. The zones were considered non-commercially productive and the well was deepened by coring to a total depth of 2,074 feet, 77 feet into the Vedder zone. The well was completed with 6⅝-inch oil string including 675 feet of 100 and 120 mesh perforated on bottom. Production for the next few months was used for fuel in the early development program following discovery.

Three dry holes, indicating the western limits of the field, were drilled immediately following the completion of the discovery well. These wells were Kern River Oilfields of California Ltd. No. "Kernco" 1, in the SE¼ Sec. 13, T. 28 S., R. 28 E., M. D.; Little & Bell Producing & Drilling Company No. "Jewett" 1, near the center of Sec. 19, T. 28 S., R. 29 E., M. D.; and General Petroleum Corporation No. "Conroy" 1, in the northeast corner of Sec. 30, T. 28 S., R. 29 E., M. D.

Formations east of the main Round Mountain fault were found to be non-commercially productive in Shell Oil Company well No. "Jewett" 3 located near the northeast corner of Sec. 29, T. 28 S., R. 29 E., M. D., and Honolulu Oil Corporation well No. 940 near the east quarter-corner of Sec. 20, T. 28 S., R. 29 E., M. D.

During the remaining 7 months of 1927, no additional producers were completed. In the year 1928 twelve wells were completed as producers, and three others, non-productive, were abandoned. The Jewett zone was proved commercially productive in Shell Oil Company No. "Jewett" 1, in Sec. 29, T. 28 S., R. 29 E., M. D., completed in April 1928.

During the years 1929 and 1930 there were 33 wells completed as producers and one dry hole was drilled on the west edge of the field near the north quarter-corner of Sec. 19, T. 28 S., R. 29 E., M. D.

Development was suspended during the next 3½ years, only two wells having been completed for the period. Low price of oil and unitization of a portion of the field were the principal reasons for cessation of development.

The years 1934 to 1938 saw considerable activity, during which time the field was completely developed except for a few wells in the Northwest Extension area and the western end of the Pyramid Hill area. In January 1941 there were 170 producible wells, 21 of which were idle.

The Coffee Canyon area was discovered in August 1928 by Lindsay Oil Company well No. 1 (now Golden Bear Oil Company, Ltd.) located in the SW¼ Sec. 6, T. 28 S., R. 29 E., M. D.

The Pyramid Hill area of the Round Mountain field was discovered by Crestmont Oil Company well No. "Olcese" 1, completed in the Vedder zone in May 1937.

Round Mountain and Coffee Canyon are served by three oil pipe lines, Standard Oil Company 8-inch line, Shell Oil Company 8⅝-inch line, and Golden Bear Oil Company, Ltd., 5-inch line.

South of the Pyramid Hill area, near the west quarter-corner of Sec. 21, T. 28 S., R. 29 E., M. D., a small accumulation of oil has been found in the Jewett and Elbe zones. The Vedder sand is wet at this location.

DISTINGUISHING FEATURES

The Round Mountain field pools are all strictly fault-closed reservoirs.

The Round Mountain field is the southernmost and second largest field in an area 3 miles wide by 14 miles long, extending from Sec. 29, T. 28 S., R. 29 E., M. D. on the south, to Sec. 20, T. 26 S., R. 28 E., M. D. on the north. Production is from formations of Miocene age in this area, a fact that distinguishes it from all previously developed fields on the east side of the San Joaquin Valley, where production is obtained from formations of Pliocene age.

The main zone, the Vedder, is one of unusually high porosity and permeability, determinations of which have been as high as 30,000 millidarcys in some cores tested. Production is affected by a very active but not necessarily beneficial water drive.

The southern portion of the Round Mountain field is the only locality in the area which has established commercial production in the Jewett or Elbe zones.

* Geologist, Honolulu Oil Corporation. Manuscript submitted for publication July 16, 1941.

STRATIGRAPHY

PLIOCENE				
Kern River series				Continental
MIOCENE				
Monterey	Lower	Round Mountain silt	Round Mountain silt	Marine
Temblor	Upper		Olcese sand	Marine
	Lower		Freeman silt	Marine
Vaqueros			Jewett silt	Marine
			Vedder	Marine
			Walker	Continental
?		Basement complex	Granite	Igneous

The Kern River series is believed to be of fresh-water delta origin, and to contain no known marker fossils. The formations consist of poorly sorted sands and mudstones grading from very coarse to finer sediments toward the base. This formation is not present within the productive limits of the field, but outcrops a mile to the west.

The Round Mountain silt, exposed at the surface, ranges from 0 to 180 feet in thickness at Round Mountain, and consists of firm silty fine-grained brown sand with occasional streaks of diatomaceous silt and frequent gray-brown clay streaks. Both deep- and shallow-water fauna are represented. Fossil shark teeth are found in the upper Round Mountain silt in the NW¼ Sec. 18, T. 28 S., R. 29 E., M. D. The diatomite beds yield *Turritella ocoyana* and the lower formations yield deep-water forms such as *Turritella modyi*.

The Olcese sand consists of 850 feet of firm to hard medium- to coarse-grained sand and occasional clay streaks toward the top. Sediments increase in siltiness toward the base. Calcareous streaks and boulders are found throughout the section. This is the first formation fully penetrated in Round Mountain wells.

The Freeman silt consists of 650 feet of firm micaceous to micromicaceous gray to blue-gray silt and very fine-grained sandy siltstone with occasional calcareous streaks. This formation is characterized by an abundance of forams and fish scales.

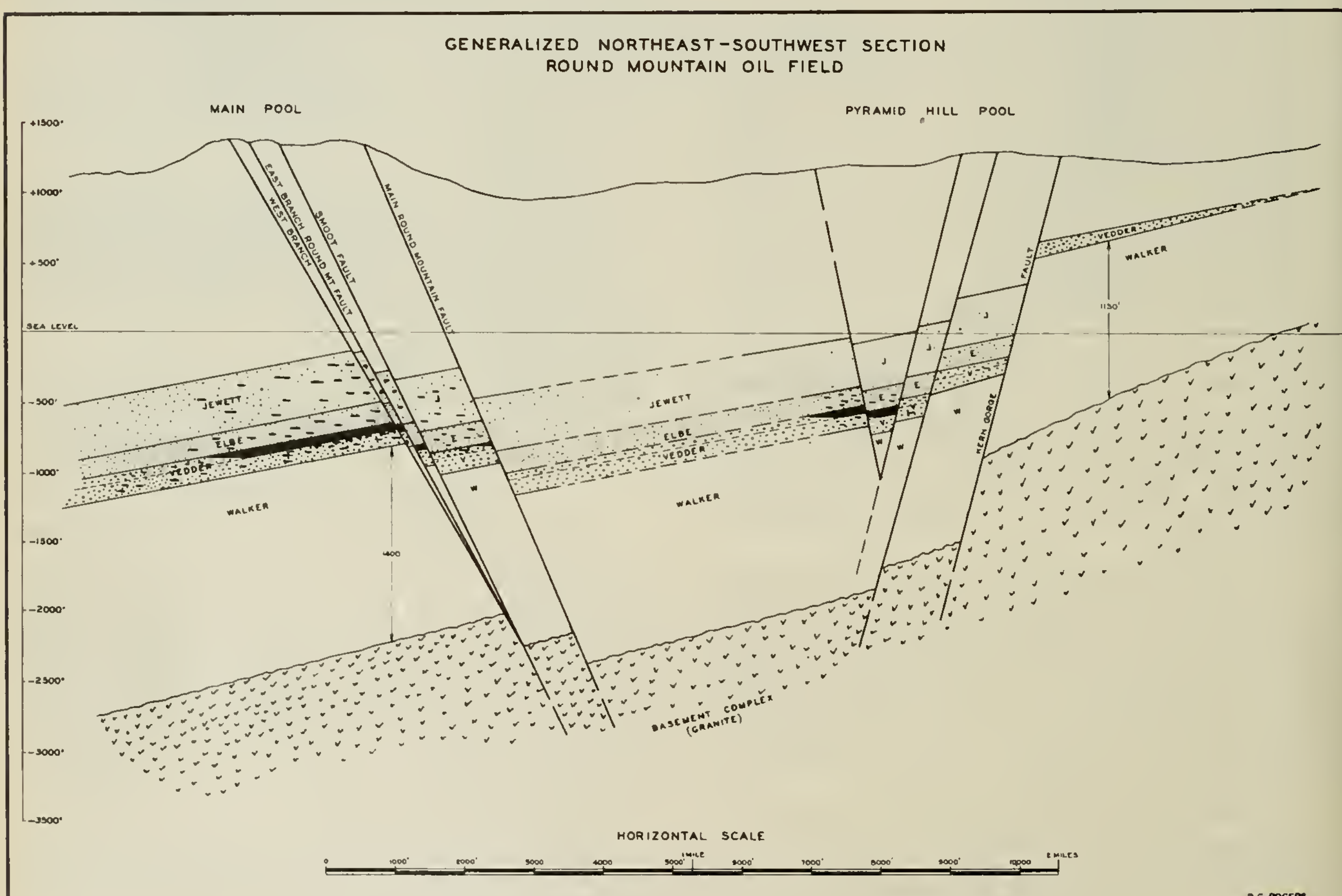


FIG. 256. Round Mountain oil field: generalized northeast-southwest section.

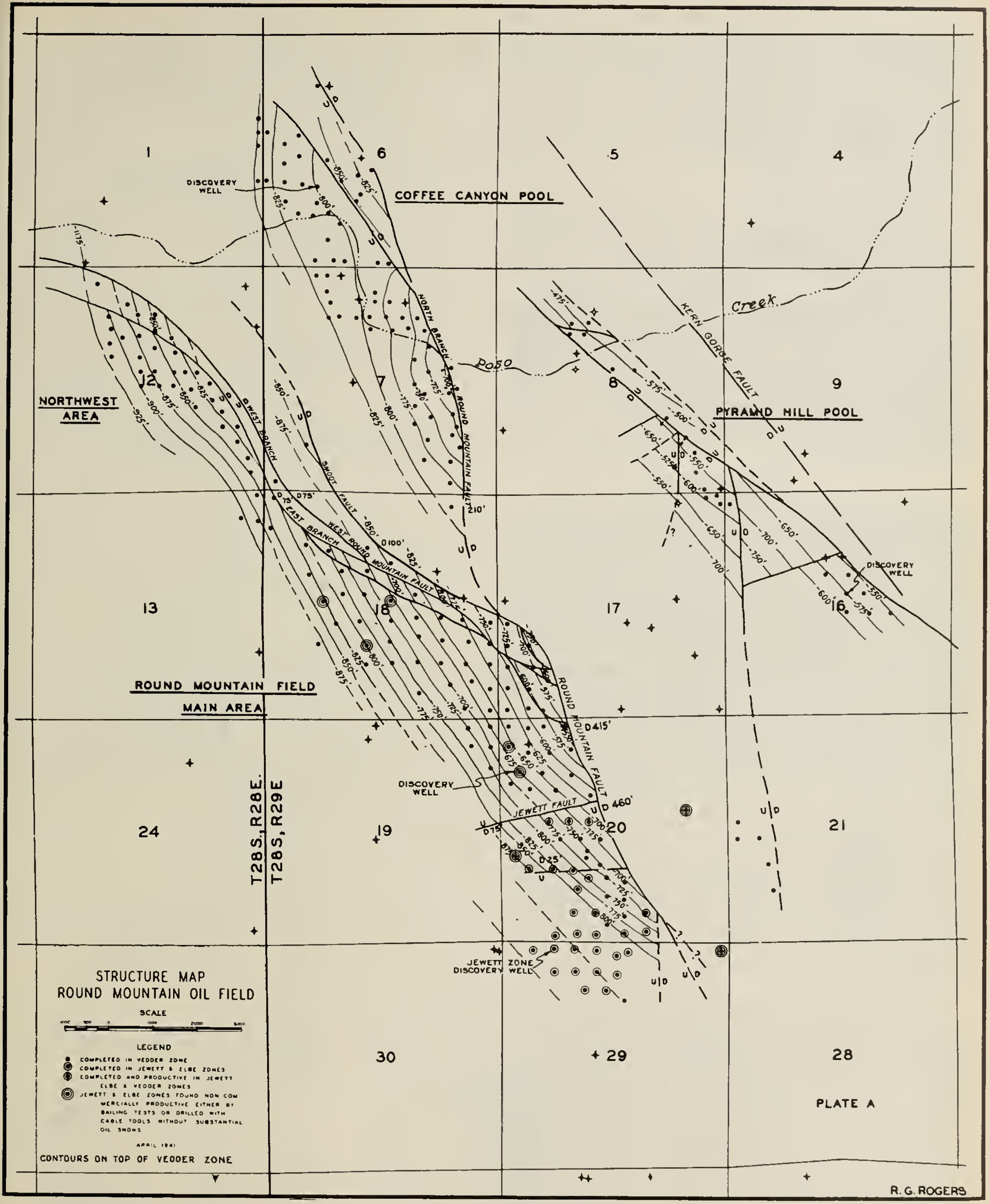


FIG. 257. Round Mountain oil field: structure map.

The Jewett silt consists of 590 feet of firm to hard gray-brown micaceous silt and silty fine-grained sand with occasional greenish sandy silt streaks and ashy clay streaks at the top. The basal 10 to 15 feet ("grit zone") consists of unsorted fine to coarse sand with large quartz grains and rounded chert pebbles. The fauna contained are deep-water forms, noteworthy among them being *Acila conradi*, *Fusinas corpulentus*, and *Cardita subtanta*.

The Vedder formation consists of 40 to 50 feet of unconsolidated medium- to coarse-grained blue-gray sand with thin, hard calcareous streaks, followed by 110 to 200 feet of increasingly finer and siltier sediments. The Vedder sand is not known to outcrop, but wedges out to the east.

The Walker formation consists of 1,100 to 1,400 feet of sediments of continental origin, typified by unsorted angular quartz grains, biotitic flakes and altered feldspars often in a limy matrix with variegated coloring. It lies unconformably on the granite.

The basement complex is principally granite, being weathered granite at the contact, grading into granodiorite with depth.

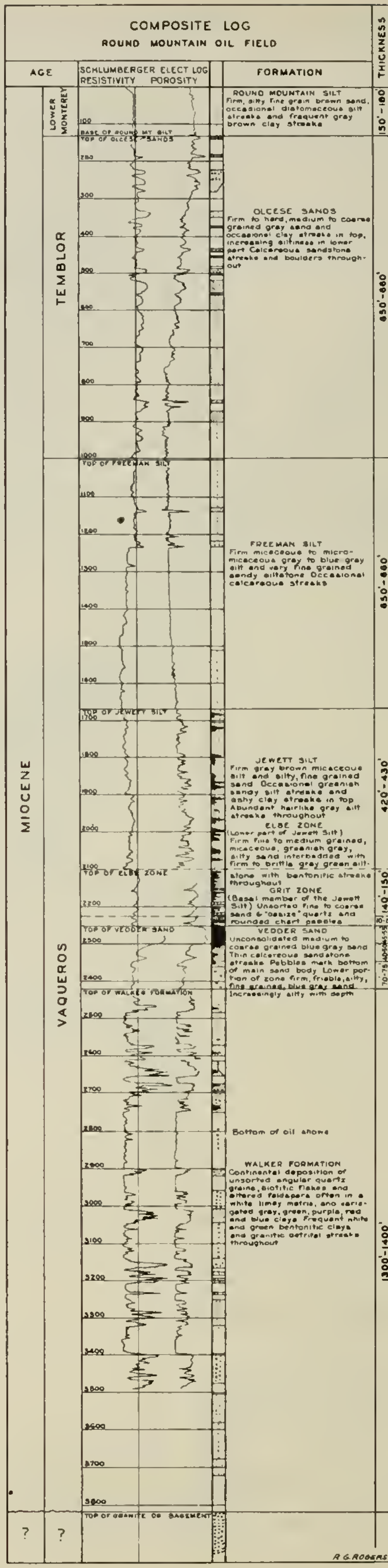


Fig. 258. Round Mountain oil field: composite log.

STRUCTURE

The structure of the Round Mountain field is that of a gently dipping monocline closed by a system of normal faults. The regional dip of formations is 5 to 7 degrees to the southwest. The main Round Mountain fault trends approximately N. 15° W.; it is downthrown on the east, and has a dip of approximately 65 degrees at the surface. Displacement ranges along the main fault from 460 feet near the center of Sec. 20, T. 28 S., R. 29 E., M. D., to 380 feet near the east quarter-corner Sec. 18, T. 28 S., R. 29 E., M. D., whence it swings on a north-south trend to Poso Creek. Displacement in Sec. 7, T. 28 S., R. 29 E., M. D., is approximately 200 feet.

The west Round Mountain fault branches from the main fault near the east quarter-corner of Sec. 18, T. 28 S., R. 29 E., M. D., and trends northwestward to the north quarter-corner of Sec. 12, T. 28 S., R. 28 E., M. D. The aggregate displacement of this fault is 200 to 350 feet, and the down-throw is on the northeast.

The Jewett fault intersects the main Round Mountain fault in the NW¼ Sec. 20, T. 28 S., R. 29 E., M. D., strikes approximately S. 78° W., and dips southward. Displacement is approximately 75 feet, the down-throw being on the south. This fault may prove to be the northern barrier to commercial production from Jewett and Elbe zones.

The main and west faults are not single displacements, but are a series of step-tension faults. It is probable that the main displacements extend into the basement complex and reflect major basement slippages, while the others are tension adjustments which may or may not extend to the granite. Success and accuracy in the identification and plotting of secondary faulting has been materially aided by the use of electric logs.

Reservoir closure is formed by a slight strike swing from N. 50° W. in the south to N. 25° W. in the northwest area closing against the main and west faults. The Vedder oil-water interface is found to vary from —775 feet at the south end of the field to —925 feet at the north end.

PRODUCTIVE ZONES

The accumulation of petroleum products in the Round Mountain field has been confined to three zones, namely the Jewett, the Elbe, and the Vedder. Jewett and Elbe zones are found to be commercially productive only south of the Jewett fault. The Vedder zone, which is the more important and widespread, is found to be productive over the entire field except for that portion southwest of the —775-foot contour in Sec. 20 and 29, T. 28 S., R. 29 E., M. D. The area from this contour to the Jewett fault, comprising approximately 100 acres, is commercially productive in all three zones. Numerous tests have been conducted to determine the productivity of the Jewett and Elbe zones north of the Jewett fault, but production in commercial quantities has not been obtained except in the small area of minor importance south of Pyramid Hill area.

Jewett zone consists of the upper 440 to 450 feet of the Jewett silt series. Approximately 30 percent of the zone is fine oil sand and oily silt.

Production from the Jewett zone ranges from 23 to 27 degrees gravity and carries very little gas. Because of the low permeability, the potentials established averaged only 200 to 400 barrels per day. Rate of decline is low, resulting in long life for this zone.

The Elbe zone is the lower 150 to 160 feet of the Jewett silt. It is usually well oil-stained, and in some wells appears to be well saturated. However, wells in which it has been tested north of the Jewett fault have indicated insufficient saturation for commercial production. Production from this zone is 18 to 22 degrees gravity.

The Vedder zone ranges in thickness from approximately 300 feet at the west edge of the Main pool to approximately 100 feet just east of the Pyramid Hill pool. The formation consists of 40 to 50 feet of loose, medium-grained sand that grades downward into a tight sandy clayey silt. Tests indicate that probably only the upper 40 to 50 feet of this zone carry production of commercial value. The oil ranges in gravity from 12 to 16 degrees, the lighter oil being at the high structural locations, closest to the controlling faults. Potentials established vary from 250 to 1,400 barrels per day with capacity of equipment the limiting factor. Average of initial potentials is approximately 1,200 barrels per well per day.

Most of the drilling has been with rotary tools employing steam or electricity for power. Considerable drilling has been done with portable rotary drilling machines powered by electricity. A few wells were drilled with cable tools early in the life of the field. The only severe development problem generally affecting drilling progress has been maintenance of rotary mud circulation. It was found practically impossible to regain circulation by mud treatment or the cementing off of zones where extreme losses occurred. Drilling in most instances is now continued without attempting to regain lost circulation until after cementing the water string.

In general, $11\frac{3}{4}$-inch or $13\frac{3}{8}$-inch casing is cemented above the upper productive portion of the Jewett zone as a primary water shut-off in the area where this zone is productive. In areas where only the Vedder zone is productive, $8\frac{5}{8}$-inch water string cemented below the top of the "grit zone" is nearly universal practice. The wells are generally finished with $6\frac{5}{8}$-inch liners containing one joint of blank at the top and the balance 100 to 200 mesh slotted. Early wells were generally drilled 70 to 80 feet into the Vedder zone. Later wells were usually bottomed with 30 to 50 feet of Vedder penetration. The average well is drilled to completion in less than three weeks.

All wells are produced by rod pumps, only two having been completed as flowing wells. Many types of pumping units are employed. These are generally powered by 15 horsepower motors capable of producing more than 1,000 barrels per day gross fluid.

Total production from Round Mountain, Coffee Canyon, and Pyramid Hill pools to January 1, 1941, was 28,356,597 barrels from 1,750 productive acres or 16,204 barrels per acre. An equivalent amount of water has been produced with the oil. In January 1941 approximately 75 percent of the gross fluid produced was water.

Less than half the oil is cleaned by electric dehydrators, the balance being effectively cleaned to pipeline requirements by the use of chemicals and heat.

Distribution of production for the month of January 1941 was as follows:

Pool	*Barrels*	*Per cent*
Round Mountain		
Main area	138,313	60.9
Northwest area	30,169	13.3
Pyramid Hill	17,368	7.7
Coffee Canyon	41,083	18.1
Field Total	226,933	

CITATIONS TO SELECTED REFERENCES—Continued

ROUND MOUNTAIN OIL FIELD

Cadle, A. 28; California Oil World 41h; Clements, T. 36; Clute, W. S. 36; Diepenbrock, A. 34; Godde, H. A. 26b; 28a; Howard, P. J. 39; McCollough, E. H. 34; Musser, E. H. 30; 39; Stockman, L. P. 35i; Taff, J. A. 34; Van Tuyl and Parker 41; Wagy, E. W. 27; Wilhelm, V. H. 38.

Coffee Canyon Area

Clements, T. 36; Clute, W. S. 36; Diepenbrock, A. 34.

North Round Mountain (McDonald) Area

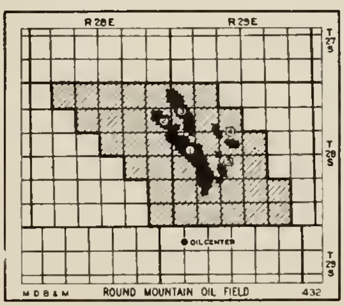
Hoots, H. W. 38.

Pyramid Hills

Hoots, H. W. 38.

Round Mountain Area

Diepenbrock, A. 34.



Round Mountain oil field. Areas: (1) Round Mountain; (2) McDonald; (3) Coffee Canyon; (4) Eastmont; (5) Olcese.

Tampico (Eastmont) Area

Hoots, H. W. 38, p. 702.

TERRA BELLA OIL FIELD

Franke, H. A. 30b; Musser, E. H. 30; Suverkrop, L. 31.

RIVERDALE OIL FIELD

California Oil World 42; 42a.

HELM OIL FIELD

California Oil World 42; 42a.

RAISIN CITY OIL FIELD

California Oil World 42; 42a; Petroleum World 41e; 41h; Sanders, T. P. 41c.

CHOWCHILLA (MERCED) REGION

Dodd, H. V. 30; 39; Oil and Gas Journal 41f; Rousselot, N. A. 35; Stalder, W. 41.

Chapter XII

Northern San Joaquin Valley, Sacramento Valley, and Northern Coast Ranges

CONTENTS OF CHAPTER XII

CITATIONS TO SELECTED REFERENCES—Continued

NORTHERN SAN JOAQUIN VALLEY, SACRAMENTO VALLEY, AND NORTHERN COAST RANGES

Allen, V. T. 41; Anderson and Russell 39; Anderson, F. M. 40; Bryan, K. 23; Burkhart, H. W. 10; Clark, B. L. 29; Cooper, A. S. 11a; Eldridge, G. H. 01; Hinton, A. R. 37; Louderback, G. D. 40; Porter, W. W. II 39b; Stalder, W. 31a; 32a; 33; Stockman, L. P. 36b; Tolman, C. F. 31; Trask and Hammar 34; U. S. Geological Survey 34; Uren, L. C. 37; Vander Leck, L. 21; Wagner, P. 26a.

Butte County

Logan, C. A. 28; McLaughlin and Waring 14; Vander Leck, L. 21.

Colusa County

Boalich, E. S. 20; Bradley, W. W. 16; Crawford, J. J. 96; Goodyear, W. A. 90; Logan, C. A. 29; McLaughlin and Waring 14; Mining and Scientific Press 65d; 65e; 65o; Prutzman, P. W. 10; Taff, J. A. 34; Vander Leck, L. 21; Watts, W. L. 93; 00.

Glenn County

Averill, C. V. 29b; Boalich, E. S. 20; Bradley, W. W. 16; Vander Leck, L. 21; Watts, W. L. 93.

Lake County

Anderson, C. A. 36; Becker, G. F. 88; Boalich, E. S. 20; Bradley, W. W. 16; Fairbanks, H. W. 93; Goodyear, W. A. 90; Irelan, W., Jr. 88c; McLaughlin and Waring 14; Vander Leck, L. 21; Weber, A. H. 88.

Marin County

Bradley, W. W. 16; Crawford, J. J. 96; Laizure, C. McK. 26a; McLaughlin and Waring 14; Mining and Scientific Press 65; Prutzman, P. W. 10; Stalder, W. 41; Vander Leck, L. 21; Weber, A. H. 88.

Mendocino County

Averill, C. V. 29a; Boalich, E. S. 20; Clark, S. G. 40; Irelan, W., Jr. 88b; 88c; Lowell, R. L. 15; McGregor, A. 90; Prutzman, P. W. 10; Vander Leck, L. 21; Watts, W. L. 00; Weber, A. H. 88.

Merced County

Boalich, E. S. 20; Vander Leck, L. 21; Watts, W. L. 90; 94.

Napa County

Averill, C. V. 29; Bradley, W. W. 16; Crawford, J. J. 96; Laizure, C. McK. 22a; McLaughlin and Waring 14; Mining and Scientific Press 65; Taff, J. A. 34; Vander Leck, L. 21; Watts, W. L. 00.

Nevada County

Weber, A. H. 88.

Placer County

Vander Leck, L. 21.

Sacramento County

Brown, C. C. 30; Bryan, K. 23, pp. 276-280; Crawford, J. J. 94; 96; Lindgren, W. 94; Logan, C. A. 25; Stalder, W. 41; Vander Leck, L. 21; Watts, W. L. 90; 94; Weber, A. H. 88.

San Bernardino County

Cloudman, Huguenin, Merrill, and Tucker 19; Goodyear, W. A. 88; Prutzman, P. W. 13.

San Joaquin County

Boalich, E. S. 20; Crawford, J. J. 94; 96; Irelan, W., Jr. 88b; 88c; Laizure, C. McK. 25; Lowell, R. L. 16; Oil Weekly 37; Prutzman, P. W. 10; Vander Leck, L. 21; Watts, W. L. 90; 94; Weber, A. H. 88.

Shasta County

Diller, J. S. 06; Prutzman, P. W. 10; Vander Leck, L. 21.

Solano County

Boalich, E. S. 20; Bradley, W. W. 16; Crawford, J. J. 96; Laizure, C. McK. 27a; McLaughlin and Waring 14; Prutzman, P. W. 10; Stalder, W. 41; Vander Leck, L. 21; Watts, W. L. 90; Weber, A. H. 88.

Sonoma County

Bradley, W. W. 16; Dickerson, R. E. 22; Goodyear, W. A. 90; Hanna, G. D. 23a; Laizure, C. McK. 26b; McLaughlin and Waring 14; Prutzman, P. W. 10; Vander Leck, L. 21; Watts, W. L. 93; Weber, A. H. 88.

Stanislaus County

Boalich, E. S. 20; Vander Leck, L. 21; Watts, W. L. 90; 94.

Sutter County

Boalich, E. S. 20; Oil Weekly 37; Vander Leck, L. 21; Waring, C. A. 19.

Tehama County

Averill, C. V. 28; Tucker, W. B. 23; Vander Leck, L. 21; Weber, A. H. 88.

Trinity County

Vander Leck, L. 21.

Yolo County

Crawford, J. J. 94; Vander Leck, L. 21.

Yuba County

Lindgren and Turner 95; Vander Leck, L. 21; Watts, W. L. 93.

TRACY GAS FIELD

By H. T. Beckwith *

OUTLINE OF REPORT

HISTORY

The Tracy gas field is located in Secs. 15 and 22, T. 2 S., R. 5 E., M. D., in the extreme northwestern portion of San Joaquin County. It lies about 20 miles southwest of Stockton, near the town of Tracy.

The field was located by a seismograph survey made by the Amerada Petroleum Corporation. The discovery well was drilled by Amerada in the SE¼ Sec. 15, T. 2 S., R. 5 E., M. D., in 1935. Six commercial gas wells have been completed, of which four are still producing. Two dry holes were drilled and abandoned, one by the Holly Development Company on the Padden lease in Sec. 16, T. 2 S., R. 5 E., M. D., and one by the Amerada Petroleum Corporation in Sec. 23, T. 2 S., R. 5 E., M. D. All of the productive acreage in the field is held by Amerada.

* Geologist, Monrovia, California. Manuscript submitted for publication September 2, 1941.

DISTINGUISHING FEATURES

The field is significant in that it is the first commercial gas field found in the northern part of the State; and it is the first field to produce gas commercially from Cretaceous sediments. It is also interesting to note that Eocene formations are entirely missing in this area.

SIGNIFICANCE

When compared with some of the other gas fields of the State, the total gas reserve developed in the Tracy gas field is relatively small. The field covers approximately 600 acres, and the average thickness of the producing sand above the water table was 100 feet. The gas is dry (no oil is produced with the gas) and has a calorific value of 935 B. t. u.

The field is connected to the Stanpac major trunk line by a 6-inch line, and this, in turn, is connected with the main trunk of the Pacific Gas and Electric Company's natural gas transmission line at Milpitas.

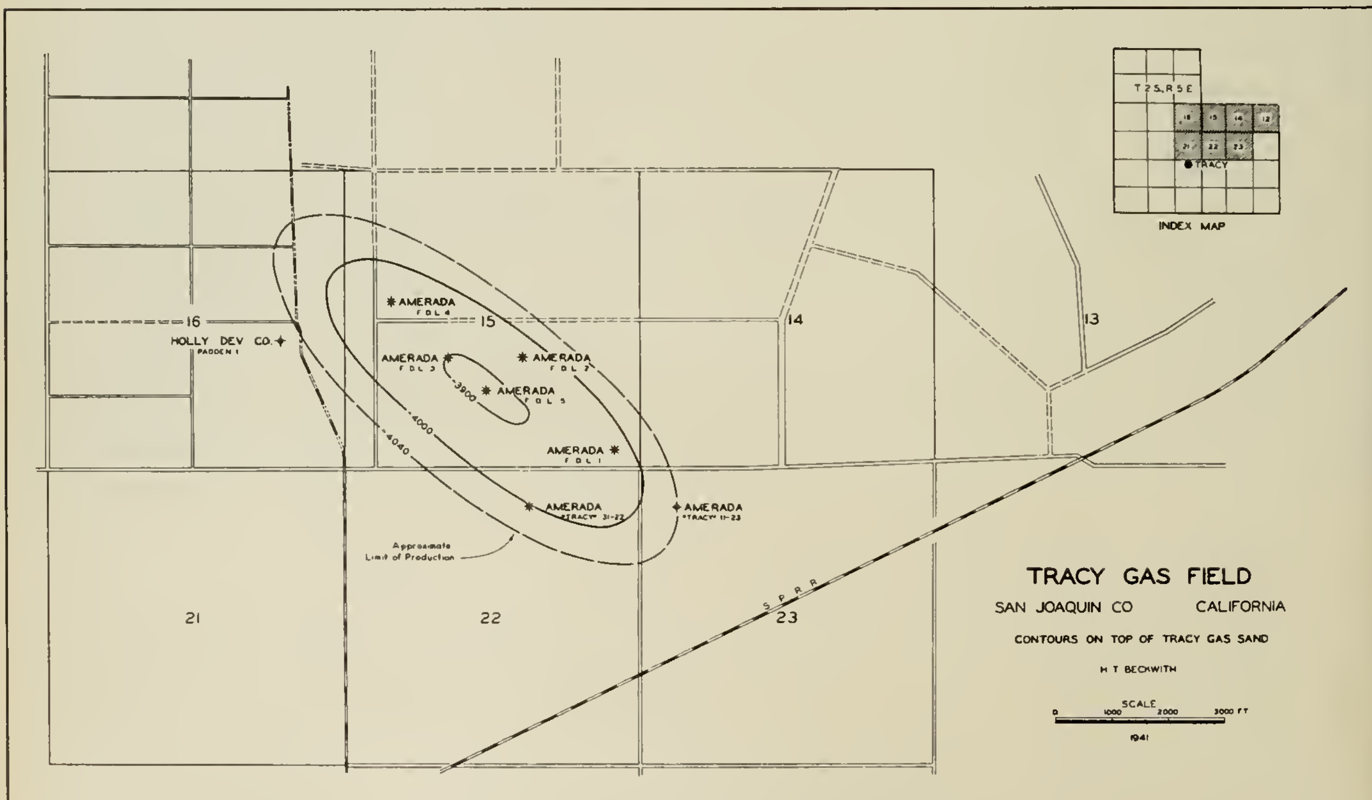


Fig. 259. Tracy gas field: structure map; index map.

TABLE 1

Completion Data—Wells Drilled in the Tracy Gas Field

Company	Well	Location			Depth		Status	Initial Prod. M.C.F.	Date completed
		S.	T. (S.)	R. (E.)	Effective	Total			
Amerada Petroleum Corp.	FDL 1	15	2	5	4,070	9,690	Gas well	5,000	1/ 7/36
Amerada Petroleum Corp.	FDL 2	15	2	5	4,063	4,063	Discovery	35,000	8/11/35
Amerada Petroleum Corp.	FDL 3	15	2	5	4,029	4,029	Gas well	65,000	1/ 6/36
Amerada Petroleum Corp.	FDL 4	15	2	5	4,050	5,050	Gas well	35,000	2/ 9/36
Amerada Petroleum Corp.	FDL 5	15	2	5	4,025	6,160	Gas well	25,000	3/10/36
Amerada Petroleum Corp.	31-22 Tracy	22	2	5	4,060	4,133	Gas well	33,800	10/24/35
Amerada Petroleum Corp.	11-23 Tracy	23	2	5	Dry	5,107	Abandoned	None	12/18/35
Holly Development Company	Padden No. 1	16	2	5	Dry	4,125	Abandoned	None	5/16/36

TABLE 2

Annual Gas Production, Tracy Gas Field

Year	*Annual Prod. M. C. F.*	*Remarks*
1935	1,228,964	
1936	3,012,083	
1937	2,510,965	
1938	653,372	Shut in during summer months
1939	622,856	Shut in during summer months
1940	906,688	Shut in during summer months
1941	500,000	Approximate production for first half of year

It has to be noted that since the year 1937 the annual production has been much less than in previous years. This is due to the fact that since 1937 the Tracy field has been used as a stand-by for the gas-transmission trunk lines and has delivered gas into these lines only during the winter months or periods of increased gas consumption. During the summer months, periods of low gas consumption, the wells have been shut in and the pressures allowed to become stabilized. This is shown by the following shut-in pressure readings: The original shut-in surface pressure was between 1,690 and 1,700 pounds per square inch; on July 25, 1940, the average shut-in surface pressure reading, of the four wells then producing, was 1,110 pounds per square inch; and at none of the wells did the surface pressure vary more than 11 pounds per square inch from this average.

STRATIGRAPHY

The Amerada Petroleum Corporation well No. "FDL" 1 was the first well drilled in the Tracy field, and was carried to a depth of 9,690 feet. It was later plugged back and brought in as the second producing gas well. The following notes on the formations encountered are based upon the cores secured in this well, their correlation with similar data from several other wells in this general area, and a study of surface outcrops in the Ingram Creek region.

From the surface to 3,477 feet, all sediments penetrated were nonmarine in origin. In the main they consisted of soft sands, sandy shales, clay shales, and sandstones. Most of them were similar in character to the San Joaquin clay shales to the south. No attempt has been made to subdivide this 3,400 feet of sediments. While there is probably some Recent and Pleistocene near the top; it is believed that most of these sediments of this region are Pliocene in age, with possibly a small thickness of Miocene (San Pablo?) at the base.

At 3,477 feet the well passes through an unconformity and directly into Cretaceous sediments. The Cretaceous in this well was over 200 feet deeper than in the Union Oil Company well No. "Tracy" 1 some 10 miles to the southeast. However, micropaleontologic evidence places the top of the Cretaceous zone encountered in No. "FDL" 1 some 1,200 feet higher than the same zone was encountered in the Union Oil Company well. The Miocene-Eocene section from 2,130 to 3,119 feet and the Cretaceous *Bulimina prolixa* zone from 3,199 to 3,956 feet as found in the Union well, were missing in the Amerada test.

The uppermost Cretaceous beds, encountered from 3,477 to 3,895 feet, were classified by Dr. Paul P. Goudkoff as the *Siphogenerinoides* zone, Moreno in age. From 3,895 to 5,700 feet is the *Nodosaria spinifera* zone, Panoche in age. This zone contains the gas-producing horizon near the top, the top of the gas sand being found in the well No. "FDL" 1, at 4,005 feet.

From 5,700 feet to the bottom of this well at 9,690 feet, all the sediments are classed as Cretaceous (Panoche) in age. Dr. Goudkoff has subdivided them as follows: From 5,700 to 6,900 feet is the *Planulina constricta* zone; and from 6,900 to 9,690 feet is the *Bathysiphon taurinensis* zone.

This Cretaceous shelf or island in which the Tracy gas field is located, and upon which the Eocene sediments are absent, appears to be quite extensive. It extends from the foothills west of the field, south and east some 11 miles to the Standard Oil Company well No. "Blewett' 1. In this well no Eocene sediments were encountered. To the east 8 miles, in the Texas Company well No. "Lawrence Stephens" 1 on Roberts Island, Eocene sediments were also missing.

STRUCTURE

Other than a bulging of the surface topography, there are no surface indications of structure in the Tracy field, and location of the northwest-trending dome that forms the trap for the gas was accomplished entirely by geophysical methods. Contours shown on the accompanying map are on top of the "Tracy" gas sand, the producing horizon. The location of the closing contour is approximate, and is here considered as the probable limit of the original gas-producing area.

McDONALD ISLAND GAS FIELD*

By GEORGE L. KNOX **

OUTLINE OF REPORT

HISTORY

The McDonald Island gas field is located on McDonald and Roberts Islands, in the southeast part of T. 2 N., R. 4 E., M. D., and the southwest part of T. 2 N., R. 5 E., M. D. It is 10 miles northwest of Stockton and immediately southwest of the San Joaquin River.

The McDonald Island gas field was discovered as a result of a reflection seismograph survey carried out by the Geophysical Service, Inc., for the Standard Oil Company of California. Reconnaissance work in the fall of 1935 indicated an anticline in the area, and detailed work revealed the presence of a closed dome. The area is rather difficult to work with a reflection seismograph; however, the fact that the first well is structurally the highest of the seven drilled to date is fair evidence that it was possible to predict the general shape of the structure from seismograph data.

McDonald Island Farms No. 1 was spudded in March, and completed in June, 1936. A formation test on the sand below 4,200 feet, yielded about 8 million cubic feet of gas, but water beneath the gas prevented production from that horizon in No. 1. With 9-inch casing at 5,153 feet, the well was finally completed in the McDonald Island sand for over 26 million cubic feet of dry gas through a ¾-inch orifice. The gas was chiefly methane. Shut-in pressures were about 2,100 pounds. Since that date, five other producers and one failure have been drilled. A gas line from the local gathering system delivers the gas to the Pacific Gas and Electric valley gas line on the west side of the valley.

STRATIGRAPHY

The surface of McDonald Island is a perfectly flat plane at sea level elevation. Like other islands of the San Joaquin-Sacramento delta area, it is protected by large, expensive levees, which exclude river and tide waters. River steamers go past the island to Stockton by way of the Stockton deep-water channel of the San Joaquin River. An auto ferry connects McDonald and Roberts Islands.

The soil covering McDonald Island contains a considerable percentage of peat and plant remains in various stages of decomposition, particularly in the top 5 to 10 feet. No clue to subsurface structure is offered by the soil, topography, or drainage pattern. The peaty soil is a handicap to seismographic work, but is properly constituted for raising excellent crops of potatoes and beets.

* The writer is indebted for permission to publish this article to Mr. G. C. Gester, Chief Geologist of the Standard Oil Company of California. For their aid in preparation or criticism the writer is grateful to Mr. E. C. Doell, Mr. W. P. Winham, Mr. T. H. Crook, and Mr. W. F. Barbat.

** Standard Oil Company of California. Manuscript submitted for publication June 28, 1938.

The stratigraphy of McDonald Island is best known from cores of the first well drilled thereon. Loose dark-gray sands and green and yellow clays encountered in McDonald Island Farms No. 1 above 1,450 feet are considered Pleistocene and Pliocene in age. The lower portion may be equivalent to the Tehama.

Between depths of 1,470 and 2,772 feet are 1,300 feet of sediments which are tentatively placed as equivalent to the Mehrten formation. Cores in this interval include a considerable amount of cross-bedded sandstone with blue-coated grains. The coating on these grains is blue opal. Pebbly sandstones, fine siltstones, and green and variegated clays are also present in the same interval. The Mehrten formation has been described by Piper, Gale, Thomas, and Robinson (39) in a report for the U. S. Geological Survey. They named it after exposures along the Mokelumne River near the Mehrten damsite, about 3½ miles upstream from the Clements bridge in the SW¼ Sec. 6, T. 4 N., R. 9 E., M. D. They described the Mehrten as a fluviatile sandstone, siltstone, and conglomerate of dominantly andesitic detritus, overlying and truncating the pumice, ash, tuff, clay, sand, and conglomerate of the Miocene Valley Springs formation. They regarded the Mehrten as questionably Miocene. It seems at least as likely that it is lower Pliocene.

Fresh water sediments in McDonald Island Farms No. 1 between 2,797 and 3,555 feet are believed to be of Miocene age. They are possibly roughly equivalent to the Zilch. The zone is predominantly clay, but includes sands and conglomerates, with ash beds below 2,797 feet and bentonite beds below 3,407 feet.

The brackish-water Miocene zone between 3,570 and 3,846 feet includes variegated sands (blue, black, and brown) with worm borings, lignitic material, and pyritized plant remains. Marine fossiliferous fine sands between 3,866 and 3,968 feet are Miocene in age.

Typical deep-water upper Eocene Markley shale is present between 3,968 and 4,208 feet. The Markley here is a brown to gray, compact, hard shale. Bentonitic and carbonaceous materials and glauconite are intermittently present. Radiolaria and fish scales are common. Macrofossils are sparse, but Foraminifera are present in great diversity and abundance.

Between 4,208 feet and the uncored interval 4,218 to 4,224 feet are 10 to 16 feet of fine glauconitic sandstone and siltstone. This zone is characterized by the presence of *Pecten interradiatus*. It is basal Markley in age.

The sediments between 4,224 and 4,973 feet are Domengine. A good Domengine marine microfauna is present at 4,258 feet, and intermittently at greater depths. The upper 200 feet of the Domengine consists of interbedded siltstones, fine sands, and thin shales with carbonaceous material, pyritized plant remains, and occasional groups of glauconite grains. The portions below 4,408 feet are predominantly medium to coarse quartzose gray sand with some interbedded brown shale. White sandy bentonite is present at the base. The mega-fauna and micro-fauna are both characteristic and abundant.

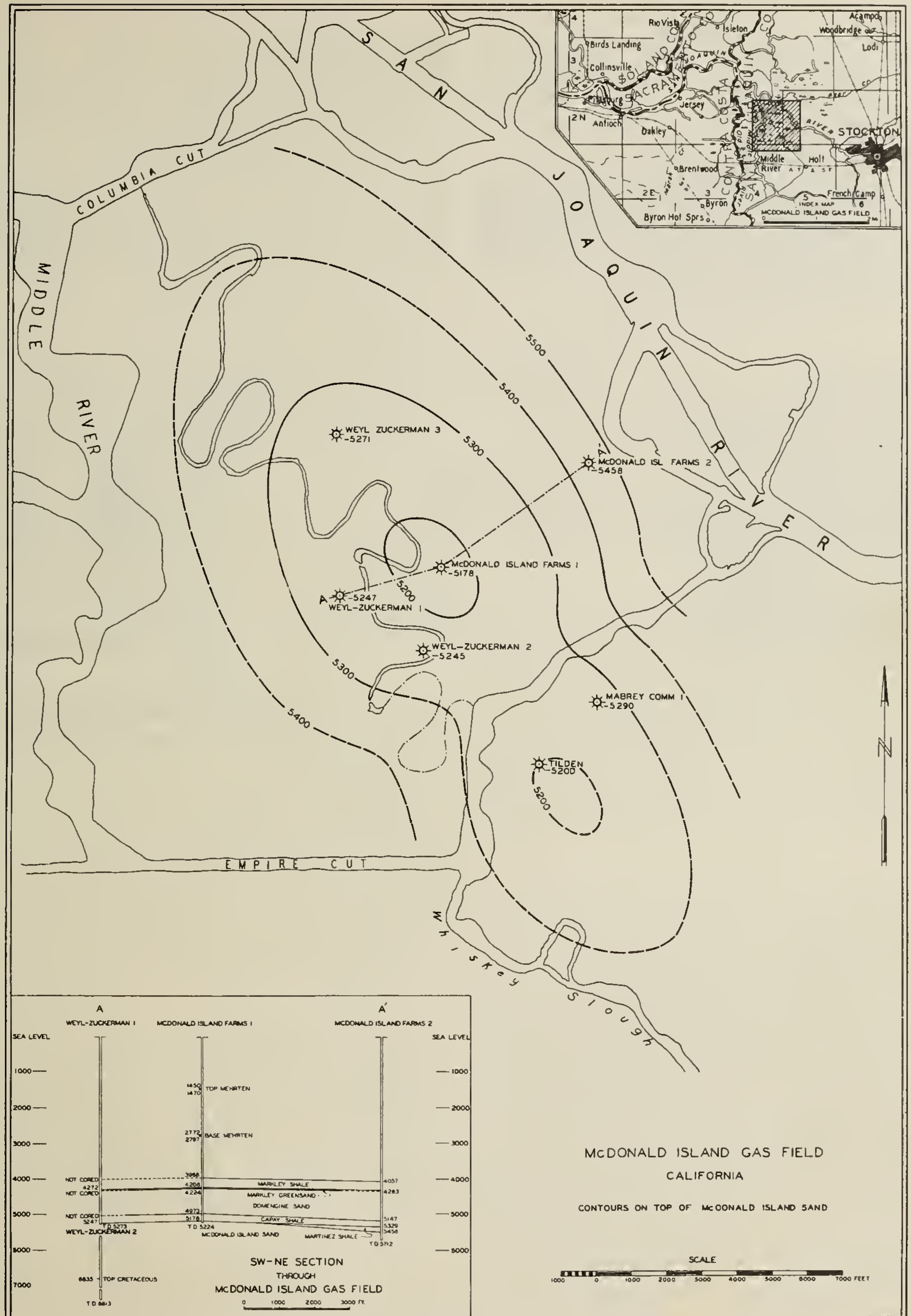


Fig. 260. McDonald Island gas field; structure map; cross-section; index map.

The Capay shale is present in McDonald Island Farm No. 1 between 4,973 and 5,178 feet. It is a brown to gray shale with phosphatic nodules, pyritized plant remains, and some glauconite. The base is marked by a glauconitic sandy conglomerate. Small gastropod and pelecypod fragments are common, and a characteristic assemblage of Foraminifera is present.

In McDonald Island Farms No. 1 the Capay rests directly on the McDonald Island sand. However, 130 feet of Martinez shale intervene between the Capay shale and the McDonald Island sand in the McDonald Island Farms No. 2. This Martinez shale is a grayish-brown shale with phosphatic nodules, worm borings, scattered glauconite grains, and sparse Martinez forams.

The McDonald Island sand is the producing gas sand of the structure. It is a fine to medium friable gray sand, with interbedded siltstones and brownish-gray shales and occasional streaks of carbonaceous material. A thickness of 254 feet of this sand was penetrated in McDonald Island Farms No. 2. Weyl-Zucherman penetrated 1,590 feet of similar sandstone and shale regarded as Martinez, between 5,245 and 6,835.

The Cretaceous was reached by Weyl-Zucherman No. 2. The top of the Cretaceous has been placed at 6,835 feet. A good Cretaceous (Garzas) fauna is present at 7,162 feet. The Cretaceous consists of foraminiferal dark-gray to brown shales, with fish scales and carbonaceous material, interbedded with fine gray sands.

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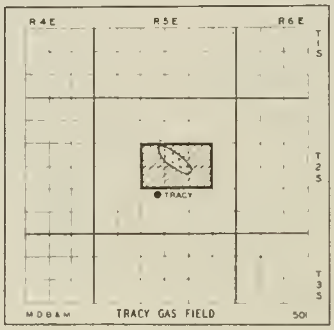
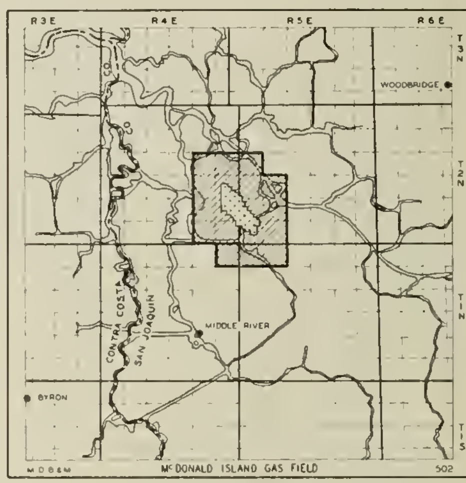


Tracy gas field.



McDonald Island gas field.

RIO VISTA GAS FIELD*

By E. K. Soper **

OUTLINE OF REPORT

HISTORY

The Rio Vista gas field is located on both sides of the Sacramento River in Solano and Sacramento Counties. It is possible that future development may extend the field southward across the San Joaquin River into Contra Costa County. The present area of development surrounds the town of Rio Vista, which is located on the west bank of the Sacramento River.

The field was discovered by the Amerada Petroleum Corporation in its No. "Emigh" 1 well completed June 18, 1936, located in Sec. 26, T. 4 N., R. 2 E., M. D. On production test the well flowed at the rate of 81,000,000 cubic feet of gas through a $^{90}/_{64}$ bean from a total depth of 4,485 feet, with $11\frac{3}{4}$-inch casing cemented at 4,278 feet. Tubing pressure was 1,565 pounds per square inch, casing pressure 1,550 pounds per square inch, and shut-in pressure (reservoir pressure) 1,725 pounds per square inch.

At this date (September 15, 1940) 30 wells have been drilled within the Rio Vista area, 27 of which were completed as gas wells, and 3 of which were abandoned as non-productive, edge locations. One additional well is now in process of drilling. Of the 27 productive gas wells, 18 were drilled by the Amerada Petroleum Corporation; 3 by the Standard Oil Company of California; 2 by the Tracy Drilling Company; 2 by the Texas Company; 1 by the Bishop Oil Company; and 1 by the Superior Oil Company. The Amerada Petroleum Corporation, Standard Oil Company of California, and Bishop Oil Company have each drilled one unsuccessful well to date. All but four of the wells completed to date are located on the west side of Sacramento River near the town of Rio Vista. All of the wells are shown on the accompanying map.

An interesting and almost unique feature of the development of the Rio Vista gas field is the fact that the numerous branches, channels, and sloughs of the Sacramento and San Joaquin rivers meander over the eastern half of the geologic structure where the land surface is quite flat and but little above sea level. Under these navigable sloughs and channels the gas rights are owned by the State of California, and in order to produce gas from beneath these water-courses it will be necessary to resort to slant drilling from the shores or adjacent uplands.

* The writer wishes to express his appreciation for the cooperation extended by operators in the field in supplying the data for this summary.

** Department of Geology, University of California at Los Angeles. Manuscript submitted for publication September 30, 1940.

The total depths of the wells successfully completed to date west of the Sacramento River vary between 4,333 feet and 4,507 feet. The drilling depth to the top of the gas zone in these wells varies from about 3,888 feet to about 4,370 feet. East of the Sacramento River, where only three gas wells have as yet been completed, the drilling depths have been comparable to those west of the river.

PRODUCTIVE AREA

Notwithstanding the fact that to date only the northwestern part of the Rio Vista gas field has been developed, drilling has already demonstrated that the field will extend over a very large area. The distance between the northernmost and southernmost productive wells is about $5\frac{1}{4}$ miles, and the east-west distance between outer wells is about $4\frac{1}{2}$ miles. The western and northern edges of production have been approximately indicated by drilling but as yet the east and south limits of production are unknown. It seems probable that the total productive area may exceed 18,000 acres.

TOPOGRAPHY

The topography of the Rio Vista area presents two features of special interest: (1) the apparent topographic reflection of the geologic structure west of the Sacramento River in the Montezuma Hills, where most of the drilling to date has been done; (2) the striking contrast between the rolling, stream-dissected Montezuma Hills west of the Sacramento River, and the flat, featureless plain, almost at sea level, east of the river. This feature is probably the result of the lateral erosion of the hills by the westward-shifting river in its effort to remove this topographic barrier to its normal course to the sea.

STRATIGRAPHY

The sequence of geologic formations encountered in drilling with their descriptions as determined by a study of well cores and electric logs, is shown in the accompanying table of rock formations encountered in drilling wells in the Rio Vista gas field. The thicknesses of the different formations given in the table are taken from the discovery well (Amerada No. "Emigh" 1). Since the dip of the strata is very gentle (except for local abnormalities) the thicknesses as measured in the wells will closely approximate the true stratigraphic thicknesses of the formations.

The only surface outcrops in the area consist of a few exposures of non-marine beds of probable Pleistocene age in the ravines of the Montezuma Hills west of the Sacramento River where dips of 2 to 4 degrees may be observed at several localities.

The formations penetrated in the wells range in age from Quaternary to Upper Cretaceous, but to date only one well (Amerada No. "Happe" 1) is definitely known to have penetrated formations older than the upper Arroyo Hondo formation of middle Eocene age. The

ROCK FORMATIONS ENCOUNTERED IN DRILLING WELLS IN RIO VISTA GAS FIELD

Geologic age	Formation	Foraminiferal zone (Laiming, B. 39)	Molluscan stage (Clark and Vokes 36)	Approximate thickness	Depth to top in discovery well (feet)	Description
Recent	Sandy alluvium			100±	0	Non-marine, gray to black, soft, coarse, poorly sorted sands
Pleistocene to possibly upper Miocene	Non-marine beds. Correlations as yet uncertain			1,830	100±	Non-marine; non-fossiliferous. Mostly muddy brown clay-shale and dark-gray to black, medium to coarse sand; gravel beds; some green clay-shale in lower 600 feet
Unconformity. (erosion with possible slight angular discordance)						
Upper Eocene	Markley (Kreyenhagen)	A-1	Tejon and Transition	2,035	1,930	Brown, clay-shale and gray to dark-gray, medium-grained, carbonaceous sand. Several hard sandstone reefs in lower part. Marine
	Nortonville (Emigh shale)	A-2		290±	3,965	Brown shale with several thin sandstone reefs. Marine
Unconformity. (overlap)						
Middle Eocene	Domengine ("green sand") } Gas producing horizon	B-1A	Domengine	112±	4,255	Greenish-gray, fossiliferous sand, *containing gas*. Bentonitic clay bed 125-150 feet below top. Marine
	Ione ("white sand") } Gas producing horizon	B-2	Capay	397	4,367	Light-gray to dirty white sand *containing gas*, with some thin beds of bluish-gray shale. Marine
	Upper Arroyo Hondo (upper part of Meganos, division E, of Clark and Woodford 27)	B-3 and B-4		650	5,017* (Not penetrated in discovery well)	Dark, greenish-gray shale or clay-stone; poorly stratified. Marine
	Lower Arroyo Hondo (lower part of Meganos, E and D of Clark and Woodford)	C		255±	5,272* (Not penetrated in discovery well)	Dark-gray to black shale and gray sand. Marine. (Equivalent of Cantua sand of Cantua Creek section)
Lower Eocene or Paleocene	Martinez	D and E	Meganos and Martinez	1,257	6,529* (Not penetrated in discovery well)	Dark-gray to brown shale. Marine
Upper Cretaceous	Moreno			?	(Not penetrated in discovery well)	Dark-brown shale. Marine

* Stratigraphy of formations below depth of 4,485 feet taken from records of Amerada well No. Happe 1, which reached a total depth of 7,029 feet.

upper 1,900 feet of strata penetrated consist of non-marine, unfossiliferous beds of sands, clay-shales and gravels of uncertain age. The upper few hundred feet are probably Quaternary, but the greater part of the sequence may be Pliocene, and (or) upper Miocene. These non-marine beds rest with erosional unconformity upon the Markley (Kreyenhagen) formation of upper Eocene age, which represents the youngest marine formation encountered in the area. The Markley formation also has the greatest thickness of any of the Tertiary formations thus far penetrated in the area. In the discovery well the overlying non-marine beds show a total thickness of about 1,930 feet. The Markley formation is about 2,035 feet thick. However, because of the erosional unconformity between these two formations, it is possible that the Markley may show a lesser thickness in some wells.

From 125 feet to 150 feet below the top of the Domengine formation (upper part of the gas zone) there is a persistent horizon 10 feet to 15 feet thick of bentonitic clay associated with some white sand, which may prove to be a good geologic marker throughout the field.

STRUCTURE

Although it is too early in the development of the field to determine even the approximate shape or size of the Rio Vista structure, enough data are available to indicate with reasonable certainty that it is a broad, flat, faulted dome, with an axial line trending northwest. Dips are very flat throughout the field with few local exceptions. The highest point on the top of the gas zone thus far encountered west of the Sacramento River is —3,915 feet in Amerada E. D. & A. R. Mayhood No. 1 well. The extreme range in the elevation of the top of

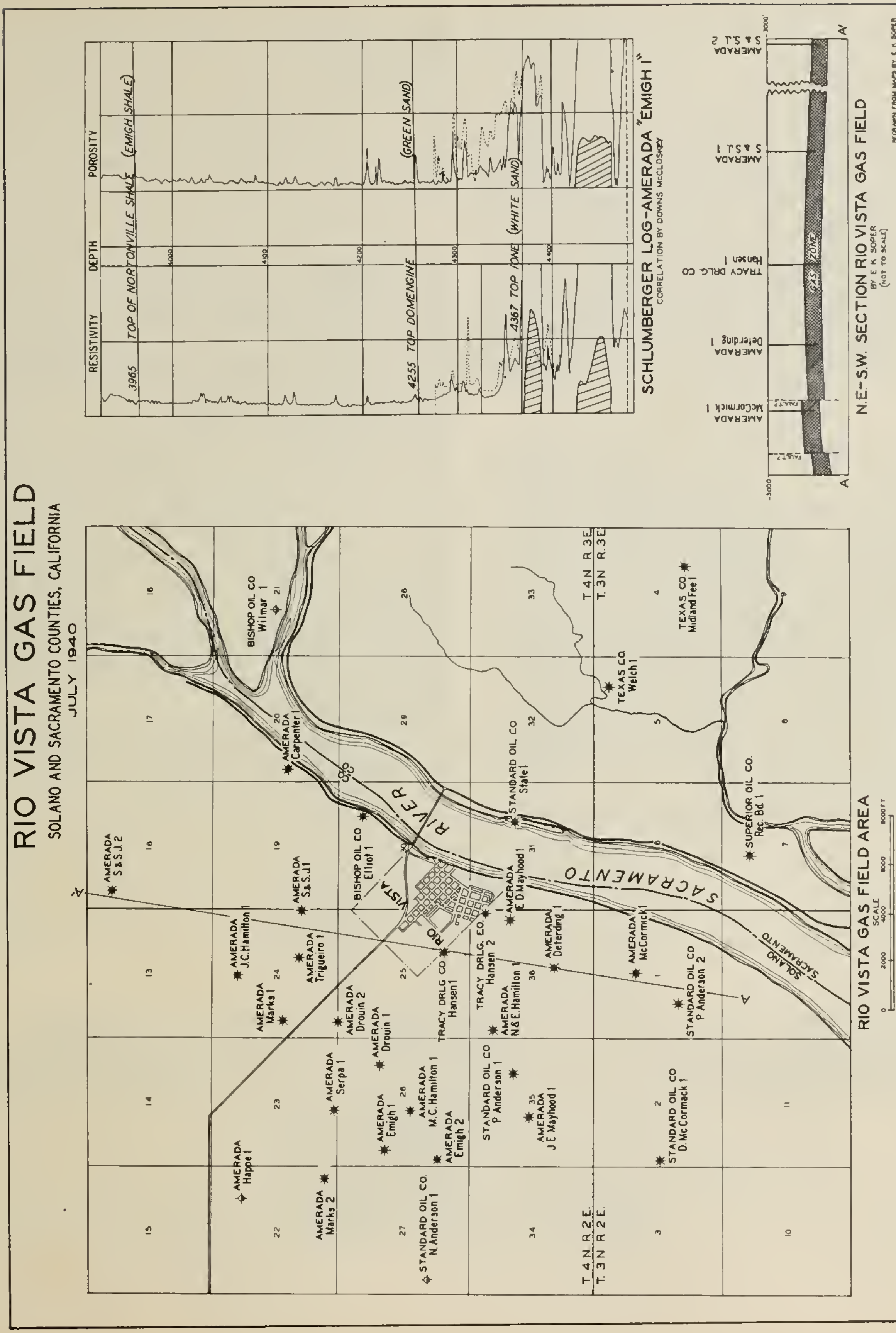


Fig. 261. Rio Vista gas field; map; Schlumberger log; cross-section of gas zone.

the gas zone in all productive wells west of the Sacramento River is 430 feet across a distance from north to south of about 3.1 miles, clearly showing the flat nature of that portion of the structure. Well correlations indicate a structurally high area extends across the Sacramento River from northwest to southeast about half a mile south of the town of Rio Vista. The structurally highest well drilled to date in the field is Superior Oil Company No. "Reclamation Board" 1, east of the Sacramento River. It is noteworthy that this is the southernmost well drilled in the field to date. Between this well and the above-mentioned structural high south of Rio Vista, several wells show a south dip of the top of the gas zone, thus demonstrating that the structure does not rise continuously from Rio Vista to Superior well No. "Reclamation Board" 1. This may indicate either faulting, or merely an irregularity in the shape of the fold. Discrepancies in elevations of the top of the gas sand in certain wells, and in the depths to bottom-water indicate the presence of several faults.

PRODUCTIVE HORIZON

The gas-producing horizon in the Rio Vista field extends from the top of the Domengine formation ("green sand") to the base of the Ione formation ("white sand"), both of upper-middle Eocene age. The top of the gas zone lies immediately below the Emigh shale (Nortonville) and is clearly indicated in the electric logs of most wells drilled thus far. The accompanying figure shows the Schlumberger electric log of the upper contact of the gas zone in the Amerada well No. "Emigh" 1, which is typical of the wells drilled to date west of the Sacramento River. The lower part of the gas zone was not penetrated in this well and hence does not show on the electric log.

The average thickness of the gas zone is about 400 feet. Bottom-water is encountered at about 4,400 feet below sea level throughout the portion of the area west of the Sacramento River, where the minus 4,400-foot structural contour drawn on top of the gas zone indicates the approximate limit of the productive area. East of the Sacramento River, where only four wells have been drilled to date, there is evidence that at least in a part of that area bottom-water may exist at a higher level than on the west side of the river. However, since it is probable that bottom-water has been reached in only one of the four wells thus far completed east of the river, it is not yet possible to make definite comparisons regarding the water levels in various parts of the field.

There is considerable evidence of faulting, such as certain localized abnormalities of dip, variations of original reservoir pressures, discordant levels of the top of the Domengine (which may be due to unconformity), and the discordance of bottom-water levels mentioned above. However, the small number of wells so far completed, the wide spacing between them, and the extensive underdrilled areas in the field make it impossible at this time to prepare a reliable structural contour map of the field, or to justify an attempt to map the positions or trends of any suspected faults.

The average porosity and permeability of the gas sands are fairly uniform in the developed area west of the Sacramento River. In the Amerada well No. "Carpenter" 1, the average porosity of the Domengine ("green sand") is 30 percent, and that of the Ione ("white sand") is 38 percent. For net effective porosity these averages would have to be corrected for connate water. The average permeability of the entire gas zone, as determined from cores from the same well, is 2,812 millidarcys. A comparison of the above figures with those obtained from other wells indicates that west of the Sacramento River the average porosity of the gas zone may be 30 to 34 percent and the average permeability about 2,000 millidarcys.

The original reservoir pressure in the field was 1,725 pounds per square inch, except in the Texas Company well No. "Midland Fee" 1 where the reservoir pressure was 1,590 pounds per square inch.

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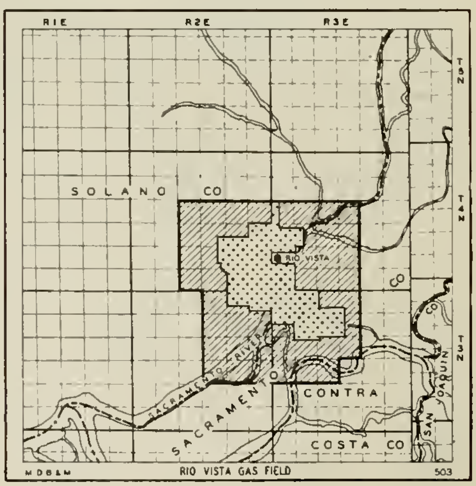

Rio Vista gas field.

POTRERO HILLS GAS FIELD

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POTRERO HILLS GAS FIELD*

By Frank B. Tolman **

OUTLINE OF REPORT

HISTORY

The Potrero Hills gas field, located in T. 4 N., R. 1 W., M. D., 40 miles northeast of San Francisco, is the fifth in the series of recently discovered gas fields in northern California.

The structure, generally known as the Potrero Hills anticline (Bailey, T. L. 31), coincides in general with the topography of Potrero Hills, an isolated range 5½ miles long and 2 miles wide, which rises from adjoining alluviated tidelands of Suisun Bay. Its easterly trend is contrary to the general northwesterly trend of topography and structure in this area.

The discovery well, Richfield Oil Corporation's No. "Potrero" 1, and the only one completed to date (January, 1940), is situated in the eastern part of this elongated eastward-plunging asymmetrical anticline. The well was spudded in April. 1938, and was drilled and cored to a depth of 5,334 feet. After testing several lower sand beds, the hole was plugged to 3,265 feet and the well was completed producing gas from 30 feet of Cretaceous sands between 3,235 and 3,265 feet. The initial daily production, on a short test, was rated at 5,000 M.c.f. per day through a $^{16}/_{64}$-inch bean with 475-pound tubing pressure and 990-pound casing pressure. The well has been shut in pending pipe-line connections and a market for the gas. The economic importance of this discovery will not be evident until a sustained production test can be made and until additional wells can be drilled to determine the structural characteristics at depth and the extent of the productive zone.

One other well was drilled prior to the discovery, a cable-tool well by Honolulu Oil Corporation in 1921. Total depth was 3,047 feet. Frequent gas showings were reported, the most important at 2,100 feet.

STRATIGRAPHY

The stratigraphy, both surface and subsurface, is shown on the accompanying chart and is in large part self-explanatory. The following supplemental notes, however, may be of interest.

The foraminiferal "upper Markley" shales, well developed north and east of Mount Diablo, were not recognized in this area, and regional studies indicate that their probable absence is due to unconformity rather than lateral gradation of the "upper shale" into sand.

Microfaunas in the upper two members of the "Nortonville"[1] ("Domengine") include an *Amphistegina californica* assemblage, which may be placed in Clark and Vokes' (36) inadequately defined "transition stage," pending formal naming and correct stratigraphical delimitation of this important zone.

A restricted Domengine fauna (Clark, B. L. 26) with *Turritella buwaldana* s.s. rather than the "transition" mutation figured by Marcus Hanna (27), or one of the pre-Domengine forms usually listed as *T. buwaldana*, is prominent in the basal "Domengine" sandstone reef on the west side of Potrero Hills and is associated with the following fauna:

Acila decisa (Conrad)
Lucina (Here) taffana (Dickerson)
Nemocardium linteum (Conrad)
Crasatella sp.
Glycymeris sagittata (Gabb)
Glycymeris perrini Dickerson
Pseudoperissolax blakei (Conrad) subsp.
Galeodea tuberculiformis Hanna
Cadulus gabbi Sharp and Pilsbry
Plagiocardium brewerii (Gabb)
Olivella mathewsoni Gabb
Xenophora stocki Dickerson
"Turbinolia clarki Quayle"
Cylichnina tantilla (Anderson and Hanna)
Ostrea idriaensis Gabb
Dentalium stramineum Gabb
Calyptraea diegoana (Conrad)
Eocypraea castacensis (Stewart)
Rimella macilenta White
Trachycardium (Agnocardia) sorentoense (M. A. Hanna)
Exilia sp.
Corbula parilis Gabb

This occurrence is of considerable interest in view of the very restricted areal and time distribution of B. L. Clark's type Domengine fauna.

The "Capay" shale contains two foraminiferal assemblages; one above the "Capay" megafossil reef at Potrero correlates with one found near the base of the Arroyo Hondo as used by R. T. White (40); and the second assemblage found below the "Capay" fossil reef at Potrero is similar to one found at the top of White's (40) Cerros.

The stratigraphic positions at which Martinez megafossils were found are indicated on the chart. These fossils include:

Brachidontes ornatus lawsoni Nelson
Acila decisa (Conrad) Martinez subsp.
"Solen" stantoni Weaver
Saccella gabbi (Gabb), Martinez subsp.
Cylichnina tantilla Gabb, Martinez subsp.
Turritella pachecoensis Stanton
Cucullaea (Cyphoxis) mathewsonii Gabb
Glycymeris major Stanton

* This paper was prepared with the aid of manuscript reports by Cordell Durrell, Paul Goudkoff, and Mrs. Daisy Hansen.

** Geologist, Richfield Oil Corporation. Manuscript submitted for publication March 15, 1940; revised July 10, 1941.

[1] Formational name used by R. W. Burger, B. L. Clark, and Paul Goudkoff in manuscript.

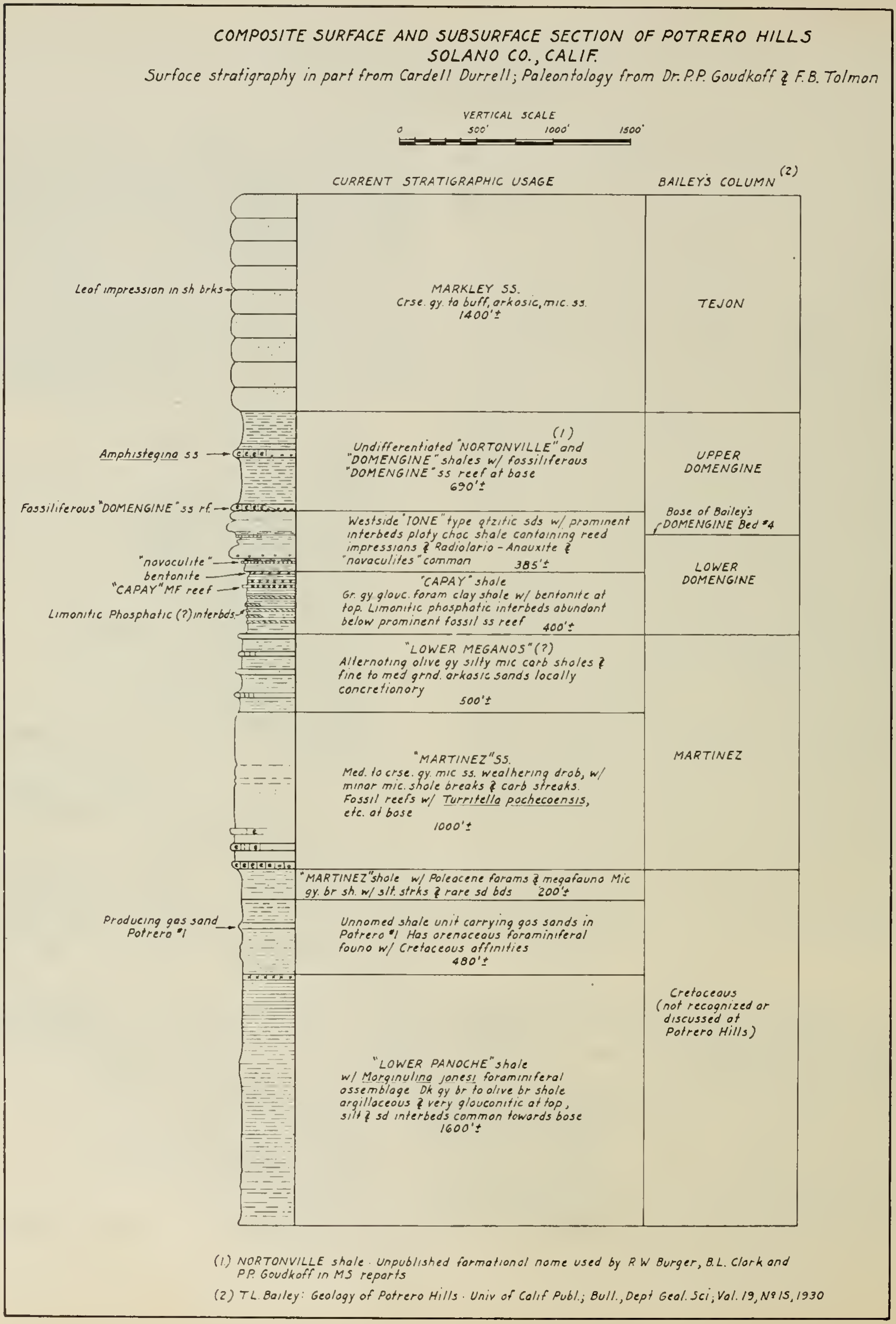

FIG. 262. Potrero Hills gas field: columnar section.

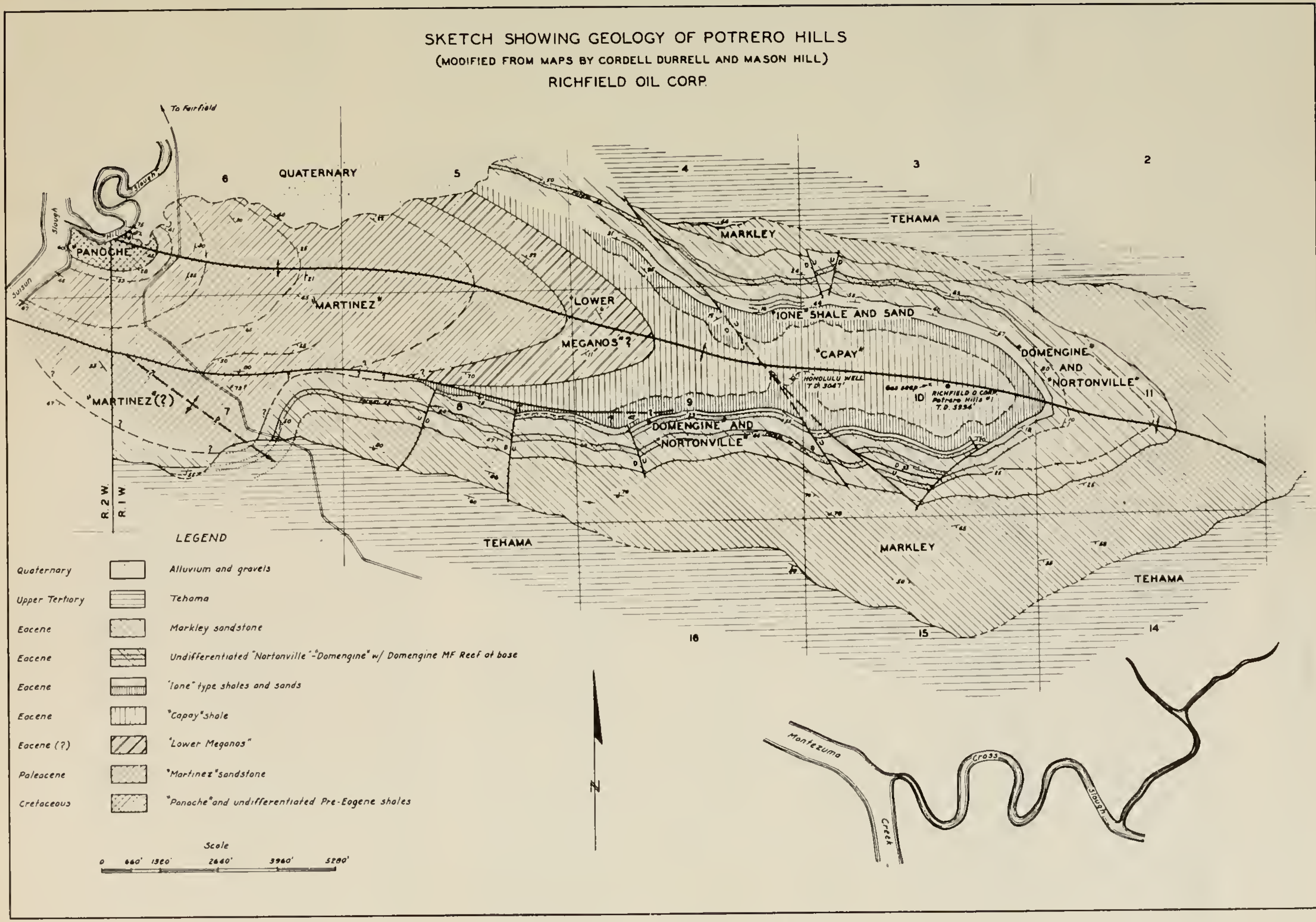

FIG. 263. Potrero Hills gas field: geologic map.

The shale at the base of the "Martinez" contains Martinez Foraminifera and megafossils. In Richfield Oil Corporation's No. "Potrero" 1, the lithology of this shale does not differ appreciably from that of the underlying Cretaceous shale.

The upper 400 feet, plus or minus, of shale below the "Martinez" in No. "Potrero" 1 contains a foraminiferal fauna, largely arenaceous, the exact age of which cannot be determined with certainty at the present time. It has, however, marked Cretaceous affinities. The lower half of this 400-foot interval in No. "Potrero" 1 is in places sandy, and it is here the producing gas horizon occurs.

The remaining Cretaceous cored in No. "Potrero" 1 belongs to Goudkoff's *Marginulina jonesi* zone ("lower Panoche"). While sands are common here, especially near the base, commercial gas production from them was not obtained at this location.

STRUCTURE

The map reproduced here indicates considerable structural complexity in the Potrero Hills anticline, particularly at the western end, where the complexity is further increased by intense crumbling of the relatively incompetent Cretaceous beds in the axial part of the fold.

Two probable faults are worth attention. The east-west fault along the south limb in the western part of the hills is nowhere exposed, but is thought to be present because a section 400 feet thick of Capay and Martinez is cut out.

The northwest-southeast-curving fault pattern which cuts across the anticline to the east of the first fault is of much smaller magnitude but is easier seen due to offsets which show up in the middle Eocene cliff-forming sands.

In the central part of the hills numerous small faults cut both limbs, and they appear to have been formed as minor adjustments to differential stresses along the length of the fold.

FAIRFIELD KNOLLS GAS FIELD

By J. M. Kirby *

OUTLINE OF REPORT

HISTORY

Fairfield Knolls gas field is located in Secs. 29 and 32, T. 9 N., R. 1 E., M. D., Yolo County, about 3 miles north of Putah Creek and midway between the towns of Davis and Winters. Airline distances from Sacramento and Oakland are 20 miles and 55 miles, respectively.

Location for the initial test well, on this structure (Standard Oil Company No. "Hooper" 1, located 990 feet south and 990 feet west of northeast corner Sec. 32, T. 9 N., R. 1 E., M. D.), was made and drilling begun on July 4, 1937. Formation tests which indicated the presence of natural gas in commercial quantity in sands between 3,675 feet and 3,714 feet were conducted on August 14 and 15, 1937. Following the above tests, drilling was continued to a depth of 5,181 feet without disclosing additional gas-bearing sands. The well was then plugged to 3,400 feet, redrilled to 3,700 feet and 6⅝-inch casing cemented at 3,669 feet. On November 9, 1937, No. "Hooper" 1 was completed and shut in.

The second well to be drilled at Fairfield Knolls, Standard Oil Company No. "Corcoran" 1, located 1,650 feet west and 990 feet north of the southeast corner of Sec. 29, T. 9 N., R. 1 E., M. D. (elevation 111 feet), was begun August 14, 1939, and completed September 19, 1939, at a total depth of 3,682 feet. Top of the Hooper sand was logged at 3,662 feet and 6⅝-inch casing cemented at 3,634 feet.

Lacking an outlet, both wells capable of commercial gas production at Fairfield Knolls have been shut in since completion. No estimate of the areal extent or gas reserves of the field can be made at the present time because of insufficient development.

STRATIGRAPHY

Exposures of rock formations in the immediate vicinity of Fairfield Knolls gas field are limited to small, isolated outcroppings of Red Bluff (Pleistocene) gravels and Tehama (upper Pliocene) sands and clays. These exposures occur over the area of low topographic relief in and adjacent to Sec. 4, T. 8 N., R. 1 E., M. D. The relationship of these sediments, isolated as they are in the midst of the broadly alluviated Sacramento Valley floor, to those exposed in the foothills 7 miles to the west can only be inferred. Because of their similarity to beds found north of Winters, it is assumed, however, that the two members recognized are continuously present beneath the alluvium.

Knowledge of the subsurface stratigraphy of the area has been gained primarily through the drilling of the two gas wells in the field. The Tertiary and Cretaceous sections penetrated in the wells may be classified and correlated with surface sections to the west and with similar sections found elsewhere in central California. A generalized stratigraphic sequence in the field based on the log of Standard Oil Company's No. "Hooper" 1, Sec. 32, T. 9 N., R. 1 E., M. D., is shown below:

Upper Pliocene (Tehama formation)	0′	—2563′
Upper and middle Eocene (includes recognized Markley, Domengine and Capay)	2563′	—4170′(±)
Upper Cretaceous (Chico series)	4170′(±)	—5181′(T.D.)

STRUCTURE

The occurrence of a series of small hills of low relief, projecting a few feet above the valley alluvium and exposing Red Bluff and Tehama sediments, is the only surface evidence of folding in the immediate vicinity of Fairfield Knolls gas field. Reflection seismograph work carried on intermittently during 1935-36 and 1937 resulted in the definition of an anticlinal fold of low structural relief, oriented northwest-southeast.

KIND OF GAS

An analysis of gas from Standard Oil Company's No. "Hooper" 1 is given below:

	Percent
Hydrogen	0.14
Nitrogen	7.88
Methane	91.98
	100.00

Calculated specific gravity = 0.585 (Air = 1.00)

* Geologist, Standard Oil Company of California, San Francisco, California. Manuscript submitted for publication November 27, 1940.

CITATIONS TO SELECTED REFERENCES—Continued

FAIRFIELD KNOLLS GAS FIELD

Dodd, H. V. 39; Stalder, W. 41.

VACAVILLE REGION

Bailey, T. L. 31; Clark, B. L. 38a; Hanna, G. D. 23.

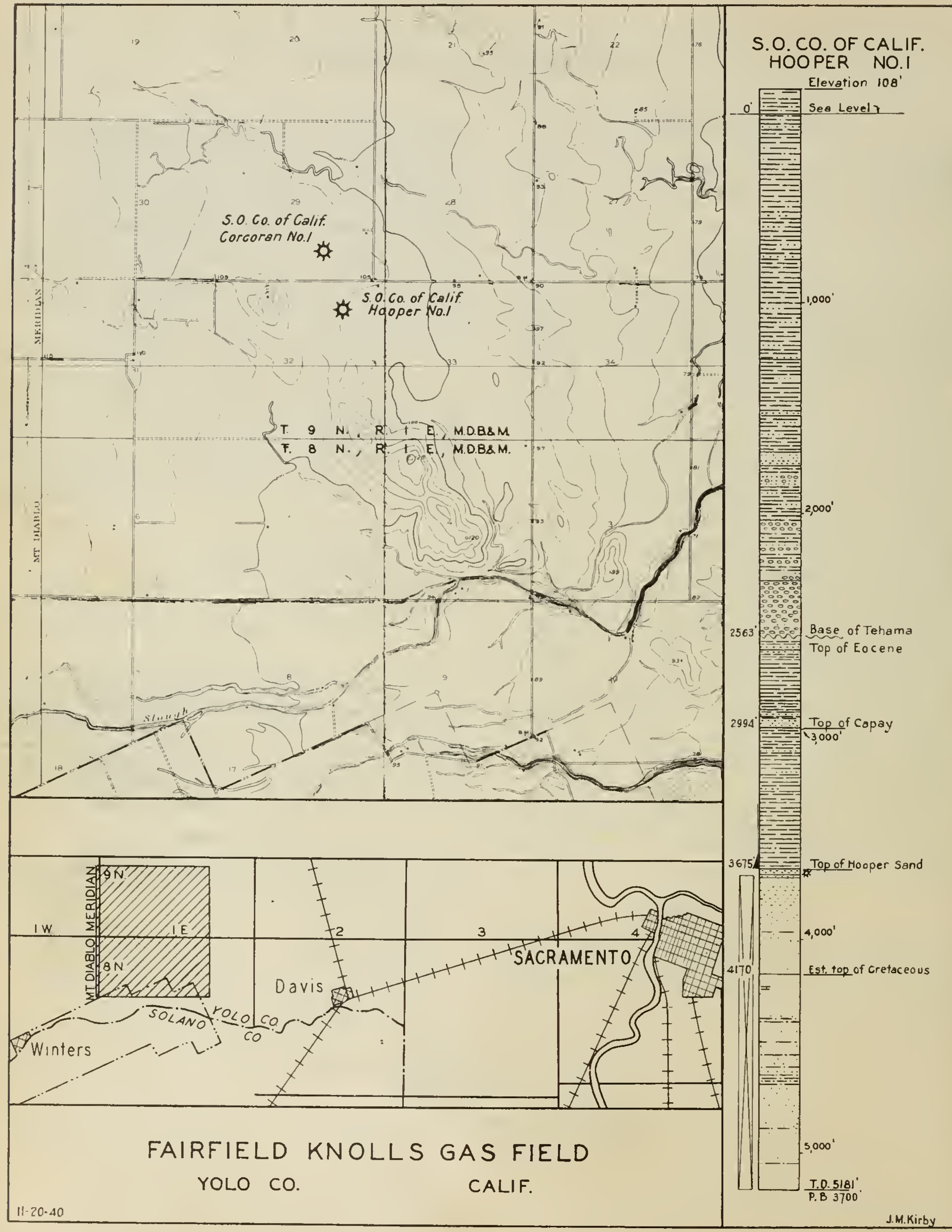

FIG. 264. Fairfield Knolls gas field: map; well log; index map.

RUMSEY HILLS AREA

By J. M. Kirby*

OUTLINE OF REPORT

LOCATION

The Rumsey Hills area forms a distinct topographic unit reflecting the Rumsey Hills anticline and associated structures, and lies along the western foothill belt of the Sacramento Valley, through T. 11, 12, and 13 N., R. 2 and 3 W., M. D., Yolo and Colusa counties. It is bordered on the west by Capay Valley, a topographic feature of synclinal origin, and on the east by Dunnigan Hills and Hungry Hollow (both topographic features related to local structure), and, in the northern part, by the broad lowlands of Sacramento Valley trough.

STRATIGRAPHY

Between 2,500 and 4,000 feet of strata, belonging to the Chico group of upper Cretaceous age, are exposed on the east flank and crest of Rumsey Hills anticline at the latitude of the Nigger Heaven Dome Oil and Gas Company No. 1 Lee-Bow well, located in the SW¼SW¼-NW¼ Sec. 23, T. 12 N., R. 3 W., M. D.

To the highest beds, of upper Cretaceous age (Chico group), exposed below the Tehama formation (upper Pliocene) on the east flank and crest of Rumsey Hills, the name Forbes formation is herein applied. The Forbes formation consists, for the most part, of soft, well-bedded to massive, light greenish-gray to gray, carbonaceous siltstones and silty shales, with occasional thin zones of fairly soft, fine- to coarse-grained or pebbly sandstone. The pebbly beds are characterized by the presence of rounded fragments of dense, gray to tan limestone. At the base of the Forbes formation is a 250- to 300-foot zone of gray or bluish-gray shale, containing many odd-shaped, gray or tan, fossiliferous limestone concretions, and characterized further by a well-preserved foraminiferal fauna, among which *Marginulina jonesi* is common and apparently diagnostic. In Salt Creek, in and adjacent to Sec. 34, T. 13 N., R. 3 W., M. D., 1,300 feet of the Forbes formation is exposed below the Tehama formation. In Petroleum Creek, Secs. 11 and 15, T. 12 N., R. 3 W., M. D., the measured thickness is 1,875 feet. The thickest section of the Forbes formation observed is in Dunnigan Creek, Secs. 35 and 36, T. 12 N., R. 3 W., M. D., where 3,065 feet of beds are exposed.

Conformably below the basal foraminiferal shale member of the Forbes formation there is an exposed section of 1,000 feet, more or less, of upper Cretaceous sediments to which the name Guinda formation is applied. The Guinda formation consists of massive to well-bedded, fine- to medium-grained, gray- to buff-weathering, concretionary sandstone. Near the middle part of the exposed section is an interval containing numerous relatively thin beds of gray, carbonaceous shale and siltstone with intercalated fine-grained, flaggy sandstone, the aggregate thickness of which approaches 150 feet. Typical exposures of the Guinda formation are present in the headwaters of Petroleum and Salt Creeks in the central and north-central parts of T. 12 N., R. 3 W., M. D., and along the faulted western escarpment of Rumsey Hills between the latitudes of Rumsey townsite and Tancred Siding (abandoned). The basal sandstones of the Guinda formation are nowhere exposed in Rumsey Hills, but were penetrated at a relatively shallow depth in the Standard Oil Company's Tippetts wells. The maximum thickness of the Guinda formation is placed at 1,400 feet.

In the well sections, the Guinda formation is conformably underlain by a succession of Chico group sediments comprising, in descending order, the Funks formation, Sites formation, Mills formation, and Golden Gate formation (basal Chico group). These units are not exposed in the area under discussion but are named and described by the writer in the following report on the Sites region, which deals with the upper Cretaceous succession of sediments on the west side of Sacramento Valley.

Along the east and west flanks and over the northern part of the crestal area of Rumsey Hills anticline, both the Guinda and Forbes formations of the Chico group are overlain with marked discordance by the Tehama formation of upper Pliocene age. The Tehama formation consists of a series of erratically bedded, nonmarine gravels, friable sands, sandy gray and yellowish-gray clays, with an occasional thin, fresh-water limestone layer near the base. The basal part of the Tehama formation is also characterized in many places by the occurrence of a series of thin, white volcanic ash members, which are correlated with the Nomlaki tuff member of the type locality of the Tehama formation in Tehama and Shasta counties. The maximum thickness of the Tehama formation, as exposed along Buckeye, Salt, and Sand Creeks on the east flank of Rumsey Hills, does not exceed 1,500 feet.

STRUCTURE

Rumsey Hills anticline is an elongate anticlinal flexure extending from the latitude of Capay, in T. 10 N., R. 2 W. (projected), M. D., to the northwest corner of T. 13 N., R. 3 W., M. D., a distance of about 22 miles. Throughout the northern half of its extent it is mantled and obscured to some degree by a cover of upper Pliocene beds belonging to the Tehama formation. South of the Yolo-Colusa County line, however, the structure in beds of the Chico group is well exposed and the

* Geologist, Standard Oil Company of California, San Francisco. Manuscript submitted for publication January 19, 1942.

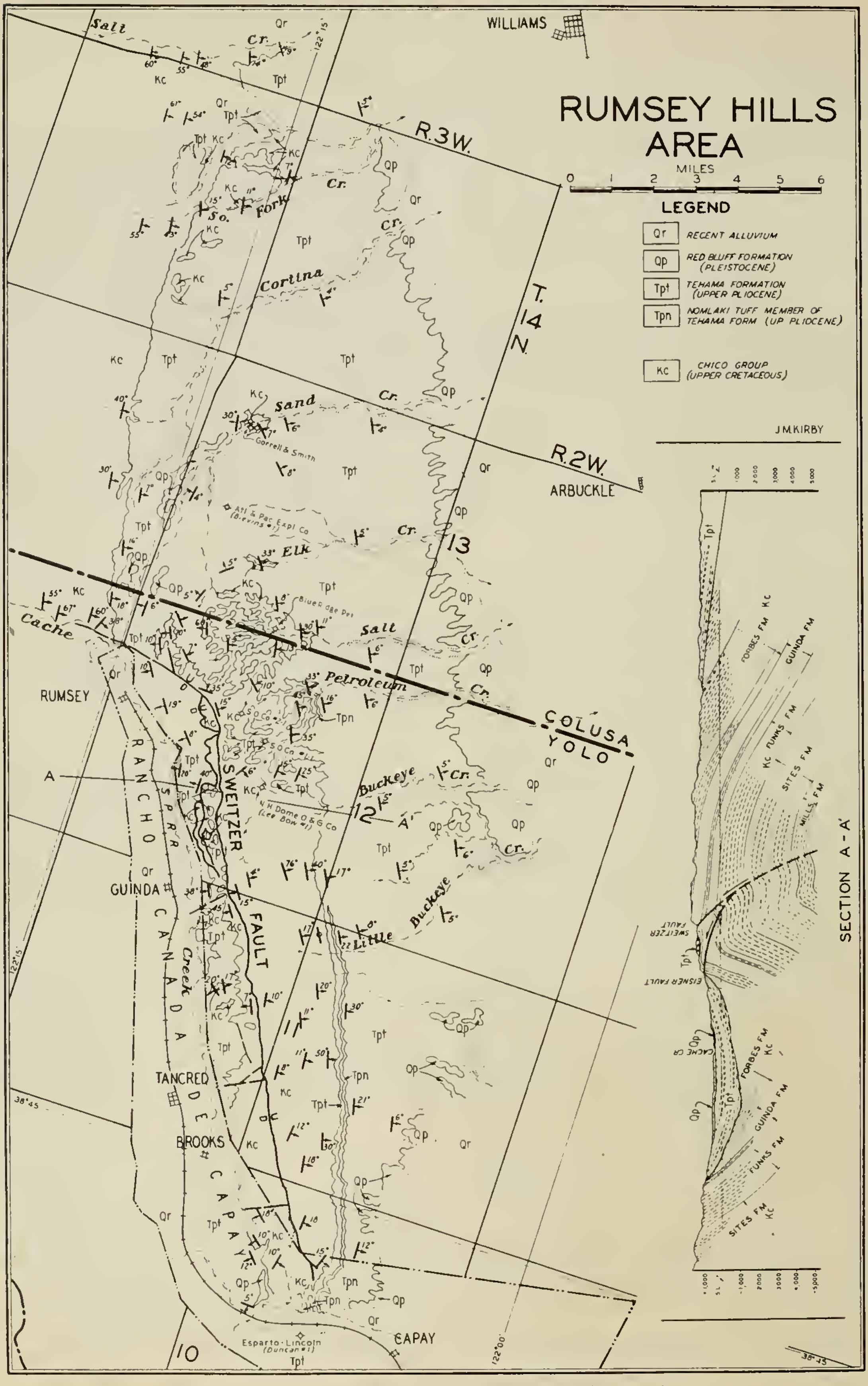

Fig. 265. Rumsey Hills area: geologic map; geologic section.

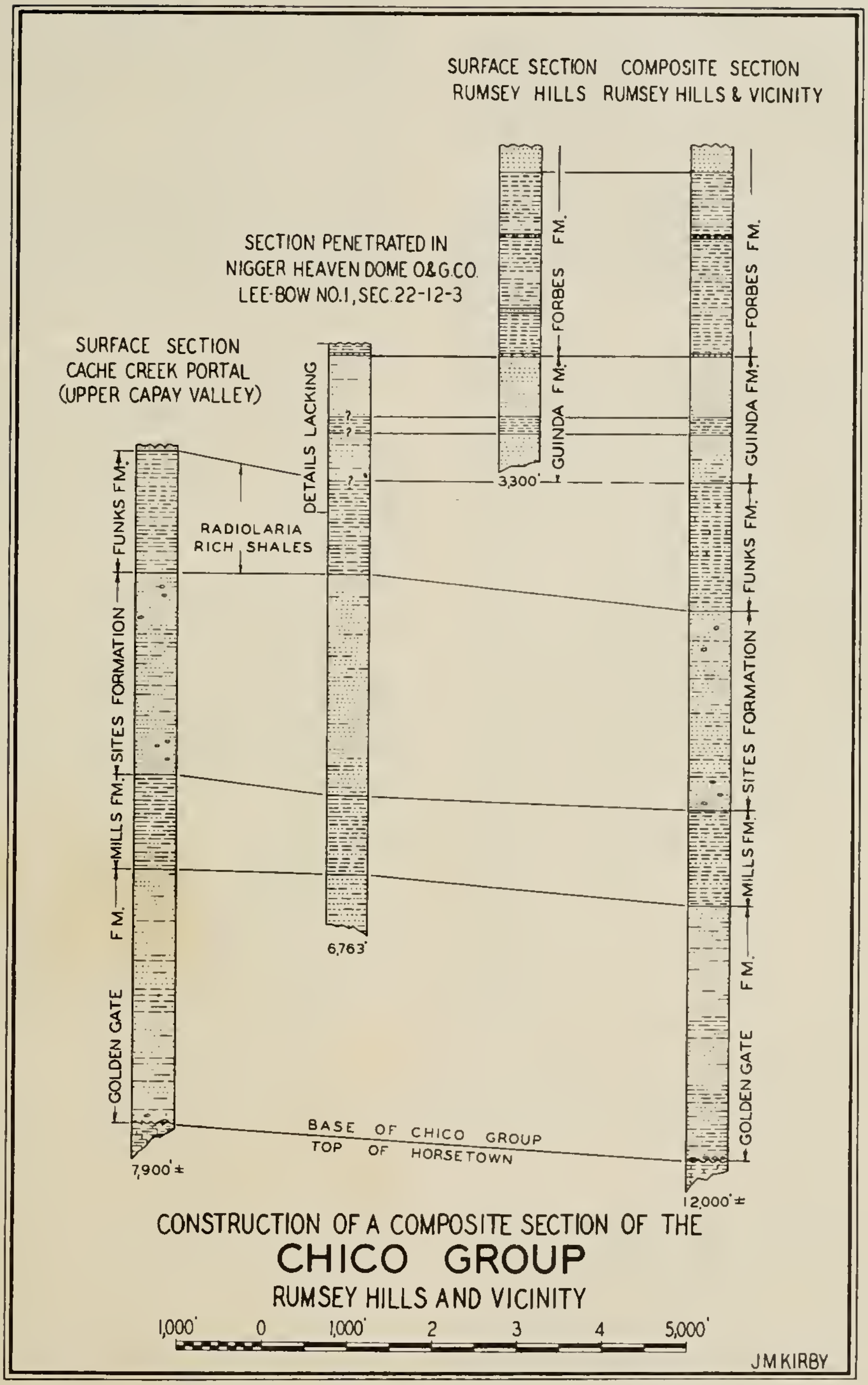

Fig. 266. Rumsey Hills and vicinity: composite columnar sections.

resultant structure appears as a sharply asymmetrical anticlinal fold with a relatively broad, flat top. The western flank is short and steepened to the point of overturning, whereas the eastern limb is longer and rarely displays persistent dips exceeding 40 degrees except at the extreme eastern edge of Chico group exposures south of the north line of T. 11 N., R. 3 W., M. D.

The prominent escarpment along the western front of Rumsey Hills, from the Yolo-Colusa County line as far south as Capay, marks the surface trace of the Sweitzer fault. This fault is of the reverse type, hading eastward at the surface at an angle of approximately 45 degrees. In all probability, this angle steepens at depth to roughly parallel the axial plane of the original fold. The displacement rarely exceeds the actual height of the escarpment—probably less than 450 feet in most cases, although the amount is observed to vary from place to place. In Sec. 8, T. 12 N., R. 3 W., M. D., the dip of the fault plane steepens rather abruptly and the general N. 25° W. trend, which has been maintained for many miles to the south, changes to N. 70° W., and the fault becomes lost in the area of Tehama gravels northeast of Rumsey. The north side is here upthrown and the evidence at hand indicates that this fault may be projected westward to join the fault exposed near the mouth of Cache Creek Canyon, 2 miles northwest of Rumsey, where the north side is shown to be uplifted approximately 450 feet stratigraphically.

The effect of the Sweitzer fault, and of the thrusting from the east which produced it, has been to form a compound crestal zone along the higher parts of the Rumsey Hills anticline. The trace of the fault does not fall along the axis of the fold, but at a variable distance to the east. The attitude of the beds adjacent to the fault line is, generally speaking, anticlinal. However, a persistent asymmetrical anticline may be traced from Sec. 16, T. 12 N., R. 3 W., M. D., as far south as the narrows of Cache Creek, midway between Cadanassa and Capay, separated from Sweitzer fault by a narrow, shallow syncline. The crumpled crestal zone of the Rumsey Hills anticline, lying to the west of Sweitzer fault, has been broken in many places by secondary dip faults, trending at right angles to the dominant grain of the major structure, and has been further complicated between Guinda and Rumsey by the development of a low-angle thrust fault along which gently dipping Cretaceous beds have been thrust a short distance from east to west across nearly vertical younger Cretaceous beds and Tehama gravels. This low-angle fault is herein named the Eisner thrust.

Despite the large areal extent of the Rumsey Hills anticline and its seemingly large structural relief, the effective closure developed on the structure as a whole probably does not exceed 1,250 feet. The limiting closure is determined by a high saddle, associated with faulting, which lies at the divide a short distance north of Rumsey. The anticlinal axis observed in Sand Creek, near the east quarter corner of Sec. 7, T. 13 N., R. 3 W., M. D., is a minor flexure associated with and en echelon to the main Rumsey Hills uplift and lies about 2,000 feet structurally lower than the crest of the major uplift.

HISTORY OF DEVELOPMENT

(1) *Gorrell and Smith Wells:*

The presence of natural gas in springs throughout Rumsey Hills early called attention to the area as prospective oil or gas territory. The earliest attempt to develop oil or gas through the drilling of wells specifically for that purpose dates back to 1900-1903, during which interval four wells were drilled by Gorrell & Smith in the bottom of Sand Creek near the east quarter corner of Sec. 7, T. 13 N., R. 3 W., M. D. The locations chosen were on the axis of the Sand Creek anticlinal flexure.

Wells No. 1 and No. 2 were 400 and 900 feet deep, respectively, and both encountered a small volume of natural gas along with flowing saline water. Well No. 3 was drilled to 1,100 feet, where a pocket of gas blew the fluid from the hole, causing the casing to freeze and resulting in abandonment. Well No. 4 was drilled to a depth of 2,100 feet without favorable results.

(2) *Blue Ridge Oil Company—Mulally No. 1:* (Loc. NW¼ SW¼ SW¼ Sec. 34, T. 13 N., R. 3 W., M. D.)

This well was abandoned in October 1922, after having reached a depth of 2,946 feet. At various depths down to 1,650 feet the well encountered shows of natural gas, some of which blew the drilling fluid from the hole. The well was never completed, however, as a commercial gas producer.

(3) *Esparto-Lincoln Oilfields, Inc.,—Duncan No. 1:* (Loc. NE¼ Sec. 21, T. 10 N., R. 2 W., projected, M. D., Rancho Canada de Capay)

This well was spudded in 1922 and abandoned 2 years later at a depth of 2,320 feet, without favorable showings of either gas or oil. The location falls on the extreme southern projection of the Rumsey Hills axis and far down the south plunge. The drill apparently passed from Tehama beds into beds of the upper Chico group at 755 feet.

(4) *Swastika Oil Company—Well No. 1:* (Loc. NE¼ NE¼ NW¼ Sec. 22, T. 12 N., R. 3 W., M. D.)

This well was spudded and abandoned in 1923, after having reached a depth somewhat less than 200 feet.

(5) *Nigger Heaven Dome Oil & Gas Company—Lee-Bow No. 1:* (Previously Pacific Northern Oil & Gas Co.—Lee-Bow No. 1 and originally George F. Getty, Inc.—Guinda No. 1)

The recorded location of this test is 2,000 feet south and 330 feet east from the northwest corner of Sec. 23, T. 12 N., R. 3 W., M. D. The well was spudded August 19, 1930, by George F. Getty, Inc., and drilled to 2,007 feet, at which depth it was suspended after considerable trouble with high-head salt water and gas. The operation was subsequently taken over by Pacific Northern Oil & Gas Company and drilled to approximately 5,240 feet, with numerous gas showings but also with constant difficulty with flowing salt water. The well was finally completed from 5,240 feet to its present total depth of 6,763 feet by Nigger Heaven Dome Oil & Gas Company, at which depth the drill had penetrated about 600 feet of the lower sandstone member of the Chico group, the Golden Gate formation.

(6) *Atlantic-Pacific Exploration Company-Blevins No. 1:* (Previously Allied Petroleum Corp., H. A. Rispin, et al.) (Loc. SW¼ SW¼ NW¼ Sec. 20, T. 13 N., R. 3 W., M. D.)

This well was abandoned November 11, 1931, after having drilled to a depth of 2,084 feet. At this depth the drill had penetrated 1,200 feet or more of Cretaceous beds below the Tehama formation, and had recorded numerous gas showings of the type found in all other wells drilled in this vicinity. None of the showings proved of commercial value.

The location of the test is a considerable distance west of the Sand Creek axis, and likewise well off the higher part of the Rumsey Hills structure.

(7) *Standard Oil Company-Tippetts 2 No. 1:* (Loc. 277 feet north and 1,287 feet west of the southeast corner Sec. 9, T. 12 N., R. 3 W., M. D.)

This well was spudded September 18, 1940, and was abandoned February 4, 1941, at a total depth of 3,240 feet without commercial production of oil or gas. Drilling began in the middle part of the Guinda formation and the base of this unit was logged at 960 feet. The shale interval between this depth and 2,993 feet is correlated with the Funks formation, and the sandstone between the depths of 2,993 and 3,240 feet with the Sites formation of upper Cretaceous age.

(8) *Standard Oil Company-Tippetts 1 No. 1:* (Loc. 2,050 feet south and 2,480 feet east of the northwest corner Sec. 15, T. 12 N., R. 3 W., M. D.)

This test well was spudded July 7, 1941, and abandoned October 18, 1941, at a total depth of 2,490 feet without commercial production of oil or gas. The Guinda-Funks contact is placed tentatively at 1,085 feet depth and the Funks-Sites contact at 2,375 feet depth.

SITES REGION

By J. M. KIRBY *

OUTLINE OF REPORT

HISTORY

The Sites anticline lies in the foothills of the western margin of Sacramento Valley in north central Colusa and central Glenn Counties. Its axis follows a nearly true north trend from the town of Sites, Sec. 20, T. 17 N., R. 4 W., to Sec. 30, T. 21 N., R. 4 W., M. D., north of which point the folding is mantled by a cover of late Pliocene beds. The total length of the structure is probably as much as 35 miles.

The first authentic record of an attempt to test the oil and gas possibilities of the Sites anticline is well No. 1-A of S. H. Keoughan, Trustee, located in the SE¼ SE¼ SE¼ Sec. 31, T. 18 N., R. 4 W., M. D. This well was located on the Peterson Ranch near the site of prominent gas springs, and was drilled to a total depth of 2,090 feet in 1925. Shows of gas were noted at 200 and 430 feet, but the well was abandoned without commercial gas or oil production.

In 1927, the Continental Oil Company began work on their No. "Peterson" 1, located also in the SE¼ SE¼ SE¼ Sec. 31, T. 18 N., R. 4 W., M. D., and the drilling was carried to a depth of 1,875 feet, where the well was abandoned with collapsed casing. Subsequently, Continental Oil Company's No. "Peterson" 1-A was drilled on the site of the old Keoughan well, and, before abandonment because of mechanical difficulties on September 10, 1928, had been drilled to a depth of 4,277 feet. Gas showings were encountered at many points in drilling, but the well did not produce in commercial quantities. Steeply dipping formations were found at nearly all points in drilling this well. The gas encountered was nearly pure methane, with only a minor amount of nitrogen and carbon dioxide.

STRATIGRAPHY

The oldest beds exposed along the axis of the Sites anticline belong to the Shasta group of Lower Cretaceous age. Approximately 5,000 feet of beds, belonging to the Horsetown formation and consisting primarily of well-bedded dark-gray to greenish drab siltstones and shales with interbedded hard thin sandstones and dense limestone layers, form the pronounced anticlinal valley and lowland area west of the lower Chico group rimrock. Overlying the Shasta group with probable unconformity is the Chico group of Upper Cretaceous age.

The Upper Cretaceous is best exposed in the prominent ridges flanking the Sites anticline along its eastern side and fronting on the broad lowland of Sacramento Valley. The thickest measurable sections occur a short distance north and east of Sites, where approximately 9,700 feet of beds were observed. This figure may be compared with the 12,000 feet of section in the vicinity of Rumsey Hills, and the 14,800 feet measurable in Putah Creek Canyon west of Winters, Yolo County; and the comparison presents a fairly reliable index of the tendency of this sedimentary group to thin toward the north.

Although the Chico group has never been satisfactorily subdivided in the western Sacramento Valley region, the exposed section on the east limb of Sites anticline lends itself well to such subdivisions on the basis of lithology, particularly the lower half of the group, which is best exposed to examination.

For convenience in mapping and discussion, four lithologic members are named in the Sites region. The basal portion of the Chico group is characterized by a dominant sandstone zone, varying in thickness from 3,000 to 3,500 feet. It has been found to persist throughout the western margin of the Sacramento Valley, and is herein designated the Golden Gate formation, a name derived from a prominent gap in the sandstone rimrock in the western half of Sec. 9, T. 17 N., R. 4 W., M. D., through which Funks Creek flows.

Conformably overlying the Golden Gate formation is a zone of well-bedded, dark-gray to greenish-gray clay shales, herein designated the Mills formation, named from its proximity to the Mills Orchard at the mouth of Stone Corral Creek, in Sec. 35, T. 17 N., R. 4 W., M. D. The best exposures of this member may be found north of Stone Corral Creek, in the NE¼ Sec. 28, T. 17 N., R. 4 W., M. D., and the zone may be followed for a considerable distance both north and south.

In the southern part of the Sites area, and along the eastern flank of the Sites anticline, the Mills shale member is conformably overlain by a second prominent sandstone zone, herein referred to as the Sites formation. The best exposures may be found both to the north and south of Stone Corral Creek, in the E½ Sec. 28, T. 17 N., R. 4 W., M. D. At this point, the Sites formation is somewhat less than 2,000 feet in thickness. To the north, the zone is observed to thin rapidly, and, at the latitude of Willows, is marked only by one or more sandstone beds less than 100 feet thick, with prominent shale members both above and below. Southward, the Sites formation persists with increasing thickness, so that, in Cache Creek Canyon north of Rumsey, a measurable section of 2,300 feet is exposed.

Conformably overlying the Sites formation in Stone Corral Creek, in the W½ Sec. 27, T. 17 N., R. 4 W., M. D., and in Funks Creek, in the W½ Sec. 10, T. 17 N., R. 4 W., M. D., a 1,200-foot zone of well-bedded shale is exposed, which is characterized by an abundance of Radiolaria. To this member, which is of wide distribution along the western margin of Sacramento Valley, the name Funks formation is herein applied.

On the east limb of the Sites structure, the Upper Cretaceous section above the Funks formation is not well exposed, but, in the vicinity of Rumsey Hills, the Funks formation is overlain in ascending order by the Guinda and Forbes formations, which are described by the writer in the preceding paper on the Rumsey Hills anticline.

* District Geologist, The California Company, Denver, Colorado. Manuscript submitted for publication December 5, 1940.

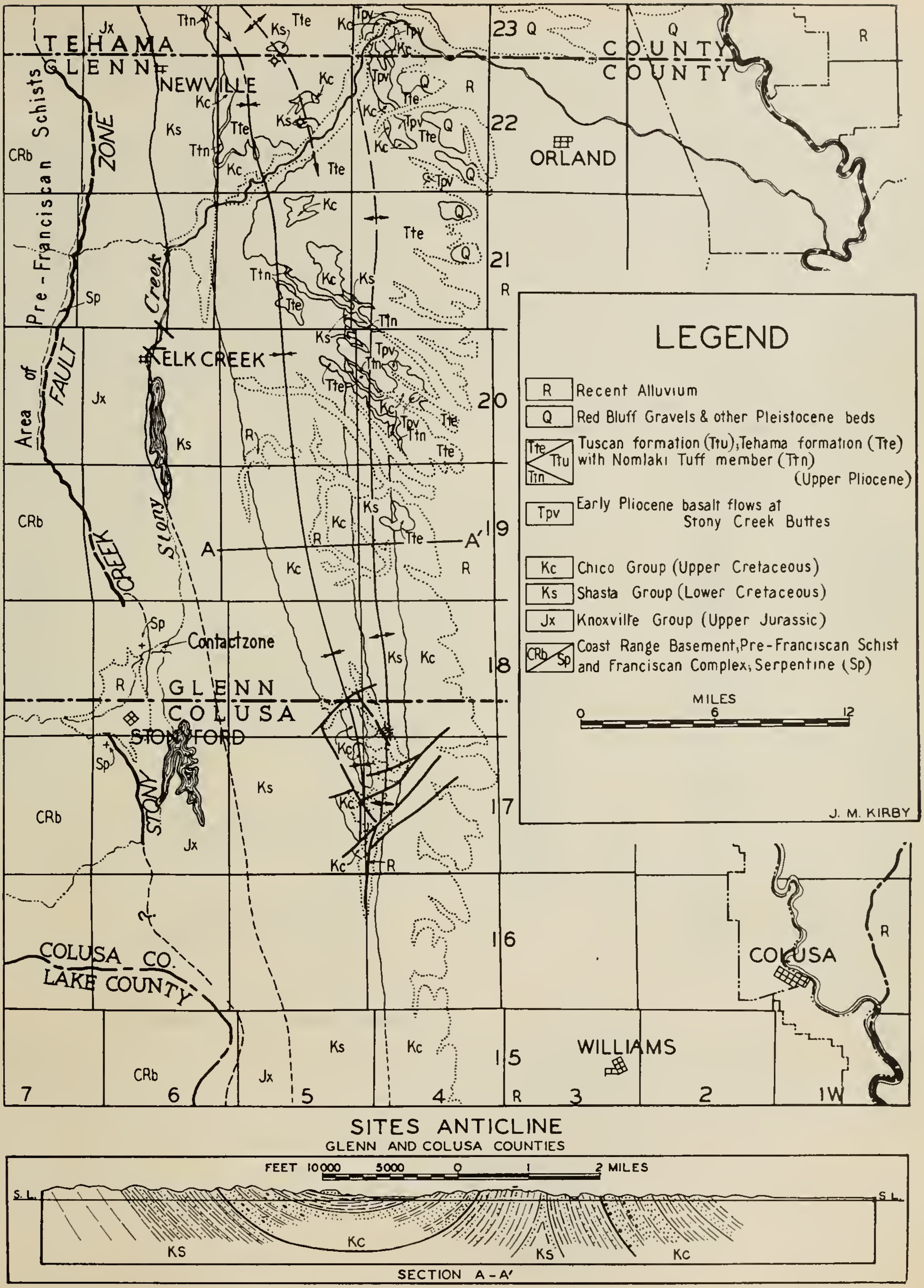

FIG. 267. Sites region: geologic map; cross-section of Sites anticline.

STRUCTURE

Sites anticline is one of the most conspicuous folds along the western foothills belt of Sacramento Valley. Attention was early called to this structure by the presence of gas seepages along the axis, particularly in the vicinity of Salt Lake Ranch, in Sec. 36, T. 18 N., R. 5 W., M. D. The fold extends from the latitude of Sites, in Sec. 20, T. 17 N., R. 4 W., M. D., as far north as Sec. 30, T. 21 N., R. 4 W., M. D., where its northern extension is obscured by a mantle of upper Pliocene gravels. Throughout its course, the axis follows a trend nearly true north. It is probable that the total length of the structure will exceed 35 miles.

One of the most striking things to be observed in a structural cross section of the Sites anticline is its nearly isoclinal nature. The axis is evident only for a limited distance north of the town of Sites. From this area northward, the position which the axis must follow is marked by nearly vertical beds for a distance of as much as 1 mile in cross section. It has not been possible to demonstrate that the axial area is associated with strike faulting. In several instances, however, particularly at its southern end, it is marked by a number of northeast trending oblique faults, which, in some instances, have a horizontal displacement of as much as 1,000 or 1,500 feet.

The syncline to the west of the Sites anticline is rather broad and flat bottomed, and exposes a thickness of several thousand feet of Chico beds, which, as will be observed from an examination of the geologic sketch, have been eroded from the axis of the Sites structure.

In its northern reaches, it is not possible to link the Sites axis definitely to the southeasterly plunging axis of the Paskenta nose. It is herein assumed that the two structural features are entirely separate, and that the Paskenta nose dies out in the southeasterly part of T. 22 N., R. 5 W., M. D.; and that, in a similar fashion, the Sites axis terminates beneath the Pliocene mantle somewhere near the north end of Stony Creek Buttes, in T. 22 N., R. 4 W., M. D.

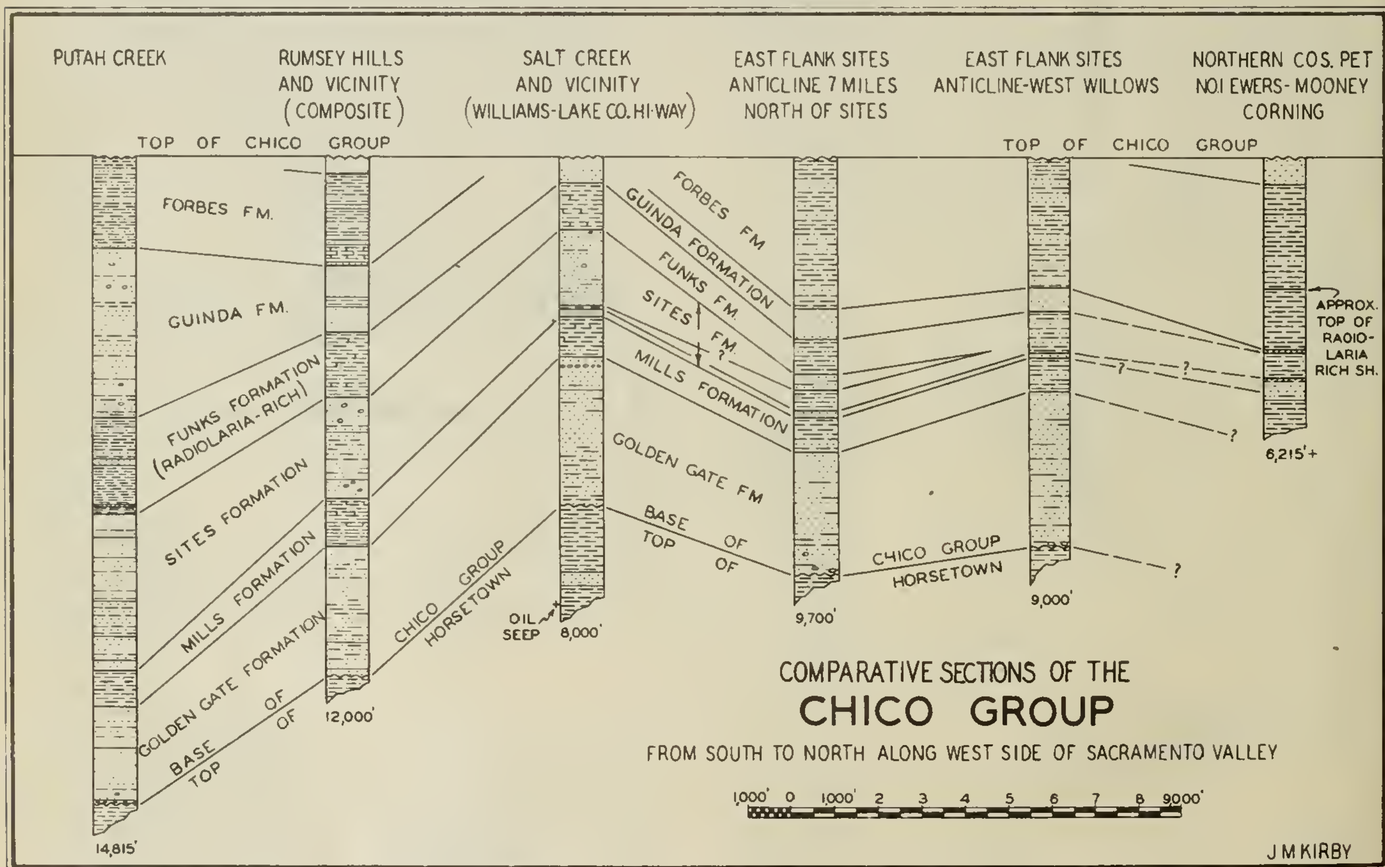

FIG. 268. West side of Sacramento Valley: comparative columnar sections of the Chico group.

CITATIONS TO SELECTED REFERENCES—Continued

RUMSEY HILLS AREA

Petroleum World 32a; Stalder, W. 41; Vander Leck, L. 21, p. 52.

Nigger Heaven Dome

Stalder, W. 41, pp. 68-69.

SITES REGION

Stalder, W. 41.

WILLOWS GAS FIELD

By R. N. Williams, Jr.*

The Willows gas field is located in Glenn County, 6 miles northeast of the town of Willows, in the Sacramento Valley. The land surface is flat, slopes gently to the southeast, and is largely under cultivation. No hint of subsurface structure is given by the topography. The field was discovered by The Ohio Oil Company as a result of a reflection seismograph survey. The first well. The Ohio Oil Company No. "Willard" 1, was spudded November 17, 1937. On January 8, 1938, while drilling at 4,505 feet, the well blew out of control. By the next day a large crater had formed into which the derrick and machinery disappeared. No accurate estimate of gas volume was possible, but estimates as high as 60 million cubic feet per day were made. The well died January 28, 1938.

A second well, the No. "Willard" 1A, was drilled and cored to 6,014 feet. It was then plugged back and completed in the interval 2,237-2,245 for an initial production of 5,236,000 cubic feet of dry gas per day through a 42/64-inch bean, tubing pressure 515 pounds, casing pressure 600 pounds. Except for the production of gas used to drill the third well, this well has remained shut-in since discovery. The third well, No. "Willard" 2 was drilled a few feet east of No. "Willard" 1 for remedial purposes and was not completed as a producer.

Well samples were studied by Dr. Paul P. Goudkoff, who reported that rocks from the interval 510 to 1,011 feet represented the Tehama formation (Pliocene), and that the rocks from the interval 1,011 to 5,717 feet were of Upper Cretaceous age, probably equivalent to a part of the Moreno shale.

Lithologically, to a depth of about 1,000 feet, cuttings were composed of greenish-gray silty clays without organic remains. From 1,000 to 2,800 feet the beds were composed of gray shales and silts, and some sand beds as much as 80 feet in thickness. It is in this series at a depth of about 2,250 feet that the productive gas sand occurs. There seemed to be few breaks in the monotonous shale section that extended from 2,800 to 6,014 feet.

Organic remains consisting of molluscan shells, Foraminifera, ostracods, and small carbonaceous particles were present in the Cretaceous section. The three wells discussed above are the only wells that have been drilled in this field to date.

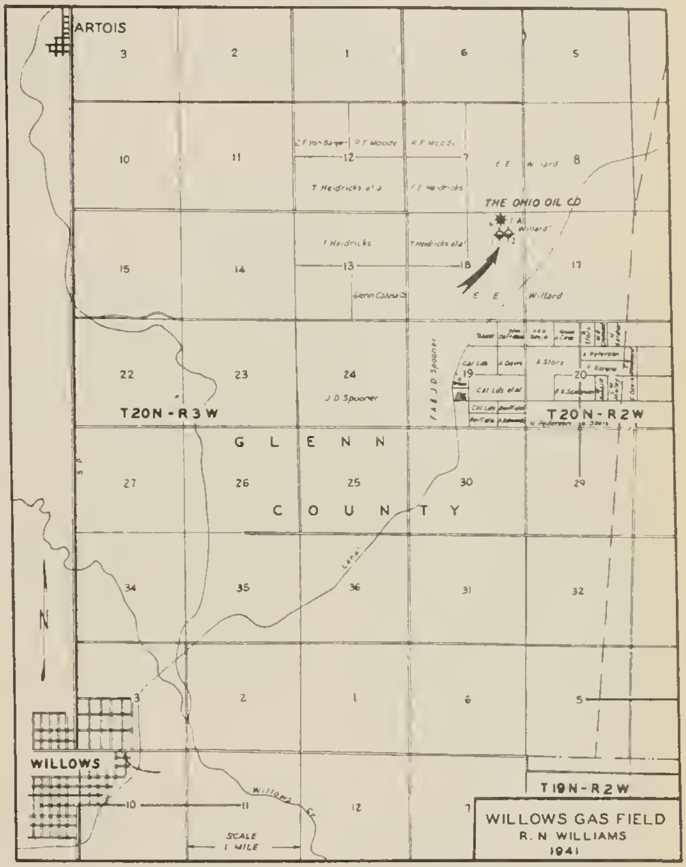

Fig. 269. Willows gas field: map.

* Geologist, Honolulu Oil Corporation. Manuscript submitted for publication September 3, 1941.

CITATIONS TO SELECTED REFERENCES—Continued

CHICO AREA

Taff, Hanna, and Cross 40.

WILLOWS GAS FIELD

Dodd, H. V. 39; Hoots, H. W. 39; Stockman, L. P. 40e.

CORNING REGION

Averill, C. V. 28; Green, H. L. 36; McLaughlin and Waring 14; Stockman, L. P. 36a.

Orchard Park Area

Bryan, K. 23, pp. 253-255.

MARYSVILLE BUTTES GAS FIELD

Allen, V. T. 39; 41; California Oil World 37h; Dodd, H. V. 30; 39; Israelsky, M. C. 40; Johnson, H. R. 40; Lindgren and Turner 95; Petroleum World 33; Schenck, H. G. 40d; Stalder, W. 32; 34; 41; Stockman, L. P. 40e; Vander Leck, L. 21, pp. 56-57; Waring, C. A. 19; Williams, H. 29.

WHEATLAND REGION

Clark and Anderson 37a; 38.

MARYSVILLE BUTTES (SUTTER BUTTES) GAS FIELD

By HARRY R. JOHNSON*

OUTLINE OF REPORT

HISTORY OF DEVELOPMENT

Marysville Buttes, a topographically prominent, isolated feature which punctuates the otherwise nearly flat, low-lying Sacramento Valley skyline at a point about 12 miles west and slightly north of Marysville in Sutter County, has long been recognized as a possible source of natural gas and possibly also of petroleum. A gas seepage in the northwest corner of Sec. 34, T. 16 N., R. 1 E., M. D., close against the great central igneous core of the Buttes, undoubtedly was responsible for the earliest development efforts since, in the sixties, two shallow holes or pits were dug at the seepages. According to State records (Anderson and Russell 39, pl. III) the first well was drilled in the district in 1927 by the Sutter Buttes Oil Company (Sec. 32, T. 16 N., R. 1 E.) to a depth of 2,900 feet. No further record is available. Other wells were drilled in the district adjacent to the western margin of the Buttes during these earlier years, without positive results.

Serious efforts to develop gas and/or oil did not begin until 1932, when Mr. Walter Stalder located Buttes No. 1 and No. 2 in the NW. ¼ Sec. 35, T. 16 N., R. 1 E., close against the contact between deformed Cretaceous strata and an intrusive andesite plug. The results of this effort were negligible, although a moderate amount of gas was obtained in one of the wells, and Buttes Oilfields, Inc., which had financed the venture, transferred its activities to an area nearer the southern margin of the Buttes in T. 15 N., R. 1 E. Since June 1935, when its No. "McPherrin" 3 was spudded, this company has completed four gas wells in the area and is at present planning tests in other structurally desirable portions of its extensive holdings.

ECONOMIC SIGNIFICANCE

Assurance of commercial natural gas reserves in the peripheral area of Marysville Buttes is a matter of considerable importance to the wide agricultural and industrial territory near the geographic center of which these reserves are located. Geologic and structural evidence indicates that, apart from the already productive southern flank of the Buttes, there are at least six more peripheral features which should provide extensive traps for gas in commercial amounts and perhaps for oil.

Marysville Buttes also occupies a strategic position with reference to a great untouched market for natural gas in the northwest.

DISTINGUISHING FEATURES

Geologically and structurally, Marysville Buttes is unique, for California, at least. The whole feature is nearly circular in shape, is 10 miles in diameter and consists of three rudely concentric topographic zones, centering approximately at an extinct mile-wide volcanic crater, now filled with its own debris. This crater was developed in a pre-existing resistant plug of andesite porphyry about 4 miles wide, some of the crags and ridges of which range in elevation from 1,500 feet to over 2,000 feet above sea level. The valley floor surrounding the Buttes lies at an elevation of less than 100 feet above sea level.

Encircling this steep-sided, rugged igneous plug is a band of tilted, folded and faulted sediments, usually well exposed, especially on the south flank of the Buttes, in a series of fairly well-rounded summits and hillocks which tend to show alignments along the strike of steeply tilted beds. The exposed band of disturbed sediments, which range in age from Cretaceous to Mio-Pliocene, varies in width from a few hundred yards to more than a mile on the south and west flanks of the Buttes. At many places within this band, secondary plugs of intrusive rhyolite porphyry create locally rugged topographic features in strong contrast with the smoother slopes of the surrounding sediments. Such, for example, is the steep-sided butte in the SE¼ Sec. 36, T. 16 N., R. 1 E.

The third and outermost concentric topographic zone encloses the sedimentary band just discussed and maintains a width varying from less than 2 miles on the west side to more than 3 miles on the east, in the region north of the town of Sutter, which is located just at the southeastern margin of the Buttes. This outermost feature rises gradually from its margin at the Sacramento flood plain (50 to 75 feet above sea level) toward the rugged central part of the Buttes and terminates in steep-sided in-facing bluffs which reach elevations varying from 500 to 1,100 feet or more above sea level. These bluffs and the slopes extending outward toward the valley floor from them expose stratified deposits of andesitic breccias and tuffs including some water-worn pebbles, but mostly characterized by great fragments and blocks of andesite porphyry in a loose matrix of finer material. It is believed that the bulk of this material originated in the central crater and was moved downward and outward therefrom through the agency of explosive mud flows. Subsequent erosion has not only removed a vast amount of these deposits to expose the tilted and folded sediments beneath, but has greatly modified the presumably smooth slope and marginal regularity of the original mud cone developed during eruptive activities.

* Consulting geologist, Los Angeles, California. Manuscript submitted for publication June 24, 1941.

GENESIS OF MARYSVILLE BUTTES

It is inexpedient to discuss the stratigraphy of Marysville Buttes without some reference to the unusual processes which have brought about existing conditions. A considerable amount of study has been given to the problem, beginning in 1892, when Waldemar Lindgren and H. W. Turner (95) of the U. S. Geological Survey visited the region and reported upon it.

Dr. Howel Williams (29) of the University of California became interested in the vulcanism of Marysville Buttes and in 1929 published an authoritative bulletin describing the series of episodes which brought the Buttes into being.

During recent years, the Buttes have received considerable study by geologists connected with oil and gas companies, but in most instances their work, which has been mainly concerned with the Cretaceous, Eocene, and Mio-Pliocene sediments, has been of a private nature.

The summer of 1940 was devoted by the writer to a detailed study of the stratigraphy and structure of the area for Buttes Oilfields Inc. and it is to the courtesy of that company that permission to publish is due.

The volcanic and other events which have resulted in the present-day aspect of Marysville Buttes were initiated at a relatively recent geologic date in the long history of the region now known as the Sacramento Valley. Howel Williams (29, pp. 112, 113) has expressed the general sequence of these events as understood by him some 10 years ago; the writer can not agree with all of these earlier concepts, and, since his present understanding is based largely upon factual data obtained during the field season just ended, it appears wise to briefly review the evidence in the order of presentation adopted by Williams.

Sequence of Events at Marysville Buttes

A) Prior to Cretaceous time, the coast of California was probably much farther west than it now is and the deposition of Cretaceous sediments was initiated during a gradual subsidence of the land mass, which thus forced the coastline eastward until the margin of the Upper Cretaceous (Chico) sea extended along the foothills of the present Sierra Nevada, a number of miles east of the present site of the town of Chico. It would appear that this Upper Cretaceous transgression extended much farther to the east than those of earlier Cretaceous time and the absence of evidence at the surface or in wells at Marysville Buttes for the pre-Chico Cretaceous sediments so widely exposed in the Coast Ranges, suggests strongly that the pre-Chico shoreline must have been not far west of the site of the Buttes. The deepest part of the great basin or trough of deposition must, therefore, lie still farther to the west. (*Note*—The Chico formation of Marysville Buttes is now known to include Williams' "Marysville formation," some of his supposed "Ione," and a portion of his "Butte gravels.")

B) The close of Cretaceous deposition resulted from a regional elevation accompanied and followed by erosion and probably planation of the newly created Cretaceous land mass, which thus furnished sediments to the adjacent shallow Eocene sea.

C) A gradual subsidence of the Cretaceous land mass took place until the Eocene sea extended perhaps as far as the Sierran foothills, but certainly eastward from the site of Marysville Buttes, where strata of Martinez (lower Eocene) and Meganos (middle Eocene) age are exposed.

D) During a shallow sea condition which existed during a part of Meganos-time, the white Ione sands were laid down, probably as a widespread deltaic deposit. These sands are believed to be equivalent in age to certain of the Eocene auriferous gravels of the Sierra Nevada and probably were derived from granitic areas of low relief, long subjected to surface decomposition under humid climatic conditions. (*Note*.—Reference is here made to a nearly identical white sand found in the Cretaceous of Marysville Buttes, the confusion of which with the true Ione of the Eocene, also present there, was one source of Williams' difficulties in interpertation of structure.)

E) In this portion of California, Oligocene and Miocene sediments are not exposed at the surface, nor, so far as known, have they been revealed in any wells drilled north of an east-west line drawn approximately through Sacramento. It is probable that land conditions existed at this time in the region. (*Note*.—As stated above, the succession of strata referred to as "Butte gravels" by Williams, which he supposed to have originated as the result of a period of intense erosion in the Sierras during Eocene time, includes beds of Cretaceous, Eocene, and, at the top, possibly of Pliocene age.)

F) Quoting Williams, with whom the writer is here in agreement, "Rhyolitic and andesitic eruptions (took place) in the Sierra Nevada, separated by periods of erosion and aggradation, beginning, perhaps, in the Oligocene or Miocene and continuing during the 'Middle Neocene' (Upper Miocene to Lower Pliocene): denudation and redeposition (?) of these volcanic rocks and of the associated gravels both during and after the volcanic episode, producing the Sutter formation in the shallow water of the Sacramento Valley, on a floor that was gently subsiding." (*Note*.—The thick bed of conglomerate which Williams includes as the upper member of his "Butte gravels" is believed by the writer to be the basal member of the Sutter formation (Mio-Pliocene). Not only do similar conglomerates occur higher in the Sutter succession, but evidence of a transgression across the beds associated with the true Ione (Eocene) along the horizon of the basal Sutter conglomerate has been observed.)

G) After the deposition of at least 1,500 feet of the Sutter formation in the region and presumably during Pliocene time, a plug or core of plastic andesite porphyry forced its way upward from an unknown, but great depth, through at least a portion of the underlying "basement complex" platform, into and through the Cretaceous, Eocene, and Mio-Pliocene sediments deposited thereon. It is believed that this plug must have either reached the then surface or even been pushed, at some points, as spire-like prominences above it. The "aggressive intrusion" of such a semi-solid plug (its diameter, as exposed today, is approximately 4 miles) greatly disturbed the sediments intruded and not only

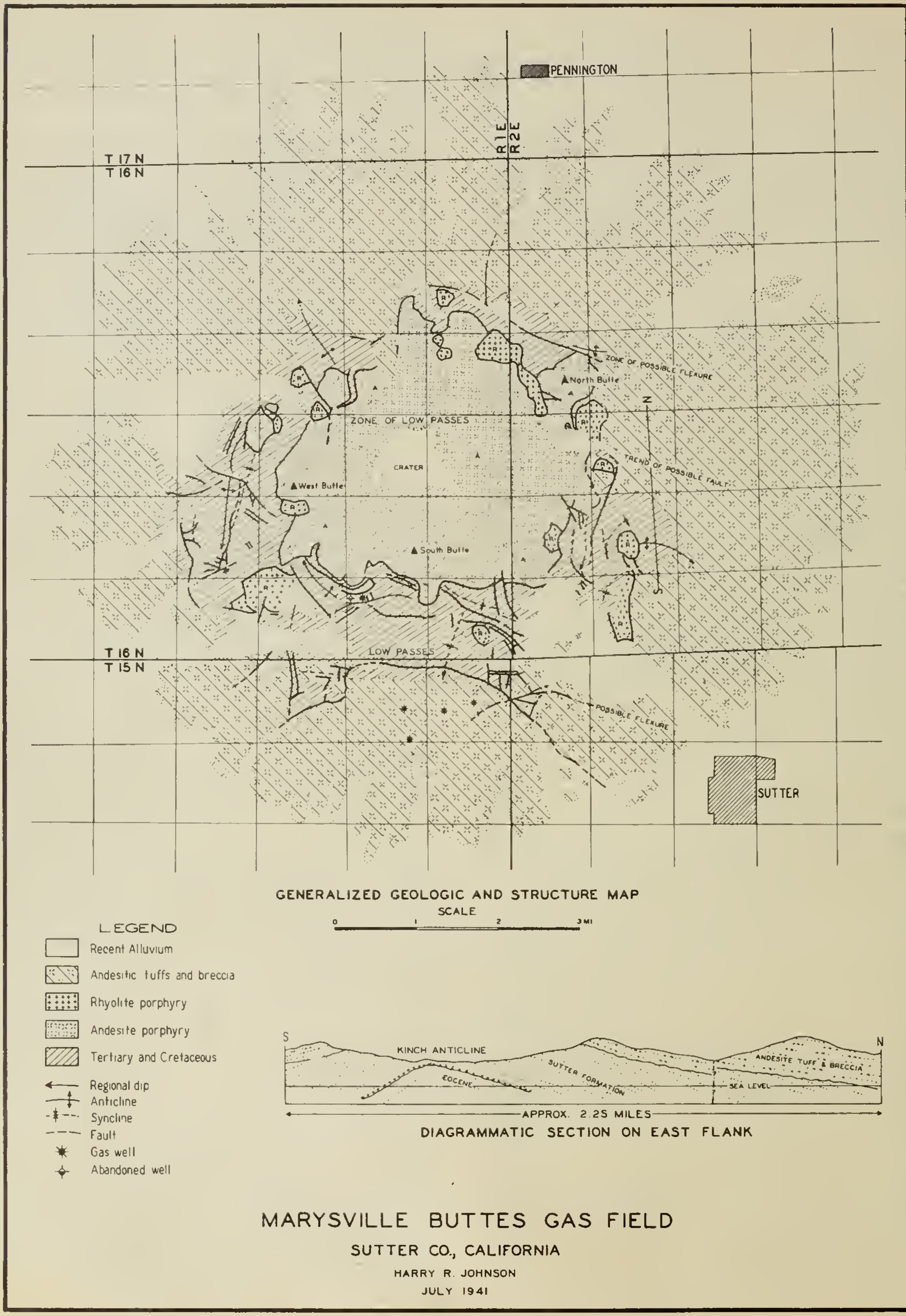

FIG. 270. Marysville (Sutter) Buttes gas field: geologic map; geologic section.

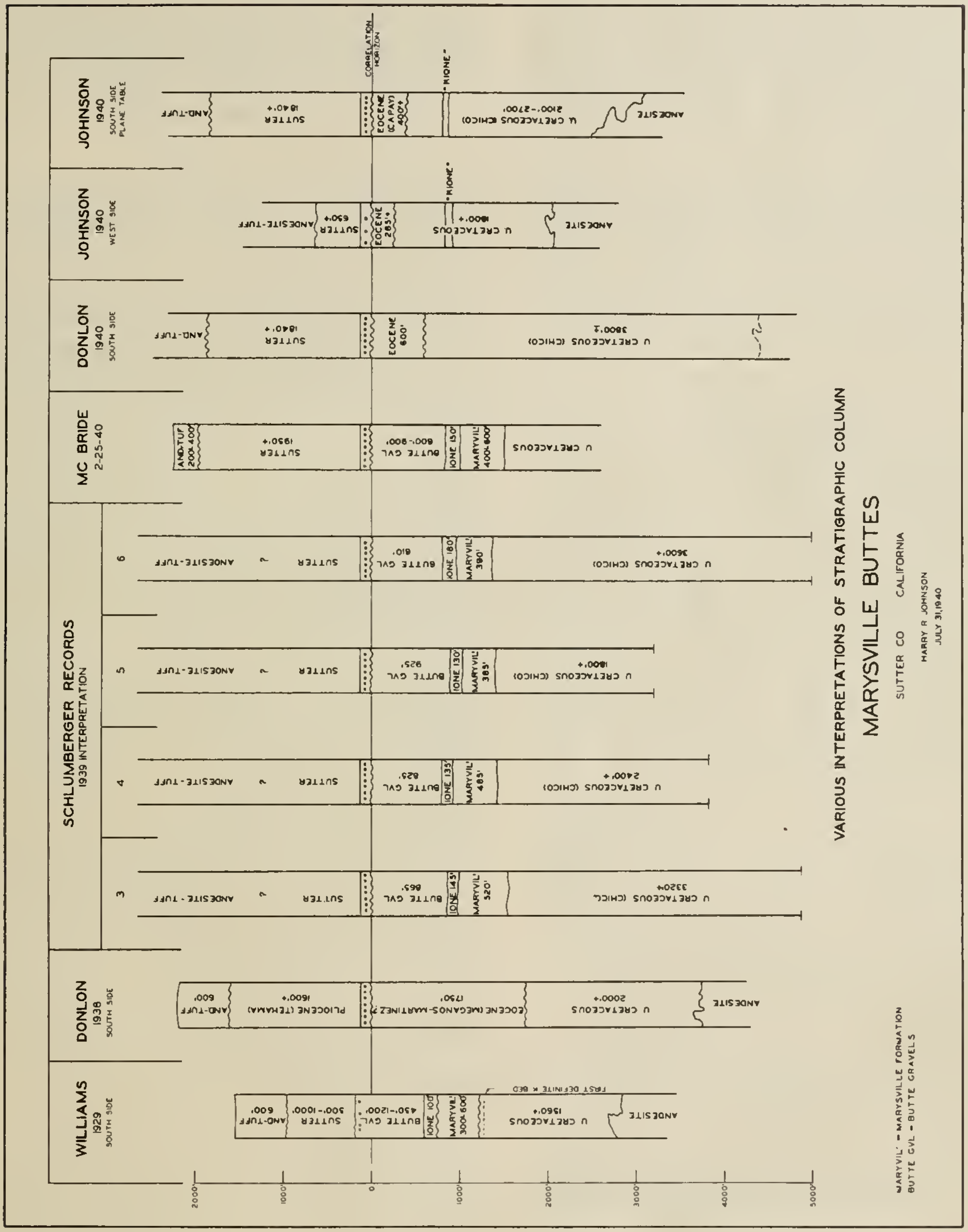

FIG. 271. Marysville (Sutter) Buttes gas field: stratigraphic columns of various authors.

sharply tilted them away from the locus of intrusion, but produced an intricate series of radial and peripheral faults. Furthermore, radial and lateral anticlines and synclines were developed, some of them of sufficient amplitude to involve all of the exposed sediments. Certain of these structural features have not previously been mapped.

It is evident that the great central plug was thrust from below at a high angle toward the south and southeast, as evidenced by the overturning of the intruded sediments in these directions. A lateral drag is suggested by the alignment of faults and folds on its western and eastern sides.

H) A considerable amount of erosion followed, but not, it is believed, to the degree suggested by Williams.

I) Rhyolitic "necks" or "domes" were intruded into both the great andesitic plug and, around its periphery, into the already faulted or folded sediments. In consequence, the latter were still more disturbed than previously

J) Erosion continued and undoubtedly some of the major present day radial valleys began to take form during this period.

K) A series of violent explosions of steam and mud took place from a mile-wide central crater located just west of the middle of the great andesitic plug. Great angular masses of andesite and rhyolite, some of them measuring 30 feet or more in diameter, were thrown from this opening and were, presumably, swept by mud flows down the slopes of the volcano to find a resting place about its periphery. (*Note.*—It is believed that the comparative regularity of bedding, the existence of pebbly beds, and the presence of intercalated layers of fine-grained tuffaceous material with the andesitic tuffs and breccias are indicative of considerable water sorting among the materials ejected from the crater, presumably after reaching the margin of the area affected by the earlier intrusions.)

It has been previously assumed that any marked divergences in attitude of the andesitic tuff layers away from normal gentle dips outward toward the nearly circular margin of the Buttes, were to be explained upon the theory of a species of "slumping" among these beds to fill pre-existing valleys or other depressions sculptured in the underlying older sediments prior to the explosive phase described under (K). The writer has found indisputable evidence that structural disturbances have taken place at Marysville Buttes subsequent to the deposition of, at least, the earlier andesitic tuffs and breccias. Not only have these earlier beds been strongly tilted and folded in approximate conformity with disturbances affecting the Sutter and earlier formations, but they have been faulted to a considerable degree. It is evident that deformative processes at Marysville Buttes did not cease with the intrusion of the rhyolite, unless such intrusive activities were prolonged to a much later date, geologically speaking, than has hitherto been suspected. Actual slumping of the tuffs and breccias has also been noted at many points.

L) Erosive processes have brought Marysville Buttes to their present form. The abundance of heavy boulders and angular to subangular blocks of andesitic porphyry at the surface and interbedded with finer material in the wide marginal band around the Buttes and the relative scarcity of such blocks and masses within the inner band of folded and faulted Cretaceous and Tertiary sediments is difficult to explain except on the assumption previously outlined, that most of the coarser ejecta thrown from the crater came to rest only after the gentler outer slopes of the upthrust area were reached. The contrast between the jagged, steep-sided, central plug, the rounded and gently sloping smooth surfaces produced in the ring of sediments about it, and the steep inface and rough texture of the outer andesitic tuff deposits is most striking.

STRATIGRAPHY

Cretaceous Sediments

The oldest exposed sedimentary rocks at Marysville Buttes are of lower Upper Cretaceous age and are mostly shales, probably referable to the Panoche. Although exposed at a number of places around the Buttes, the most complete Cretaceous section is that on the south flank, where a thickness of from 2,750 to 4,350 feet is exposed. Varying interpretations of structure account for the differences in recorded thickness, but the larger figure is probably the more accurate. Owing to the intrusive nature of the andesite porphyry, the base of the Cretaceous of Marysville Buttes is nowhere exposed.

Eocene Beds

Recent paleontological work has greatly restricted the thickness of the Eocene, through the inclusion of much of its lower portion with the Cretaceous. Williams, in 1929, supposed that a bed of white sand of Cretaceous age well exposed on the south side was correlative with the lithologically similar "Ione" of Eocene age which is found elsewhere in the Buttes and hence estimated the Eocene to be nearly 1,500 feet thick. Actually, it is between 350 and 400 feet thick, on the exposure. Because of the unconformity between the Eocene and later formations, the full thickness of the former is not exposed; it is unlikely to be more than 600 or 800 feet.

Sutter Formation (Mio-Pliocene)

A well-marked unconformity separates the Eocene from the overlying Sutter formation, which is of regional origin and consists largely of thin-bedded to massive volcanic tuffs, sandy beds and conglomerate layers, that at the base of the formation being particularly prominent. The top of the Sutter formation is not exposed, since the andesitic tuffs and breccias of later age lie unconformably above it. A measurement across the Sutter croppings on the south side of the Buttes indicates an exposed thickness of approximately 1,800 feet.

Andesite Tuffs and Breccias (Plio-Pleistocene?)

As discussed on previous pages, these deposits, unlike any of the earlier sediments, had a purely local orgin as mud flows from the now-filled central crater. They are broadly bedded and on some exposures reveal pebbly and sandy layers which suggest a certain amount of water sorting. Thickness is difficult to determine, but is probably variable in different places, owing to variances in the gradient along which the mud flows traveled and in the viscosity of the mud itself. Estimates of from 600 to 800 feet are probably reliable.

Recent Alluvium and Soils

These deposits occur along the larger stream courses, on low terraces and in areas of slumping and ponding. They are unimportant except in that they often conceal details of stratigraphy and structure.

Stratigraphic Column

The stratigraphic column presented herewith is indicative of the changes in interpretation of the age and thicknesses of the several sedimentary formations exposed at Marysville Buttes, as determined by different workers studying the region between 1929 and 1941.

STRUCTURE

To the geologist accustomed to the Coast Range structural trends, conditions at Marysville Buttes are surprising. The upward movement of the great central plug of andesite porphyry has locally pushed the formerly flat or nearly flat Cretaceous and later sediments of the Sacramento Basin into a great quaquaversal. Subsequent erosion has removed the roof of this structure, except here and there, where remnants still exist within the rugged central region, and the intruded sediments are revealed dipping away from, or overturned against the central igneous body. The subsequent secondary intrusions of rhyolite porphyry in and adjacent to the original plug have still further deformed the sediments. As a result of these disturbances, radial as well as lateral faults and folds have been developed.

The writer's study has convinced him that some of this folding and faulting took place subsequent to the last volcanic episode, since disturbances of more than local character are apparent in the andesitic tuffs and breccia series.

Several types of natural traps for gas and/or oil remain untested at Marysville Buttes. These may be grouped as anticlines, fault closures, and overlap closures, but in some instances a combination of one or more of the above types exists. A sufficient reason for the accumulation of gas in the developed area on the south flank is difficult to give; here the beds dip generally southward from the central plug and unless obscure dip-slip faults form effective barriers, or some unobserved change in depositional character occurs at depth, one is at a loss to understand the proved existence here of gas in commercial amounts.

The accompanying vertical cross section is taken in a north-south direction, across one of the divergent structures on the east flank of the Buttes. Within this feature, known locally as the Kinch anticline, much of the Eocene and all of the Cretaceous are closed against transverse faults and fault contacts to the west of the line of section.

The much-reduced and generalized geologic and structural map of Marysville Buttes is based upon evidence obtained during the summer of 1940. In this map the Cretaceous, Eocene, and Mio-Pliocene sediments have not been differentiated, but are shown under a single stippled pattern symbol.

PRODUCTIVE HORIZONS

Wells No. 3, 4, 5, and 6 of Buttes Oilfields, Inc. penetrate the andesitic tuff series and the Sutter formation to a depth of from 2,000 to 2,230 feet. Beneath the latter formation lies from 300 to 350 feet of Eocene (Capay stage) sediments, and the Cretaceous (Panoche) shales and sands are encountered at depths varying from 2,320 to 2,580 feet. The wells bottom at depths of from 5,454 to 7,650 feet in the Upper Cretaceous. All of the gas sands so far developed appear to lie within the Cretaceous, and those opened to production lie at variable stratigraphic depths, as follows: 5,365 to 5,454, 5,675 to 5,850, 5,888 to 5,912, 6,000 to 6,142 and 6,790 to 6,882 feet.

ANALYSIS OF GAS AND OIL

A number of analyses of the gas produced at Marysville Buttes have been made and that presented herewith is believed to be representative. A certain amount of liquid of a light amber color is produced with the gas and this, originally supposed to be a condensate, has been recognized as almost certainly a true petroleum, although of an unusual character An analysis of this is also presented with comments by the analyst.

Dry Gas Analysis

Buttes Oilfields, McPherrin No. 4, Sec. 2, T. 15 N., R. 1 E.
(as of March 18, 1938)

Fraction	*Percent by Volume*	*Gasoline Content Gals. per MCF*
Air	Nil	
Carbon dioxide	.10	
Methane	99.68	
Ethane	.24	
Propane and heavier	Trace	Nil
TOTAL	100.00	Nil

Calculated Specific Gravity (Air=1) 0.555
Calculated Gross B.t.u. per cu. ft. 1014.
Analyst: Edgar E. Shafer, Jr.

Analysis of Oil from Marysville Buttes Gas Well
(as of December 12, 1938)

A. P. I. at 60°	20.5°
Spec. Gravity	.9309
Lbs./gal.	7.752
Sulphur	.596%
B.t.u./lb.	18810

Distillation, 1st drop 352° F.

Percent	*Degrees F.*
10	462
20	484
30	502
40	518
50	534
60	554
70	584
80	630
90	738
99	766

"The oil is not a Paraffin Base oil. The analysis shows an asphalt base, but is unusual in this respect. Coniferous substances (rosin) indicate that pine cones or pine wood has entered into the foundation (formation?) of this oil and that the oil is not very 'normal' and therefore difficult to classify. The amount of rosin (while not determined) is small, and does not offer any solution as to its base." (Standard Chemical Company, by C. K. MacWilliams.)

BERRYESSA VALLEY

By F. M. ANDERSON *

OUTLINE OF REPORT

HISTORY

The occurrence of small quantities of petroleum associated with some of the large bodies of cinnabar in the quicksilver mines of Napa County has been known for many years. Seepages of gas and oil have also been known in the northern and eastern part of the county, in and near Berryessa Valley, as noted by Vander Leck (21, p. 52).

Drilling of prospect wells in Berryessa Valley began about 1922, and by 1928 some 12 or 15 wells had been drilled, most of them southwest and south of Monticello. Though oil was found in small quantities, neither oil nor gas has been developed commercially.

STRATIGRAPHY

Four geologic units are found in the area, which are, in order of their relative ages:

Franciscan Series

These essentially sedimentary rocks outcrop along the western and northern borders of Berryessa Valley; they cover an extensive area to the west, and extend far to the north and south as well. The series includes hard, semi-metamorphosed sandstones, sandy shales, limestone, siliceous chert, and apparently some indurated volcanic tuff.

These rocks are believed to be early or middle Jurassic in age, and they may be questionably correlated with the Mariposa-Mount Jura succession occurring in the Sierra Nevada.

Eruptive Rocks

The second oldest series in the environs of Berryessa Valley is involved with the preceding series, forming a part of the same regional terrain lying west of the valley and extending to the north and south. These eruptive rocks include areas of greenstone and serpentine (originally peridotite) widely distributed in the Coast Ranges. The peridotite was intruded into the Franciscan rocks.

Knoxville Series

Strata of the Knoxville series (late Jurassic) form a comparatively narrow zone along the west border of Berryessa Valley. The strata stand at a high angle, often vertical, and have a N. 30° W. to N. 40° W. strike, and dips of 75 to 90 degrees east, inclining away from the older Franciscan rocks, which underlie the Knoxville to the west.

The strata consist of hard or moderately hard, gray sandstones and dark-colored shales, the latter often containing fossils (*Phylloceras* sp., *Belemnites* (*Cylindroteuthis*), and *Aucella piochii* Gabb) indicating a horizon near the top of the Knoxville series as it is known farther north. The beds have a thickness of 3,500 to 4,000 feet, which is little more than half the thickness of the series as exposed near Knoxville 15 miles to the north, and only one-third the thickness found in Glenn County. These strata are sparingly bituminous in many districts in California, but they have not yet yielded commercial quantities of oil or gas.

Shasta Series

The fourth geologic unit is of great thickness and stratigraphic importance, since it embraces all the strata of the early Cretaceous period. It includes the larger part of two major groups, namely the Paskenta (lower) and the Horsetown (upper). Though these groups are, in other localities, often separable stratigraphically, in this district the line of demarkation has not been definitely traced. The Paskenta occurs in the belt of foothills lying west of Putah Creek, and in the lower section of Capell Creek. It underlies a large part of Berryessa Valley, and, according to fossil evidence, extends to the east of Putah and Capell Creeks. The Horsetown group occupies most of the hilly eastern border of the valley, its higher beds rising to the crest of the hills toward the east. The combined thickness of the two groups has been estimated as about 21,000 feet, of which 8,600 feet are referred to the Paskenta, and 12,400 feet to the Horsetown.

The lower part of the Paskenta consists of 3,300 feet of hard sandstone and sandy shale, above which are softer and more shaly beds that include lentils of limestone, apparently of limited thickness and local extent. At the quarry opened near the base of the group in Sugar Loaf Creek, the fossils *Inoceramus ovatus* Stanton, *Phylloceras* sp., and *Belemnites* (*Acroteuthis*) were found; in the sandy shale beneath were abundant specimens of *Aucella piriformis* and *Aucella keyserlingi* of early Cretaceous age. About 500 feet higher in the section, from the limestone lentils exposed on the surface, Eldridge Drew collected *Modiolus major* Gabb, *Modiolus stantoni* Anderson, *Turbo? humerosus*, *Atresius* sp., and *Acroteuthis* sp.? These species are characteristic of the limestone lentils occurring in the Paskenta in various other places in the Coast Ranges. In the upper part of the Paskenta group not far from Monticello, *Aucella inflata* has been found in abundance, and similar species have been reported by Dr. C. E. Weaver to occur high in the group some distance east of the creek.

The Horsetown group has not been studied in detail here, but for the most part, it is composed of thin-bedded, light-colored, sandy shales, that are well exposed along Putah Creek on the road between Monticello and Winters. At the Devil's Gate, near the Napa-Yolo County line, the Horsetown group is overlain by the basal conglomerates of the Chico series. These basal Chico beds

* Honorary Curator of Paleontology, California Academy of Sciences. Manuscript submitted June 6, 1938.

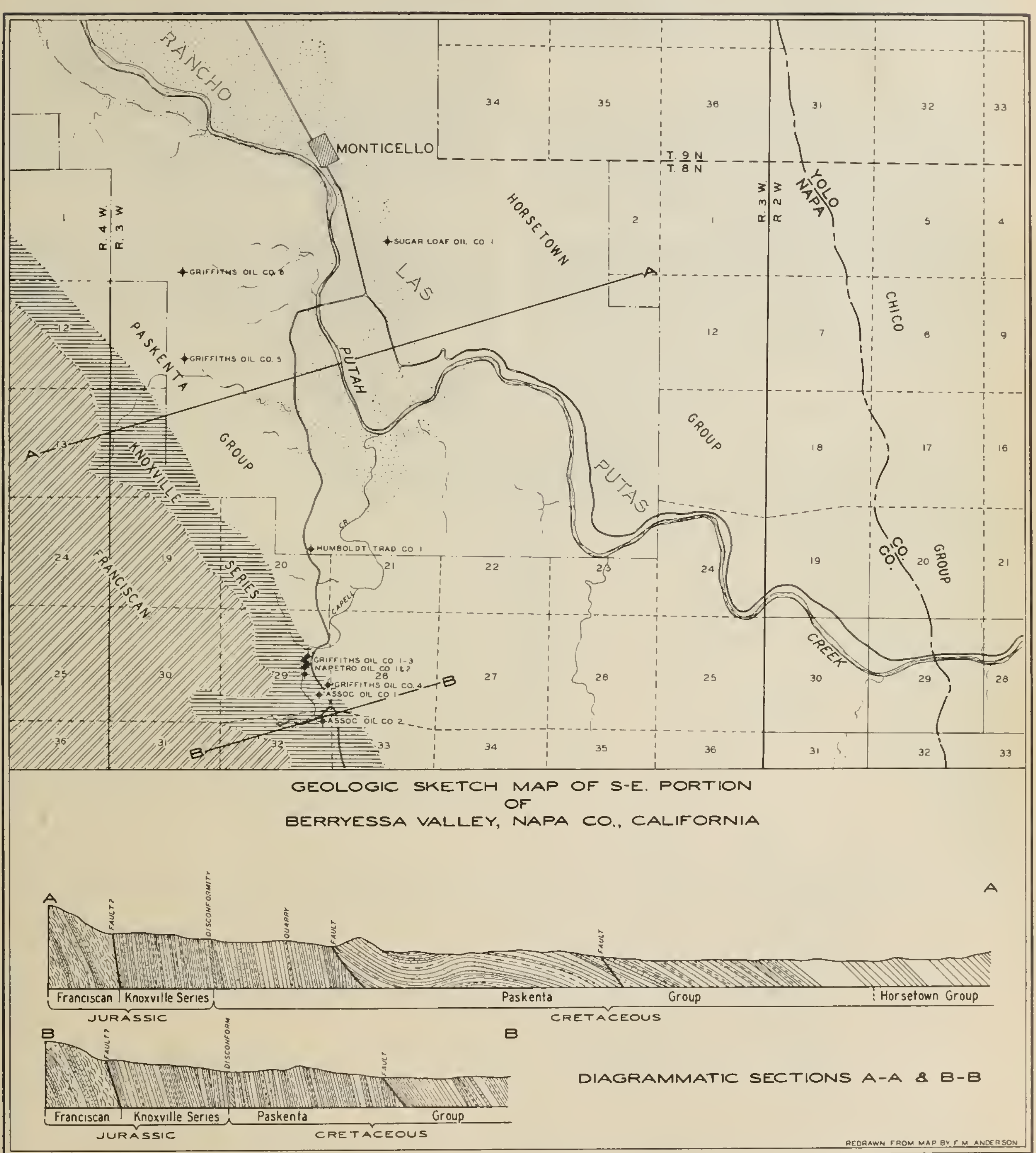

FIG. 272. Berryessa Valley: geologic sketch map; sketch sections.

form the crest of the range of hills (also the county line) north and south for many miles. Between these conglomerates and the top of the Paskenta group, the Horsetown group forms a broad zone. Structurally its strata appear to be much crumpled, so that its true thickness can be only roughly estimated; it may exceed 12,400 feet.

STRUCTURE

The Knoxville beds stand in a steeply inclined attitude, and in questionable fault contact with older (Franciscan) rocks to the west. In the much disturbed area at the south end of the valley, a fault separates them from the overlying Shasta series as well.

Thrust effects are also plainly seen in both groups of the Shasta series. In the Paskenta group both faulting and folding have resulted. The most conspicuous of these faults is at the entrance to the canyon of Sugar Loaf Creek, a short distance west of the wells, where the Paskenta beds are broken and thrust upward, forming a low ridge in front of the older, nearly vertical beds. East of this fault zone the later beds of the group have been folded up into a gentle anticlinal arch. Well No. 5 of the Griffiths Oil Company was drilled upon the west limb of this arch; well No. 6 of the Napa Oil Company is situated more nearly upon its axis. This anticline plunges toward the northwest at a gentle angle, and in this direction it passes beneath the floor of the valley and disappears under the alluvium.

The structures developed in the Horsetown group are complicated, and show much crumpling of strata, the result of east to west regional thrusting.

PRODUCTIVE HORIZON

No authentic record has been obtained of oil having been reached by wells drilled into the Paskenta or Horsetown groups of the Shasta series. In the wells drilled into the upper part of the Knoxville series, all of the oil obtained was of high gravity.

CITATIONS TO SELECTED REFERENCES—Continued

BERRYESSA VALLEY

Averill, C. V. 29; Laizure, C. McK. 22a; Vander Leck, L. 21, pp. 52, 56.

WILBUR SPRINGS (BEAR CREEK, BEAR VALLEY) REGION

Logan, C. A. 29; Vander Leck, L. 21, pp. 52, 55.

PASKENTA REGION

By Robert L. Rist * and William C. Harrington **

Paskenta is located in southwestern Tehama County, on the western limb of the Sacramento Valley geosyncline. Exposed in the area are Jurassic metamorphics, Upper Jurassic marine sediments, and a thick marine Cretaceous section which is overlapped to the east by Pliocene Tehama gravels.

The metamorphics and some of the Jurassic sediments are referred to the Franciscan. The Franciscan complex consists largely of deeply weathered shales which have been intruded by serpentine. Minor constituents include gabbro, chloritized basalt breccia, and red chert. The serpentine is also found faulted into the overlying Knoxville sediments, and to the south is intrusive into shales that are probably of Knoxville age.

Overlying the Franciscan group are 14,800 feet of shallow marine beds of the Knoxville series. These beds are essentially dark-gray shales with rare scattered interbeds of platy sandstone and occasional lenticular bodies of dark-gray limestone. These are sometimes thicker beds of sandstone. and, rarely, massive conglomerates. The molluscan fauna suggests that these beds are of Upper Jurassic age.

Conformably overlying the Knoxville is the Shasta series. Lithologically the beds of this series are almost identical to those of the Knoxville, but differ in being slightly more sandy. Basal conglomerates may or may not be present. In the Paskenta district they are present south of Thomas Creek; but to the north they are not present. These conglomerates, like the Knoxville conglomerates, are characteristically lenticular. The thickness of the series is approximately 12,600 feet, but the upper portion and the Shasta-Chico contact are irregularly overlapped by the Pliocene Tehama gravels. Mollusca present in the Shasta series distinguish these beds from the underlying Knoxville and establish the age as Lower Cretaceous. On faunal evidence the series has been broken up into the Paskenta and Horsetown divisions.

* Geologist, Standard Oil Company of California.

** Engineering Assistant, Natural Gas Division, Pacific Gas and Electric Company. Manuscript submitted for publication February 1, 1941.

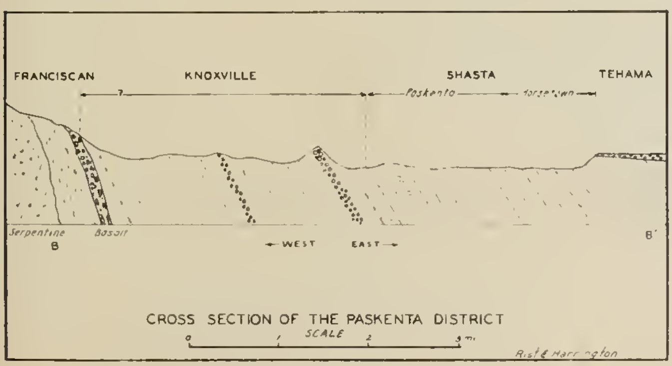

Fig. 273. Paskenta region: geologic cross-section.

The Tehama formation consists of poorly consolidated, ill-sorted, continental sands and gravels. The pebbles are subangular and in this district are dominantly red chert and white quartz. Here, on the westernmost edge of the formation, maximum coarseness is reached.[1]

The sedimentary beds of the district strike N. 10° to 30° W., and dip eastward under the valley 45 to 70 degrees. In the vicinity of Williams Buttes, a mile west of Paskenta, there is a flexure which offsets the Knoxville beds some 11,000 feet. This structure may reflect a high-angle thrust fault in deep, more competent beds. The flexure has broken and even overturned, some of the Knoxville conglomerate bodies. The structure is of Jurassic age, for the overlying Cretaceous beds have not been distorted similarly.

Structural closure for the accumulation of hydrocarbons may be obtained in the Williams Buttes region by

[1] For a more complete discussion see "Geology of the Paskenta District," by W. C. Harrington (unpublished thesis, Department of Geological Sciences, University of California, Berkeley, 1941.)

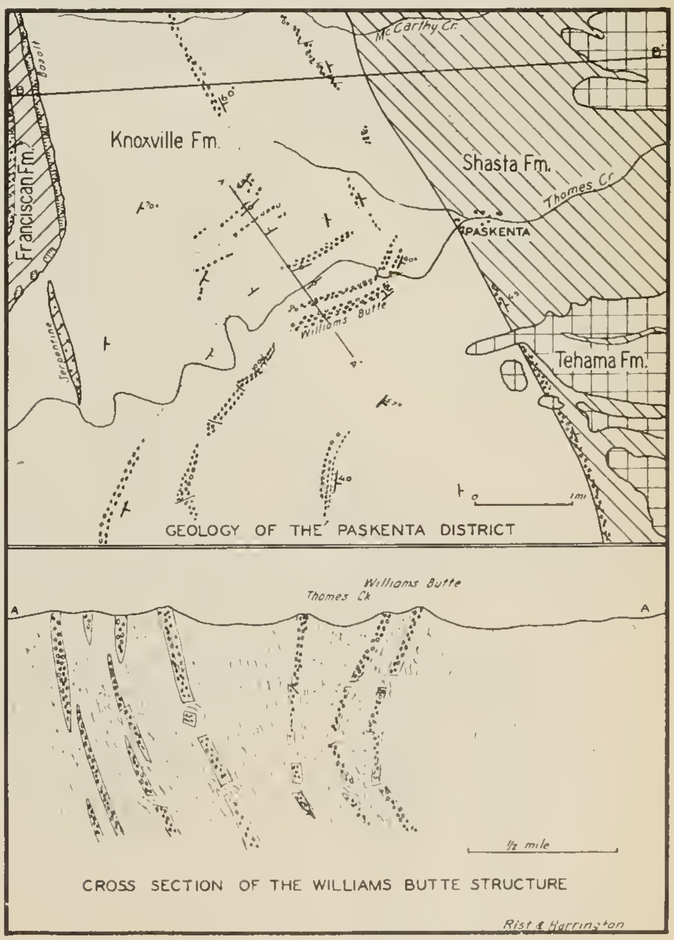

Fig. 274. Paskenta region: geologic map; cross-section of the Williams Butte structure.

the breaking of the conglomerate beds in folding and overturning, or by the lenticular nature of the beds. The lenticularity, however, would limit the reservoir volume. The total thickness of the several conglomerate bodies is approximately 2,500 feet. However, on the outcrop the conglomerates are fairly well cemented and probably have low porosity. The areal extent of these conglomerates is less than one square mile. The lenticularity of the conglomerates and sands may have resulted in stratigraphic traps in other parts of the district. There are no closed folds in the vicinity of Paskenta, but some are known to exist toward the central part of the Sacramento Valley. Since the Tehama gravels are permeable, it is doubtful that their overlapping of the Upper Shasta and Chico would effectively seal any oil- or gas-bearing beds.

It should be noted that only in local instances do these sediments contain organic remains. Where present these consist of Mollusca and carbonized wood. No micro-organisms of any sort have been noted by the writers.

Unverified oil seeps and non-commercial oil shows have been reported from shallow wells in the vicinity. Verified gas seeps occur in the district, but no commercial gas production has been obtained from Upper Jurassic or Lower Cretaceous beds.

CITATIONS TO SELECTED REFERENCES—Continued

DUXBURY POINT (GARZOLIA RANCH) REGION

Bradley, W. W. 16; Laizure, C. McK. 26a; McLaughlin and Waring 14, p. 473; Vander Leck, L. 21, pp. 35-36.

POINT REYES REGION

Anderson, F. M. 99; Dickerson, R. E. 22.

PETALUMA REGION

Anderson, F. M. 99, pp. 119-153; Arnold, R. 31; Bailey and Morse 35; Bradley, W. W. 16; Dickerson 22, pp. 527-601; Gabb, W. M. 69, pp. 1-110; Holway, R. S. 13; pp. 3, 8, 20-28, 37, 25-26, 36, 34-35; 14, p. 82; Keyes, R. L. 27; Laizure, C. McK. 26b; Lawson, A. C. 94, p. 269; Lawson et al. 08, pp. 27-28, 63-65; McLaughlin and Waring 14; Mendenhall, W. C. 27; Osmont, V. C. 05, pp. 67-69, 54-56; Stalder, W. 41; Vander Leck, L. 21, p. 38; Whitney, J. D. 65, pp. 83-85.

DUXBURY POINT REGION *

By James M. Douglas **

The Point Reyes anticline runs N. 20° W. from a point on the coast half a mile southwest of the town of Bolinas. The Monterey shale outcrops along the west flank of the anticline and is exposed along the axis except where it is covered over by alluvium or the Merced sandstone at the northern end of the structure. Along the east flank the Monterey shale outcrops in three rather narrow areas and is overlapped by the Merced sandstone. The east flank is about half a mile wide and is bounded on the east by the San Andreas fault, which is parallel to the axis of the fold.

The oil seeps and asphalt dike in the northwest part of the area, the gas seeps at Duxbury Point, and the showing of heavy oil in one of the three shallow wells drilled about 1904, indicate that the Monterey shale is a competent source of oil in this area. The sands below the Monterey shale are a suitable reservoir. However, there is no closure along the axis to the northwest, and the eastern flank of the structure is limited by the San Andreas fault and is largely covered by alluvium and the Merced sandstone, which lies unconformably on the Monterey shale.

* This paper is an excerpt from a thesis on the Point Reyes Peninsula, prepared by James M. Douglas and R. S. Rhoades for the Department of Geological Sciences, University of California, in 1914.

** Address: Paso Robles, California. Manuscript submitted for publication June 5, 1941.

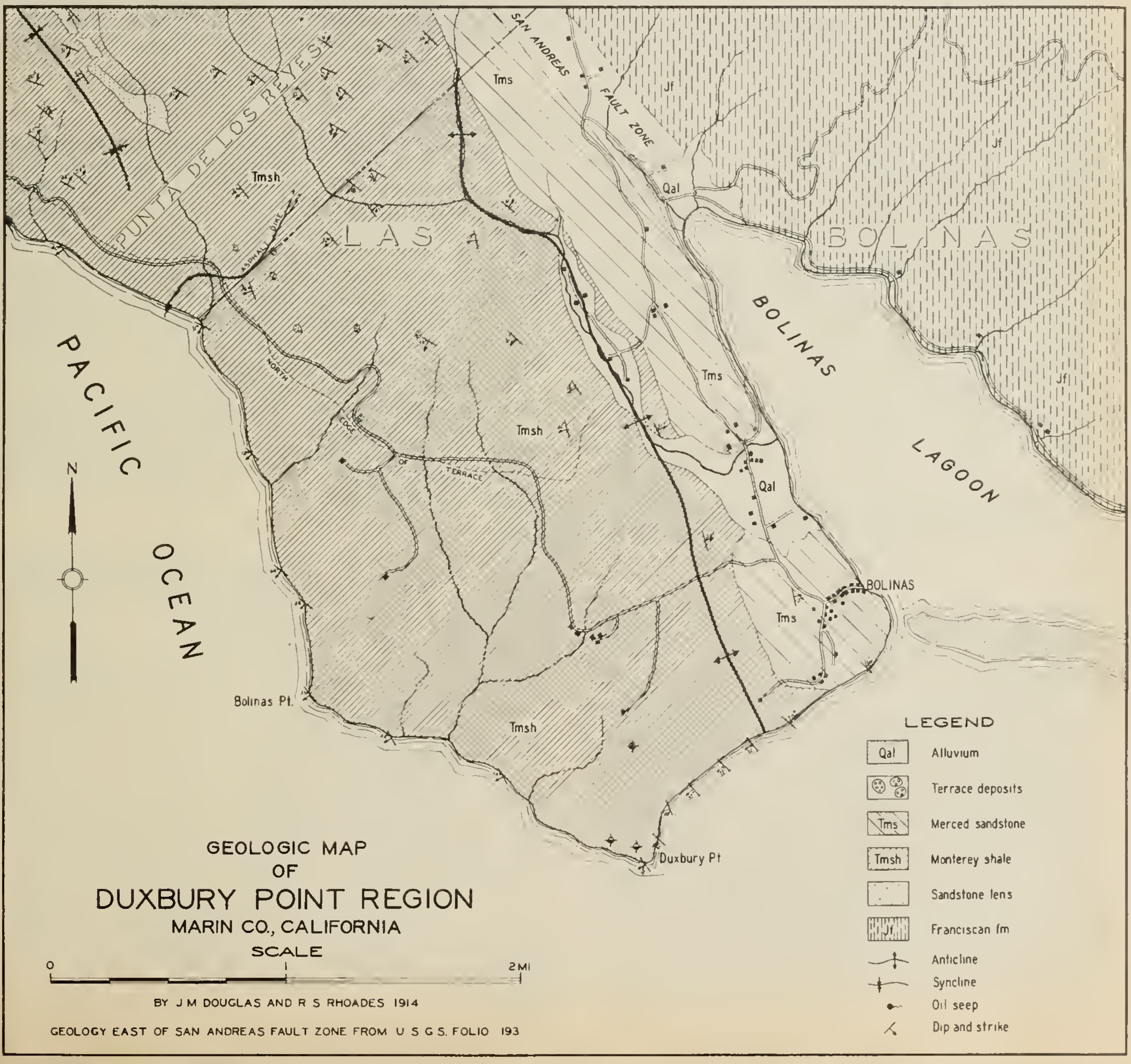

Fig. 275. Duxbury Point region; geologic map.

PETALUMA REGION*

By F. A. JOHNSON **

OUTLINE OF REPORT

GENERAL GEOLOGY

The Bodega diorite of pre-Franciscan age is the oldest rock in the Petaluma region; it outcrops along the coast from Tomales Bay to Bodega Head, where it is separated by the San Andreas rift from the Franciscan (Jurassic) group to the east. The Franciscan group consists of arkosic sandstones, radiolarian cherts, shale, basalt flows contemporaneous with the deposition of the sediments, and sills and dikes of peridotite and diabase, intrusive into the sediments. At the contact of the peridotites with the sediments, soda-rich metamorphic rocks (glaucophane schists) were formed.

Cretaceous sediments, consisting of sandstones, shales, and conglomerates, are correlated with the Chico of Upper Cretaceous age; they outcrop along the coast near Fort Ross where they are separated from the Franciscan group by the San Andreas rift.

No Eocene, Oligocene, Miocene, or lower Pliocene formations have been encountered in the area. The Petaluma formation of middle Pliocene age, consisting of clays, sandstones, conglomerates, and minor limestone lenses and lignites, is in contact with the Franciscan along a fault or high-angle unconformity. The Petaluma formation was highly folded, faulted, and eroded before the Sonoma volcanics and Merced formation were deposited unconformably upon it and upon the Franciscan.

The Sonoma volcanics are tuffs, tuff breccia, and basalt, which interfinger with the Merced formation of upper Pliocene age. The Merced is composed of marine and interfingering fresh-water sediments. The marine Merced is chiefly fine-grained sandstone with minor amounts of clay, coarse-grained sandstone, and conglomerates; the fresh-water beds are cross-bedded sandstones and conglomerates, clays, and interbedded tuffs. The Sonoma volcanics and the Merced formation are gently folded and, in places, faulted.

The area during the Pleistocene was reduced to a surface of rather low relief, then elevated, as two well-defined marine terraces testify. Later depression resulted in the formation of Tomales and Bodega Bays, and in the drowning of streams of the region.

DESCRIPTION OF THE FORMATIONS

Bodega Diorite

The Bodega diorite is confined to the southwestern part of the area, and is limited on the east by the San Andreas rift zone. It is well exposed in the sea cliffs of Bodega and Tomales peninsulas. The rock is a coarse-grained hornblende-biotite-quartz diorite. It is deeply weathered, badly crushed, sheared, and faulted, and possesses a gneissoid banding caused by the parallel alignment of the coarse biotite flakes. Pegmatite, aplite, and lamprophyre dikes are occasionally present and generally have a westerly trend. Quartz veins and schlieren, though present, are of minor importance.

The Bodega diorite is correlated with the quartz diorites and its differentiates occurring in the Santa Cruz, Santa Lucia, and Gabilan Ranges. Accordingly, it is regarded as the equivalent of Trask's (26, p. 136) Santa Lucia quartz diorite, which is pre-Franciscan and post-Sur series in age.

Franciscan Group

The Franciscan outcrops over about half the area mapped. It represents the floor upon which the Merced formation was deposited, except for a small territory at the southeastern corner of the area.

The most common sedimentary rock in the Franciscan group of the area is a massive, well-indurated, medium- to coarse-grained, quartz-feldspathic sandstone composed of angular to sub-angular grains, locally traversed by veinlets of quartz and calcite, and commonly containing flakes of black shale.

The shales of the Franciscan are fissile, lenticular, and dark gray or black in color. The best sections were observed near the mouths of the Esteros San Antonio and Americano, where black shales are interbedded with massive sandstones in beds usually a foot or more thick, though sometimes less. In sea cliffs, the shales are sometimes associated with sandstones, but they have usually been so contorted, sheared, and crushed that the original thickness and the nature of the bedding have been largely destroyed.

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* *Editor's Note:* In a small area east of Petaluma, exploration for oil and gas was carried on during the years 1926 to 1937. The geology of that area, described by Bailey and Morse (35), is briefly reviewed herewith by Mr. Johnson, who has also included a summary of his own report prepared from a much longer thesis on the sedimentation of the Merced formation in Sonoma and Marin Counties. Field and laboratory studies for the thesis were carried on by Mr. Johnson during the years 1931 to 1934 under the direction of Dr. G. D. Louderback, Department of Geological Sciences, University of California. Field expenses were borne in part by the Geologic Branch of the California State Division of Mines.

The accompanying "Geologic Map of a Portion of Sonoma and Marin Counties" covers the Sebastopol and Duncans Mills quadrangles. At the time this investigation was made, these topographic quadrangles were available only as reconnaissance U. S. Army Tactical maps. More recently, however, an advance topographic sheet of the Sebastopol quadrangle has been issued by the U. S. Geological Survey.

Since no information on the geology of these quadrangles has hitherto been published, with the exception of the material supplied by Mr. Johnson and included on the Geologic Map of California (Jenkins, O. P. 38), and since the region adjoins the smaller drilled area to the southeast, the abstract of Mr. Johnson's more extensive investigation is presented in this bulletin. Adjoining Mr. Johnson's map on the northwest, and also published in this same bulletin, is the "Preliminary Geologic Map of Point Arena—Fort Ross Area, Mendocino County", by Charles E. Weaver.

** Geologist, Los Angeles, California. Manuscript submitted for publication February 14, 1941.

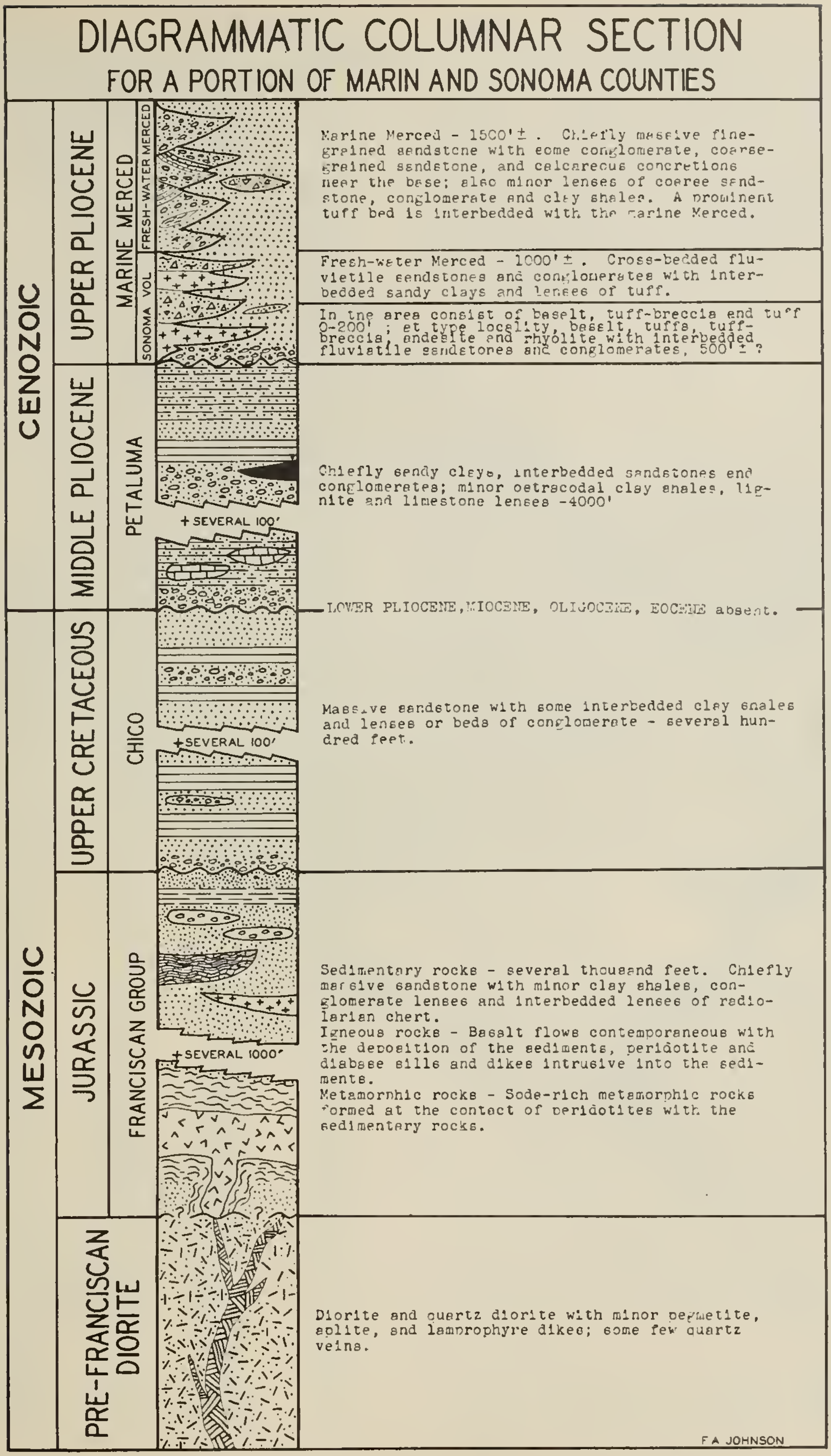

FIG. 276. Sonoma and Marin Counties: diagrammatic columnar section.

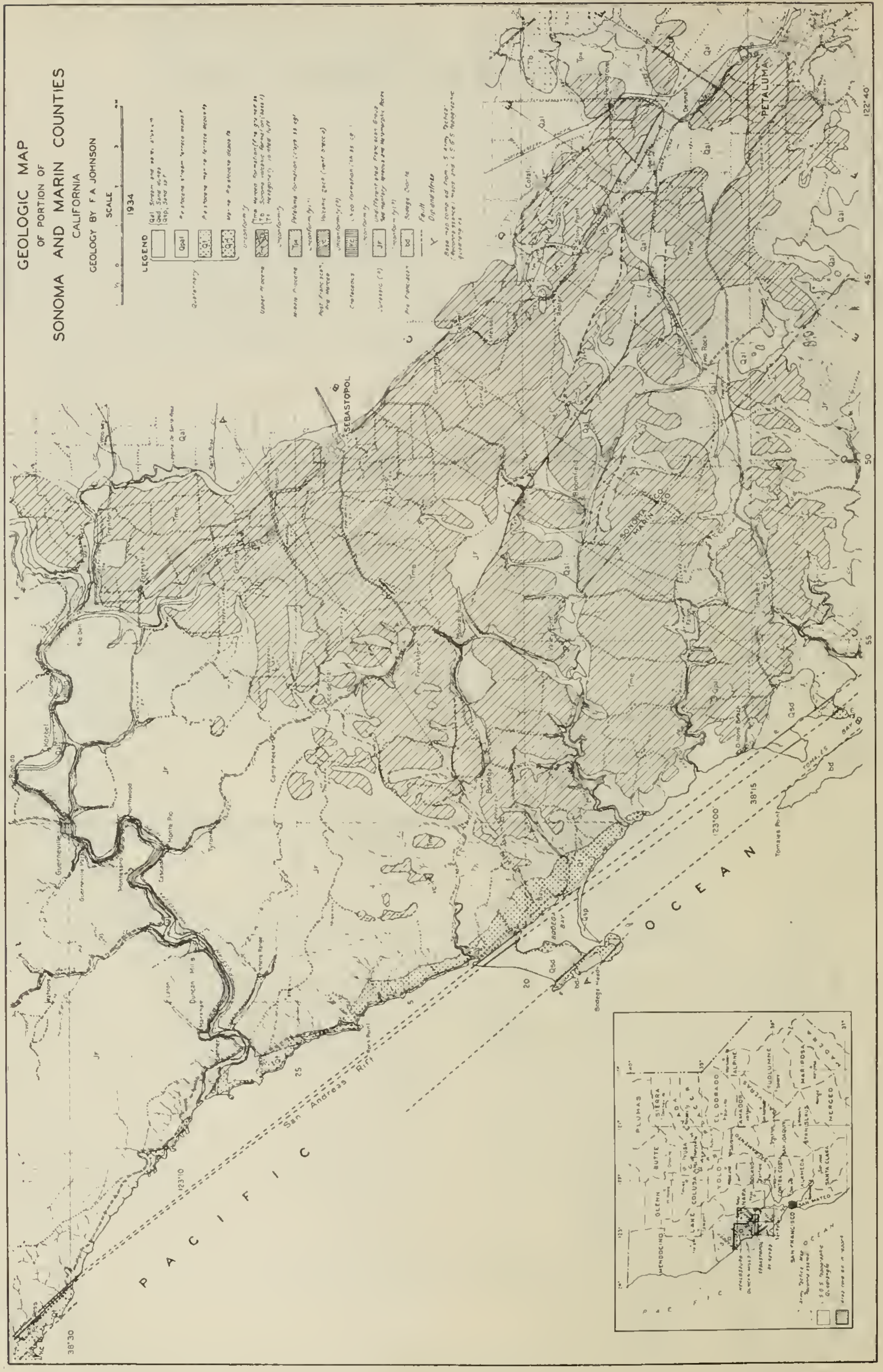

FIG. 277. Sonoma and Marin Counties: geologic map; index map.

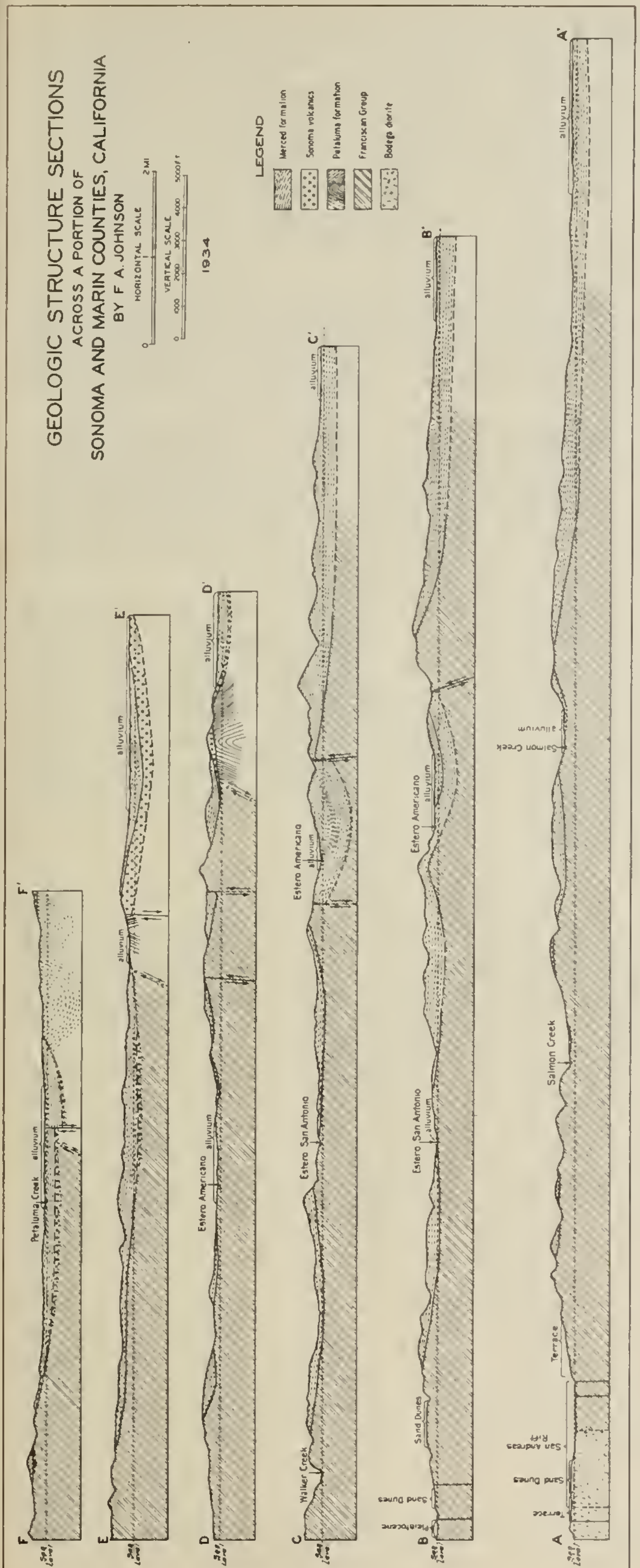

FIG. 278. Sonoma and Marin Counties; geologic structure sections.

Conglomerates occur at two localities. On the east shore of Tomales Bay directly east of Toms Point, there is a lens of well-cemented conglomerate consisting of rounded chert and quartz pebbles in a matrix of typical Franciscan sandstone. A conglomerate consisting of well-rounded pebbles and a few boulders is exposed in a road cut about an eighth of a mile east of the bridge crossing the Russian River near Jenner.

Several lenticular bodies of radiolarian chert, generally less than 100 feet in thickness, were encountered in the Franciscan of the area. Both banded and massive varieties are present, and show numerous colors brownish red, green, gray, white, and yellow.

Three types of igneous rocks were observed in the area: (1) peridotite, the most abundant, which is almost universally altered to serpentine; several large bodies occur in the area; (2) basalt, in occasional small exposures; and (3) one small outcrop of diabase.

Metamorphic rocks occur in the Franciscan of the area at contacts with serpentine bodies, or in isolated outcrops where it is presumed that the serpentine has not as yet been uncovered by erosion. They do not occur as a continuous aureole about the intrusive, but appear to form discontinuous bodies, often several feet away from the apparent intrusive contact. They consist chiefly of quartz rocks and schists, quartz-albite schists, albite schists, epidote schists, and amphibolite schists.

Cretaceous

Cretaceous rocks, consisting chiefly of sandstones with minor interbedded shales and conglomerates, occur in a small exposure in the northwest corner of the area on a headland on the coast three-quarters of a mile southeast of Fort Ross, where they are faulted against the Franciscan. They then disappear beneath a small bay, but are encountered again at Fort Ross, where excellent exposures in the sea cliffs show them to be still faulted against the Franciscan. However, to the east of the fault, the Cretaceous is in complex fault relation to the Franciscan.

Petaluma Formation

The Petaluma formation is confined to the southeastern corner of the area, where it lies unconformably beneath the Sonoma volcanics and Merced formation. It consists chiefly of clays with some interbedded sandstone, minor beds of conglomerate and conglomeratic sandstone, and rare thin beds and lenses of clayey limestone. The clays are in general thin-bedded, discoidal, and range in color from gray to brown or light green. Occasional clayey limestone or lime concretions, and infrequent streaks of lignite and ostracodal clay shales are found in the clays. Rare lenses or thin beds of conglomerate are encountered within the sandstone, which is massive, friable, and occasionally shows well-developed cross-bedding.

It appears that the Petaluma formation[1] is younger than the Pinole tuff or any known Orinda, and is of upper middle Pliocene age.

Sonoma Volcanics

The Sonoma volcanics (Dickerson, R. E. 22, p. 551) at the type locality, Sonoma Mountain, consist of basalts, andesites, rhyolites, tuff, and tuff breccia; but in the area

[1] Stirton, R. A., *Oral communication.*

mapped only basalts (with or without olivine), dacite tuffs, and tuff breccias are present.

The basalt is confined to the southeastern part of the area, rests unconformably upon the Franciscan and Petaluma, and is nearly always in apparent conformable relationship to the Merced; it is generally from 50 to 75 feet, and probably nowhere exceeds 200 feet in thickness. The unconformable depositional (where tuff) and flow (where basalt) relationship of the contact between the Petaluma formation and Sonoma volcanics, although locally complicated by high-angle normal faulting which has occurred subsequent to the deposition of the volcanics, can be seen 2 miles east of Penngrove. The nature of the contact has been checked and proved by means of frequent excavations as far south as Eureka school.

A prominent bed of dacite tuff, the Sonoma tuff of Osmont (05, pp. 59-73), containing casts of marine Merced fossils, is interbedded with the Merced sandstone and undoubtedly represents a phase of volcanism to be correlated with the Sonoma volcanics lying to the east of the Santa Rosa Valley or tuffs interbedded with the fresh-water Merced. The tuff bed is about 40 feet thick (maximum) and can be traced from a locality a short distance west of Roblar quarry to a little beyond Freestone; it is not encountered again until the north branch of Mark West Creek just north of Trenton.

The Sonoma volcanics rest unconformably upon the Petaluma formation of middle Pliocene age. Marine Merced, upper Pliocene, is present under the Sonoma volcanics at Burdell Mountain; in several places in the area, the Merced rests with apparent conformity upon the Sonoma basalt. A 40-foot bed of tuff is interbedded with the marine Merced. From these relations, it appears that the Sonoma volcanics are in part contemporaneous with the deposition of the Merced formation, and are upper Pliocene in age.

Merced Formation

The Merced formation, upper Pliocene, is represented by both marine and fresh-water deposits. The former consists chiefly of fine-grained, generally massive, quartz-feldspathic sandstone, conglomerate, and clay shale. The latter consists of fluviatile conglomerates and sandstones of varying coarseness accompanied in many places by siltstones and clays.

The marine Merced occurs in the southeastern half of the area mapped, where it persistently outcrops. It is limited to the west side of the Santa Rosa Valley, where in the vicinity of Penngrove there is evidence in gully exposures of interfingering of marine and fresh-water sediments; but the critical area is in the Santa Rosa Valley where the Merced is buried beneath Quaternary alluvium, so that to gain further information core holes would have to be drilled.

The marine Merced rests unconformably upon the Franciscan over the entire area, with the exception of the southeastern corner, where east of Penngrove and Petaluma it is apparently conformable upon the Sonoma volcanics which in turn rest unconformably upon the Franciscan group and Petaluma formation.

Fresh-water deposits occur north of Santa Rosa. In the hills east of the State Highway they form part of the western limb of an asymmetric anticline, the axis of which strikes and plunges northwest. They consist of sandy clays, tuffaceous sandy clays, minor tuffs, fine-grained sandstones, and conglomerates, resting in conformable depositional contact upon the Sonoma volcanics represented here by basalt.

The writer has referred the Merced to the upper Pliocene, since it rests unconformably upon the Petaluma, now regarded as middle Pliocene in age.

Pleistocene Formations

Marine Pleistocene deposits rest unconformably upon the Franciscan at Toms Point, a small peninsula extending into Tomales Bay. These deposits lie within the San Andreas rift zone and apparently have been tilted by faulting.

Pleistocene stream terraces are represented by a small thin remnant a mile north of Franklin school and a mile south of the bridge over the Estero San Antonio at the Jens Pelegaard Ranch. From this deposit, R. A. Stirton of the Department of Paleontology of the University of California collected partial remains of a mastodon, a mammoth, and a bison.

Marine Pleistocene terrace deposits are represented by a well-marked lower terrace, with deposits of coarse material derived from the underlying Franciscan or Cretaceous. It attains a maximum thickness of about 50 feet. This terrace is fairly continuous along the coast, but was mapped only in a reconnaissance manner. In addition, there are some remnants of a second, higher terrace, the deposits of which have been removed by erosion, for the most part. No attempt has been made to map them.

STRUCTURE

The Merced and the Sonoma volcanics rest unconformably upon the Franciscan and the Petaluma. The marine Merced is gently folded; dips rarely exceed 10 degrees, though dips greater than 20 degrees have been produced by drag along faults. The fresh-water Merced and the Sonoma volcanics may have dips of 30 to 70 degrees, but lower dips are the rule.

The chief fault in the area is the San Andreas rift which has a width of 1 to 1½ miles. It is shown on the map by three fault lines. The outer two lines delimit the width of the rift zone. The middle line is the one along which the movement took place during the earthquake of 1906. Since most of the fault trace is covered by the ocean, the best place to study it is at Fort Ross where the features produced by the movement of 1906 can still be seen.

Five faults, which involve the Merced, have been mapped in the area. They are normal faults and the throw does not appear to have been great. The chief of these is about a mile north of Bloomfield; it strikes northwest with a downthrow of Merced against the Franciscan on the south side. The maximum throw is about 500 feet.

There is a fault along the west side of Meachia Hill, about 2 miles west of Penngrove, that brings Petaluma against the Merced and the Sonoma volcanics; the maximum throw is probably about 300 feet.

EXPLORATION FOR OIL AND GAS

Exploration for oil has been carried on about 5 miles east of Petaluma and just east and south of the mapped area.

The earlier exploration was confined to shallow holes. Gas was reported to have been struck in one hole in the Petaluma beds at a depth of 800 feet, and oil sands were reported in the same beds in a second hole at depths of 335 to 340, 346 to 352, and 397 to 399 feet (Bradley, W. W. 16, p. 341).

The Shell Oil Company's exploration for oil in the district has resulted in an excellent paper by Morse and Bailey (35). They give a great deal of direct information concerning the Petaluma formation and the Tolay volcanics, conformably underlying the Petaluma formation; and some indirect evidence concerning the petroleum possibilities of the region.

The stratigraphy which they give is based partially on surface work, but is chiefly derived from cores of five holes drilled in the district, and may be summarized as follows (Morse and Bailey 35, pp. 1444-1445):

Upper Petaluma clays, sands, and gravels.
 Surface and well information, about 3,500 feet.
Lower Petaluma ostracod shales and thin sands.
 Well thickness 500 to 600 feet.
Transition zone, alternating volcanics and ostracod shales.
 Well thickness 122 to 168 feet.
Tolay volcanics—tuffs, agglomerates, and flows. Maximum well thickness 4,162 feet.

" . . . . . . the total thickness (of the Tolay volcanics) is unknown, the deepest well having failed to reach the base after penetrating these volcanics for more than 4,000 feet." (p. 1441)

As to what may lie beneath the Tolay volcanics, the following statements are made (pp. 1439-1440):

"In the Petaluma region these volcanics (Tolay) may rest directly upon the Franciscan; (or, if) San Pablo strata are . . . . present, they may occur in the unknown interval below the Tolay volcanics."

In speaking of the oil and gas possibilities of the region, Morse and Bailey state (p. 1439):

"It is possible that oil and gas encountered in wells in the Petaluma district arose from underlying 'Monterey' source horizons reaching their present position in the Pliocene through fractures in the intervening volcanic series. Judging from structural observations, many such fractures are probably now available. However, the occurrence of oil and gas in the region can scarcely be considered as proof of the presence of concealed marine Monterey here."

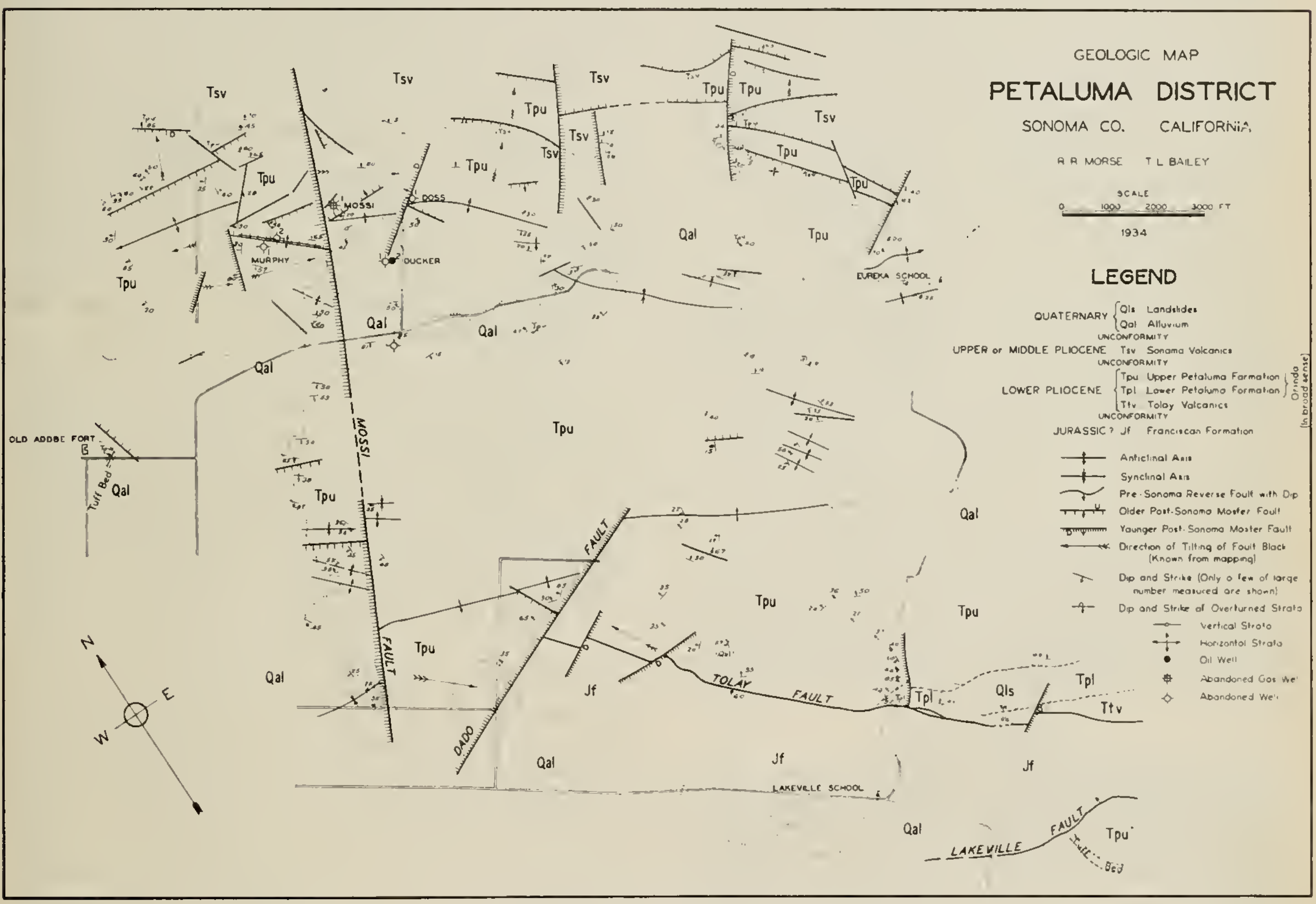

FIG. 279. Petaluma district: geologic map.

POINT ARENA–FORT ROSS REGION

By CHARLES E. WEAVER *

OUTLINE OF REPORT

GENERAL STATEMENT

The purpose of this report is to present a preliminary description and discussion of the geology of an area in California which heretofore has received very little study. The region investigated is situated 75 miles northwest of San Francisco in Mendocino and Sonoma Counties, and embraces an area of approximately 95 square miles between the San Andreas fault zone and the Pacific Ocean. This area is traversed from northwest to southeast by the State coast highway No. 1 and is accessible from the cities and settlements in the Russian River Valley by several east and west mountain highways. The principal towns in the area are Point Arena, Gualala, Manchester, Stewarts Point, and Fort Ross.

The coast from Fort Ross northwestward to Point Arena lighthouse is characterized by precipitous cliffs averaging 50 feet in height, and rugged westward-projecting headlands usually impassable even at low tide. Immediately east of the coast for several thousand feet are wave-cut terraces whose surfaces have been modified by erosional agencies and differentially tilted as the result of numerous small normal faults. Still farther east and parallel to the coast there is an elongate mountain ridge with altitudes as great as 1,000 feet along its summit. It extends from near Manchester on the north, southeastward toward Fort Ross, and forms the drainage divide between short streams flowing directly westward into the ocean and the elongate parallel valleys containing portions of Gualala and Garcia Rivers on the east. The lower courses of these two streams have carved channels through this ridge and also flow directly into the ocean. The greater part of the surface of this area is densely covered with forest and undergrowth as well as a deep soil, so that good rock outcrops are difficult to find.

STRATIGRAPHY

The rocks exposed in the mountains immediately east of the San Andreas fault are composed entirely of sandstones, cherts, and shales of the Franciscan group together with associated igneous and metamorphic rocks. The Franciscan has not been observed in any part of the area studied on the west side of the fault. The formations between the fault and the ocean from the mouth of Alder Creek southeastward for a short distance beyond Fort Ross include the Gualala series; the Galloway beds and Point Arena beds of Miocene age; the Skooner Gulch basalt of probable early Tertiary age; and uplifted Pleistocene terrace deposits. These formations possess a total aggregate thickness of about 25,000 feet of sedimentary rock which have been complexly folded and locally faulted. They are a residual of an earlier and more extensive land mass which has foundered beneath the marginal floor of the Pacific Ocean.

The older quartz diorites which are well exposed farther south in the Point Reyes Peninsula and at Bodega Head west of the San Andreas fault are not present at the surface in the area studied. However, the basal conglomerates of the Gualala series exposed in the cliff sections south of Fort Ross contain cobbles and boulders composed in part of quartz diorite with a mineralogical composition similar to that at Bodega Head.

Franciscan Group

The mountains east of the San Andreas fault in the area studied are composed entirely of rocks of the Franciscan group and associated igneous materials. The sediments are composed mainly of massive, thick-bedded arkosic brownish-gray medium-grained sandstone with occasional interstratified lenses and layers of radiolarian cherts. Associated with these are small patches of actinolite, mica, and glaucophane schists together with intrusive masses of gabbro and serpentinized pyroxenites. Vesicular flows of basalt and sills of diabase are intercalated within the sandstones in a few localities. The sandstones constitute over 95 percent of the total volume of the Franciscan group. The prevailing lithology of all these rock types is similar to that described in the Mt. Tamalpais quadrangle of the San Francisco Folio (Lawson, A. C. 14).

The lithology of the sandstones of the Franciscan group is uniform and the principal constituents are quartz, plagioclase with a composition of Ab^{50}-An^{50}, orthoclase, hornblende, and biotite, together with fragments of slate, schist, quartzite, and carbonaceous material. Occasional lenses of pebbly and coarse conglomerate are present which consist of well-rounded cobbles of quartzite and quartz diorite up to 6 inches in diameter. Ordinarily the sandstone is considerably fractured near the surface and the resultant disintegration and decay have caused the accumulation locally of a thick sandy soil.

Massive and thinly laminated radiolarian cherts in lenses and layers, ranging in thickness from 1 to more than 50 feet, are interstratified with the sandstones as in other described areas in the Coast Ranges north and south of San Francisco. The thinly laminated types are characterized by the uniform alternations of chert layers 2 to 5 inches thick and layers of brownish and greenish-gray shale usually under half an inch thick. These cherts are often intricately contorted and squeezed in contrast to the relatively undisturbed condition of the underlying and overlying sandstones. The nonlaminated cherts are also abundant and commonly several feet thick. The general aspect of these rocks does not differ greatly from that of the Franciscan cherts in other parts of the Coast Ranges. Insomuch as this report has to do mainly with the geology on the west side of the San Andreas fault and as the different units of the Franciscan group are not separated on the accompanying map no further discussion will be attempted here.

* Department of Geology, University of Washington, Seattle, Washington. Manuscript submitted for publication May 13, 1941.

Gualala Series

The Gualala series was named by White (White, C. A., 85a, pp. 7. 8) from the town of Gualala situated at the mouth of Gualala River on the coast of Mendocino County. The geology of the area was not examined personally by White and his report is based on a study of field notes and collections of fossils made by G. F. Becker.

The Gualala series consists of alternating members or lithologic units composed of massive and stratified grayish-brown medium- and coarse-grained sandstone often gritty and pebbly, massive and stratified gray and brown clayey and sandy shales, units of interstratified layers of shale and sandstone, and members made up of layers or lenses of fine and coarse conglomerate.

The conglomerates are thickest and best developed near the base of the series at Black Point and at a similar stratigraphic level immediately south of Fort Ross. Massive and stratified sandstones containing lenses of conglomerate are conspicuous in the middle of the section exposed in the vicinity of Horsheshoe Point. Similar pebbly and conglomeratic sandstones characterize the upper half where exposed north of the mouth of Gualala River. The Gualala series as a whole may be considered as made up of 70 percent sandstone and conglomerate and the remainder of stratified and massive sandy shales and shaly sandstones.

The sandstones are composed prevailingly of cleanly washed light brownish-gray angular and rounded grains of white and milky quartz averaging 1 to 3 millimeters in diameter. Imbedded with these are small fragments of muscovite and rounded pieces of quartzite, schist, slate, and chert. Locally this material is stained a ferruginous brownish yellow. Here and there beds and lenses of coarse sandstone or pebbly sandstone are intercalated in the main mass. The pebbles vary in size from a small marble to 3 or 4 inches in diameter and are composed of quartzite, jasper, slate, and schist. The very thick, massive sandstones such as are exposed at Horseshoe Point usually show only obscure traces of stratification, and weather in rugged masses that have a somewhat cavernous appearance. Excellent examples of this may be seen on the headland at Havens Neck north of the mouth of Gualala River. Both above and beneath the thick sandstone members are thick sections composed of alternating strata of fine- and medium-grained sandstone and clay-shale or sandy shale, the individual layers ranging from 1 inch to over several feet thick. The sandstone layers show the same lithologic variations as have been described already for the thick members.

Pure non-sandy shales play a very subordinate part in the composition of the Gualala series, yet there are several hundred feet of thick-bedded grayish-brown sandy shales exposed in the sea cliffs north of the town of Gualala and north and south of Anchor Bay. Units consisting of alternating layers of varying thicknesses of dark-brown clay-shale, sandy shale, and sandstone lie between thick sandstones. The detailed lithology of each thick member varies from one locality to an adjacent one, as may be seen in a comparison of the measured sections in the east and west flanks of the Horseshoe Point syncline with the section in the Black Point anticline. The principal differences are in the relative proportions of sandy material and in the thickness of the alternating layers.

The sea cliffs between Iversen Landing and Fort Ross afford almost continuous exposures of strata of the Gualala series. Additional data are available in some localities between the coast and the San Andreas fault, but the greater part of that area is concealed beneath a dense covering of forest growth.

Stratigraphic and structural data in this area show the Gualala beds folded into two major synclines and anticlines whose axes have a prevailing trend of about N. 60° W. and are diagonal to the course of the San Andreas fault zone. From Fort Ross northwestward these folds are named the Horseshoe Point syncline, the Black Point anticline, the Gualala syncline and the Ferguson anticline. Numerous minor folds and faults occur in the flanks of these structures. Originally the Gualala series must have extended east of the San Andreas fault zone but perhaps not into the area included in this investigation. The rocks in the block west of the fault may have moved a long distance northwestward to their present position as the result of numerous lateral dislocations.

Stratigraphic sections measured in detail along the sea cliffs in the limbs of these major folds indicate a thickness of approximately 21,600 feet for the entire Gualala series. The lowermost exposed beds, which probably represent the base of the series, are composed mainly of conglomerate occurring in the sea cliffs for a distance of 1¼ miles south of Fort Ross and also in the Black Point anticline at Black Point. Eleven stratigraphic units, each with a distinctive lithology, have been measured from the base of the series to the top. The lower half of the section is repeated three times in the flanks of these folds.

Fossils are known at only a few localities in the middle part of the Gualala series where they occur mostly in sandy shales or sandy lenses in conglomerates. They are poorly preserved and the number of species and individuals is relatively small. Great thicknesses of strata yield not even a fragmentary trace of former animal life although some of the sandy shales contain minute fragments of carbonaceous material.

Skooner Gulch Basalt

The Skooner Gulch basalt is exposed in the sea cliffs, highway cuts, and in outcrops on the hill slopes within an area approximately 100 feet wide by 3 miles long, and extends from near Iversen Point northward to and beyond the mouth of Skooner Gulch. The northeastern end of this area narrows and passes beneath a covering of Pleistocene terrace deposits. The southern end extends out onto the floor of the ocean for an unknown distance.

The rock is prevailingly a massive dense fine-grained basalt which breaks with conchoidal fracture. Megascopically, phenocrysts are not usually visible. Specimens studied in thin-section that are representative of the entire cross-section from base to top are almost entirely lacking in phenocrysts but consist of a fine-grained groundmass composed of extremely minute microlites of labradorite embedded in glass clouded with grains of olivine and occasional specks of magnetite. Some of the larger fragmentary crystals of olivine might be considered as small phenocrysts. These minerals are mostly altered to serpentine and iron oxide. Patches of alteration products of opal and calcite are irregularly scattered through the mass. In some slides flow structure is well developed and the plagioclase microlites are fairly large and relatively unaltered and have a composition of about Ab^{45}-An^{55}.

Miocene

Sedimentary deposits of Miocene age are exposed over an area of approximately 11 square miles situated between the Point Arena lighthouse and the mouth of Skooner Gulch. These strata occur in the sea cliffs and in much of the territory for a mile or more inland where they have been upturned and beveled by erosion and are covered with nearly horizontal deposits of Pleistocene sands, gravels, and clays averaging 30 feet in thickness. Almost continuous outcrops of strata are present in the sea cliffs from the mouth of Skooner Gulch northward to the Point Arena lighthouse and the mouth of Garcia River, and detailed sections measured here in the flanks of several small anticlines and synclines show a thickness of about 5,380 feet of Miocene beds.

The lower 2,075 feet of the section (Gallaway beds) is composed largely of grayish-brown moderately indurated medium-grained sandstone in layers 50 feet or more in thickness, foraminiferal sandy shales which show some stratification, and units several hundred feet thick consisting of interstratified layers of grayish-brown shale and fine- to medium-grained sandstone. These beds are strongly folded but do not contain the thick layers of light-colored diatomaceous shale and thinly stratified alternating layers of white siliceous shales which are greatly contorted and very abundant in the upper 3,350 feet of the series.

The upper part of the Miocene (the Point Arena beds) of this area is best exposed from the Point Arena lighthouse southward to Abalone Cove. The basal 900 feet of the Point Arena beds is characterized by interstratified thinly bedded siliceous shales and clay shales together with subordinate amounts of sandy shale and sandstone. Immediately above are gray-brown foraminiferal shales and tuffaceous shales which in turn are followed by nearly 1,000 feet of predominantly sandy beds some of which west of the town of Point Arena are saturated with oil residues. The remainder of the section above grades into a prevailingly massive and stratified sandy shale which near the top contains thick layers of thickly laminated siliceous light-colored shale together with subordinate amounts of sandy shales, shaly sandstones, and gritty sandstones.

The cherty siliceous shales are well exposed in the cliff sections south of the Point Arena lighthouse where they consist of evenly banded layers of white, gray, and creamy colored chert, ranging in thickness from less than 1 inch to 4 inches; and alternating partings of soft brown shale only a fraction of an inch thick. These units of intricately contorted layers are interbedded with relatively soft white to creamy chalky shales which are both thick bedded and distinctly stratified. The chalky phase contains some volcanic ash and considerable quantities of the remains of diatoms.

No fossils other than Foraminifera have been collected from any of the Miocene strata in the area investigated. The species listed by Kleinpell (Kleinpell, R. M. 38, pp. 76-77), contain *Uvigerina gallowayi* Cushman which characterizes the lower Zemmorian zone or lower-

STRATIGRAPHIC TABLE

				Lithology	
Cenozoic	Quaternary	Pleistocene	Terrace deposits	Poorly consolidated layers and lenses of brownish-gray to buff medium- to coarse-grained sandstones, pebbly sandstones, gravels, conglomerates, clays and sandy clays resting unconformably on an approximately plane surface dissected here and there with erosional gutters	25–60
Cenozoic	Tertiary	Miocene	Point Arena beds	An assemblage of alternating units of interstratified grayish-brown clay shales, diatomaceous shales, foraminiferal shales, cherty shales strongly contorted, and units of thinly laminated sandstones and cherty shales and clay shales. At occasional intervals there occur layers of sandstone nearly 50 feet thick. Two of these are saturated with petroleum residues	3,355
Cenozoic	Tertiary	Miocene	Gallaway beds	Alternating units of dark-gray and brown argillaceous shale, mudstones and medium-grained sandstone. Interstratified with these are thick units of massive and bedded brownish-gray sandy shales and foraminiferal shales. Foraminfera suggest correlation with zone of *Uvigerina gallowayi* (lower Zemorrian)	2,075
Cenozoic	Tertiary		Skooner Gulch basalt	Dark-gray to black dense fine-grained basalt with alternating flows of vesicular and amygdaloidal rock. Intercalated within these flows are occasional lens-like masses of tuffaceous sandstone. Pillow structure. Probably submarine. Rest unconformably on the older shales and sandstones of the Gualala series	900
Mesozoic	Cretaceous		Gualala series	Alternating thick and thin members consisting of massive and stratified brownish-gray medium- to coarse-grained quartzose sandstones, often gritty and pebbly with lenses of conglomerate. Congomerates especially abundant near base and middle of series. Thick members of clay shale. Interstratified shaly sandstones and sandy shales consituting 30 per cent of the entire stratigraphic sequence. Conglomerates containing pebbles probably derived from former land areas now under the ocean but composed of quartz diorites, schists and quartzites like Sur series in Coast Ranges south of San Francisco	21,650
Mesozoic	Jurassic (?)		Franciscan group	Thick-bedded layers of massive brownish-gray, medium grained arkosic sandstone with occasional interbedded layers and lenses of radiolarian cherts and subordinate amounts of grayish-brown sandy and carbonaceous shale. Associated with these are small masses of actinolite, mica, and glaucophane schists. There occur also flows of vesicular and amygdaloidal basalt, sills of diabase and intrusive masses of gabbro and pyroxenite for the most part altered to serpentine	10,000

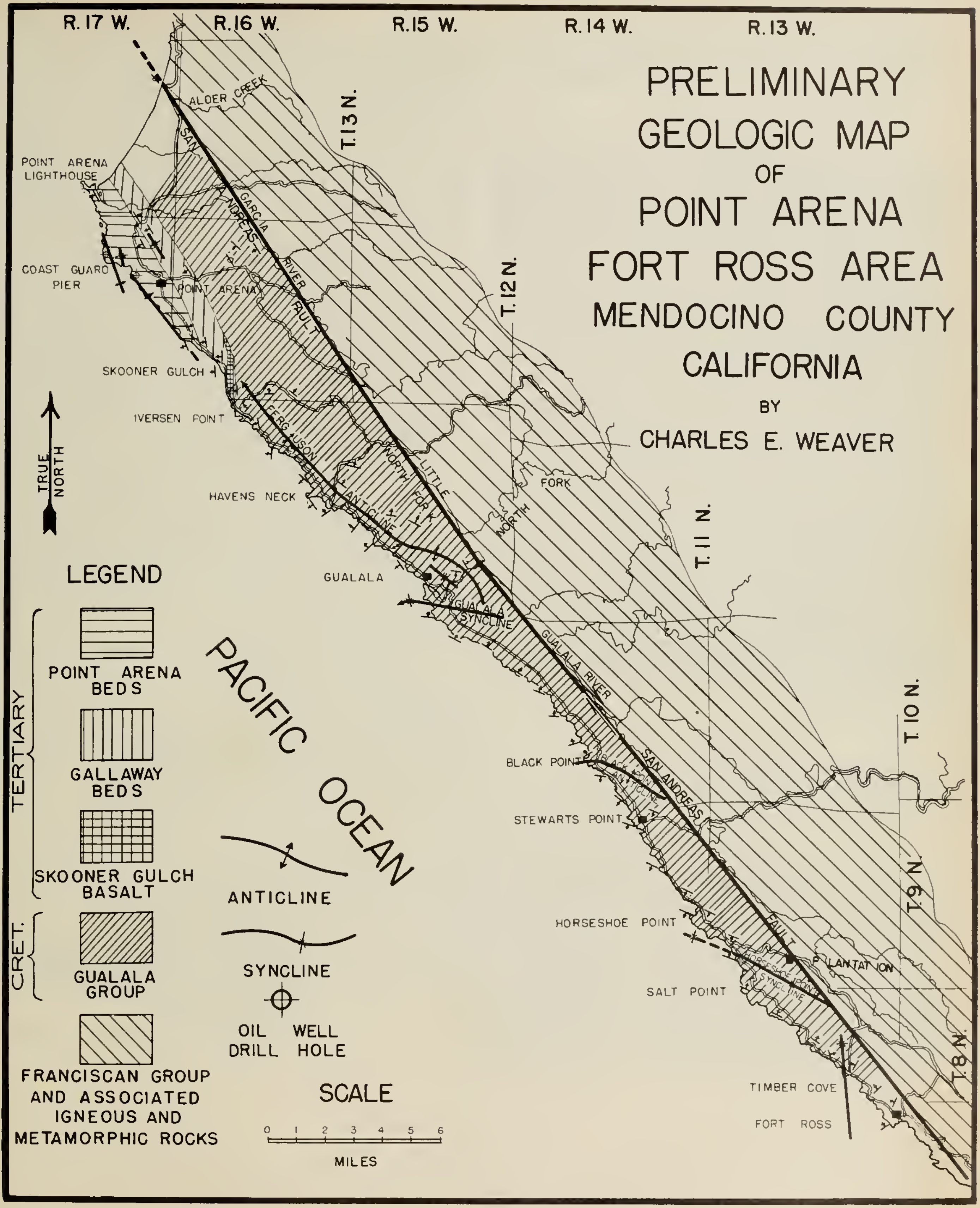

Fig. 280. Point Arena-Fort Ross region: geologic map.

most Miocene on Zemorra Creek in the Coast Ranges farther south. The entire fauna from the Point Arena area determined by Kleinpell is regarded as belonging to this zone and came from the lower 200 feet of the Gallaway beds as measured by the writer.

STRUCTURE

The four major folds in the Gualala series are designated as the Horseshoe Point syncline, the Black Point anticline, the Gualala syncline, and the Ferguson anticline. They originated in part at least before the outpouring of the Skooner Gulch lavas as indicated by the unconformable relations between the two rock units. Their axes are diagonal to the surface trend of the San Andreas fault zone.

The San Andreas fault extends in a general northwest direction across the area investigated. It separates sandstones of the Franciscan group and associated igneous rocks on the east from formations of Cretaceous and Miocene age on the west. The fault trace farther south after leaving the coast at the mouth of Tomales Bay continues northwestward beneath the floor of the ocean to the neck of land just east of Bodega Head, which it crosses, and again continues through the floor beneath the ocean. It again enters the coast in the area studied approximately 1½ miles south of Fort Ross in Sonoma County, from which point its course may be followed northwestward by a series of depressions, swamps, fault scarps, landslides, and offsets, for a distance of about 48 miles. It leaves the coast at the mouth of Alder Creek in Mendocino County 5 miles northeast of the Point Arena lighthouse and once more continues through the floor of the ocean. The fault trace immediately north of Fort Ross trends approximately N. 42° W. and in its northward course gradually curves toward the east. Near Alder Creek the prevailing trend is N. 28° W., a deviation of approximately 14 degrees.

OCCURRENCE OF OIL

No seepages or other indications of the occurrence of petroleum have been observed by the writer in any of the strata of the Gualala series. Such evidences of its occurrence are present in the Point Arena beds of Miocene age about a mile west of the town of Point Arena in Mendocino County, where layers of coarse-grained sandstone interstratified with sandy shales are exposed in the sea cliffs. Two of these layers, each under 20 feet thick, that occur west of the Coast Guard pier, have a pronounced odor of petroleum and are stained a dark brown to black. They are situated about 1,500 feet stratigraphically downward from the top of the exposed part of the Point Arena beds and lie in the east limb of a northwestward-plunging anticline. The axis of this fold passes through the high hill at the point just south of the Coast Guard station, where well No. "Soldani" 1 (Sec. 14, T. 12 N., R. 17 W., M. D.) was drilled (May 1929 to November 1931) to a reported depth of 7,632 feet, by the Twin States Oil Company. The cores from this well were studied by the micropaleontologists of the Standard Oil Company of California and by permission of Mr. S. H. Williston of the Sun Oil Company the following information is available. Foraminifera were obtained from several parts of the core down to a depth of 7,060 feet. Samples from 4,275-4,287 feet and from 4,337-4,354 feet were examined by Mr. W. F. Barbat, who considered their fauna as of definite Miocene age and representative of strata in the Coast Ranges of California which is widely known to occur directly above the Vaqueros. He regards the fauna as corresponding to the lower part of Kleinpell's "*Nodosaria* zone" which overlies the Vedder sand in the Bakersfield district and which occurs above the producing sand in the Elwood field, Santa Barbara County. Samples obtained from depths of 4,450 feet and 4,707 feet are thought to be of similar age.

A derrick was erected in the summer of 1940 in Sec. 3, T. 12 N., R. 17 W., M. D., just inside the edge of the sea cliff 1½ miles northwest of Point Arena, and five hundred feet west of the surface position of the axis of an anticlinal fold in the Point Arena beds. This well, the Point Arena Land Company No. "Kyte" 1, was being drilled on the Thomas O'Neal Ranch and had reached a reported depth of between 1,100 and 1,200 feet August 1, 1941.

CITATIONS TO SELECTED REFERENCES—Continued

POINT ARENA-FORT ROSS REGION

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HUMBOLDT COUNTY

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Bear Creek (Bear River) Area

McLaughlin and Waring 14, pp. 444-445; Vander Leck, L. 21, pp. 40-43.

Etters Area

Vander Leck, L. 21.

Mattole Region

Weber, A. H. 88.

Petrolia Region

Weber, A. H. 88.

Tompkins Hill Gas Field (Eureka Field)

Hoots, H. W. 38, p. 710.

CALIFORNIA, NORTHERN

Anderson, C. A. 40; 41; Anderson, F. M. 31a; Averill, C. V. 31; Crawford, J. J. 94; Diller, J. S. 92; 95; 02; 03; Gilbert, C. M. 41; Lindgren, W. 00; Mayo, E. B. 30; 34; Prutzman, P. W. 10; Vander Leck, L. 21; Wagner, P. 25; Wheeler, H. E. 33.

Mono Lake Wells

McLaughlin and Waring 14; Vander Leck, L. 21, pp. 154-155.

CENTRAL AND SOUTHERN HUMBOLDT COUNTY

By Harry D. MacGinitie *

OUTLINE OF REPORT

STRUCTURE AND STRATIGRAPHY

The geologic structure pattern in central and southern Humboldt County is similar to that in the middle Coast Ranges, although there is some modification due to the proximity of the Klamath old-land. The main structural trend is roughly northwest, parallel to the boundary between the Coast Ranges and the Klamath Mountains. There has been extensive thrusting toward the southwest from the older land mass. This movement has resulted in a series of parallel thrust faults and overturned structures. Some of these thrust faults involve sediments of Pleistocene age.

The stratigraphic sequence of the rock formations in central and southern Humboldt County is similar to that in the middle Coast Ranges, with this exception: in the former region no sediments of Upper Cretaceous or lower Tertiary age have yet been found. The Franciscan formation occupies the largest area in the region, and in thickness and lithology corresponds to the type section. In general, the layers of the Franciscan sediments are inclined at high angles; dips of 70 to 90 degrees are common. The structures are detailed and complex, and faulting is extensive. Field evidence indicates that the Franciscan sediments were strongly folded soon after deposition. This period of deformation was much more intense than any which succeeded it, with the possible exception of the Pleistocene orogeny.

Considerable thicknesses of dark, organic shales are associated with the Franciscan, particularly in the Briceland-Ettersburg area and just west of Bridgeville. These shales are not so strongly deformed as the Franciscan rocks. They are nearly everywhere in fault contact with the Franciscan. Although fossils are extremely rare, it is probable that the organic shales are of Lower Cretaceous age.

There is a fairly complete sequence of Miocene and Pliocene marine sediments. These show a striking similarity to sediments of the same age in the southern Coast Ranges. The correspondence of the Pliocene formations of Humboldt County and of Ventura County is remarkable for its completeness. The Tertiary outcrops are found as elongated strips following the structural trends. The strips are synclinal in nature and are usually overturned toward the south and bounded by overthrust blocks of the Mesozoic rocks on the north side. The synclines become narrower and more strongly folded inland; they widen toward the coast and the folding becomes less sharp. It is probable that the Tertiary formations form a nearly continuous belt some distance off shore.

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ROCK FORMATIONS

Pleistocene	Maximum thickness about 350 feet.	Clays and sands.
Pliocene	Wildcat formation.	
Upper Pliocene	Ferndale sandstone; thickness 2500+ feet.	Fine-grained gray sandstone with thin interbeds of clay shale.
	Upper Pico; thickness about 2100 feet.	Alternate massive beds of fine sandstone or siltstone and bluish-gray mudrock.
Middle Pliocene	Middle Pico; thickness approximately 900 feet.	Rhythmically bedded sandstone and brownish-gray siltstone.
Lower Pliocene	Lower Pico; thickness 1000+ feet.	Massive, brownish-gray siltstone with concretionary limestone layers.
Lowest Pliocene	Repetto formation; thickness 750+ feet.	Thin-bedded, gray, fine-grained sandstone with interbedded layers of gray siltstone.
Upper Miocene	Santa Margarita; minimum thickness 900 feet; maximum about 1200 feet.	Massive, dark mudrock, much fractured, weathers buff colored. Stringers of calcareous, medium-grained standstone.
Upper lower to middle Miocene	Probably equivalent to the Temblor formation; maximum thickness 1300 feet.	Punky, light-brown diatomaceous shales, with abundant Foraminifera. Massive sandstone bed at the base, yellow to rusty, medium-grained, 60 feet thick.
Lower Cretaceous	Paskenta (tentative assignment); minimum thickness 3000 feet.	Black, organic shales, thin interbeds of fine sandstone and concretionary sandy limestone, pebble conglomerate at base.
Upper Jurassic	Franciscan formation; thickness in excess of 5000 feet.	Indurated dark-gray, greenish or bluish sandstones with interbeds of slaty dark shales. Pillow basalts, soda diabase and accompanying contact metamorphics and chert. Massive conglomerate near the base.

BASINS OF DEPOSITION

The present "basins" of Tertiary rocks do not necessarily coincide with former basins of deposition. They are remnants of a formerly extensive and nearly continuous cover, and have been preserved from erosion by down-faulting and down-folding. The Pliocene beds overlap those of Miocene age toward the north. From the Briceland district north, the Miocene formations successively drop out and the northernmost outcrops are of upper Pliocene age. Judging from the nature and coarseness of the deposits, the older rocks forming the ridge south of Redwood Creek represent the northern boundary of the Tertiary marine transgression. The Tertiary formations once covered all of southern Humboldt County with the exception of a narrow strip along the eastern boundary, and extended an unknown distance to the south. Late Tertiary continental beds which outcrop near Laytonville indicate that the southeastern limit was west of that place.

OIL INDICATIONS

Oil and gas indications are found at several localities in southern Humboldt County: near Petrolia, along the lower course of Bear River, along Rainbow Ridge, and east of Briceland. Oil and gas seeps have been noted near Ettersburg, northwest of Garberville, and above Lentell's on Mad River. These occur in connection with major lines of faulting and nearly always along fault contacts of the Franciscan and Lower Cretaceous (?) rocks. Since the indications of oil are numerous and since the upper Tertiary formations reflect the same conditions of deposition as existed in the oil-bearing formations of the Ventura anticline, it has seemed logical to suppose that these sediments should be the source of considerable oil if suitable structures could be located. The great thickness—in excess of 12,000 feet—of the Tertiary beds is also a favorable factor. There is good reason to believe, however, that the source of the oil in the seeps and from the wildcat wells may be found in the black, organic shales

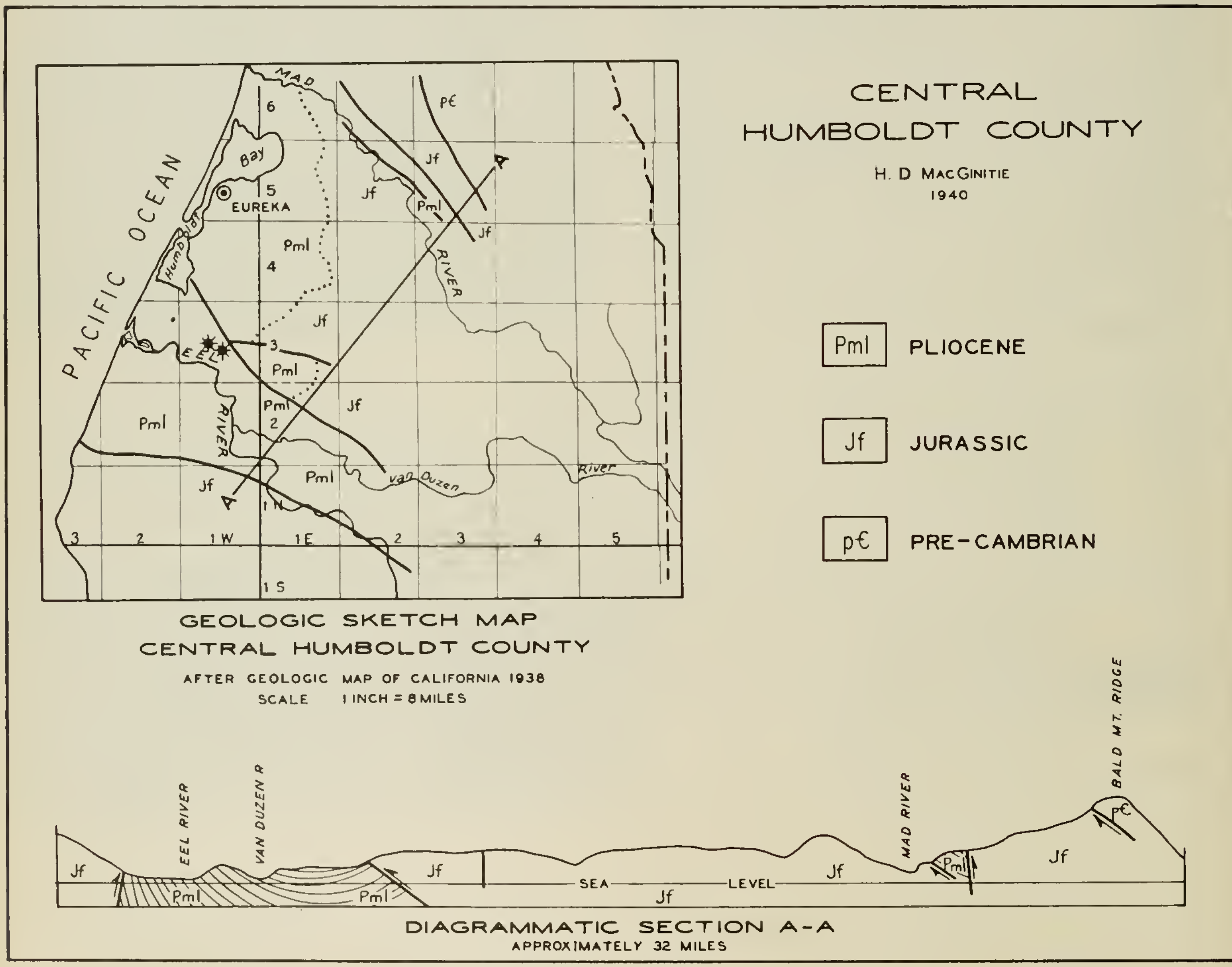


Fig. 281. Central Humboldt County: geologic sketch map; diagrammatic section.

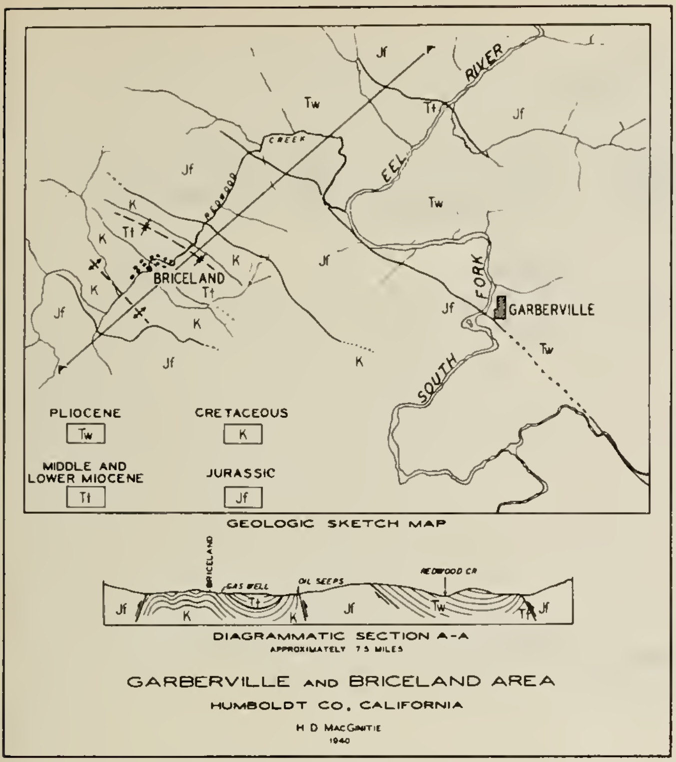


Fig. 282. Garberville-Briceland area; geologic sketch map; diagrammatic section.

of Lower Cretaceous (?) age. As noted above, the seeps occur in connection with the older sediments. The oil is of paraffin base—this is true for the seeps near Petrolia, for several of the wildcat wells in that region, and for the oil shales of Repetto (lower Pliocene) age found near the bottom of the first deep Texas Company well on Tompkins Hill near Loleta. It is probable that the oil in the Repetto is derived from the Cretaceous beds below, with which it is in contact. It is generally accepted (but not yet proved) that oil from upper Tertiary source rocks is always of asphalt base. If this be true, then all the oil indications noted so far point to the Cretaceous, rather than lower Pliocene rocks, as a source. This does not, however, exclude the Tertiary formations in this region from the possibility of future oil discoveries.

The folding and faulting have been so strong in the areas where oil indications occur that the majority of the structures are too broken to furnish satisfactory oil storage. Areas which may repay detailed investigation are three in number: (1) along the front of the Kneeland thrust fault east and southeast of Eureka; (2) the Eel River syncline on the Van Duzen River a few miles west of Bridgeville; and (3) the Briceland Tertiary-Cretaceous basin. Numbers 1 and 3 present the most favorable aspects.

EXPLORATION FOR OIL AND GAS

The most extensive oil exploration carried on by any major oil company was done by The Texas Company north of Loleta. No commercially valuable oil deposits were found, although a rather abundant supply of gas was discovered. In spite of certain evidence to the contrary, it appears that these wells were drilled on the north limb of a faulted syncline. Enough indications of oil were noted in this area to warrant further exploration to the north, along the front of the Kneeland thrust as noted above.

Exploration and wildcat drilling have been carried on in southern Humboldt County since the earliest days of the oil industry in California. The results thus far have been disappointing. This may be due in part to methods of locating and financing. It is doubtful if any well in this area has been located by trained and experienced geologists. Drilling has been handicapped by inadequate financing, and in certain instances, by inexperienced well crews. Some of the wells may have been stock-selling schemes. It was often true that once a well was started, insufficient funds were available for thorough and satisfactory exploration. All the wells visited by the author have been drilled in the Mesozoic rocks and many of them in the Franciscan formation. It is doubtful if oil-bearing structures of any size and continuity can be found in these rocks. Oil indications are so abundant, however, that additional exploration is justified. A well about 600 feet deep was drilled just northeast of the town of Briceland nearly 40 years ago. This well is in the Lower Cretaceous (?) and located on the south limb of a syncline. It has furnished gas for cooking and heating continuously since its completion. There is evidence of anticlinal structure just south of this, and, although the structure is not large, it is perhaps the most favorable area for exploration in the southern part of the county.

Chapter XIII

Tabulated Data on Wells Drilled Outside of the Principal Oil and Gas Fields

CONTENTS OF CHAPTER XIII

TABULATED DATA ON WELLS DRILLED OUTSIDE OF THE PRINCIPAL OIL AND GAS FIELDS

Assembled largely from data of the Petroleum World

Editorial note:

The locations of the wells included in this list are shown on the "Outline Geologic Map of California Showing Oil and Gas Fields and Drilled Areas." Other wells, within the limits of the shaded areas of the map, indicating official and available maps of the Division of Oil and Gas, have been omitted from this list. Some wells of questionable location, or lacking in authentic and useful data, have also been omitted. By reason of the difficulty of securing authentic data, especially regarding wells drilled at an early period in the history of the oil and gas development in California, this list is necessarily incomplete, and in many instances will be found to need further revision. Data for wells drilled in 1940 are included.

The "California Dry Hole Record," published since 1936 by the *Petroleum World* in its Annual Review, has served as a basis for this list, and appreciation is gratefully acknowledged to Mr. Russell Palmer, publisher, for granting the Division of Mines permission to use the data. Other sources of information were also consulted and used; these include reports of the State Division of Oil and Gas, the State Division of Mines, and of the U. S. Geological Survey. Much of the clerical work in making up the list was provided by the Works Progress Administration. Editing of this list has been done in part by a number of field geologists, both independent consultants and geologists in the employ of companies. To all these contributors, appreciation is acknowledged for the data they have presented and for the time they have spent to improve this assemblage of information. It must be understood, however, that the information herein presented is far from being complete or without error.

LIST OF WELLS TO ACCOMPANY "ECONOMIC MINERAL MAP No. 2—OIL AND GAS" (in pocket)

ALAMEDA COUNTY

T	*R*	*Sec.*	*B & M*	*Name of Company and Well*	*Yr. Aband. or Last Active*	*Depth Ft.*	*Geology at Bottom of Hole*
2S	1W	19	MD	Elsinore Oil Co. of Nevada well No 1	1925-1926	630	Miocene (?)
2S	2E	22	MD	Alameda Oil Co. of San Francisco		1175	
2S	2E	26	MD			1100	
2S	3E	27	MD	Standard Oil Company	Pre-1914	1090	Cretaceous
2S	3E	28	MD	Standard Oil Company	1914	2878	Cretaceous
2S	4E	19	MD	Burney Syn. well No. 1	1934	1200	Monterey
3S	1W	29	MD	Hayward Oil Co., Ltd., well No. 1	1932	708	Cretaceous
3S	3E	6	MD	Atlantic & Western Oil Co. well No. 1			
3S	3E	6	MD	Atlantic & Western Oil Co. well No. 2	Pre-1925	200(?)	Cretaceous
3S	3E	9	MD	Conniff, James E., Calhoma Oil Corp. well No. 1	1929	1523	Monterey
3S	3E	13	MD	Seaboard Oil Corp. of Delaware well No. "Johnson" 1	1936	5952	Cretaceous
3S	3E	15	MD	Well No. Doane (?)	Pre-1915		
3S	3E	15	MD	Independence Oil Co.	Pre-1915	1700	Cretaceous
3S	3E	15	MD	Alisal Oil Co.	Pre-1915	979	Cretaceous
3S	3E	15	MD	W M & S Co.	Pre-1915	600	Cretaceous
3S	3E	15	MD	Atlantic & Western Oil Co.	1933	3151	Cretaceous
3S	3E	15	MD	Gilstrap, A. M., well No. 1	1933	1335	
3S	3E	15	MD	Fifteen Three Oil Co.		600	
3S	3E	15	MD	Fifteen Three Oil Co.		1400	
3S	3E	16	MD	Thomas & Hammill well No. 1	1928	1025	Cretaceous (?)

COLUSA COUNTY

T	*R*	*Sec.*	*B & M*	*Name of Company and Well*	*Yr. Aband. or Last Active*	*Depth Ft.*	*Geology at Bottom of Hole*
18N	4W	31	MD	Continental Oil Co. well No. 1	1925	1876	Cretaceous
18N	4W	31	MD	Continental Oil Co. well No. "Patterson" 1-A	1929	4277	Cretaceous
18N	4W	31	MD	Mutual Oil Co.	1925	2090	Cretaceous
17N	3W	3	MD	Sacramento Valley Irrigation Co.	1937	832	
17N	3W	8	MD	Jackson, Wm. P., well No. 1	1934	855	Cretaceous
17N	2W	31	MD	Maxwell Oil Co. well No. 1	1931	1780	Cretaceous
16N	5W	36	MD	Empire Oil & Gas Corp. well No. "Dunlap" 1	1939		Lower Cretaceous (?)
16N	2W	28	MD	Smith & Vickers well No. 1	1933	960	
16N	1W	34	MD	Amerada Petroleum Corp. well California Lands Colusa 1	1938	8152	Rhyolite
15N	4W	4	MD	Colusa County Oil Co. well No. Harlan 1		1100	Cretaceous
15N	4W	7	MD	Williams Oil Co. well Thompson No. 1	1908	800	Cretaceous
15N	4W	7	MD	Mountain House Oil Co. well No. 1	1922	711	Cretaceous
15N	4W	15	MD	Empire Oil & Gas Corp. well No. "Seaver" 1	1939	105	
15N	4W	16	MD	Williams Oil Co. well No. "Brim" 1	1902	2540	Cretaceous
15N	4W	17	MD	Williams Oil Co. well No. "Vangilt" 3	1907	1810	Cretaceous
15N	4W	18	MD	Mountain House Oil Co. well No. 5	1931	1322+	Cretaceous
15N	4W	18	MD	E & G Products Co. well No. "Evans" 1	1929	148	Cretaceous (?)
15N	4W	18	MD	Smith & Vickers well No. 1	1931	1028	Cretaceous (?)
15N	4W	19	MD	Evans Carter well No. 1	1929	306	Cretaceous (?)
15N	4W	20	MD	Williams Oil Co. well Freshwater Creek	1865	800	Cretaceous
15N	4W	25	MD	Birch Ranch Oil Co. & Irwin S. Burgess well No. "Stovall-Wilcoxson" 1	1936	800	Cretaceous (?)
15N	4W	25	MD	Birch Ranch Oil Co. & Irwin S. Burgess well No. "Stovall-Wilcoxson" 2	1939		
15N	4W	31	MD	Jacobs, W. T., well No. 4	1933	160+	Cretaceous
15N	4W	31	MD	Jacobs, W. T., well No. 3	1929	828	Cretaceous
15N	4W	31	MD	Brown & Foster well No. 1	1929	930	Cretaceous
15N	4W	31	MD	Jacobs, W. T., well No. 1	1925	925	Cretaceous
15N	4W	31	MD	Williams Oil Co. well No. 5	1861	360	Cretaceous
15N	4W	31	MD	Colusa Oil Co. well No. "Bush" 4		1040	Cretaceous
15N	4W	31	MD	Jacobs, W. T., well No. 2	1929	721	Cretaceous
15N	4W	32	MD	Smith & Vickers well No. 1	1937	1040	Cretaceous
14N	5W	1	MD	American Chemical Co. well No. "King" 1		925	Cretaceous
14N	5W	2	MD	E & G Products Co. well No. 1	1930	1073	Cretaceous
14N	5W	21	MD	Young Oil Co. well No. 1	1923	100+	Lower Cretaceous (?)
14N	5W	21	MD	D & M Oil Co. well No. 1	1937	516	Lower Cretaceous (?)
14N	5W	23	MD	Grover Herring well No. 1	1931	1000	Lower Cretaceous (?)
14N	5W	27	MD	Amalgamated Oil Co. of Nevada well No. 1	1929	2848	Lower Cretaceous (?)
14N	5W	27	MD	Empire Oil & Gas Corp. well Grandfather Fuiger	1939	150	Lower Cretaceous (?)
14N	5W	27	MD	Meeker, Leslie F., well Grandfather	drilled 1844	105	Knoxville (?)
14N	5W	35	MD	Herron Oil Co.	1901	1000+	Serpentine
14N	3W	6	MD	Birch Ranch Oil Co. & Irwin S. Burgess well No. "Johnston" 1	1936	540	Cretaceous (?)
14N	1W	17	MD	Prize Oil & Gas Co. well No. 1	1932	870	Upper Cretaceous (?)
13N	3W	7	MD	Gorrell & Smith	1900	543	Cretaceous
13N	3W	7	MD	Youle Oil Co.	Pre-1901	1200+	Cretaceous
13N	3W	20	MD	Allied Petroleum Corp. well No. "Blevins" 1	1932	2043	Cretaceous
13N	3W	34	MD	Blue Ridge Petroleum Co. well No. 1	1922	2946	Cretaceous

CONTRA COSTA COUNTY

T	*R*	*Sec.*	*B & M*	*Name of Company and Well*	*Yr. Aband. or Last Active*	*Depth Ft.*	*Geology at Bottom of Hole*
2N	4W	29	MD	Point Richmond Oil Co. (2 wells)		100	
2N	4W	29	MD	Sobrante Oil & Inv. Co.	1909		
2N	2W	31	MD	Edwards, Wm., well No. 1	Pre-1925	2224	Monterey
1N	4W	8	MD	Mount Diablo Oil Co. (several wells)		170	
1N	4W	5 or 6	MD	San Pablo Oil Co.	1900	670	
1N	3W	26	MD	Leachman and Marshall well No. 1	1926	450	Monterey
1N	3W	27	MD	8 wells	Pre-1936	2750 to 750	Monterey shale
1N	3W	27	MD	Tidewater Oil Dev. Co.	1904	300	
1N	3W	32	MD	Grand Pacific Oil Co. (1 or more wells)			
1N	3W	32	MD	Orinda Petroleum Co., Ltd.			
1N	3W	33	MD	Central Calif. Oil Co. well No. "Old Flood" 1	Pre-1925	1640	Monterey
1N	2W	28	MD	National Paraffin Co.		1694	
1N	1E	15	MD	Harding well	Pre-1936	978	
1N	1E	15	MD	Atlas Dev. Co. well No. 1	Pre-1921	1823	
2S	1W	25	MD	Brady Sure Shot Oil Co. well No. 1	1925-1926	300	Miocene

FRESNO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Abond. or Last Active	Depth Ft.	Geology at Bottom of Hole
11S	21E	31	MD	San Joaquin Valley Oil & Dev. Assn. well No. 1	Pre-1925	2500	Miocene (?)
12S	11E	12	MD	Bergman Oil Co. well No. "Ora Loma Farms" 1	1935	6008	Cretaceous (?)
12S	11E	12	MD	Milham Expl. Co. well No. "Ora Loma" 1	1935	5802	Cretaceous
12S	11E	28	MD	Hewitt Oil Co. well No. 1	1935	5065	Cretaceous
12S	21E	18	MD	Fresno Madera Oil Co. (Harris, C. C., Trustee) well No. 1	1934	4382	Schist
13S	11E	21	MD	Los Banos Oil Co. well No. 1	1924	3432	Cretaceous
13S	11E	22	MD	Helen D. Oil Co. well No. 1	Pre-1925	200	Pleistocene
13S	13E	35	MD	Emerich Oil Corp., Ltd. well No. "Mason" 1	1935	4557	Kreyenhagen
13S	16E	35	MD	Associated Oil Co. well No. 1	1926	5737	Cretaceous
13S	16E	35	MD	Rio Grande Oil Co. well No. "Edison" 1	1930	4980	Eocene
13S	16E	36	MD	Associated Oil Co. well No. 1	1927	5078	Eocene
13S	17E	14	MD	Rio Grande Oil Co. well No. "Mosesian" 1	1930	4971	Eocene
13S	22E	5	MD	Taylor Oil Co. well No. 1	1927	2120	Basement
14S	12E	32	MD	Merced Oil Co. well No. 1	1927	2140	Cretaceous
14S	18E	32	MD	Justice & Ellerby well No. 1	1933	3637	Miocene
14S	20E	23	MD	Fresno Assoc. O. & G. Co. well No. 1	1928	575	Pleistocene
15S	12E	21	MD	Kern, John, well		3000	
15S	12E	26	MD	Western Gulf Oil Co. well No. "Lillis-Welch" 1	1930	5624	Eocene
15S	12E	32	MD	Ohio well	Pre-1936	1600	
15S	17E	20	MD	San Joaquin Valley Farm Lands Co. well No. 1	Pre-1925	4574	Miocene
15S	18E	14	MD	Associated Oil Co. well No. 1	1925	6884	Eocene
15S	18E	20	MD	Fresno United Oil Co. well No. 1	1923	3000	Miocene
15S	18E	20	MD	Graham-Loftus Oil Corp. well No. 1	1934	5783	Eocene
15S	18E	23	MD	Fresno United Oil Co. well No. 2	Pre-1925	5352	Miocene
15S	18E	23	MD	Fresno United Oil Co.; Fresno Long B. Oil Co. well No. 3	1929	3960	Miocene
15S	18E	26	MD	Fresno Pet. Co. well No. 1	1925	6042	Miocene
15S	20E	17	MD	Cornell & Givan well No. "Fresno" 1	Pre-1925	2651	
16S	12E	22	MD	Ohio well No. 1	Pre-1936	1500	
16S	12E	25	MD	Standard Oil Co. well No. "Bates" 1	Pre-1925	3869	Cretaceous
16S	13E	9	MD	Union Oil Co. well No. "Lillis" 1	1921	1531	
16S	13E	9	MD	Union Oil Co. well No. "Lillis Welch" 2	1925	2528	
16S	13E	10	MD	Seaboard Oil Corp. of Del. well No. "Welch" 1	1936	4445	Cretaceous
16S	13E	20	MD	Superior Oil Co. well No. "Ciervo Unit Plan" 1	1938	6001	Cretaceous
16S	14E	18	MD	Harmon, A. K. P., well No. 1	Pre-1925	500	Pleistocene
16S	14E	30	MD	Seaboard Oil Corp. of Del. well No. "Lillis" 1	1936	3243	Cretaceous
16S	15E	30	MD	Mohawk Pet. Co. well No. "Langdon" 1	1936	6935	Eocene
16S	15E	32	MD	Western Gulf Oil Co. well No. "Skelly Est." 1	1937	6578	Eocene
16S	19E	15	MD	Associated Oil Co. well No. "Carruthers" 1	1925	5303	Santa Margarita
17S	14E	16	MD	Superior Oil Co. well No. "Lillis-Welch" 1	1927	2203	Eocene
17S	15E	3	MD	Western Gulf Oil Co. well No. "S. P. Land" 3	1937	8542	Eocene
17S	15E	11	MD	Western Gulf Oil Co. well No. "S. P. Land" 2	1934	7379	Eocene
17S	15E	15	MD	Western Gulf Oil Co. well No. "S. P. Land" 1	1934	8868	Eocene
18S	15E	27	MD	Standard Oil Co. well No. "Domengine" 1	Pre-1925	4200	Eocene (?)
18S	15E	34	MD	Tavern Oil Co. well No. 1		2265	Eocene
19S	18E	15	MD	Shell Oil Co. well No. "Boston Land Co." G	1929	1009	Tulare
19S	18E	26	MD	Shell Oil Co. well No. "Boston Land Co." B	1929	3701	Tulare (?)
20S	13E	20	MD	Bald Mountain Dr. Co. well No. 1	1926		
20S	16E	34	MD	Mohawk Oil Co. well No. 1	1926	4027	
20S	18E	6	MD	Shell Oil Co. well No. "Boston Land Co." E	1929	3607	Tulare (?)
20S	18E	11	MD	Shell Oil Co. well No. "Boston Land Co." F	1929	1856	Tulare
20S	18E	13	MD	Seaboard Oil Corp. of Del. (Milham-Seaboard?) well No. "Boston Land" 1	1936	3501	Etchegoin (?)
21S	13E	8	MD	Worthen Canyon Oil Co. well	1935	921	
21S	14E	28	MD	Currency Pet., Inc. well No. 1	1930	3610	Cretaceous (?)
22S	16E	6	MD	Superior Oil Co. well No. "Mantes" 1	1934	7838	Domengine
22S	16E	7	MD	Miley, E. J., well No. 1	Pre-1925	5264	Kreyenhagen
22S	16E	4	MD	Continental Oil Co. well No. "Kreyenhagen" 1	1940	11,020	Cretaceous
22S	16E	33	MD	Richfield Oil Co. well No. "Schrock" 1	1930	3434	Cretaceous
22S	16E	33	MD	Taft Well Drilling Co. well No. 1	1935	5005	Eocene (?)
22S	16E	33	MD	Oceanside Oil Co. well No. 1	1931	660	Temblor
22S	16E	33	MD	MCA Drilling Co. well No. "Kreyenhagen" 1	1939	2003	Temblor

GLENN COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
22N	5W	4	MD	E. F. Stella, Trustee, well No. 1	1937	4697	Lower Cretaceous (?)
22N	5W	10	MD	E. F. Stella, Trustee, well No. "Murdock-Simpson" 1	1936	1145	Lower Cretaceous (?)
20N	5W	23	MD	Williams Oil Co. well	1902	2900	Cretaceous
20N	2W	18	MD	Ohio Oil Co. well No. "E. E. Willard" 1	1938	4505	Cretaceous
20N	2W	18	MD	Ohio Oil Co. well No. "E. E. Willard" 2	1938	2253	Cretaceous
20N	2W	18	MD	Ohio Oil Co. well No. "E. E. Willard" 1A	1938	6014	Cretaceous Gas blowout

HUMBOLDT COUNTY

T	*R*	*Sec.*	*B & M*	*Name of Company and Well*	*Yr. Aband. or Last Active*	*Depth Ft.*	*Geology at Bottom of Hole*
4N	1W	17	H	Eich, Walter W., well No. 1	1936	779	Pliocene (?)
4N	1W	17	H	Dinwiddie, Willard W., Well No. "Buhne" 1	1936	1600	Pliocene
4N	1W	21	H	Eich, Walter W., well No. 3	1938	580	
4N	1W	21	H	Eureka Oil Co. well No. 1	1936	3200+	Pliocene (?)
3N	2W	1	H	The Texas Co. well No. "Eureka" 1	1935	6133	Franciscan
3N	1W	21	H	The Texas Co. well No. "Eureka" 3	1939	5067	Pliocene (gas)
3N	1W	22	H	The Texas Co. well No. "Eureka" 2	1939	7708	Pliocene (gas)
1N	3W	12	H	Bear River well	Pre-1914		
1N	3W	13	H	Briceland well		780	Gas piped
1N	3W	14	H	McWherter well	Pre-1921		
1N	3W	24	H	Well No. 4			
1N	2W	6	H	Well No. 3			
1N	2W	16	H	Bear River wells (3)	Pre-1914		
1N	2W	19	H	Fortuna well	Pre-1914	200	
1N	2W	20	H	Well No. 5			
1N	2W	21	H	Fortuna well		200	
1N	1W	18	H	Fortuna well	Pre-1914	600	
1S	3W	12	H	Anthony, H. M., Wilson, Edna A., and Werle, W. C., well No. 1	1939	485	Mesozoic
1S	3W	13	H	Far West Co. well Davis Creek	Pre-1921	800	
1S	2W	14	H	Reed well		400	Mesozoic Oil produced
1S	2W	15	H	Joel Flat (Henderson) well	Pre-1921	500	Mesozoic Oil
1S	2W	15	H	Wild Goose well	Pre-1914	1033	Mesozoic
1S	2W	15	H	Wild Goose well	Pre-1914	700	Mesozoic
1S	2W	21	H	Cape Mendocino Oil Co., Ltd. well No. 1		1132	Mesozoic
1S	2W	21	H	Cape Mendocino Oil Co., Ltd. well No. 2	1939	2720	Mesozoic
1S	2W	24	H	Brown & Knowles (2 wells)		(1) 300 (2) 220	Mesozoic Mesozoic
1S	2W	25	H	Brown & Knowles	Pre-1914	300	Mesozoic
1S	2W	26	H	Knowlton well			Mesozoic
1S	2W	28	H	Bushnell Oil Corp. well No. "Daisy Cook" 1	1937+	600±	Mesozoic
1S	2W	29	H	McIntosh well	Pre-1914	1700	Oil Mesozoic
1S	2W	30	H	McNutt Gulch well	Pre-1921	300	Mesozoic
1S	2W	30	H	Matthews, Ernest C., well No. 1	1939	428	Mesozoic
1S	2W	33	H	Davis well		1400	Mesozoic
1S	1W	30	H	Craig wells (2)		(1) 700 (2) 800	Mesozoic Mesozoic
1S	1W	30	H	Paragon well	Pre-1914		Mesozoic
1S	1W	30	H	Union or Mattole Petroleum (8 wells)	Pre-1914	(1) 30 (2) 35 (3) 60 (4) 64 (5) 90 (6) 95 (7) 1000 (8) 1003	Mesozoic Mesozoic Mesozoic Mesozoic Mesozoic Mesozoic Mesozoic Oil (?) Mesozoic
2S	2W	4	H	Jeffery well	Pre-1914	900	Mesozoic
2S	2W	9	H	Bushnell Oil Co. well No. "Clark" 1	1938	592	Mesozoic
2S	1W	5	H	Far West Co. well Burrows	Pre-1921	800	Oil (?) Mesozoic
2S	1W	6	H	Humboldt well	Pre-1914	2000	Mesozoic
2S	1W	6	H	Humboldt Oil Co. well No. 2	1937	3306	Mesozoic
2S	1W	28	H	Fonner wells (2)		(1) 250 (2) 300	Mesozoic Mesozoic
2S	1W	33	H	Burrows well		800	Mesozoic
2S	1W	33	H	Fonner well		300	Mesozoic
2S	1W	36	H	North Counties Oil Co. well No. 1	1936	2315	Mesozoic
2S	1W	36	H	North Counties Oil Co. well No. 2	1936		
2S	1W	36	H	North Counties Oil Co. well No. 3	1941	2435	Mesozoic
3S	1W	1	H	Hoaglin well	Pre-1921	1800	
3S	1W	1	H	Schaufele & Reynolds Well No. 1	1935	90	Pleistocene
3S	1W	2	H	Hoagland well		2100	
3S	1E	6	H	Revert Mining Co. well No. 1	1930	1718	Mesozoic
4S	3E	18	H			780	Gas producer
4S	3E	20	H	Humboldt Oil Co. well			
4S	3E	34	H	Redwood Oil Co. well No. 1A	1939	1657	
4S	4E	33	H	Briceland Oil & Land Co. well	Pre-1921	2100	

IMPERIAL COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
11S	9E	25	SB	Nelson, Jesse M., Diamond Bar well No. 1	1926	3085	
11S	10E	32	SB	Imperial Valley Oil & Development Co., Brawley well		2570	
11S	13E	12	SB	*Pacific Imperial Dri-Ice (Einhart, Carl M., Trustee) well No. 7		623	Shale
11S	13E	12	SB	*Well No. 6		500	
11S	13E	13	SB	*Well No. 3		511	
11S	13E	13	SB	*Pacific Imperial Dri-Ice well No. 10	1937	673	Pleistocene (?)
11S	13E	14	SB	*Well No. 4		440	
11S	13E	14	SB	*Einhart, Carl M., Trustee, well No. 9	1936	660	
11S	13E	25	SB	*Well No. 5	Pre-1936	954	Hard rock
11S	13E	28	SB	*Well No. 1	Pre-1936	1054	
12S	10E	27	SB	Yuha Oil Co., Mesquite well		850	
12S	10E	34	SB	Harper (Mesquite drill hole) well No. 1	Pre-1921	850	
13S	9E	17	SB	Hanna well		800	
14S	16E	11	SB	104 Oil & Drilling Co. well No. 1		1000	
14S	16E	11	SB	104 Oil & Drilling Co. well No. 2			
14S	16E	11	SB	104 Oil & Drilling Co. well No. 3			
15S	9E	11	SB	Barrett drill hole	Pre-1914	1100	
16S	10E	9	SB	San Diego & Imperial Valley Oil Co., James Well	1936	1100	
16S	11E	6	SB	Southwestern Pipe Line & Petroleum Co. well No. 1	Pre-1936	700	
16S	11E	32	SB	Yuha Oil Co., Yuha well	Pre-1913	1363	Miocene (?)

* Carbon-dioxide wells of Niland area.

KERN COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
25S	17E	32	MD	Kibele, J. A. well No. 1	1937	1670	Shale
25S	19E	12	MD	Standard Oil Co. well No. "San Francisco and Fresno Land Co."	1926	5541	Pliocene
25S	19E	13	MD	Shell Oil Co. well No. "McGuire" 1	1933	384	Tulare
25S	19E	13	MD	Shell Oil Co. well No. "McGuire" 2	1933	516	Tulare
25S	20E	7	MD	Continental Oil Co. well No. "Gatchell" 28-7	1935	7849	Miocene
25S	21E	28	MD	Marland Oil Co. well No. "Ferguson" 1	1924	5016	Pliocene
25S	25E	35	MD	General Pet. Corp. of Calif. well No. "Stiles" 1	1928	5769	Miocene
25S	26E	5	MD	North Amer. Oil Cons. well No. "Wallace" 1	1928	3672	Santa Margarita
25S	26E	5	MD	North Amer. Oil Cons. well No. "Wallace" 1-A	1928	5700	Walker
25S	27E	14	MD	Alford, John W., well No. "Quinn" 1	1936	2404	Granite
25S	27E	14	MD	Cimarron Oil Corp. well No. "Quinn" 1	1934	2399	Walker
25S	27E	15	MD	Doyle Pet. Co. well No. "Quinn" 1	1939	2956	Basement
25S	27E	15	MD	Doyle Pet. Corp. well No. "Quinn" 2	1937	2922	Granite
25S	27E	20	MD	C. C. M. O. Co. well No. 1	1926	3875	Granite
25S	27E	20	MD	Hall-Baker well No. "Quinn" 1		2647	Olcese sand
25S	27E	23	MD	C. C. M. O. Co. well No. "Jasmine" 1	1927	2301	Granite
25S	27E	23	MD	Helen Pet. Corp., Ltd. well No. 1		2665	Walker
25S	27E	25	MD	North Amer. Oil Cons. well No. "Quinn" 1	1934	2064	Walker (?)
25S	27E	31	MD	Cochran Oil Co., Inc. well No. "Bishop" 1	1936	4861	Granite
25S	27E	33	MD	Johnson, E. C., well No. "Jasmine" 1	1928	3005	Vedder
25S	28E	31	MD	C. C. M. O. Co. well No. "Villard" A-1	1931	2554	Granite
25S	28E	34	MD	Pottenger, Dr. F. M., well No. "Orcier" 1	1938	1288	Basement
25S	28E	35	MD	Pottenger, Dr. F. M., well No. "Girard" 1	1938	632	Basement
26S	18E	17	MD	Cumberland Oil Co. well No. "Cumberland" 2	1938	4758	Cretaceous
26S	18E	28	MD	Gerrard Oil Co. well No. "Watkins" 1	1930	903	Shale
26S	18E	35	MD	Ash Oil Syn. well No. 1	Pre-1925	1075	Maricopa (?)
26S	18E	35	MD	Pearson & Phillips well No. 1	Pre-1925	600	Maricopa
26S	18E	35	MD	Shale Hills Dev. Co. well No. 1	Pre-1925	1350	Maricopa
26S	19E	22	MD	Amerada Pet. Corp. well No. 5	1938	8296	Oligocene shale
26S	19E	35	MD	Standard Oil Co. well No. "Cahn" 1	1925	2709	Etchegoin
26S	19E	36	MD	Standard Oil Co. well No. "Lazard" 1	1925	2405	Etchegoin
26S	22E	21	MD	Richfield Oil Co. well No. "Kerwin" 1	1929	5210	Etchegoin
26S	25E	17	MD	Tide Water Assoc. well No. "K. C. L." 1	1938	9190	Miocene
26S	25E	25	MD	General Pet. Corp. well No. "K. C. L." 25-1	1929	6219	Temblor
26S	25E	35	MD	Shell Oil Co. well No. "K. C. L.-A." 83-35	1938	10,061	Basement
26S	26E	9	MD	White, C. C., well No. "Armstrong" 1	1938	2380	Etchegoin
26S	26E	11	MD	McFarland Oil Syn. well No. 1	Pre-1925	3530	Etchegoin
26S	26E	16	MD	Webb, John H., well No. "Alta" 1	1936	4551	Temblor
26S	26E	34	MD	Perry, Constance V. D., well "De Villiers" 1	1934	3394	Temblor
26S	27E	4	MD	Dalzell, S. A., well No. 1	1929	3982	Granite
26S	27E	4	MD	Shell Oil Co. well No. "Keystone" 1	1938	3748	Granite
26S	27E	9	MD	Associated Oil Co. well No. 1	1921	2345	Miocene
26S	27E	11	MD	Superior Oil Co. well No. "Smith" 1	1927	3446	Granite
26S	27E	13	MD	Federal Drilling Co. well No. "Bass and Goodnight Glide" 3	1938	2206	Miocene
26S	27E	13	MD	Federal Drilling Co. well No. "Bass and Goodnight Glide" 4	1938	2115	Miocene
26S	27E	16	MD	Shoup, Root, & Milliken well No. 1	Pre-1925	1681	

KERN COUNTY—Continued

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
26S	27E	20	MD	Republic Oil Co. No. "Long" 1	1935	2405	Miocene
26S	28E	2	MD	Pottenger, Dr. F. M., well No. "Villard" 1	1938	569	Basement
26S	28E	3	MD	Pottenger, Dr. F. M., well No. "Girard" 1	1938	1042	Walker
26S	28E	6	MD	Frame, A. Bruce, well No. "Villard" 1	1928	2414	Walker
26S	28E	7	MD	Santa Carla Oil Co. well No. "Glide" 1	1936	2008	Vedder sand
26S	28E	8	MD	Sayre, Fred M., well No. 1	1929	1555	Walker
26S	28E	16	MD	Shell Oil Co. well No. "Corral Canyon" 1	1928	1133	Slate
26S	28E	17	MD	Trico Oil & Gas Co. well No. "Villard" 1	1938	1790	Vedder sand
26S	28E	17	MD	Trico Oil & Gas Co. well No. "Villard" 2	1939	1763	Vedder sand
27S	19E	7	MD	Mineral Mountain Mining Co. well No. 1			
27S	19E	7	MD	Rio Grande Oil Co. well No. "Utting" 1	1932	3181	Cretaceous
27S	19E	8	MD	Standard Oil Co. well No. "Mercantile" 1	Pre-1925	4050	Eocene
27S	19E	18	MD	Mountford, Howard S., well No. 1	1928	2960	Eocene (?)
27S	19E	19	MD	The Texas Co. well No. "Mountford" 1	1938	2142	Cretaceous
27S	19E	19	MD	The Texas Co. well No. "McClennon" 1	1911	1758	Cretaceous
27S	22E	16	MD	Shell Oil Co. well No. 4	Pre-1925	1241	Tulare
27S	22E	22	MD	Shell Oil Co. well No. 1	Pre-1925	1050	Tulare
27S	22E	22	MD	Shell Oil Co. well No. 2	Pre-1925	1052	Tulare
27S	22E	22	MD	Shell Oil Co. well No. 3	Pre-1925	1053	Tulare
27S	22E	28	MD	Shell Oil Co. well No. 4	Pre-1925	353	Tulare
27S	22E	34	MD	Shell Oil Co. well No. 4	Pre-1925	1040	Tulare
27S	26E	8	MD	Shell Oil Co. well No. "K. C. L.-A" 58-8	1938	9297	Basement
27S	26E	29	MD	Woodward & Sheedy well No. 1	1927	4563	Etchegoin
27S	26E	34	MD	Famosa Oil Co. well No. "Mattei" 1	1928	4228	Etchegoin
27S	26E	36	MD	General Pet. Corp. well No. "Umbsen" 1	1937	6070	Miocene
27S	29E	6	MD	Garner Bros. Oil Co. well No. "Garner" 1	1938	760	Basement
27S	29E	30	MD	Johnson, A. S., Drilling Corp. well No. 1-K	1938	1120	Lower Miocene
27S	29E	31	MD	Pan-May Oil Co. well No. "Pan-May" 1	1938	1085	Lower Miocene
28S	19E	12	MD	Bering, R. E., Trustee, well No. "Maylan" 2	1935	1067	Santa Margarita
28S	20E	7	MD	Continental Oil Co. well No. "Maylan" 1	1935	5304	Kreyenhagen
28S	20E	18	MD	Continental Oil Co. well No. "Layman" 1	1935	1783	Kreyenhagen
28S	20E	18	MD	Rio Grande Oil Co. well No. "Layman" 1	1936	2649	Kreyenhagen
28S	20E	20	MD	Casamera Oil Co. well No. "Theta" 1	1935	3698	Pliocene (?)
28S	20E	20	MD	Elkhorn well No. 1	1936	3600	Middle Monterey
28S	20E	29	MD	Casamera Oil Co. well No. 1-A	1935	6504	Media Shale
28S	22E	3	MD	Shell Oil Co. well No. 1	Pre-1925	1214	Tulare
28S	22E	3	MD	Shell Oil Co. well No. 3	Pre-1925	812	Tulare
28S	22E	8	MD	Balfour Guthrie Co. well	Pre-1925	837	Tulare
28S	22E	9	MD	Shell Oil Co. well No. 2	Pre-1925	1326	Tulare
28S	22E	15	MD	Standard Oil Co. well "Miller & Lux" (Option No. 1)	1925–1926	2560	Tulare
28S	22E	27	MD	Standard Oil Co. well No. "Miller & Lux" 2	1925–1926	2911	Upper Etchegoin
28S	26E	23	MD	Shell Oil Co. well No. "Lee" 1-1	1930	4628	Santa Margarita
29S	23E	20	MD	Elkern Oil Co. well No. 1	Pre-1925		
29S	23E	26	MD	McAdams, Ed., Trustee, well No. "G. & Y." 1	1928	5953	Etchegoin
29S	25E	30	MD	Tide Water Assoc. Oil Co. well No. 1	1937	9002	Reef Ridge transition
29S	25E	32	MD	Superior Oil Co. well No. "K. C. L." 1	1931	4808	Etchegoin
29S	28E	23	MD	The Texas Co. well No. "Newman" 1	1930	6287	Temblor
29S	29E	3	MD	Standard Oil Co. well No. "M. & T. Inc." 1	1935	3807	Miocene (?)
29S	29E	4	MD	Amerada Pet. Corp. well No. "Olcese" 1	1938	3400	Lower Miocene
29S	29E	4	MD	Tavis, J. J., well No. "Olcese-Tavis" 1	1937	3715	Granite (?)
29S	29E	14	MD	Pet. Securities Co. well No. "Johnson-Moss" 1	1930	4242	Vedder
29S	29E	19	MD	Wicker & McCarter well No. "Jewett" 1	1935	1926	
29S	29E	22	MD	George F. Getty, Inc., well No. "Beaizley" 1	1927	3757	Miocene (Vedder)
29S	29E	22	MD	Pet. Drill & Exp. Co. well No. "Beaizley" 1	1935	1055	Kern River (?)
29S	29E	24	MD	South Co., O. & G., well No. 1	1932	2103	
29S	29E	24	MD	Superior Oil Co. well No. "Bloemer" 1	1928	3508	Vedder
29S	30E	6	MD	Continental Oil Co. well No. "Williams" 1	1930	1022	Walker
29S	30E	29	MD	Midway North. Oil Co. well No. "Brown" 1	1929	3759	Basement
29S	30E	33	MD	Johnson, George W., well No. "Brown Pallette" 1	1938	1320	Schist
29S	37E	27	MD	Ricardo Oil Co. well	Pre-1925	4050	
30S	26E	11	MD	Superior Oil Co. well No. "K. C. L." 8	1937	12,618	Mid-Miocene
30S	27E	21	MD	Signal Oil & Gas Co. well "K. C. L." A-1	1937	8502	Upper Miocene
30S	27E	23	MD	Speik Oil Co. well No. "Ricomini" 1	1936	6327	Santa Margarita
30S	28E	17	MD	Sunset Oil Co. well No. "Sunset-Starr" 1	1938	6694	Miocene
30S	28E	31	MD	O'Donnell, J. E., well No. "Houghton" 1	1928	4058	Chanac (?)
30S	30E	15	MD	Elmer Co., Ltd. well No. "Tejon" 1	1930	5057	Walker (?)
30S	30E	22	MD	Stevens, Ray W., well No. "Tejon Ranch" 1	1938	1104	Granite
30S	30E	23	MD	East Edison Oil Co. well No. 1	1937	1895	Granite
30S	30E	23	MD	East Edison Oil Co. well No. A-1	1937	1035	Granite

KERN COUNTY—Continued

T	*R*	*Sec.*	*B & M*	*Name of Company and Well*	*Yr. Aband. or Last Active*	*Depth Ft.*	*Geology at Bottom of Hole*
31S	29E	27	MD	Big McKittrick Oil Co. well No. "Sea Cliff Houghton" 1	1935	6757	Pliocene
31S	30E	21	MD	Bear Mountain Oil Co. well No. "Tejon" 1	1937	1669	Granite
31S	30E	32	MD	Petrix, Inc., well No. "Petrix" 1	1938	5290	Granite
31S	38E	10	MD	Parsons, George A., well No. 1	Pre-1925	151	
31S	38E	19	MD	Red Rock Oil Ass'n (Chas. W. Harlow) well No. 1		2781	
31S	38E	22	MD	Fremont Oil Corp. well No. 1	1925	1440	
31S	38E	22	MD	Fremont Oil Corp. well No. 2	1931	2625	
32S	23E	31	MD	Spiers, E. W., well No. 1	1926	500(?)	Miocene (?)
32S	23E	32	MD	Belridge Oil Co. well No. "Gonyer" 1	1925-1926	3091	Maricopa
32S	23E	32	MD	Shell Oil Co. well No. "Gonyer" 1	1930	4134	Oligocene
32S	28E	30	MD	T. & T. Oil Co. well No. 1	Pre-1925	4820	Kern River
32S	29E	1	MD	General Pet. Corp. well No. "Mattson" 1	1935	8847	Schist
32S	29E	23	MD	Comanche Pt. Oil Co. well No. "Comanche" 1	Pre-1925	2301	Granite
32S	29E	23	MD	Stabler, W. W., well No. "Tejon" 1	1930	3392	Temblor (?)
32S	29E	23	MD	Tejon Ridge Oil Co. well No. 1	1934	2513	Diorite
32S	30E	6	MD	Salient Oil Co. well No. 1	Pre-1925	804	Paso Robles
32S	30E	30	MD	Signal Oil & Gas Co. well No. "Tejon" 1	1936	283	Granite (?)
12N	19W	33	SB	Honolulu Oil Corp. well No. "Honolulu—T. W. A.—S. B." 33 1	1938	8005	Chanac
11N	22W	11	SB	The Texas Co. well No. "K. C. L. Co." C-11-49	1936	10,014	Etchegoin
11N	22W	21	SB	Shell Oil Co. well No. "San Emigdio" 1	1927	4826	Etchegoin
11N	22W	26	SB	Shell Oil Co. well No. "San Emigdio K. C. L." 1-A 4-26	1938	10,374	Upper Miocene
11N	22W	28	SB	Standard Oil Co. well No. "K. C. L." 3-1	1925-1926	5663	Etchegoin
11N	22W	30	SB	Associated Oil Co. well No. "KC" 1	Pre-1925	3502	Maricopa
11N	22W	31	SB	Union Oil Co. well No. "Morrison" 1	1937	2070	Miocene
11N	22W	32	SB	Associated Oil Co. well No. 2	Pre-1925	3533	Maricopa
11N	22W	32	SB	Milham Expl. Co. well No. "Pioneer" 1	1925-1926	2115	Maricopa
11N	22W	33	SB	Milham Expl. Co. well No. "Pioneer" 2		2036	Maricopa
11N	22W	35	SB	Standard Oil Co. well No. "K. C. L." 6-1	1929	3782	Etchegoin
11N	20W	15	SB	Barnsdall Oil Co. well No. "K. C. L." 1	1932	7126	Pliocene
11N	19W	21	SB	Ohio Oil Co. well No. "T. I. T." D-1	1937	9654	Lower Miocene
11N	19W	23	SB	Ohio Oil Co. well No. "Tejon Ranch Co." D-2	1938	5896	Middle Miocene
11N	19W	31	SB	The Petrol Corp. well No. "Badger" 1	1935	6229	Temblor
11N	19W	32	SB	The Petrol Corp. well No. "Reserve Petrol" 32-2	1938	6022	Middle Miocene
11N	19W	33	SB	Reserve Oil & Gas well No. 33-2	1936	4508	Miocene
11N	19W	33	SB	Reserve Oil & Gas well No. 33-3	1937	4431	Miocene
11N	19W	33	SB	Reserve Oil & Gas well No. 33-4	1938	5443	Middle Miocene
11N	19W	33	SB	Ritchie, Dr. J. J., well No. 1	1932	6035	Temblor
11N	19W	36	SB	Ohio Oil Co. well No. "Title Ins. & Trust" 1	1936	5507	Temblor (?)
11N	18W	4	SB	Stabler, W. W., well No. "Southwest" 1	1932	1811	Granite
11N	18W	28	SB	Ohio Oil Co. well No. "Tejon Ranch" D-3	1938	2275	Middle Miocene
11N	12W	14	SB	Mojave Oil Co. well		1100	
11N	9W	14	SB	Conway Oil Syn. well No. 1	1928	400	
11N	9W	27	SB	Kendall Dev. Co., Ltd. well No. 1	1932	1340	Granite
10N	22W	5	SB	Standard Oil Co. well No. "K. C. L." 4-1	1925-1926	2254	Maricopa
10N	21W	5	SB	Union Oil Co. well No. "K. C. L." 1	1929	2335	Etchegoin
10N	21W	5	SB	Union Oil Co. well No. "K. C. L." 2	1930	3916	Maricopa
10N	19W	2	SB	Reserve Oil & Gas Co. well No. 2-1	1936	3708	Santa Margarita
10N	19W	2	SB	Reserve Oil & Gas Co. well No. 2-4	1936	2777	Santa Margarita
10N	19W	2	SB	Reserve Oil & Gas Co. well No. 2-5	1936	2582	Santa Margarita
10N	19W	2	SB	Reserve Oil & Gas Co. well No. 2-6	1937	2686	Etchegoin (?)
10N	19W	2	SB	Reserve Oil & Gas Co. well No. "Tejon Ranch" 1	1936	3708	Walker (?)
10N	19W	2	SB	Reserve Oil & Gas Co. well No. "Tejon Ranch" 4	1935	2777	Miocene
10N	19W	2	SB	Reserve Oil & Gas Co. well No. "Tejon Ranch" 5	1936	2582	Miocene
10N	19W	5	SB	Wilshire Oil Co. well No. "Tejon" 1	1937	5405	Lower Miocene (?)
10N	19W	7	SB	Silver Gate Co. well No. 1	1939	2985	Upper Miocene
10N	19W	7	SB	Smith, C. P., well No. 1		2985	Chanac (?)
10N	19W	12	SB	Reserve Oil & Gas Co. well No. "Tejon Ranch" 2	1935	2508	Basalt
10N	19W	12	SB	Reserve Oil & Gas Co. well No. "Tejon Ranch" 3	1935	1862	Basalt
10N	14W	26	SB	Regina Oil Corp., Ltd., well No. "Marsh" 1	1934	3312	Granite
10N	10W	5	SB	Harding, John B., well No. 1		1045	
10N	10W	5	SB	Harding, John B., well No. 2		600	
10N	10W	21	SB	Crusaders Oil Co. well No. 1	Pre-1925	800	Metamorphics (?)
9N	17W	27	SB	Watchhorn, Robert, well No. 1	Pre-1925	4150	
9N	15W	11	SB	Meridian Oil Co. Ltd. well No. 1	1935	3970	Granite
9N	10W	13	SB	Kern-Torrance Pet. Corp. well No. 1	Pre-1925	500	

KINGS COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
18S	23E	8	MD	Turner & Goldsberry well No. "Goldurner" 1	1934	1400	Pliocene (?)
19S	19E	17	MD	Shell Oil Co. well No. "Boston Land Co." D	1929	3835	Pliocene (?)
19S	19E	27	MD	Justice & Ellerby well No. 1	1929	1000	Tulare
20S	20E	24	MD	Calif. Nat. Gas & Dev. Co. well No. 1	Pre-1925	1290	Tulare
20S	20E	24	MD	Pacific Oil & Gas Co. well No. 2	Pre-1925	1218	Tulare
20S	20E	25	MD	Stone, Glen G., well No. "Teeter" 1			
21S	18E	24	MD	Penn. Wes. Oil Co. well No. 1	1931	1338	Tulare
21S	19E	33	MD	Little Chief Oil Co. well No. 1	Pre-1925	4000	Etchegoin
21S	21E	7	MD	Monocline Dev. Co. (Norell, T. G.) well No. 1, or No. "Guess" 1?		6189	Pliocene (?)
22S	19E	5	MD	Milham Expl. Co. well No. "West Tulare" 1	1935	5423	Etchegoin
22S	20E	21	MD	Commonwealth Cons. Gas, Ltd., well No. 1			Tulare
22S	20E	21	MD	Commonwealth Cons. Gas, Ltd., well No. 2		2350	Tulare
22S	20E	28	MD	Union Oil Co. well No. "Hancock-Union Giannini" 1	1936	5338	Etchegoin
22S	20E	32	MD	Yarrow, Helen, well No. 1	1935	1744	Tulare
22S	20E	32	MD	Woodward, Glenn, well No. 1	1936	780	Tulare
22S	22E	20	MD	Millheim Oil Co. well No. 1	1937	5803	Pliocene
23S	16E	10	MD	Kettleman Reef Ridge Oil Co. well No. 1	1932	1110	Miocene (?)
23S	16E	10	MD	Hiatsura Shigaki well 2A	1941	1219	
23S	16E	11	MD	Weller, Carl W., well No. "Baby King" 2	Pre-1939	1775	Miocene
23S	16E	24	MD	Blair Oil Co. well No. "Blair" 1B	1941	2015	Cretaceous
23S	17E	5	MD	Birch Ranch & Oil Co. well No. "Orr" 1	1937	3112	Miocene
23S	17E	18	MD	Big Tar Canyon Oil Co. well No. 1	Pre-1925	1335	Temblor (?)
23S	17E	35	MD	Associated Oil Co. well No. "Avenal" 1	1936	3110	Temblor
23S	17E	35	MD	Associated Oil Co. well No. "Avenal" 2	1937	3088	Middle Miocene
23S	17E	35	MD	Whitley & Van Antwerp well No. 1	1922	2100	
23S	17E	36	MD	Knudsen & Schmidt well No. 1	1936	6854	Kreyenhagen
23S	20E	5	MD	Triume Oil, Gas & L. Co. well No. 1	1935	1103	Tulare
23S	20E	7	MD	California Oil Co. well No. 1	1928	355	
23S	20E	7	MD	Irma Invest. Corp., Ltd. well No. "Watson" 1	1931	1343	
23S	20E	7	MD	Irma Invest. Corp., Ltd. well No. "Watson" 2	1931	1224	
23S	20E	7	MD	O'Donnell Gas Co., Ltd. well No. "Dudley Ridge" 2	1931	4309	Upper Etchegoin
23S	20E	9	MD	Dudley Dome Oil & Gas Co. well No. 1			
23S	20E	9	MD	Dudley Dome Oil & Gas Co. well No. 2		518	Tulare-Recent
23S	20E	13	MD	Pacific Oil & Gas Co. well No. 2	Pre-1925	1800	Tulare
23S	20E	15	MD	Eagle Oil & Gas Co. well No. 1	1933	675	Tulare
23S	20E	15	MD	Eagle Oil & Gas Co. well No. 2	1935	1355	Tulare
23S	20E	20	MD	Valley Expl. Co., Ltd. well No. "Brennan" 1	1931	3750	Etchegoin
23S	20E	24	MD	Dudley Ridge Dev. Co., well No. "Josephine" 1		1305	Tulare
23S	20E	24	MD	Dudley Ridge Dev. Co. well No. "Josephine" 2	1938	6498	Jacalitos
23S	21E	18	MD	Pacific Oil & Gas Co., well No. 1	Pre-1925	2715	Etchegoin
23S	22E	10	MD	Tri-Counties Oil Co. well No. "Olson" 1		4300	Tulare
23S	22E	12	MD	Calif. Nat. Gas & Dev. Co. well No. 1	Pre-1925	2076	Tulare
23S	22E	12	MD	Calif. Nat. Gas & Dev. Co. well No. 2	Pre-1925	2255	Tulare
23S	22E	12	MD	Calif. Nat. Gas & Dev. Co. well No. 3	Pre-1925	4040	Etchegoin
23S	22E	12	MD	Calif. Nat. Gas & Dev. Co. well No. 4	Pre-1925	1831	Tulare
23S	22E	12	MD	Dudley Pet. Co. (B. B. & E. R.) well No. 1	Pre-1925	1780	Tulare
23S	22E	12	MD	Guess, E. B., well No. "Guess" 2	1932	2208	Tulare
24S	17E	9	MD	Welport Oil Co. well No. "Avenal" 1	1932	3940	Cretaceous
24S	18E	16	MD	Royalty Service Corp., Ltd. well No. "Spreckles" 1	1936	4201	Miocene
24S	18E	20	MD	General Pet. Corp. well No. "Martin" 1	1935	2077	Temblor
24S	18E	20	MD	Pyramid Hills Syn. well No. 1	Pre-1925	2465	McClure (?)
24S	18E	34	MD	General Pet. Corp. well No. "McRae" 1	1921	3045	Kreyenhagen
24S	18E	34	MD	Standard Oil Co. well No. "Kettleman" 1	Pre-1925	6602	McClure
24S	19E	35	MD	South Dome Oil Co. well No. "Clarence G. Smith" 1		2913	Etchegoin
24S	20E	11	MD	Bisconer, Raymond, well No. 1		2496	Tulare
24S	21E	19	MD	Shell Oil Co. well No. 2	Pre-1925	1187	Tulare
24S	21E	22	MD	Shell Oil Co. well No. 1	Pre-1925	1141	Tulare
24S	22E	33	MD	Magee & Stone well No. 2	1934	3082	Etchegoin
24S	22E	33	MD	Trico Oil & Gas Co. well No. 1	1934	3811	Etchegoin
24S	22E	34	MD	Magee & Stone well No. 1	1933	5215	Etchegoin
24S	22E	36	MD	Trico Oil & Gas Co. well No. 3	1935	4824	Etchegoin

LOS ANGELES COUNTY

T	*R*	*Sec.*	*B & M*	*Name of Company and Well*	*Yr. Aband. or Last Active*	*Depth Ft.*	*Geology at Bottom of Hole*
8N	18W	14	SB	Tejon Ranch Oil Co. well No. 1	Pre-1925	2050	Granite (?)
8N	13W	23	SB	Andrews, O. G., and Sons, well No. 1	1928	2063	Igneous rock (?)
8N	12W	24	SB	Denison Co., George A., well No. 1	1932	1000	
7N	12W	11	SB	Antelope Oil & Gas Co. well No. 1	1925–1926	1640	Non-marine (?)
7N	9W	36	SB	Citizens Oil & Land Corp. well No. 1	Pre-1925	100	
6N	11W	34	SB	Christenson, Roy M., well No. 1	1930	1098	
5N	17W	10	SB	Ellsworth, C. W., well No. "Paducah" 1	Pre-1925		
5N	17W	23	SB	Castaic Oil Co. well	Pre-1921	1000	
5N	16W	18	SB	Castaic Oil Association well	Pre-1921	1400	
5N	16W	18	SB	Rose Oil Company well	Pre-1921	1700	
5N	16W	18	SB	Stabler, W. W., well No. "Jenkins" 1	1929	3404	Modelo
5N	15W	35	SB	Tick Canyon Oil Syn. well No. 1	1923	4391	
5N	15W	35	SB	Newhall Cons. Oil Co. well No. 1	Pre-1925	830	
5N	12W	1	SB	Wright Oil Tool Co. well No. "Wright" 1	1937	1420	
5N	11W	2	SB	Rock Creek Dev. Co. well No. 1	1926	100	
4N	15W	32	SB	Walker, Pierson, & McGreggor well	Pre-1925	320	Pico (?)
4N	12W	11	SB	Burlingham Tr. No. 1 well No. "Carl Bedford" 1	1929	1682	
4N	12W	11	SB	Burlingham Tr. No. 1 (Burlingham Pet. Corp.) well No. "Dubin" 1	1927	1650	
4N	12W	19	SB	Moffatt & Campbell Pet. well No. 1	1931	4143	Pico
4N	11W	16	SB	Jones, Charles T. B., well No. 1	1925–1926	3944	
3N	15W	3	SB	San Miguel Oil & Dev. Co. well No. 1	Pre-1925	1000	
3N	15W	4	SB	New Century well	Pre-1925	700	Jurassic (?)
3N	15W	4	SB	Turner & Trickett well No. 1	Pre-1925	965	Jurassic (?)
3N	15W	8	SB	Calif.-Newhall Oil Co. well No. 1	Pre-1925	1865	Pico
3N	15W	17	SB	Graves Oil Co. well	Pre-1925	1500	Pico (?)
3N	15W	32	SB	San Fernando Oil & Gas Co. well No. 1	Pre-1925	1953	Modelo (?)
3N	15W	36	SB	Griffith, D. W., well No. 1	Pre-1925	1646	Pico (?)
3N	14W	22	SB	Russian Oil Co. well No. 1	Pre-1925	1874	Granite
2N	15W	1	SB	San Fernando Oil Co. well No. 1	Pre-1925	2880	Modelo
2N	15W	4	SB	Shell Oil Company well No. "Mission" 1	1928	4953	Modelo
2N	15W	4	SB	Shell Oil Company well No. "Mission" 2	1929	5687	Modelo
2N	15W	5	SB	Mission Hills Oil Co. well No. 1	Pre-1925	1421	Modelo (?)
2N	15W	11	SB	Pacoima Pet. & Helium Gas Corp., Ltd., well No. 1		2700	
2N	15W	15	SB	Standard Oil Co. well No. "University" 1	1927	5938	
2N	15W	24	SB	Union Oil Co. well No. "Howland" 1	1926	5326	
2N	14W	2	SB	Sunland Oil Ass'n. well No. 1	1926	1845	
2N	14W	6	SB	57 Pet. Corp. (Associated Oil Co.)		3363	
2N	14W	11	SB	Cotton & Fleming well No. 1	Pre-1925	440	
12N	14W	11	SB	Hummel, Joseph		800	
2N	14W	15	SB	Interstate Oil Corp. well No. "Continental" 1		2885	
1N	18W	18	SB	Wells, Burt F., well No. 1	Pre-1925		
1N	18W	35	SB	Kneuper, A. D., well No. 1	Pre-1925		
1N	17W	10	SB	Price, W. C., well No. "Hale" 1	1921	2930	
1N	17W	18	SB	Simi Oil Co., Ltd. well No. 1	1932	4898	
1N	17W	18	SB	Simi Oil Co., Ltd. well No. "Hearst" 2	1932	221	Modelo
1N	17W	22	SB	Martin, J. W., well No. 1	1931	1825	Modelo
1N	17W	26	SB	Rucker, Lyle W., well No. 1	Pre-1938 (?)	802	Hard gray sandstone (Topanga formation)
1N	17W	34	SB	Reider-Haag well No. 1			
1N	17W	34	SB	Reider-Haag well No. 2	Pre-1925	1000	
1N	16W	14	SB	San Val Oil Co., Ltd. well No. 1	1931	2100	Miocene (?)
1N	16W	23	SB	Golden State Oil Co. well No. 1	Pre-1925	1190	Modelo (?)
1N	16W	27	SB	Bonnie Brae Oil Co. well	Pre-1925	505	Modelo
1N	16W	27	SB	Golden Gate Oil Co., well No. 2	1926	1685	Puente
1N	15W	16	SB	Van Nuys Oil Co., Van Nuys Com. No. 1	1927	3858	Miocene
1N	14W	13	SB	Luttge, H. E., well No. 1	Pre-1925	1700	Modelo (?)
1N	14W	27	SB	Gaddie Oil & Dev. Co. well No. 1	1922	4198	
1N	14W	34	SB	Black Wolf Canyon Oil well No. 1	1922	1725	
1N	13W	34	SB	Calwin Oil Co. well No. 1	1927	6142	
1N	11W	34	SB	Baash-Ross Tool Co. (Vosburgh Oil Corp.), Vosburgh No. 1 well	1925	4875	
1S	19W	28	SB	Santa Monica Pet. & Dev. Co. well No. 1	1923	407	
1S	19W	28	SB	Santa Monica Royalty Oil Wells, well No. 1	Pre-1925		
1S	18W	3	SB	Hoyt, George W., well No. 1	Pre-1925		
1S	18W	34	SB	Waring, Bruce, well No. 1	Pre-1925		
1S	17W	6	SB	Las Virgenes Pet. Co. well No. 1	Pre-1925		
1S	17W	6	SB	Miller Drilling Co. well No. "Colyear" 1	1929	2547	
1S	17W	11	SB	Standard Oil Co. well No. "Austin" 1	1927	2503	Martinez
1S	17W	31	SB	Ferguson Francisco Pet., well No. 1	1925	1185	
1S	16W	5	SB	Monarch Oil Corp. well No. "Sylvia Park" 1	1939	1823	Pliocene

LOS ANGELES COUNTY—Continued

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
1S	13W	5	SB	Sullivan, William, well No. 1	Pre-1925	2410	Puente
1S	13W	11	SB	Preston well	Pre-1925	2200	Puente
1S	13W	24	SB	Calif. Pacific Oil Co. well No. 1	1922	2059	
1S	13W	24	SB	Calif. Pacific Oil Co. well No. 2	Pre-1925	1980	Puente
1S	13W	24	SB	Jordan Crude Oil Co. well		3760	
1S	13W	24	SB	O'Donnell & Wilde well No. 1			
1S	13W	24	SB	Republic Pet. Co. well No. "Jordan" 1	1936	1567	Upper Puente
1S	13W	24	SB	Yellowstone Oil Co., Ltd. well No. "Huntington Seger" 1		3919	
1S	13W	25	SB	Amalgamated Oil Co. well No. "Huntington" 1	Pre-1925	3664	Puente
1S	13W	25	SB	Amalgamated Oil Co. well No. "Huntington" 2	Pre-1925	3745	Puente
1S	13W	25	SB	Bell, C., well No. 1	Pre-1925		Puente
1S	13W	25	SB	Santa Fe Springs Mutual Oil Syn. well No. 1	1928	2995	Puente
1S	13W	25	SB	Walsh Pet. Co. well No. 1	Pre-1925		
1S	13W	26	SB	Herrou, Joseph L., well No. 1	1935	615	Puente
1S	13W	26	SB	Hoard, F. F., well No. 1	Pre-1925	435	Puente
1S	12W	18	SB	Rekar, J. J. well No. 1	1924	1100	
1S	12W	19	SB	Jordan Crude Oil Co. well	1923	3760	
1S	12W	19	SB	McDonald, Norman, well No. 1	Pre-1925	1138	Puente
1S	12W	19	SB	Yellowstone Oil Co., Ltd., Well Yellowstone-Castruccio No. 1	1932	2014	Puente (?)
1S	12W	25	SB	Celito Oil Corp. well No. "Jepsen" 1	1933	5301	Pliocene
1S	12W	25	SB	Ventura Oil Syn. well No. 1	Pre-1925	825	
1S	12W	28	SB	Standard Oil Co. well No. "Monterey" 2	1910	3500	
1S	12W	29	SB	Puente Oil Co. well No. "Rowland" 1	Pre-1925	2600	
1S	12W	30	SB	White, Ben, well No. 1	Pre-1925	604	
1S	12W	32	SB	Taylor, W. H., well No. 1	1929	5825	Repetto
1S	11W	11	SB	Andrus & Hutcheson, Inc. well No. 1	1934	2200	Miocene (?)
1S	11W	17	SB	Bramham, W. C., well No. 1	Pre-1925		
1S	11W	28	SB	Hillman-Long, Inc., well No. "Mulholand" 1	1936	6265	Pico
1S	11W	30	SB	Rancho Oil Corp., Ltd., well No. "Harmon" 1	1931	5874	Pico
1S	11W	35	SB	Barnsdall Oil Co. well No. "Merlo" 1	1925-1926	4498	Pico (?)
1S	11W	35	SB	Shell Oil Company Tract B1 well	1919	3670	Pico (?)
1S	10W	30	SB	North Amer. Oil Cons. well Smith 3-1	1936	5952	Upper Puente
1S	10W	32	SB	Mascot Oil Co. well No. 1	Pre-1925	1600	
1S	10W	35	SB	Shell Oil Co. well No. "Sentous" 1	Pre-1925	3652	Puente
1S	9W	7	SB	Goodrum, George, well No. "Charter Oak"-1	1937	1037	Miocene
1S	9W	33	SB	Camaroo Oil Co. well No. "Stern" 1	1937	2670	Puente
1S	9W	33	SB	Durgin, Allen, & Cosby well No. "Stern" 1	1932	1765	Puente
1S	9W	34	SB	Lamona Oil Ass'n well No. 1	1930	975	Granite
1S	9W	34	SB	Spadra Oil Co. well No. 1	1926	528	
1S	9W	34	SB	Spadra Oil Co. well No. 2	1927	555	
1S	9W	34	SB	Spadra Oil Co. well No. 7	1927	908	
1S	8W	5	SB	Hamilton, Franklin H., well Hamilton-Claremont 1	1932	1130	
1S	8W	32	SB	Pomona Oil Ass'n well Comm. No. 1	1929	1207	
2S	19W	1	SB	Raleigh Oil Co. well No. "Malibou" 1		2237	
2S	18W	7	SB	Marblehead Land Co. well No. 1	1931	3764	Miocene
2S	15W	17	SB	Standard Oil Co. well No. "L. A. Investment" 1-1	Pre-1925	2134	Pico
2S	13W	3	SB	Hostetter, D. Herbert, well No. 1	Pre-1925	5010	Repetto (?)
2S	13W	13	SB	Richfield Oil Co. well No. "Vernon" 1	1929	6016	Lower Pico
2S	12W	4	SB	The Texas Co. well F & M Bank No. 1	1931	4890	Repetto
2S	12W	6	SB	Superior Oil Co. well No. "Anderson" A-1	1925-1926	5023	Repetto
2S	12W	13	SB	The Texas Co. well No. "Pico" 1	1933		
2S	12W	14	SB	Empire Drilling Co. well No. "Gaffey" 1	1929	5500	Pico
2S	12W	14	SB	Honolulu Oil Corp. well No. "Montebello" 1	1937	4302	Lower Pico
2S	12W	15	SB	Superior Oil Co. well No. "Vail" 1	1925-1926	5453	Repetto
2S	12W	16	SB	Western Gulf Oil Co. well No. "Vail" 1	1935	6971	Repetto
2S	12W	17	SB	West American Oil Co. well No. "Bandini" 1	1935	4676	Repetto
2S	12W	18	SB	Pet. Securities Co. well No. "Bandini" 1	1927	5805	Repetto
2S	12W	18	SB	Wilshire Oil Co. well No. "Arcadia" 1	Pre-1925	5282	Repetto
2S	12W	20	SB	West American Oil Co. well No. "Bandini" 2	1935	3104	Repetto
2S	12W	21	SB	Bandini Pet. Co. well No. "De Baker" 1	1925-1926	3963	Pico
2S	12W	21	SB	Bandini Pet. Co. well No. "De Baker" 2	1925-1926	5400	Repetto
2S	12W	22	SB	Fullerton Oil Co. well No. "Simons" 1	Pre-1925	5436	Repetto
2S	12W	22	SB	Oak Ridge Oil Co. well No. "Couts Com." 1	1925-1926	5083	Repetto
2S	12W	22	SB	Oak Ridge Oil Co. well No. "K-B" 1	Pre-1925	5513	Pico
2S	12W	22	SB	Oak Ridge Oil Co. well No. "Ogden" 1	Pre-1925	1040	Upper Pico
2S	12W	22	SB	Oak Ridge Oil Co. well No. "Rossi" 1	Pre-1925	5060	Pico
2S	12W	23	SB	Standard Oil Co. well No. "Hadley" 1	1925-1926	5900	Pico
2S	12W	26	SB	Burbank Oil Co. well No. 1	Pre-1925		Pico
2S	12W	26	SB	George F. Getty, Inc. well No. "Marland" 1	1927	5010	Pico
2S	12W	27	SB	George F. Getty, Inc. well No. "Kellam" 1	1930	5001	Pico
2S	12W	28	SB	Oak Ridge Oil Co. well No. "Gage" 1	Pre-1925	5035	Pico
2S	12W	30	SB	Shell Oil Co. well No. "Loomis" 1	Pre-1925	5406	Pico
2S	12W	31	SB	Jones, Wm. L. (Oakes, J. A. & Mead, C. E.) well No. "Graham" 1	1934 (?)	4976	

LOS ANGELES COUNTY—Continued

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
2S	12W	33	SB	Associated Oil Co. well No. "Taylor" 1	1929	6166	Pico
2S	12W	33	SB	Giant Pet. Co. well No. 1	Pre-1925	3500	Pico
2S	12W	34	SB	Rio Grande Oil Co. well No. "Osborne" 1	1929	5149	Pico
2S	12W	35	SB	Co-operative Pet. Syn. well No. 3	Pre-1925	5392	Lower Pico
2S	12W	35	SB	First National Pet. Co. well No. 1	Pre-1925	5005	Lower Pico
2S	12W	35	SB	M. & H. Oil Co. well No. 1	Pre-1925	4660	Pico
2S	12W	35	SB	Santa Fe Chief Oil Syn. well No. 1	Pre-1925		Pico (?)
2S	12W	35	SB	Southwest Pet. Syn. well No. "Harris" 1	Pre-1925	960	Pleistocene
2S	12W	35	SB	Stall Oil Ass'n. well No. "C. C. Stall" 1	1925-1926	4892	Pico
2S	12W	35	SB	Tricolor Oil Co. well No. 1	Pre-1925	700	Pleistocene
2S	11W	4	SB	Brown, Ralph J., well No. "Lapworth" 2	1936	3337	Upper Puente
2S	11W	4	SB	Wilshire Oil Co. well No. "Pellissier" 1	1935	3981	Repetto
2S	11W	4	SB	Woodworth Oil Co., Ltd. (Signal Oil & Gas Co.) well No. "Lapworth" 1		4959	
2S	11W	4	SB	Womac, Inc. well No. "Womac" 1	1936 (?)	2946	
2S	11W	11	SB	Shell Oil Co. of Calif. well No. "Baldwin" 1		4563	
2S	11W	11	SB	Shell Oil Co. of Calif. well No. "Baldwin" 1-A	1922	4563	
2S	11W	11	SB	Shell Oil Co. of Calif. well No. "Cole" 1	1921	4556	
2S	11W	11	SB	Wilshire Annex Oil Co. well No. "Baldwin" C-1	1936	4297	Repetto
2S	11W	12	SB	Superior Oil Co. well No. "Andres" 1	1925-1926	1212	
2S	11W	19	SB	Jackson, R. W., well No. "Florey Com." 1	1929	1331	Pleistocene
2S	11W	19	SB	Midfield Oil Co. well No. "Midfield-Walker" 1	1934	5027	Repetto
2S	11W	19	SB	Standard Oil Co. well No. "Culp Comm." 1	1925-1926	5770	Pico
2S	11W	29	SB	Tureco Oil Co. well No. "Cole" 1	1930	5586	Pico
2S	10W	2	SB	Bardeen Pet. Co. well No. "Puente" 2	1931	3000	Puente
2S	10W	2	SB	Pet. Dev. Co. well No. 1	Pre-1925	3953	Puente
2S	10W	3	SB	D & B Oil Co. well No. 1	1932	4532	Puente
2S	10W	3	SB	St. Helens Pet. Co. well No. "Garnier" 1	Pre-1925	2338	Puente
2S	10W	3	SB	St. Helens Pet. Co. well No. "Garnier" 1-B	Pre-1925	5282	Puente
2S	10W	4	SB	Bardeen Oil Co. well No. 1	Pre-1925	4095	Puente
2S	10W	4	SB	Jose Oil Co. well No. 1	Pre-1925	2419	Puente
2S	10W	10	SB	Bardeen, H. A., well No. 2	1925	1645	Puente
2S	10W	11	SB	Rancho de la Puente well No. 1	Pre-1925	4416	Puente
2S	10W	13	SB	Associated Oil Co. well No. "Patterson" 1	1931		
2S	10W	14	SB	Butler, C. R., well No. "Butler" 1	1937	4133	Puente
2S	10W	14	SB	Guaranty Oil Co., Ltd. well No. 1		3726	
2S	10W	14	SB	Shively, N. O., well No. "Shively" 1		3183	
2S	10W	14	SB	Signal Pet. Co. of Cal., Ltd., well No. "Rowland" 1		4908	
2S	10W	14	SB	Vega Oil Co., Ltd., The, well No. 1		2419	
2S	10W	15	SB	Honolulu Oil Corp., Ltd. well No. "Butler" 1	1937	3768	Puente
2S	10W	24	SB	Stanton, A. A., well No. 1	Pre-1925	2870	Puente
2S	10W	27	SB	Rucker, Smith, Croul well No. 1	1930	3644	Puente
2S	9W	5	SB	Julian, C. A., and Criswell, D. S. well No. "Koch Comm." 1			
2S	9W	6	SB	McVicar-Rood well No. "Sentous" 1	1936	3050	Upper Puente
2S	9W	16	SB	Gold Seal Pet. Co. well No. 1	Pre-1925	4347	Puente
2S	9W	20	SB	Copa de Ora Pet. Co. well No. 1	Pre-1925	3990	Puente
2S	9W	27	SB	Tonner Oil Co. well No. 1	1925-1926	2125	Puente
2S	9W	28	SB	Western Gulf Oil Co. well No. 1	1930	6823	Lower Puente
2S	9W	30	SB	Beard, G. F., well No. "Brea Canyon Heights" 1		3079	
2S	9W	30	SB	Pressel, Perry, & Tull well No. "Thornhill" 1	1937	4535	Puente
3S	15W	12	SB	Larco Oil Co. well No. "Van" 1	1936	7600	Schist
3S	15W	12	SB	Rider, George R., well No. 1			
3S	15W	24	SB	Staple Oil Co., Ltd. well No. "Comm." 1	1935	7315	Puente
3S	15W	24	SB	Staple Oil Co., Ltd. (Standard Oil Co.?) well No. "Community" 1	1933	2640	
3S	14W	10	SB	Signal Finance Corp. well No. 1	1939	9317	Miocene
3S	14W	10	SB	Republic Pet. Co., well No. 1	1930	4548	Pico
3S	14W	22	SB	Hancock Oil Co. well No. "Alondro" 1		6069	
3S	14W	22	SB	Kitselman, A. L., well No. "Bodger" 2	Pre-1925	5170	Lower Pico (?)
3S	14W	22	SB	Kitselman, A. L., well No. "Lawndale" 1	Pre-1925	1095	Pico
3S	14W	22	SB	Sovereign Oil Corp. well No. "Sovereign-Long" 1	1936	8303	Miocene
3S	14W	22	SB	Standard Oil Co. well No. "Bodger" 1	1936	8044	Schist
3S	14W	27	SB	Union Oil Co. well No. "Sommers" 1	Pre-1925	5000	Repetto (?)
3S	14W	28	SB	Allied Pet. Corp. well No. "Lincoln" 1	1929	5703	Puente
3S	14W	28	SB	Winwell Oil Co. well No. 1	1927	5540	Puente
3S	14W	29	SB	Mohawk Pet. Corp. well No. 1	1932	6264	Puente
3S	14W	29	SB	Mohawk Pet. Corp. well No. "Towell" 1	1929	4597	Puente (?)
3S	14W	29	SB	Mohawk Pet. Corp. well No. "Towell" 1-A	1929	6479	Puente
3S	14W	29	SB	Shell Oil Co. well No. 61	1928	5592	Puente
3S	14W	30	SB	Doyle Pet. Corp. well No. "G. C. Martin" 1	1935	7108	Puente
3S	14W	30	SB	Manhattan Pac. Oil Co. well No. 1	Pre-1925	3831	Puente
3S	14W	30	SB	Manhattan Pac. Oil Co. well No. 2	Pre-1925	3800	Puente
3S	14W	30	SB	Rosenberg-Barnett	Pre-1925	3505	Repetto (?)
3S	14W	30	SB	Calif. Ventura Oil Co. well No. "Carlin & Smith" 1	1929	5033	Puente

LOS ANGELES COUNTY—Continued

T	*R*	*Sec.*	*B & M*	*Name of Company and Well*	*Yr. Aband. or Last Active*	*Depth Ft.*	*Geology at Bottom of Hole*
3S	13W	1	SB	Moore, M. J., well No. 1	1928	4440	Upper Pico
3S	13W	4	SB	Southwest Pet. Co. well No. "Ramsaur" 1			
3S	13W	13	SB	Craig, A. A., well No. 1	1929	5347	Pico
3S	13W	16	SB	Combs, E. U., well No. 1	1930	575	
3S	13W	16	SB	Pacific Dev. Co. well No. "Saulque" 1			
3S	13W	21	SB	Creasey, Frank O., well No. "Veach" 1			
3S	13W	22	SB	Dominguez Ext. Oil Co. well No. 1	1928	5510	Pico
3S	13W	22	SB	Sovereign Oil Corp. well No. "Sovereign" 1	1936	8766	Schist (?)
3S	12W	2	SB	Union Oil Co. well No. "Downey Comm." 1	Pre-1925	4968	Pico
3S	12W	4	SB	Downey Syndicate well No. 1	Pre-1925		Upper Pico
3S	12W	5	SB	Giant Pet. Co. well No. 1			
3S	12W	5	SB	Lamb, E. A., well No. 1	Pre-1925		
3S	12W	9	SB	Santa Fe Extension well No. 1			
3S	12W	9	SB	Superior Oil Co. well No. "Quill" 1	Pre-1925	3194	Upper Pico
3S	12W	9	SB	Superior Oil Co. well No. "Quill" 1-A	Pre-1925	3070	Upper Pico
3S	12W	11	SB	Chase Oil Co., L. B., well No. 1	Pre-1925	4514	Pico
3S	12W	15	SB	Calpetro Producers Syn. well No. 2	Pre-1925	2170	Upper Pico
3S	12W	15	SB	Calpetro Producers Syn. well No. 2-A	Pre-1925	2170	Upper Pico
3S	12W	16	SB	Clearwater Pet. Co. well No. 1	1925-1926	4250	Upper Pico
3S	12W	16	SB	Clearwater Pet. Co. well No. 2	1927	1700	Pleistocene
3S	12W	17	SB	Huntington-Downey Oil Co. well No. 1	Pre-1925		Pico
3S	12W	17	SB	Huntington-Downey Oil Co. well No. 2			
3S	12W	19	SB	Globe Pet. Co. well No. "Vallecitos" 1	Pre-1925	2030	Upper Pico
3S	12W	21	SB	Clearwater Oil Co., Ltd. well No. 1			
3S	12W	22	SB	Superior Oil Co. well No. 1	Pre-1925	4419	Upper Pico
3S	12W	23	SB	World Pet. Corp. well No. "Bellflower" 11	1929	5008	Upper Pico
3S	12W	24	SB	Marine Corp.; Western Corp. well No. "Strong" 1	1925-1926	5872	Upper Pico
3S	12W	25	SB	Artesia Oil Co. well No. 1	1925-1926	5232	Pico
3S	12W	25	SB	Benson, E. D., well No. 1	1926	5232	
3S	12W	25	SB	Julian Pet. Corp. well No. "Okell" 1			
3S	12W	25	SB	Vanco Dev. Co., Ltd. well No. "Millard" 1			
3S	12W	31	SB	Clayton, George L., well No. 1	1936	6570	Repetto (?)
3S	12W	31	SB	Peoples Oil & Gas Co. well No. 1			
3S	12W	31	SB	Shiflet, R. C., well No. 1	Pre-1925	268	Pleistocene
3S	12W	32	SB	Clayton, George L., well No. "Clayton" 1			
3S	11W	17	SB	Equitable Oil Syn. No. 1 well No. 1-A	Pre-1925	2106	Upper Pico
3S	11W	19	SB	Hawley, Mark L., well No. 1	Pre-1925	1900	Pleistocene
3S	11W	19	SB	Hawley, Mark L., well No. 1-A	Pre-1925	4624	Upper Pico
3S	11W	28	SB	Pet. Midway Co. well No. "Neal" 1	Pre-1925	5495	Upper Pico
3S	11W	29	SB	Union Oil Co. well No. "Gardena" 1			
4S	14W	34	SB	Jergins, A. T., Trust, well No. "Palos Verdes" 1	1925	2782	
4S	14W	35	SB	Pet. Securities Co. well No. "Narbonne" 1	1925-1926	4554	Puente
4S	14W	36	SB	Lewis, E. G., well No. "Palos Verdes" 1	Pre-1925	4498	Puente
4S	14W	36	SB	Pet. Securities Co. well No. "Palos Verdes" 1	1925-1926	2521	Puente
4S	13W	11	SB	Shell Oil Co. well No. "Carson" 1	Pre-1925	6283	Repetto
4S	13W	11	SB	Tenacity Oil Co., Ltd., well No. "Del Amo Est." 1	1932	8580	Repetto
4S	13W	12	SB	Shell Oil Co. well No. "Virginia" 1	1925-1926	5461	Lower Pico (?)
4S	13W	12	SB	Skinner Drilling Co. well	Pre-1925		
4S	13W	14	SB	Marland Oil Co. well No. "Los Cerritos" 1	1925-1926	4504	Middle Pico
4S	13W	17	SB	Black, F. A., well No. 1	Pre-1925	4886	Puente
4S	13W	17	SB	Hansen, Nelson J., well No. "Watson" 1	1930	6297	Puente
4S	13W	17	SB	Oliger, A. L., well No. 1			
4S	13W	17	SB	Packard Oil Corp., Ltd., well No. 1			
4S	13W	17	SB	Wilmington Cons. Oil Co., Ltd. well No. 1			
4S	13W	20	SB	Ewert, W. S., well No. 1			
4S	13W	20	SB	Ewert, W. S., well No. 2			
4S	13W	20	SB	Ewert, W. S., well No. 3			
4S	13W	20	SB	Ewert, W. S., well No. 4			
4S	13W	23	SB	Silverado Oil Co. well No. 1	1925	5955	
4S	13W	31	SB	Carson Oil Corp. well No. "Carson Oil Corp." 1	1937	4013	Upper Puente
4S	13W	31	SB	McAdams Explor. Co. well No. "Paso Verdes" 1	1936	4496	Upper Puente
4S	12W	5	SB	Clayton, George L., well No. "Clayton" 1			
4S	12W	8	SB	The Texas Co. well No. "Mont. Land Co." 1	1929	5531	Pico
4S	12W	11	SB	Caltana Corp. well No. "Caltana" 1	1937	6382	Lower Pico
4S	12W	11	SB	Hilldon Oil Co. well No. "Flood Contol" 1			
4S	12W	17	SB	Black, F. A., well No. 1	1925-1926	4688	Pico
4S	11W	18	SB	Duncan, A. W., well No. "Bixby Midfield" 1	Pre-1925	2000	Upper Pico
5S	14W	1	SB	Keck Syndicate No. 6, well No. 2	Pre-1925	3200	Puente
5S	14W	2	SB	So. Calif. Drilling Co. well No. "Burkhard" 1	1937	1440	Puente
5S	14W	14	SB	Pacific Investment Co., Ltd. well No. 1			
5S	14W	14	SB	Pedro Pet. Corp., Ltd. well No. 1			
5S	14W	14	SB	Wehrman, John Kenneth, well No. 1			
5S	14W	25	SB	L. A. Harbor Dev. Co. well No. 1	Pre-1925	2044	Puente
5S	14W	25	SB	San Pedro-Pt. Fermin Oil & Gas Co. well No. 1	1925-1926	3735	Puente
5S	14W	26	SB	Harbor Land & Oil Co. well	Pre-1925		Puente

MADERA COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
10S	13E	12	MD	Pure Oil Co. well No. "Chowchilla" 5	1936	3045	Cretaceous
10S	14E	6	MD	Pure Oil Co. well No. "Security Co." 1	1936	2777	Kreyenhagen
10S	14E	7	MD	Pure Oil Co. well No. "Chowchilla" 1		8399	Basement
10S	14E	8	MD	Getty, George F., Inc. well No. "Chowchilla" 1	1930	4343	Eocene
10S	14E	8	MD	Pure Oil Co. well No. "Chowchilla" 2		5593	Cretaceous
10S	14E	17	MD	Pure Oil Co. well No. "Chowchilla" 3		2923	Kreyenhagen
10S	14E	20	MD	Pure Oil Co. well No. "Chowchilla" 4	1936	5496	Cretaceous (Panoche)
10S	17E	21	MD	L. A. Madera Co. Syn. well No. "M. & L." 2	1929	2560	Eocene (?)
10S	17E	22	MD	Barnhart-Marrow Cons. well No. "Arnold" 1	1938	3190	Cretaceous
10S	17E	22	MD	Fort-Wayne-Madera Syn. (Rex B. Goodsell, Trustee) well No. 1	1928	2243	Eocene (?)
10S	17E	22	MD	West. Cont. Min., Ltd. well No. "La Golondrina" 1	1936	3111	Cretaceous
12S	15E	27	MD	Seaboard Oil Corp. well No. "Gill" 1	1937	6438	Cretaceous
12S	20E	17	MD	Acme Oil Co. well	Pre-1925	840	
13S	16E	18	MD	Getty, George F., Inc. well No. "Gill" 1	1930	4615	Temblor

MARIN COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
3N	6W	14	MD	McCarthy, C. F., et al. well No. 1	1937	812	
1N	8W	24?	MD	Garzolia Ranch or Duxberry Point wells	1904(?)	1800± (?)	Monterey
1N	8W	25?	MD	Garzolia Ranch or Duxberry Point wells	1904(?)	2800±	Monterey
1N	8W	25?	MD	Garzolia Ranch or Duxberry Point wells	1904(?)		Monterey

MENDOCINO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
19N	13W	30	MD	Mendocino-Midway Syn. well No. 1	1925-1926	2174	Franciscan (?)
12N	17W	3	MD	Point Arena Land Co. well No. "Kyte" 1	(Drilling) 1940-1941		
12N	17W	11	MD	Mendocino Coast Oil Co., Robbins well		2240	Monterey Shale
12N	17W	11	MD	Brandenstein & Silverberg well		780	Miocene
12N	17W	14	MD	Twin State Oil Co. well No. "Soldani" 1	1932	7632	Harder rock beneath Oligocene (?); probably Cretaceous
12N	12W	11	MD	Fresno Co. (?), John D. well		1700	Franciscan (?)

MERCED COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
6S	9E	14	MD	Turlock Oil & Gas Co. well No. 1-A	Pre-1925	3152	Kreyenhagen
6S	10E	24	MD	Cornell, Cox, & Meirdiercks well No. 3	1931	1159	
6S	10E	24	MD	Delhi Oil Assoc. well No. 2	1931	4620	Hard sand
6S	11E	19	MD	Delhi Oil Assoc. well No. "Delhi Drill. Trust No. 1"	1931	1180	
7S	16E	22	MD	Fantz, E. R. (Att'y-in-Fact) well No. "Cunningham" 1			
9S	9E	31	MD	Kuns, Henry L., well No. 1	Pre-1925	200	Pleistocene (?)
9S	17E	4	MD	Le Grande Syn. well No. 1	1932	3605	
10S	9E	8	MD	Murrell, T. R., well No. 1	1937	1200	Cretaceous (?)
10S	11E	19	MD	Amerada Pet. Corp. well No. "Cavano" 1	1938	8385	Cretaceous
12S	9E	5	MD	Kuns, Henry L., well No. 2	1930	850	Cretaceous
12S	9E	8	MD	Kuns, Henry L., well No. 3	1930	550	Cretaceous
12S	9E	9	MD	Kuns, Henry L., well No. 1	1930	1200	Cretaceous
12S	11E	1	MD	San Joaquin Oil Co. well No. 1	1936	5024	Cretaceous
12S	11E	8	MD	Stone, Elmer B., well No. 1	1939	1981	Eocene
12S	11E	12	MD	Milham Exploration Co. well No. "Ora Loma" 1	1935	5802	Eocene

MONO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
3N	29E	19	MD	Bauchwitz, Fred, well No. "Almedia" 1	1934	836	
2N	26E	29?	MD	Paoha Island well		900	
2N	26E	29?	MD	Paoha Island well		2010	Blue shale

MONTEREY COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
12S	2E	29	MD	Western Gulf Oil Co. well No. "Johnson" 1	1933	3198	Granite
13S	2E	6	MD	Elba Oil Co. well No. "Elba" 1	Pre-1939	3970	Pliocene
15S	2E	24	MD	Danish Oil & Dev. Co. well No. "Sta. Rita" 1	Pre-1925	795	
19S	5E	11	MD	The Texas Oil Co. Arroyo Seco well		4265	Upper Relizian
19S	5E	13	MD	The Texas Oil Co. well No. "E. T. Lewis" 1	1938	4537	Upper Relizian
19S	6E	20	MD	Jones Oil Co., Harriman, well No. 1	1925	4610	Monterey
19S	6E	21	MD	Jones Oil Co., Harriman, well No. 2	1925–1926	150	Monterey
19S	6E	35	MD	Okell Well Mch. Co. well No. 1	1925	295	Monterey
19S	6E	35	MD	Okell Well Mach'y Co. well No. 2	Pre-1925	1000	Monterey
19S	7E	30	MD	The Texas Co., well No. "Dunphy" 1	1937	4759	Lower Miocene (?)
19S	9E	14	MD	Doheney well	Pre-1914	900	Granite
19S	10E	5	MD	Clark, Sam well No. 1	1927-1928	960	
19S	10E	7	MD	Lonoak Oil Co. well No. 1	Pre-1914	2700	Granite
19S	10E	9	MD	Salinas well No. 1	Pre-1921	450	
19S	10E	9	MD	Salinas Oil Co.	Pre-1936	1200	Late Miocene ss.
19S	10E	19	MD	Standard Oil Co. well No. "Tompkins" 1	Pre-1914	1794	Santa Margarita
19S	10E	19	MD	Standard Oil Co. well No. "Tompkins" 2	Pre-1914	1600	Sandstone and shale
19S	10E	28	MD	Standard Oil Co. well No. "Landrum" 1	Pre-1914	2965	Santa Margarita
20S	6E	12	MD	Santa Lucia Oil Co. well No. 1	Pre-1925	1170	
20S	6E	16	MD	Ross & Herbert well No. 1	Pre-1925	110	Monterey
20S	7E	3	MD	Henigene & Schwenigan well No. "Smart" 1	1926	3725	
20S	9E	12	MD	The Texas Co. well No. "Gabilan Mesa" 3	1938	658	Miocene
20S	9E	14	MD	The Texas Co. well No. "Gabilan Mesa" 2	1938	1189	Miocene
20S	9E	30	MD	The Texas Co. well No. "Gabilan Mesa" 4	1938	784	Miocene
20S	10E	12	MD	Homestead Dev. Co.	Pre-1925	1300	Cretaceous (?)
20S	10E	24	MD	Union Oil Co. well No. "Miller" 1	Pre-1914	2600	
21S	8E	4	MD	Excelsior Oil Co. well No. 1	1927	685	
21S	9E	12	MD	Rosebrand Pet. Co. well No. 1	1925	2960	
21S	9E	26	MD	Pyramid Oil Co. well No. "Tresceny" 1	1932	3200	
21S	10E	10	MD	The Texas Co. well No. 1	1938	2642	Miocene
22S	7E	23	MD	Standard Oil Co. well No. "Piedmont" 1	1931	6093	Vaqueros
22S	8E	8	MD	Union Oil Co. well No. "Page" 1	1930	3215	Vaqueros
22S	9E	2	MD	Pet. Securities Co. well No. "Aniotzbehere" 1	1927	2655	
22S	9E	12	MD	Newell well	Pre-1918	1310	Oil sand
22S	9E	12	MD	San Ardo Cons. Oil Co. well No. 1		846	Shale
22S	9E	15	MD	Shell Oil Co. well No. "Dudley" 1	1929	5466	Schist
22S	9E	36	MD	Douglas, James M., well No. "Smith" 1	1934	4158	Vaqueros
22S	10E	6	MD	San Ardo Cons. Oil Co. well No. 2		1000	
22S	10E	19	MD	Capt. Barrett well	Pre-1918	1000	
22S	10E	19	MD	Tomboy Oil & Improvement Co.		700	
22S	10E	19	MD	Tomboy Oil & Improvement Co.	1901	1325	
22S	10E	20	MD	Doheney well (No. 1 ?)		1000	
22S	10E	20	MD	San Antonio Oil Co.	Pre-1914	700 (?)	River gravel
22S	10E	29	MD	San Antonio Oil Co.	Pre-1914	700 (?)	River gravel
22S	10E	30	MD	San Antonio Oil Co.	Pre-1914	700 (?)	River gravel
22S	11E	36	MD	Standard Oil Co., Powell well	Pre-1918	1800	
22S	13E	31	MD	Eureka Oil Co., Eureka well		800	Granite
22S	14E	31	MD	Cholame Valley Oil & Dev. Co. 4 wells	Pre-1900	950 800 200 200	
22S	14E	31	MD	Parkfield-San Antonio Oil Co.	Pre-1914	100	
22S	14E	31	MD	Thomas Pet. Corp. well No. "Flentge" 1			
22S	14E	31	MD	Thomas Pet. Corp. well No. "Flentge" 2			
22S	14E	31	MD	Thomas Pet. Corp. well No. "Flentge" 3			
22S	14E	31	MD	W. I. T. Syn. well No. "Flentge" 4		163	
22S	14E	32	MD	Waverly Oil Co. well		800	Monterey shales
23S	10E	4	MD	Norman Oil Co.			
23S	11E	1	MD	Standard Oil Co. well No. "Powell" 1	Pre-1914	875	Pliocene (?)
23S	13E	27	MD	Pet. Securities Co. well No. "White" 1	1927	3405	Temblor (near granite)
23S	13E	34	MD	Cholame Syn. well No. 1	Pre-1925	2525	Temblor
23S	14E	5	MD	Well No. 2			

MONTEREY COUNTY—Continued

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
23S	14E	8	MD	Garland, W. W., well No. 1	Pre-1925	1909	
23S	14E	8	MD	Monterey Oil Co. well No. "Oak Shade" 1	Pre-1925	1910	Monterey (?)
23S	14E	13	MD	Parkfield-Spokane Co. well No. 1		110	Shale
23S	14E	13	MD	Parkfield-Spokane Co. well No. 2		245	
23S	14E	13	MD	Parkfield-Spokane Co. well No. 5		513	
23S	14E	13	MD	Table Mountain Oil Co., Miller or Raymond well		800	
23S	14E	15	MD	Taylor, Clyde F., well No. 1	1934	997	
23S	14E	15	MD	Pacific Oil Co. well No. 1	Pre-1924	3000	Miocene (?)
23S	14E	15	MD	Tri County Oil Co. well No. 1	Pre-1925	4160	Santa Margarita (?)
23S	14E	16	MD	Parkfield Oil Co.	Pre-1900	100	
23S	14E	18	MD	Middle Ridge Oil Co.		1700	
23S	14E	25	MD	Paso Robles Asso. Oil well No. 1	Pre-1925	650	
23S	14E	26	MD	Parkfield Syndicate		500	Vaqueros sandstone
23S	15E	18	MD	(A Canadian Co.)		250	Franciscan
23S	15E	18	MD	Future Success Co. Livermore well	Pre-1936	1815	Franciscan serpentine
23S	15E	19	MD	Dominion Well		150–300	Serpentine
23S	15E	19	MD	Pacific Inland Oil Co. well No. 1	1934	3100	Franciscan
23S	15E	33	MD	California Oils, Inc. well No. 1	1938(?)	2532	Miocene
24S	10E	26	MD	Pleyto Oil Co.	1912	3300	
24S	10E	27	MD	Monterey Oil Co.	1914	1100	Monterey
24S	10E	34	MD	Shell Oil Co. well No. "Branch" 1	1937	8994	Vaqueros
24S	10E	34	MD	Shell Oil Co. well No. "Branch" 2	1937	8662	Vaqueros
24S	10E	35	MD	Great American Oil Co. well			
24S	10E	35	MD	Hames Valley Oil Co., Metropolis well	1913	3100	
24S	10E	35	MD	Veratina well	Pre-1921		
24S	10E	35	MD	White Oaks Oil Co.	1918	800	
24S	10E	36	MD	Associated Oil Co. well No. "King" 1	Pre-1919	2035	
24S	11E	8	MD	Oak Ridge Oil Co. well No. "Sargent" 1	1936	3986	Monterey
24S	11E	32	MD	Continental Oil Co. well No. "Nacimiento" 1	1929	5955	Vaqueros
24S	12E	32	MD	Shell Oil Co. well No. "Flint" 1	1921	4665	Monterey
24S	14E	15	MD	Anderson, Amil A., well No. "Hillman" 1	1939	4004	
24S	14E	16	MD	Baker Oil Co. well	Pre-1918	1600	Monterey shale

NAPA COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
10N	3W	32	MD	Mount Shasta Oil Co. well No. "Ferguson" 1	1904	400	Lower Cretaceous
9N	3W	6	MD	Wreden, C. V. well	1937	1024	Lower Cretaceous
9N	3W	25	MD	Fearless Oil Co. well No. 1	1904	1475	Lower Cretaceous
9N	3W	25	MD	Mount Shasta Oil Co. well	1936	400	Lower Cretaceous
8N	3W	4	MD	Sugar Loaf Oil Co. well No. 1	1922	400	Lower Cretaceous
8N	3W	4	MD	Sugar Loaf Oil Co. well No. 2	1922		Lower Cretaceous
8N	3W	7	MD	Griffiths, W. B., et al. well No. 6	1939	4515	Lower Cretaceous
8N	3W	7	MD	Griffiths Oil Co. well No. 5 (new)	1925	3710	Lower Cretaceous
8N	3W	19	MD	Callahan, John E., well No. "Prospect" 1			Knoxville
8N	3W	20	MD	Rambke, H. (2 wells)			Lower Cretaceous
8N	3W	29	MD	Associated Oil Co. well No. 1	1922	505	Knoxville
8N	3W	29	MD	Associated Oil Co. well No. 2	1922	1700+	Knoxville
8N	3W	29	MD	Carter, J. H., well No. "Prospect" 1			Knoxville
8N	3W	29	MD	Griffiths Oil Co. well No. 2	1930	50	Knoxville
8N	3W	29	MD	Griffiths Oil Co. well No. 3	1930	65	Knoxville
8N	3W	29	MD	Griffiths Oil Co. well No. 4	1930	153	Knoxville
8N	3W	29	MD	Lincoln & Kuhns well No. 1	1936	295	Cretaceous
8N	3W	29	MD	Lincoln & Kuhns well No. 2	1938	426	Cretaceous
8N	3W	29	MD	Lincoln & Kuhns well No. 3	1939	942	Cretaceous
8N	3W	29	MD	Napetro Pet. Syn. (Rambke, H., et al.) well No. 1	1925	360	
8N	3W	29	MD	Napetro Pet. Syn. (Rambke, H., et al.) well No. 2	1925		
7N	3W	15	MD	Capell Oil Corp. well No. 1	1923	854	Lower Cretaceous (?)
5N	4W	10	MD	East Napa Mining Co. well	1914	1200	
4N	5W	12	MD	Northern Calif. Pet. Co. well No. 1	1930	3875	Cretaceous

ORANGE COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
3S	10W	27	SB	Dolke Syn., Thos., well No. 1	Pre-1925	2122	Pico
3S	10W	27	SB	Dolke Syn., Thos., well No. 1-A	Pre-1925	2176	Pico
3S	9W	12	SB	National Expl. Co. well No. "Chino" 1	Pre-1925	2418	Puente
3S	9W	13	SB	General Pet. Corp. well No. "Rimpau" 1	1930	4865	Puente
3S	9W	24	SB	Keoughan, S. H., Trustee, well No. 1	Pre-1925	5395	Puente (?)
3S	8W	7	SB	Quadri Pet. Co. well No. 1			
3S	8W	29	SB	Capitol Oil Co. well No. 1	1925-1926	3224	
3S	8W	29	SB	Capitol Oil Co. well No. 3		1600	
3S	8W	36	SB	Calny Oil Co. well No. "Irvine" 1	1927	4247	
3S	8W	36	SB	New York-Calif. Oil Co. well No. 1	1925	600	
4S	11W	2	SB	Standard Oil Co. well No. "Mitchell" 1	Pre-1925	5384	Upper Pico
4S	11W	9	SB	Ohio Oil Co. well No. "G. B. Miller" 1	1928	6079	Upper Pico
4S	11W	11	SB	Petroleum Midway Co. well No. "Bennett" 1	Pre-1925	2409	Upper Pico
4S	11W	16	SB	Jones, Chas. T. B., well No. 1	Pre-1925	3944	Upper Pico
4S	11W	19	SB	Shell Oil Co. well No. "Llewellyn" 1	Pre-1925	5542	Pico
4S	11W	36	SB	Oregon California well No. 1	Pre-1925		
4S	10W	7	SB	Superior Oil Co. well No. "Brookhurst" 1	Pre-1925	5005	Upper Pico
4S	10W	9	SB	Shell Oil Co. well No. "Harbeson" 1	1937	8608	
4S	10W	13	SB	Standard Oil Co. well No. "Wagner Comm." 1	Pre-1925	5635	Pico
4S	10W	17	SB	Miley, E. J., well No. 1	Pre-1925	3825	Upper Pico
4S	10W	17	SB	Miley, E. J., well No. 1-A	Pre-1925	5312	Upper Pico
4S	10W	23	SB	Shell Oil Co. well No. 1	1937	5944	
4S	10W	32	SB	Standard Oil Co. well No. "Chaffee" 1	Pre-1925	5525	Pico
4S	10W	35	SB	The Texas Co. well No. "Crawford" 1	1929	5342	Pico
4S	9W	6	SB	Harrington-Dumas well No. 1	Pre-1925		
4S	9W	6	SB	Superior Oil Co. well No. "Davis" 1	1929	1418	Pico
4S	9W	7	SB	The Texas Co. well No. "Olive Comm." 1	1931	5434	Pico
4S	9W	8	SB	Olive Pet. Co. well No. 1		3640	
4S	9W	9	SB	Jameson Oil Co. well No. 1	1924	4710	
4S	9W	9	SB	Long B. Cons. Oil Co. well No. 1	1921	2678	
4S	9W	9	SB	Long B. Cons. Oil Co. well No. 2			
4S	9W	9	SB	Olive-Ventura Oil Corp. well No. 1		4710	
4S	9W	11	SB	Bixby Lease No. 1, well No. 1	1922	4673	Repetto
4S	9W	14	SB	Northland Oil Co. well No. "Irvine" 1		1050	
4S	9W	14	SB	Northland Oil Co. well No. 1-A		1945	
4S	9W	17	SB	Standard Oil Co. well No. "Zaiser-Brelje Comm." 1	1927	5045	Miocene vol.
4S	9W	24	SB	Orange County Pet. Co. well No. 1		2646	
4S	9W	29	SB	Orange Comm. Oil Ass'n well No. 1	Pre-1925	5000	Pico (?)
4S	8W	30	SB	National Security Oil Co. well No. 1	1925	5147	
5S	11W	2	SB	Walton, J. H. well No. 1	1932	4612	Middle Pico
5S	11W	2	SB	W. Santa Ana Oil Co. well No. 1		4610	Pico
5S	11W	13	SB	McCollum & Taylor well No. "Sterling Price" 1	1928	5864	Repetto
5S	11W	14	SB	Hillman-Long, Inc., well No. "Westminster" 1	1936	8705	Upper Puente
5S	11W	14	SB	Westminster Oil Co. well No. 1	Pre-1925	4438	Lower Pico
5S	11W	16	SB	Guiberson, S. A., Jr., well No. 1	1935	3282	Pico
5S	11W	17	SB	Terry, George, well No. "Westminster Gun Club" 1	1936	5345	Repetto
5S	11W	18	SB	Shell Oil Co. well No. "A. L. & W. Co." 1	1930	4573	Repetto
5S	11W	19	SB	General Pet. Corp. well No. "Lomita" 1	1927	5454	Repetto
5S	11W	19	SB	Olympic Refining Co. well No. 1	1928	5557	Repetto
5S	11W	19	SB	Superior Oil Co. well No. "Alamitos" 1	1934	5823	Repetto
5S	10W	5	SB	Portland Pet. Corp. well No. "Adlai" 1	Pre-1925		
5S	10W	14	SB	Continental Oil Co. well No. "Santa Ana Comm." 1	1935	4411	Pico
5S	10W	27	SB	Standard Oil Co. well No. "Santa Ana Gardens" 1	1925-1926	5219	Pico
5S	10W	30	SB	Shell Oil Co. well No. "Von Schriltz" 1	1925-1926	5128	Pico
5S	9W	5	SB	Son, Charles A., Trustee (Shoreline Oil Co.) well No. "Orangeana" 1	1928	3625	
5S	9W	6	SB	Trustees Dev. Ass'n well No. 1	1925-1926	4144	Pico
5S	9W	31	SB	Gale, Hoyt S., well No. "Irvine" 1	1925-1926	2224	Miocene
5S	7W	34	SB	Sunrise Cons. Oil Co. well No. 1	1925	850	
6S	10W	7	SB	Julian Pet. Corp. well No. "Farnsworth" 1	1925-1926	1490	Pico
6S	10W	7	SB	Julian Pet. Corp. well No. "Farnsworth" 2	1925-1926	3910	Pico (?)
6S	10W	7	SB	Shell Oil Co. well No. "Anaheim" 1	1936	3518	Pico
6S	10W	7	SB	Shell Oil Co. well No. "Anaheim" 3-1			
6S	10W	18	SB	Western Drill. & Prod. Co. well No. "Meyer" 1	1929	2261	
6S	10W	18	SB	Western Drill & Prod. Co. well No. "Pacific" 1	1929	4461	Puente
6S	10W	19	SB	Bradford, W. G. (B. & B. Oil Co.) well No. "B. B." 1	1935	4586	

ORANGE COUNTY—Continued

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
6S	9W	14	SB	H. T. & K. Syn. well No. 1	Pre-1925	3775	Miocene
6S	9W	18	SB	W. G. R. Oil & Pet. Co. well No. 1	Pre-1925	3005	Miocene
6S	9W	18	SB	Wucherer-Gray Oil Co. well No. 3	1925-1926	4880	Miocene
6S	9W	19	SB	W. A. G. Oil Co. well No.1	Pre-1925	4305	Miocene
6S	9W	19	SB	Wucherer-Gray Oil Co. well No. 2	1925-1926	5194	Miocene
6S	9W	20	SB	San Joaquin Hills Oil Co. well No. 1	Pre-1925	1150	Miocene
6S	9W	20	SB	Wucherer-Gray Oil Co. well No. 1	1925-1926	4305	Miocene
6S	9W	20	SB	Wucherer-Gray Oil Co. well No. 4	1925-1926	2037	Miocene
6S	9W	22	SB	Northland Oil Co. well No. "Irvine" 1	1921	1238	
6S	9W	23	SB	Northland Oil Co. well No. 1		1970	
6S	9W	23	SB	Northland Oil Co. well No. 1-A	1922	1970	Miocene
6S	7W	12	SB	Tepothol Oil Co. well No. 1	1928	2500	Slate
7S	8W	9	SB	Hartman, Roy, well No. 1	1925-1926	4437	Miocene
7S	8W	25	SB	Laguna Beach Oil Co. well No. 1	Pre-1925	5000	Miocene (?)
7S	7W	30	SB	Union Oil Co. well No. "O'Neill" 1	1921	4530	Sespe
8S	8W	13	SB	Carr, O. K., well No. 1	1928	3961	Sespe
8S	8W	13	SB	Robinson, Edward H., well No. 1		2414	
8S	7W	8	SB	Mineral Expl. Co. well No. "Echenique Rancho" 1	1934	4303	

RIVERSIDE COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
2S	7W	35	SB	Tannehill, L. B., well No. 1	1925	525	
2S	6W	15	SB	Kosanke, J. F., well No. 1	1937	896	
2S	5W	31	SB	Arl Oil Co. well No. 1	Pre-1925	1125(?)	
2S	3W	14	SB	Cheney Oil Lease Syn., well No. 1	1926	1950	
2S	2W	16	SB	Beaumont Midway Oil Co. well No. 1	1926	5358	
2S	2W	16	SB	Midway Oil Syn. well No. 1			
2S	2W	35	SB	Alberta Oil Co. well No. 1	1933	3180	
2S	1W	12	SB	Riverside County Oil Co. well No. 1	Pre-1925	2235	
2S	3E	25	SB	Painted Hills Oil Ass'n well No. 1	1925	1400	
2S	4E	11	SB	Amundson, Floyd, well No. 1	1926	212	
2S	4E	14	SB	Century Oil Ass'n well No. 1	Pre-1925	500	
2S	4E	30	SB	Painted Hills Oil Ass'n well No. 2	Pre-1925	400	
2S	4E	33	SB	Wallenberg well No. "Daisy" 1	Pre-1925		
3S	7W	2	SB	Corona Oil Co. well No. 1			
3S	7W	26	SB	Neuvo Oil Co. well No. 1			
3S	7W	27	SB	Corona Oil Co., Ltd. well No. "Wardlow" 1			
3S	7W	27	SB	Stevens, Fred E., well No. "Everett" 1			
3S	6W	25	SB	Easton-Monell well No. 1	1933	3090	
3S	5W	6	SB	Arl Oil Co. well No. 1	Pre-1925		Granite
3S	5W	32	SB	Santa Ana Canyon Oil Co. well No. 1	Pre-1925	4165	
3S	4W	12	SB	Mathews Rowland & Dalziel well No. 1	1927	2610	Granite (?)
3S	2W	15	SB	Moreno Oil Co. well No. 1	1925	1700	
3S	2W	26	SB	Nuevo Oil Co. well No. 1		2225	
3S	1W	15	SB	Beaumont Crude Oil Co. well No. 1	Pre-1925	1925	
3S	1W	15	SB	Rippeto, L. W., well No. 1		1270	
3S	2E	3	SB	Clark, L. R., well No. 1			
3S	2E	5	SB	Clark, L. R., well No. 5	1928	1960	
3S	3E	9	SB	Cabazon Oil Co. (Cabazon Central Oil Co.) well No. 1	Pre-1925	650	
3S	4E	5	SB	Banning Oil Co. well No. 1	1930	975	
4S	6W	28	SB	Trabuca Oil Co. well No. 1	1931	4500	
4S	6W	28	SB	Trabuca Oil Co. well No. 1-A	1931	4490	
4S	2W	2	SB	Nuevo Oil Co. well No. 1	1926	2225	
5S	5W	36	SB	Great Coastal Oil Corp. well No. 1	1937	2991	Basement
5S	1W	10	SB	Hemet Pet. Corp. well No. 1	1931	3625	
5S	1E	23	SB	Pioneer Oil Syn. well No. 1	1923	460	
7S	3W	14	SB	Murrietta Valley Oil Co. well No. 1	1925-1926	1120	Jurassic
7S	3W	23	SB	Hall, Holtz, & Hennessy, Trustees (Fidelity Realty Corp.) well No. "Watt" 1	1929	956	
7S	3W	23	SB	Hall, Holtz, & Hennessy, Trustees (Fidelity Realty Corp.) well No. "Watt" 2	1936	2786	Jurassic
7S	10E	25	SB	Spindle Top Oil Ass'n well No. 1		3800	

SACRAMENTO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
9N	6E	8	MD	Central Pet. Co. well No. 1	1925	2868	
8N	4E	11	MD	Pacific Gas & Electric Co. well No. 2	1932	1790	
8N	4E	11?	MD	Sacramento Natural Gas Co. well No. 1		1300–1400	Gas producer
8N	4E	11?	MD	Sacramento Natural Gas Co. well No. 2		1800	Gas producer
8N	4E	11?	MD	Sacramento Natural Gas Co. well No. 3		2005	Gas producer
8N	4E	11?	MD	Sacramento Natural Gas Co. well No. 4		1600–1700	Gas producer
8N	4E	11?	MD	Sacramento Natural Gas Co. well No. 5		1600–1700	Gas producer
8N	4E	11?	MD	Sacramento Natural Gas Co. well No. 6		1560	Gas producer
8N	4E	11?	MD	Sacramento Natural Gas Co. well No. 7		1680	Gas producer
8N	4E	11?	MD	Sacramento Natural Gas Co. well No. 8		2016	Gas producer
8N	4E	11?	MD	Sacramento Natural Gas Co. well No. 9		2212	Shale; gas producer
7N	8E	28	MD	Sacramento Pet. Co. well No. "Meiss" 1	1931	1214	
7N	6E	19	MD	Independent Drilling	1940	4800±	Basement
6N	7E	25	MD	Associated Dev. Co. well No. "Mitchell" 1	Pre-1925	2000	
6N	7E	25	MD	Associated Dev. Co. well No. "Mitchell" 2	1926	2963	
6N	7E	25	MD	Great American Pet. Co. well No. "Rubens" 1	1937	3045	Cretaceous
6N	7E	36	MD	Laguna Oil Co. well No. 1	Pre-1925	1357	

SAN BENITO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
12S	4E	10	MD	Petroleum Midway Oil Co. well No. "Miller & Lux" 1	1925	5200	
12S	4E	31	MD	McAbee, L. A., well No. 1-A	1932	2170	
12S	4E	33	MD	Harper, Henry, well No. 1	1932	1490	
13S	5E	10	MD	Simms, James, well No. "Skow" 1		1396	
16S	10E	13	MD	Panoche, S. F., well	Pre-1925		
16S	11E	19	MD	Hamiltonian Oil Co. well No. 1	Pre-1925	225	Pleistocene
17S	8E	15	MD	Standard Oil Co. well No. "Brown" 1	Pre-1921		Granite
17S	8E	27	MD	Standard Oil Co. well No. "Stone" 1	Pre-1925	2610	
17S	8E	28	MD	Standard Oil Co. well No. "Leonard" 1	Pre-1925	753	
17S	9E	33	MD	Standard Oil Co. Le Franc well	Pre-1925	2408	
17S	10E	32	MD	McMurty Hoeffner well No. 1	Pre-1936	1462	
17S	11E	3	MD	Range 16 Oil Co.'s well No. 1	Pre-1921	2300	Miocene (?)
17S	11E	8	MD	Cal-O-Tex Expl. Co. well No. 1	1936	1957	
17S	11E	8	MD	Merced Paraffine Oil Co. well No 1	Pre-1925	1500	Eocene (?)
17S	11E	8	MD	Reilly well	Pre-1921	1500	Vaqueros
17S	11E	8	MD	Homestake Oil Co. well No. 1	1929	300	Eocene
17S	11E	8	MD	San Carlos well (?)	1901	200	
17S	11E	8	MD	Snelling well	Pre-1921	1000	Kreyenhagen shale
17S	11E	12	MD	Vallecitos Dev. Co. well No. 1	1911	2000	
17S	11E	14	MD	Homestake Oil Co. well No. 2	1929	376	Eocene (?)
17S	11E	14	MD	Homestake Oil Co. well No. 3	1932	510	Eocene (?)
17S	11E	14	MD	Homestake Oil Co. well No. 4		600	
17S	11E	24	MD	Hamiltonian Oil Co., Hamiltonian well		1500	Martinez (?)
17S	12E	5	MD	Hadley, G. H., Jr., well No. 1		500	
17S	12E	5	MD	New Bedford well			
17S	12E	6	MD	New Bedford Oil Co. well No. 1	Pre-1936	3000	Martinez (?)
17S	12E	18	MD	Calistoga well	Pre-1921	1100	Jacalitos and Etchegoin clay
18S	9E	36	MD	Union Oil Co. well No. "Griffin" 1	Pre-1925	3480	Igneous
18S	10E	32	MD	Lonoak Oil Co. well No. 2	Pre-1914	3009	Blue shale
18S	10E	32	MD	Nonpareil well No. 3	Pre-1936	1300	
18S	10E	33	MD	Alvarez Oil Co. well No. 1	Pre-1936	900	
18S	10E	33	MD	Nonpareil Oil Co. well No. 1	Pre-1936	1038	Blue shale
18S	10E	33	MD	Nonpareil Oil Co. well No. 2	Pre-1936	653	
19S	10E	5	MD	Associates Pet. Corp. well No. 2	1928	1108	
19S	10E	5	MD	Clark, Sam, well No. 1	1927	975	

SAN BERNARDINO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
11N	1W	35	SB	Chicago Oil Co., well No. 1	Pre-1936	2000	
10N	5W	2	SB	Mojave Basin Oil Co. well No. 1	1933	700	Non-marine
10N	5W	11	SB	Equitable Pet. Expl. Co. well No. 1		2187	
10N	5W	11	SB	Interstate Oil Co. well No. 3	Pre-1925	2942	Igneous rock (?)
10N	5W	11	SB	Kramer Cons. Oil Co. well		3000	
10N	4W	3	SB	Western Pacific Oil Co. well No. 3	1933	3417	
10N	4W	4	SB	Western Pacific Oil Co. well No. 2	1932	3397	
5N	6W	22	SB	Victor Valley Land Owners Oil & Gas Corp. well No. "Victor" 1	1936	3216	
4N	4W	29	SB	Hesperia Oil & Gas Co. of Calif. well No. 1	1925	3103	
4N	4W	29	SB	Hesperia Oil & Gas Co. of Calif. well No. 1-A			
4N	1W	17	SB	Peterson, P. M., well No. "Moore" 1		1470	
3N	6W	14	SB	Como Oil Co. well No. 1	1933	2880	
3N	6W	22	SB	Braly, Carl E., well No. "Davis" 1	1935	442	
3N	6W	24	SB	Taylor, E. D., well No. 1	1933	1560	
3N	24E	23	SB	Honolulu Oil Corp. well No. "Valenzuela" 1	1933	7873	Fernando
1N	6W	6	SB	Marquardt, J. C., well No. 1	Pre-1925		
1N	4W	6	SB	San Pedro Oil & Dev. Co. well No. 1	Pre-1925		
1N	4W	13	SB	Del Rosa Oil & Gas Co. well No. 1	1926	2460	
1S	8W	34	SB	B. & G. Dev. Co. well No. "Bruce" 1	1931	4110	
1S	7W	26	SB	Italian Vineyard Co. well No. 1	1924	1320	
1S	5W	25	SB	Colton Terrace Oil Co. well No. 1	1930	1779	
1S	4W	16	SB	S. B. & Colton Oil Co. well No. 1	1922	160	
1S	4W	16	SB	S. B. & Colton Oil Co. well No. 2	Pre-1925	600	
2S	8W	7	SB	Great American Pet. Co. well No. D-1	1935	1010	
2S	8W	8	SB	Gerrard-Grimes Oil Co. well No. 1	1930	1502	
2S	8W	11	SB	Summar, C. S., well No. 1	Pre-1925	1559	
2S	8W	17	SB	Theriot, J. C., well No. 1	1923	710	
2S	8W	18	SB	Great American Pet. Co. well No. "Gapco" A-1	1935	2640	
2S	8W	18	SB	Great American Pet. Co. well No. "Gapco" B-1	1937	3142	Miocene
2S	8W	19	SB	Pomona Oil Co. well No. 1	1923	5276	
2S	8W	21	SB	Lamona Oil Ass'n well No. "Vizio" 1	1927	900	
2S	8W	28	SB	Pomona Pet. Co. well			
2S	8W	30	SB	Chino Valley Beet Sugar Co. well No. 1	Pre-1921		
2S	8W	32	SB	Bannon, Thos. C., well No. 1			
2S	8W	32	SB	Chino Land & Water Co. well	Pre-1921		
2S	8W	32	SB	Riner, H. E., well No. 2		624	
2S	8W	32	SB	Zenith Oil Co. well No. 3	1925	550	
2S	8W	33	SB	Sherman, John W., et al., well No. 1	1932	843	
2S	8W	33	SB	Tehama Pet. Corp. well No. "Kraemer-Backs" 1		1296	
2S	7W	31	SB	Marker & Collier well No. "Ranger" 1	Pre-1925	2138	
3S	8W	1	SB	Chino-Corona United Oil Co. well No. 1	1923	4850	Jurassic
3S	8W	2	SB	Hillman-Long, Inc., well No. "Pellisier" 1	1936	2412	Repetto
3S	8W	11	SB	Clampett Bros. well	1912	3000	
3S	8W	12	SB	Western Gulf Oil Co. well No. "Abacherli" 1	1938 (?)	3267	Sespe (?); oil producer
3S	8W	12	SB	Melbourne Oil Co. (Chino Pet. Co.) well No. "Abacherli" 2	1936	2233	Oil producer
3S	8W	12	SB	Selegna Drilling Co. well No. "Abacherli" 3	1938	3159	Sespe ? lithology
3S	8W	13	SB	Mahala Oil & Gas Co. well No. 1	1938 (?)	4217	Oil producer
3S	8W	13	SB	Mahala Oil & Gas Co. well No. 2	1927	5080	Miocene
3S	8W	13	SB	West, W. W., well No. 1		4010	
3S	7W	6	SB	Riggins Oil Co. well No. "Pate" 1	1928	820	

SAN DIEGO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
11S	5W	24	SB	Oceanside Oil & Gas Co. well		1600	
12S	4W	26	SB	Clark, Laura F. well		2265	
12S	4W	26	SB	La Costa Oil Co. well		2665	
12S	4W	26	SB	Pacific-Laguna Co. well	Pre-1921	1400	
12S	2W	15	SB	Turner, Stanley S., well No. 1	1931	2149	
13S	4W	15	SB	San Diego Oil Co. well		400	
13S	4W	24	SB	Cardiff Oil Corp. well No. "Turner" 1	1928	2802	Eocene
14S	3W	17	SB	McGregor Corp. well No. "Butler" 1-A	1931	2925	
14S	3W	18	SB	McGregor Corp. well No. "Butler" 1	1929	1460	
15S	3W	8	SB	Mills Oil Co. well No. 1	1928	2775	
15S	3W	23	SB	San Diego Dome Drill. Fund well No. 1	1931	1250	
15S	3W	23	SB	Linda Vista Petroleum Co. well		1095	

SAN DIEGO COUNTY—Continued

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
16S	3W	13	SB	Balboa Oil Co. well No. 1	Pre-1920	5675	
16S	3W	24	SB	Mission Valley Oil Enterprise well No. 1	1929	5501	
16S	3W	30	SB	Borderland Expl. Co., Inc. well No. "Point Loma" 1	1932	5101	Fine-grained crystalline rock
18S	2W	3	SB	Chula Vista well	Pre-1936	1812	
18S	2W	22	SB	National City Oil Co. well No. 1	1930	2625	Pliocene (?)
18S	2W	32	SB	San Diego Gas & Pet. Corp. well No. 1 (also known as Holderness No. 1, and Saratoga No. 1)	1936	6334	Black Mountain formation
18S	2W	33	SB	Itasca Pet. Co. well No. "Otay Mesa" 1	1937	1560 (?)	Pliocene (?); Metamorphosed ss
18S	1W	30	SB	Otay Oil Co. well	Pre-1936	2185	
18S	1W	31	SB	Lo Tengo Oil Co. well	Pre-1936	3400	
19S	2W	4	SB	Community Oil Co. well No. 2	Pre-1920	119	
19S	2W	5?	SB	Tia Juana well		1405	
19S	2W	9	SB	Community Oil Co. well No. "Scott" 1	Pre-1921	1474	

SAN JOAQUIN COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
4N	7E	12	MD	Pacific Pet. Producers well No. 1	1932	1975	Cretaceous
4N	8E	7	MD	Alliance Oil Co. well No. 1	Pre-1925	900	Cretaceous
1N	5E	21	MD	Madison, Lemos & Mattos well No. "Budd" 1	1934	1040	Cretaceous
1N	5E	24	MD	Standard Oil Co. well No. "Woods Comm." 1	1937	7014	Cretaceous
1N	6E	2	MD	Pacific Gas & Elect. Co. well No. 4	1932	1720	Miocene (?)
1N	6E	2	MD	Pacific Gas & Elect. Co. well No. 5	1936	2071	Miocene (?)
1N	6E	2	MD	Pacific Gas & Elect. Co. well No. 10	1932	2006	Miocene (?)
1N	6E	3	MD	Pacific Gas & Elect. Co. well No. "Citizens" 1	1932	2000	Miocene (?)
1N	6E	3	MD	Pacific Gas & Elect. Co. well No. "Citizens" 2	1936	1850	Miocene (?)
1N	6E	7	MD	*Utilities Petro. Corp. well No. "Rough and Ready Island 1"	1939	5721	Eocene
1N	6E	10	MD	Pacific Gas & Elect. Co. well No. 3	1932	1890	Miocene (?)
1N	6E	10	MD	Pacific Gas & Elect. Co. well No. 7	1936	2230	Miocene (?)
1N	6E	10	MD	Pacific Gas & Elect. Co. well No. "Stockton" 1	1932	1702	Miocene (?)
1N	6E	12	MD	Pacific Gas & Elect. Co. well No. 6	1936	1810	Miocene (?)
1S	6E	8	MD	The Texas Co. well No. "Laurence-Stephan" 1	1937	5839	Cretaceous
2S	4E	33	MD	Tracy Oil Co. well	Pre-1915	3100	
2S	4E	33	MD	Wallenberg well No. "Daisy" 1	Pre-1924		
3S	4E	2	MD	Coast Exploration Co. well No. "T-F-I" 1	1937	3469	Cretaceous
3S	4E	24	MD	Milham Exploration Co. well No. "Moy" 1	1934	1122	Eocene
3S	4E	24	MD	Milham Exploration Co. well No. "Moy" 2	1934	4002	Cretaceous
3S	6E	14	MD	Union Oil Co. well No. "Tracy Land" 1	1932	5511	Cretaceous
4S	5E	5	MD	Milham Exploration Co. well No. "Connolly" 1	1934	5800	Cretaceous

* Not shown on published map.

SAN LUIS OBISPO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
25S	10E	2	MD	Great American Oil Co. well	Pre-1921		
25S	10E	11	MD	Cavanaugh No. 1 well	Pre-1921	800	Salinas shale
25S	10E	11	MD	Cavanaugh No. 2 well	Pre-1921	2500	
25S	11E	26	MD	Continental Oil Co. well No. "Hellman" 1	1931	5095	Vaqueros
25S	12E	4	MD	Shell Oil Co. well No. "Mahoney" 1	1933	5972	Granite
25S	12E	4	MD	Oak Ridge Oil Co. well No. "Mahoney" 1	1924	3564	Monterey
25S	15E	10	MD	Willett Oil Co. (1); Cholame Synd. (2); well No. "Jack" 2	1939	3687	Basement
25S	15E	34	MD	Reliance Producers, Inc. well No. 1	1928	2005	
26S	12E	19	MD	Paso Robles Gas Co. well No. 1	1925-1926	450	Granite
26S	13E	27	MD	Atascadero Oil Co. well No. "Paso Robles Structure" 1			
27S	11E	27	MD	Pac. Coast Land & Oil Corp. well No. "Waklin" 18	1934	2610	
27S	13E	9	MD	Starr, E. G., well No. 1	1927	3576	Vaqueros (?)
27S	14E	26	MD	Vanguard Oil Co. well No. "Clarke" 1			
27S	15E	31	MD	Latin Amer. Pet., Inc. well No. "Whitley" 1	1932	4618	
28S	12E	7	MD	Emerich Oil Corp., Ltd. well No. 1	1932	2320	Cretaceous
28S	13E	34	MD	Crose, A. J., well No. 1	1935	2667	
28S	15E	20	MD	Cities Service Pet. Co., Ltd. well No. "Fay" 1	1931	1527	Granite
28S	17E	24	MD	Barnsdall Oil Co. well No. "Wreden" 1	1936	5087	Miocene
28S	17E	29	MD	Cedar Springs well		1960	
28S	17E	29	MD	San Juan Project well No. 1	Pre-1925	4770	
28S	17E	31	MD	San Juan Project well No. 2	Pre-1925		

SAN LUIS OBISPO COUNTY—Continued

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
29S	12E	1	MD	Schilling, Carl J. Co., Ltd. well No. 1	1934	1800	Cretaceous
29S	17E	10	MD	Richfield Oil Co. well No. "Wreden" 1	1933	3147	Miocene
29S	17E	15	MD	Richfield Miley Oil Co. well No. 1	1931	3785	
29S	19E	20	MD	Associated Oil Co. well No. "Carissa" 1	Pre-1925	3506	
29S	19E	20	MD	Carlston, J. F., & Associated Oil Co. well No. 1	Pre-1924	3506	
29S	19E	20	MD	Associated Oil Co. well		3400	
29S	19E	28	MD	Spreckles Oil Co. well No. 1	Pre-1925	763	Paso Robles
30S	10E	24	MD	Gretna Corp. well No. "Maino-Gonzales" 1	1937	1575	Franciscan
30S	10E	34	MD	Lewis, A. O., Pecho well		2745	
30S	20E	4	MD	Sterling Oil Co. well No. 1	1925	500	
30S	20E	8	MD	Vaqueros Oil Co. well No. 1	Pre-1925	710	Paso Robles
30S	20E	21	MD	Union Pacific Oil Co. well No. 1	1932	800	
30S	20E	22	MD	Lewis Oil Dev. Ass'n well No. 3	1922	535	Paso Robles
30S	20E	22	MD	Smith, R. M., well No. 5	1932	425	Pleistocene
30S	20E	22	MD	Lewis Oil Dev. Ass'n well No. 5	1922	603	Paso Robles
30S	20E	27	MD	Smith, R. M., well No. 4	1932		Pleistocene
30S	20E	27	MD	Smith, R. M., well No. 6	1932	800	Pleistocene
30S	20E	31	MD	Berry, C. J., well No. 1	1921	2885	
31S	12E	2	MD	Miley, E. J., well No. 1	1925-1926	2020	
31S	12E	18	MD	See Canyon Oil Co. (Clayton Dev. Co.) well No. 1	1938	2045	Basement (?)
31S	12E	30?	MD	Walker well No. 1			Monterey shale
31S	14E	36	MD	Bedicagk-Phoenix well	1909	3675	
31S	15E	34	MD	Wilson, N. S. (Midwest Oil & Refining Co.) well No. 2	1930	4390	Cretaceous
31S	15E	35	MD	Stieger well		1100	
31S	20E	18	MD	Small well	Pre-1925	380	Paso Robles
31S	21E	22	MD	Cree well			
31S	21E	22	MD	Edwards, E. T., well No. 4	1932	300	Pliocene
31S	21E	22	MD	Edwards, E. T., well No. 5	1932		
31S	21E	27	MD	Mazda Oil Co. well No. 1	Pre-1925		
31S	21E	28	MD	Russell, J. E., Co. well No. 1	1924	200	
32S	14E	1	MD	Associated Oil Co. well	Pre-1924	3675	Monterey
32S	14E	11	MD	Tex Harvey Corp. well No. "Gilmore Comm." 1	1940	4518	Monterey
32S	14E	11	MD	Tex Harvey Corp. well No. 2	1941	6140	Shale
32S	14E	12	MD	Union Oil Co. well No. "Huasna-Chandler" 1	1930	5627	Diabasic rock
32S	14E	22	MD	Doheney well No. 1	1898	875	
32S	14E	24	MD	Superior Oil Co. well No. "Tar Springs" 1	1940	6504	Temblor (?)
32S	14E	25	MD	Barenberg Oil Co. well No. 1	1927	4499	Monterey
32S	14E	25	MD	Texas Pac. Coal & Oil Co. well No. 1	1930	4450	Monterey
32S	14E	25	MD	Trustee's well, Trustee No. 1 (Barneberg 2)	1933	3945	Miocene; oil producer
32S	15E	7	MD	McKay well	Pre-1921		
32S	15E	13	MD	Squires well No. 4	1900	800+	
32S	15E	14	MD	Majestic well No. 1			
32S	15E	14	MD	New Huasna well No. 1			Monterey shale
32S	15E	14	MD	Squires well No. 5		800	
32S	15E	22	MD	Harkness well No. 2	Pre-1914	1000	
32S	15E	22	MD	Harkness well No. 3	Pre-1914	1000	
32S	15E	22	MD	Union Oil Co. well No. "Porter" 1	1937	5110	Monterey (?)
32S	15E	34	MD	Union Oil Co. well No. "Rust" 1	1930	4156	Cretaceous
32S	16E	31	MD	Downer No. 1 well			
32S	16E	31	MD	Downer No. 2 well			
32S	20E	1	MD	Barnsdall Oil Co. well No. "K. C. L. A." 1 (Barnsdall-Foster)	1937	5217	Monterey
32S	21E	2	MD	Panorama Oil Co. well No. "Panorama" 2	1939	2527	Pliocene
32S	22E	2	MD	Foster, Robt. A., well No. "McKee" 1	1939	5035	Miocene
32S	22E	2	MD	Little Bear Oil Co. well No. 1	Pre-1925	3000	Maricopa
32S	22E	2	MD	Western Drill. & Prod. Co. (Gillis, R. C., receiver) well No. "Dollar" 1	1932	296	Maricopa
32S	22E	3	MD	Dollar Oil Co. well No. "Kent & McDonald" 1	1939	3867	Miocene
32S	22E	3	MD	Midway Peak Oil Co. well No. "Midway Peak" 1		805	
32S	22E	6	MD	Union Oil Co., Schwartz well			
32S	22E	12	MD	Beer, L. P., well No. 1	1934	3648	
32S	22E	15	MD	Potter, E. K., well No. 1	1926	501	Pliocene
32S	22E	22	MD	Emerich Oil Corp., Ltd. well No. 1	1935		
32S	22E	22	MD	Theriot, J. C., well No. "Theriot" 1	1937	2124	Cretaceous
32S	22E	22	MD	Holland, J. T., well No. 1	1932	1200	
32S	22E	22	MD	Holland, J. T., Vishnu or Sperry well	1935	1734	Maricopa (?)
32S	22E	23	MD	McBurney, R. W., well No. "McBurney" 1	1937	2283	Monterey (?)
32S	22E	26	MD	Carissa Oil Co. well No. 1	1926	2070	
32S	22E	27	MD	Brittan, E. F., well No. 1	1935	502	Pliocene
33S	15E	31	MD	Downer well No. 1	1898	600	

SAN LUIS OBISPO COUNTY—Continued

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
33S	15E	31	MD	Downer well No. 2	1898	300	
12N	33W	30	SB	Wilhelm well		700	
12N	33W	30	SB	Hancock Oil Co. well No. "Scherer-Dickes" 1	1939	5591	Prod. heavy oil
12N	32W	25	SB	Clarion well	1919	1700	
12N	25W	33	SB	Macomber, Fred C., well No. 1	1926	50	
12N	25W	35	SB	Kerntaft Pet. Co. well No. 1	1926	3146	
11N	33W	16	SB	Associated Oil Co. well	1918	1434	Serpentine
11N	32W	10	SB	Associated Oil Co. well No. "Stow" 1	Pre-1925	1434	Monterey (?)
11N	27W	2?	SB	Grand Prise Oil Co. well	Pre-1921	700	Pre-Monterey
11N	26W	6	SB		Pre-1938	700	
11N	26W	12	SB	Lewis Oil Dev. Ass'n well No. 1	1921	2322	Middle Miocene
11N	25W	19	SB	Carlisle Oil Co. well No. 1	1937	2960	Cretaceous (?)
10N	26W	3	SB	Burch, I. L., well No. "Burch" 1	1938	3216	Miocene
10N	26W	4	SB	Little Cuyama Oil Co. well No. "Little Cuyama" 1	1938	3830	Miocene
10N	26W	4	SB	Little Cuyama Oil Co. well No. "Little Cuyama" 2	1938	1502	Miocene
10N	26W	4	SB	Burch, I. Lee, well No. 1	1938	1438	Miocene
10N	26W	12	SB	Bedford, E. M., well No. "Cuyama Core Hole" 1	1935	5178	
10N	26W	24	SB	Burkholder Oil Corp. well No. "Clay" 1	1938	4029	Miocene
10N	24W	19	SB	Hale, J. C., well No. 1		890	
10N	24W	19	SB	Irons Bros. well No. 1			
10N	24W	19	SB	Mapes Holdings, George, well No. 1	1925-1926	750	

SAN MATEO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
5S	5W	33	MD	Sage, W. A., well No. 1	Pre-1925	2563	Miocene
6S	5W	3	MD	Sage & Olsen well	Pre-1925	930	Miocene
6S	5W	8	MD	Shell Oil Co. well No. "Cowell" 1	1928	5905	Miocene (?)
6S	5W	8	MD	Shell Oil Co. well No. "Cowell" 2	1928	3689	Miocene (?)
6S	5W	10	MD	McClintock, H. H., well No. 1	Pre-1925	517	Monterey
6S	5W	10	MD	Midstate Oil Co. well No. 1			
6S	5W	10	MD	Poso-Moon Oil Co. well No. 1	Pre-1925	830	Miocene
6S	5W	15	MD	Elk Hills Pool Oil Co. well No. 1	1935	1114	Miocene
6S	5W	15	MD	Sage, Olsen & Blalack well No 1	Pre-1925	2100	Miocene (?)
6S	5W	15	MD	Skyline Oil & Refining Corp. well No. 1			
6S	5W	16	MD	Berger & Caglieri, well No. 1	Pre-1925	1930	
6S	5W	16	MD	Julian, C. C., well No. 4	1925-1926	1800	Miocene (?)
6S	5W	16	MD	Midstate Oil Co. well No 3			
6S	5W	16	MD	Stratton Pet. Corp. well No. 1		285	
6S	5W	17	MD	A. & C. Oil Co. well No. 1	1927	2510	Miocene
6S	5W	20	MD	Elk Hills Pool Oil Co. well No. 1	Pre-1925		
6S	5W	21	MD	Shell Oil Co. well No. "Butts" 1	1928	3369	
6S	5W	21	MD	Thompson & McNickels, well No. "Butts" 2			
6S	5W	22	MD	Berger & Caglieri, well No. 2	Pre-1925	1765	
6S	5W	26	MD	Sequoia Oil & Gas Co. well No. "Souza" 1			
7S	5W	13	MD	Old O'Brien			
7S	5W	15	MD	San Mateo Pet. Co. well	Pre-1925	480	Miocene
7S	5W	15	MD	Unity Oil Co. well No. 1	1925-1926	600	Miocene (?)
7S	4W	7	MD	Owsley, J. N., well No. 1	Pre-1925	625	Miocene
7S	4W	7	MD	Owsley, J. N., well No. 2	Pre-1925	275	Miocene
7S	4W	7	MD	Perkins well		1100	
7S	4W	16	MD	La Honda Oilfields Ass'n. well No. 1	Pre-1925	3140	Miocene (?)
7S	4W	18	MD	Elk Hills Pool Oil Co. well No. 1	Pre-1925		
7S	4W	18	MD	La Honda Oilfields Ass'n. well No. 3		786	
7S	4W	19	MD	La Honda Oilfields Ass'n. well No. 2			
7S	4W	20	MD	Elk Hills Pool Oil Co. well No. 2	Pre-1925	436	Miocene
7S	4W	21	MD	McKinney & Ellis well	Pre-1925	288	Miocene (?)
7S	4W	21	MD	Northern Explor. Co. well No. 1	Pre-1925	340	Miocene
7S	4W	21	MD	Old Bell well	1905 (?)	1300	
8S	3W	10	MD	Big Basin Paraffin Oil Co. well No. 1-A	Pre-1925	360	Miocene
8S	3W	10	MD	Royer, Frank W., well No. 1	1935	1000	Miocene (?)
9S	4W	19	MD	Smuggler Divide Mining Co. well No. 1	1930	900	

SANTA BARBARA COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
11N	28W	28	SB	Fisher, Claude (Wm. Carter, Jr.) well No. "Cuyama" 1	1938	1500	
10N	32W	19	SB	Union Oil Co. well No. "Rice" 1	1934	2280	
10N	27W	6	SB	Cuyama Pet. Co. well No. 1	1925	550	
10N	27W	13	SB	Cuyama Valley Oil Corp., Ltd. well No. 1		3950	
8N	31W	11	SB	Casey, M. H., well No. 1			
8N	31W	15	SB	West Penn Prod. Co. well No. "Shields" 1	1926	643	
8N	31W	15	SB	West Penn Prod. Co. well No. "Shields" 2	1928	639	
7N	35W	4	SB	Standard Oil Co. well No. "Packard Shyvers" 1	1929	2661	Franciscan
7N	35W	11	SB	Taylor, W. H., well No. "Shyvers" 1	1930	5638	
7N	34W	18	SB	Smith, Ernest W. et al. well No. 1		895	
7N	33W	31	SB	Jalama Oil & Dev. Co. well No. 1	Pre-1925	749	
7N	33W	31	SB	Jalama Oil & Dev. Co. well No. 2	Pre-1925	197	
7N	33W	33	SB	Hurst, T. J., well No. 1	Pre-1925	3515	Monterey
7N	32W	22	SB	Standard Oil Co. well No. "Buell" 1-C	Pre-1925	4579	Cretaceous (?)
7N	31W	1	SB	Standard Oil Co. well No. "Laguna" 1	Pre-1925	3956	Vaqueros (?)
7N	31W	19	SB	Hydro Carbon Prod. Co. well No. 1	Pre-1925	1654	Monterey (?)
7N	31W	19	SB	Sentinel Oil Co. well No. "Zaca" 1	Pre-1925	1858	
7N	31W	19	SB	Union Oil Co. well No. "Linns-Buell" 1	1930	4589	
7N	31W	26	SB	Zaca Oil Co., Ltd., well No. "Zaca" 1			
7N	31W	23	SB	Tannehill, L. B., well No. "McGillivray" 1	1930	4385	
7N	30W	10	SB	Nine Springs Oil Co. well No. "Bradley" 1	1939	3271	Basement
7N	30W	10	SB	Stockholders' Pet. Corp. well No. 1	1931	3070	
6N	36W	35	SB	Standard Oil Co. well No. "Sudden" 1	1930	2861	Cretaceous
6N	35W	26	SB	Hollywood Oil Corp. well No. 1	1929	1280	
6N	34W	2	SB	The Ohio Oil Co. well No. "Salsipuedes" 1	1930	4656	
6N	33W	3	SB	Tide Water Assoc. Oil Co. well No. "Leonis" 1	1937	4949	Monterey
6N	32W	24	SB	Steele, J. R., well No. 1			
6N	31W	5	SB	Buttram, Frank, well No. "Reuben" 1	1928	2380	Monterey
6N	30W	10	SB	Climax Oil Co. well No. 1	Pre-1925	2652	Monterey
6N	30W	14	SB	National Explor. Co. well No. "Armour" 1	1922	2655	Serpentine
6N	29W	3	SB	San Marcos Oil Co. well No. "Elliott" 1	1927	3631	Cretaceous
5N	33W	35	SB	101 Oil Co. well No. "Hollister" 1	1930	3215	
5N	31W	36	SB	Graham-Loftus Oil Co. well No. 1	1928	1617	
5N	31W	36	SB	Graham-Loftus Oil Co. well No. "Refugio" 1	1928	1650	
5N	31W	36	SB	The Texas Co. well No. "Careaga" 1	1937	1792	Middle Miocene
5N	30W	31	SB	Refugio Oil Co. well No. "Careaga" 1	1935	1297	Temblor (or older)
5N	30W	31	SB	Shell Oil Co. well No. "Orella" 1	1930	2361	
5N	30W	35	SB	La Canada Oil Corp. well No. "Rhode Is. Estates" 1	1936	1141	Sespe
5N	27W	14	SB	Orangethorpe Corp. Ltd. (Pac. Western Oil Co. ?) well No. "Gibraltar Dam" 1	1933	2344	Sespe
4N	34W	8	SB	Pan American Pet. Co. well No. 1	1919	3061	
4N	34W	8	SB	Standard Oil Co. well No. "Gerber" 1	1931	6820	Vaqueros
4N	31W	1	SB	Shell Oil Co. well No. "Rutherford" 2	1929	1887	
4N	31W	1	SB	Shell Oil Co. well No. "Rutherford" 3	1930	2329	
4N	30W	1	SB	Standard Oil Co. well No. "Edwards" 1	1929	2490	Tejon
4N	30W	1	SB	Standard Oil Co. well No. "Standard-Edwards" 2	1930	3404	Tejon (Eocene)
4N	30W	2	SB	Tide Water Assoc. Oil Co. well No. "Edwards Est." 1	1937	2450	Sespe
4N	30W	3	SB	La Canada Oil Corp. well No. "Rhode Is. Est." 2	1937	1400	Vaqueros
4N	29W	7	SB	Snow, H. H., well No. 7		5100	
4N	28W	1	SB	Carrey & Adams well No. "Wright" 1	1930	2846	Sespe
4N	27W	20	SB	Channel Oil & Dev. Co., Ltd. well No. 1	1936	6302	Upper Eocene
4N	27W	20	SB	Humphries, M. M., well No. "Edna Mae" 1	1936	1600	Middle Vaqueros
4N	27W	20	SB	Ameroll Corp. well No. "Fellowship" 1	1935	4128	Sespe
4N	27W	20	SB	Pet. Explor. Co. well No. 1	1928	3921	
4N	27W	27	SB	Hargrave, D. A., well No. 1	1930	3552	Sespe
4N	27W	27	SB	Hargrave, D. A., well No. "Low" 2	1931	1863	Vaqueros
4N	27W	30	SB	Lincoln Drill. Corp., Ltd., well No. 1	1929	2434	
4N	25W	17	SB	Cornero, Tony, well No. "Fithian" 1	1936	1035	Sespe
4N	25W	18	SB	Shell Oil Co. well No. "Fithian" 1	1930	4389	
4N	25W	26	SB	Carpinteria Gas & Oil Co. well No. 1		1703	
4N	25W	26	SB	Standard Oil Co. well No. "Shepard" 1	1930	2774	Sespe
4N	25W	26	SB	Standard Oil Co. well No. "Shepard" 2	1930	1479	
4N	25W	29	SB	Santa Barbara Oil & Gas Co. well No. "Bryce" 1		2567	
4N	25W	29	SB	Santa Barbara Oil & Gas Co. well No. "S. B." 1	1936	2650	Sespe
4N	25W	32	SB	Caspers, R. W., well No. "State Permit" 130 (No. 1-A)	1931	1029	
4N	25W	32	SB	McDonald, George A., well No. "State Permit" 120 (No. 1-A)	1931	750	

SANTA BARBARA COUNTY—Continued

T	R	Sec.	B & M	Name of Company and Well	Yr. Abond. or Last Active	Depth Ft.	Geology at Bottom of Hole
4N	25W	33	SB	Bailard, Benjamin F., well No. 127-1	1930	1055	Monterey
4N	25W	33	SB	Bailard, Kittie C., well No. 124-1A	1930	418	Monterey
4N	25W	33	SB	Bailard, Myrtle, well No. 125-1	1930	1046	Monterey
4N	25W	33	SB	Continental Oil Co. well No. 124-1	1930	5735	Temblor
4N	25W	33	SB	Continental Oil Co. well No. "Franklin" 1	1930	4169	Temblor
4N	25W	33	SB	Continental Oil Co. well No. "Kittie C. Bailard" 1	1929	4535	Temblor
4N	25W	33	SB	Franklin, Theresa, well No. 123-1	1930	1050	Monterey
4N	25W	33	SB	Higgins, Callie M., well No. 122-1	1931	1018	
4N	25W	33	SB	Higgins, Lucien M., well No. 121-1	1930	1045	Monterey
4N	25W	33	SB	Nugent, James F., Oil Co. well No. 1	1925–1926	3790	Pico
4N	25W	33	SB	Nugent, James F., Oil Co. well No. 2	1925–1926	4567	Pico
4N	25W	33	SB	The Texas Co. well No. "Carpinteria Comm." 3-1	1932	4208	Sespe
4N	25W	33	SB	The Texas Co., well No. 126-1	1931	1028	Monterey
4N	25W	34	SB	Bailard, Charles E., well No. 129-1	1930	1031	Monterey
4N	25W	34	SB	Casitas Oil Co. well No. 202-1	1933	1039	Monterey
4N	25W	34	SB	Casitas Oil Co. well No. 202-2	1933	3312	
4N	25W	34	SB	Hall, Mary B., well No. 128-1	1930	1067	Monterey
4N	25W	34	SB	Hillman-Long, Inc. well No. 202-1		1039	

SANTA CLARA COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
8S	1W	9	MD	Crossen, Carl, well No. 1	1929	615	Miocene (?)
8S	1W	10	MD	Traders Oil Corp. well No. T-1	Pre-1925	2006	Miocene
8S	1E	7	MD	Tinnally, Alfred, well No. 1	1927	2356	
9S	1W	8	MD	Norris, A. R., well No. "Logan" 1	Pre-1938	1100	
9S	1W	8	MD	Norris, A. R., well No. "Logan" 2	Pre-1938	1500	
9S	1W	8	MD	Strader Oil Co., well No. "Strader" 2	1930	2300	
9S	1W	8	MD	Madrone Oil Co. well No. 1			
9S	1E	8	MD	Trigonia Oil & Gas Co. well No. "Trigonia" 5	Pre-1925	612	Monterey
11S	4E	1	MD	Traders Oil Corp. well No. "Rasmussen" 2	Pre-1925	2675	Miocene

SANTA CRUZ COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
9S	1W	17	MD	Rhodes & Schmit well No. 1	Pre-1925	1000	Miocene
11S	1W	5	MD	Greater Santa Cruz Oil Co. well No. 1	1932	3987	Granite
11S	2W	18	MD	Marik, Frank, well No. 2		1750	
11S	2W	22	MD	Danish Oil & Dev. Co. well No. 1	Pre-1925	1200	Miocene
11S	2W	22	MD	Monterey Bay Oil Co. well No. 2		5200	Miocene (?)
11S	2W	23	MD	Swanton Improvement Co. well No. 1	1927	712	Miocene (?)
11S	2W	23	MD	United Royalties Co. well No. 1	Pre-1925		
11S	2E	14	MD	Cymric Oil Co. well No. 1	1922	1500	
11S	2E	14	MD	Wellton O. & G. Co. well No. "Galletly" 1	1933	2889	
11S	2E	14	MD	Rispin, Alan W., well No. 1	Pre-1936		
11S	2E	14	MD	Rysek, Gerald, well No. 1	1936	680	
11S	2E	14	MD	Shepherd, M. P., well No. 1	1936	685	Cretaceous (?)
11S	2E	18	MD	Marik, Frank, well No. 1	1927	1440	Monterey

SHASTA COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. ar Last Active	Depth Ft.	Geology at Bottom of Hole
30N	5W	15	MD	Red Head Oil Co. well No. 1	1930	500	Cretaceous

SOLANO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
7N	1W	18	MD	Rambke, H., well No. 1	1933	2190	Cretaceous (?)
7N	1W	22	MD	Rambke, H., well No. 1	1930	150	Cretaceous (?)
7N	1W	22	MD	Taecker, A. T., well No. 1	1930	4854	Cretaceous (?)
5N	1W	10	MD	Trico Oil & Gas Co. well No. "Noonan" 1	1935	1045	Cretaceous
5N	1W	13	MD	Honolulu Cons. Oil Co. well No. 1	Pre-1925	3292	Cretaceous (?)
5N	1W	24	MD	Rochester Oil Co. well		1820	Chico ss.
5N	2E	15	MD	Standard Oil Co. well No. "Calif. Packing Corp." 1	1939	6837	Cretaceous
4N	3W	11	MD	Cordelia Oil & Gas Co. well No. 1 (C. & H. Mangels)	1939	2200	Eocene (?)
4N	1W	9	MD	Honolulu Consl. Oil Co. well No. 1?	Pre-1925	3047	Cretaceous (?)
4N	1W	10	MD	Richfield Oil Corp. well No. "Potrero Hills" 1		5334	Cretaceous (?)
4N	1W	10	MD	Richfield Oil Corp. well No. "Potrero Hills" 2(?)			
3N	3W	4	MD	Hauluth, Wm., well No. 1	Pre-1925	1400	Cretaceous (?)
3N	3W	20	MD	Midas Oil Co. well	Pre-1925	2000	Cretaceous
3N	1E	2	MD	Pacific Gas & Elect. Co. well No. 1	Pre-1925	5002	Eocene (?)

SONOMA COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
10N	11W	24	MD	Skaggs Springs O. & G. Co. well No. 1	1927	205	Franciscan (?)
10N	11W	24	MD	Skaggs Springs O. & G. Co. well No. 2	1927	405	Franciscan (?)
9N	8W	8	MD	Mortara Oil Co. well No. "Bidwell" 1	1936	2881	Franciscan (?)
9N	8W	8	MD	Mortara Oil Co. well No. 2	1927	3772	Franciscan (?)
5N	8W	29	MD	Two Rock Oil Corp. well No. "Two Rock" 1	1937	475	Franciscan
5N	8W	34	MD	Cardoza, Antonio J., well No. 1	1936		
5N	7W	14	MD	Shell Oil Co. well No. "Ielmorini" 1	1927	2101	Pliocene volc.
5N	6W	19	MD	Shell Oil Co. well No. "Mossi" 1	1929	2140	Pliocene volc.
5N	6W	19	MD	Shell Oil Co. well No. "Murphy" 1	1928	6385	Miocene or Pliocene volcanics
5N	6W	19	MD	Shell Oil Co. well No. "Murphy" 2	1927	1956	Pliocene volc.
5N	6W	20	MD	Shell Oil Co. well No. "Doss" 1	1929	2182	Pliocene volc.
5N	6W	25	MD	O. F. W. Drilling Co. Inc. well No. 1	1926		
5N	6W	30	MD	H. N. Witt & Assoc. well No. "Ducker" 1	1935	1303	Pliocene seds.
5N	6W	30	MD	H. N. Witt & Assoc. well No. "Ducker" 2	1935	2082	Pliocene volc.
5N	6W	33	MD	Petaluma Expl. Co. well No. "Bourke" 1	1937	1869	Pliocene seds.

STANISLAUS COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
1S	10E	34	MD	Northern Pet. Corp. well No. 1			
1S	12E	18	MD	Clary, W. H., well No. 1	1930	4000	
2S	10E	1	MD	Southern Oil & Gas Co. well No. 1	1930	3696	
2S	10E	3	MD	Barnhart Oil Trust, well No. 1			
2S	10E	3	MD	Oakdale Oil Corp., Ltd. well No. 1	1937	4711	Cretaceous
3S	13E	16	MD	Thomas, L. W., well No. 1	1926	169	
3S	13E	20	MD	Rushing O. & D. Corp. well No. 1	1935	2600	Cretaceous (?)
4S	9E	30	MD	Coast Exploration Co. well K-2-1	1937	6311	Cretaceous
6S	7E	2	MD	San Joaquin Pet. Co. well No. "Birch & Royer" 1	1926	2775	Cretaceous
6S	7E	14	MD	Stanislaus Co. Oil Syn. well No. 1	1925	430	
6S	7E	36	MD	Bud Hildebrand, well No. 1	1937	2831	Cretaceous
6S	8E	30	MD	The Texas Co., well No. "Bacon" 1	1937	1133	Eocene
6S	8E	30	MD	Irons, E. D., wells No. 1	Pre-1925	550	Miocene
7S	8E	12	MD	Tavares, J. G., well No. 1	1927	3409	Miocene
7S	8E	30	MD	Tavares, J. G., well No. 1	1931	2705	Cretaceous
7S	8E	34	MD	Orestimba Oil Co. well No. "Orestimba" 1	Pre-1925	1701	Pliocene

SUTTER COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
16N	1W	36	MD	Tannehill Oil Co. well No. "Maggie Wilson" 1	1935	2505	Cretaceous (?)
16N	1E	32	MD	Sutter Butte Oil Co. well No. 1	1927	2900	Cretaceous (?)
16N	1E	35	MD	Buttes Oilfields Inc. well No. "Buttes" 1	1938	2727	Porphyritic andesite (?); small gas producer
16N	1E	35	MD	Buttes Oilfields Inc. well No. 2	1935	7014	Peridotite
15N	1E	1	MD	Buttes Oilfields Inc. well No. 5	1939		Upper Cretaceous
15N	1E	1	MD	Buttes Oilfields Inc. well No. 6			Upper Cretaceous
15N	1E	2	MD	Buttes Oilfields Inc. well No. 4	1938	5855	Upper Cretaceous; gas producer
15N	1E	2	MD	Buttes Oilfields Inc. well No. 3	1938	6954	Upper Cretaceous; gas producer

TEHAMA COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
28N	7W	12	MD	Burgess, Irvin S., well No. 1			
28N	4W	25	MD	Tuscan Oil Co. well No. 1	1922	1845	
26N	4W	24	MD	Tehama Co. Oil Co. & Hooker Dome Oil Co. well No. 1	1924	575	
25N	5W	31	MD	Marker Drilling Co. well No. 1	1936	4425	Cretaceous
25N	4W	27	MD	Los Chicos Oil Co. well No. "Scharr" 1	1936	2650	
25N	3W	35	MD	Richfield Land Co. well No. 10	Pre-1937	524	
24N	5W	20	MD	Crockett Drilling Syn., Inc. (Burgess & Goodale) well No. 1	1931	1885	Cretaceous
24N	5W	20	MD	Crockett Drilling Syn., Inc. well No. 3	1936	2101	Cretaceous
24N	3W	14	MD	Apex Drilling Co. well No. "Flood" 1	1935	200±	
24N	3W	25	MD	Northern Counties Pet. Co. well No. "Ewers-Mooney" 1	1936	8253	Cretaceous
23N	4W	30	MD	Stella, E. F., Trustee, well No. "Johnston" 2	1939	3326	Cretaceous (?)
23N	3W	31	MD	Orland Oil Syn. Ltd. well No. "Johnston" 1	1931	3780	Cretaceous (?)

TULARE COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
16S	23E	12	MD	Martin Pet. Co. well No. 1	1927	1670	Etchegoin
16S	23E	28	MD	Alford, John W., well No. "Williams" 1	1937	1023	Etchegoin
16S	23E	29	MD	Kingsburg Explor. Co. well No. 1	1934	2897	Kern River (?)
16S	23E	29	MD	Kings River Oil Pool well No. 1	1936	3157	Cretaceous
17S	23E	32	MD	Wilson, Daisy, well No. 1	Pre-1925	500	Tulare
17S	24E	24	MD	Inland Valley Oil Co. well No. 1	1936	2090	Pliocene (?)
19S	27E	17	MD	Thew, Richard, well No. 1	Pre-1925	800	
19S	27E	35	MD	Givan Cons. Oil Corp. well No. 1	1921	100	
20S	24E	1	MD	Tulare Oil Co. well No. 1	Pre-1925	3200	Etchegoin
20S	25E	29	MD	Brittain-Terminal Oil well No. "Gieck-Stephens" 1	1931	4160	Basement (?)
20S	26E	28	MD	Hitchcock, J. R., well No. 1	Pre-1925	1330	
21S	23E	19	MD	Bartholomew, M. W., well No. "Palmer" 1	1934	5643	Etchegoin
21S	23E	19	MD	Gilbert, William, well No. 1		3000	
21S	23E	19	MD	Kings Tulare Dev. Co. well No. 1	Pre-1925	5647	Miocene
21S	25E	5	MD	Standard Oil Co. well No. "Kern Cy." 1-2	Pre-1925	5865	Pliocene (?)
21S	25E	27	MD	Trico Oil & Gas Co. well No. "Callison" 1	1937	4686	Miocene
21S	25E	35	MD	Trico Oil & Gas Co. well No. "Valley" 2	1937	3704	Miocene
21S	25E	36	MD	Trico Oil & Gas Co. well No. "Valley" 1	1937	4337	Miocene
21S	26E	13	MD	Baker Oil Co. well No. 1	Pre-1925	2430	Etchegoin
21S	26E	13	MD	Birch, A. Otis, well No. "Baker" 1	1928	3504	

TULARE COUNTY—Continued

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
21S	27E	35	MD	McCoy, W. D., well No. 1	1931	872	Mariposa slate
22S	23E	27	MD	Angiola Oil Co. well No. "Douglas" 1	1929	5500	(Pliocene) Etchegoin
22S	24E	15	MD	Federal Explor. Co. well No. "Kinsella" 1	1928	5763	Temblor
22S	26E	10	MD	Porterville Oil & Gas Co. well No. 1	1927	2200	Mariposa slate
22S	26E	15	MD	Turner, L. E. (Magnet Oil Co.) well No. "Turner Glaze" 1		3282	Basement
22S	26E	22	MD	Fortine, W. H., well No. "Mosesian" 1	1936	3084	Jurassic (?)
22S	27E	7	MD	Porterville Oil Syn. well No. 1	1925–1926	1947	Mariposa slate
22S	27E	15	MD	Lewis, Paul M., well No. 1	1934	1117	Mariposa slate
22S	27E	15	MD	Pettingall, C. E. well No. "Campo Verde" 1	1931	955	
22S	27E	15	MD	Shannon Oil Co. well No. 1	1925	844	
22S	27E	17	MD	Pioneer Dev. Co. well No. 1	1925–1926	966	Tulare
22S	27E	17	MD	Pioneer Dev. Co. well No. 2	1928	1290	
22S	27E	20	MD	Knoop, Geo. C., well No. 1	1932	936	Mariposa slate
22S	27E	21	MD	Richey, R. R., well No. 1	1931	1040	Mariposa slate
22S	27E	22	MD	Campbell, W. A., well No. 1		854	
22S	27E	22	MD	Campbell, W. A., well No. 2		854	
22S	27E	22	MD	Holly Dev. Co. well No. "Murray" 1	1926	1115	Mariposa slate
22S	27E	22	MD	Holly Dev. Co. well No. "Murray" B-1	1926	1200	
22S	27E	22	MD	Holly well	1925	1130	
22S	27E	22	MD	Shannon Oil Co. well No. 2	1924	430	Slate
22S	27E	23	MD	Terra Bella Drilling Co. well No. 1	1930	805	
22S	27E	23	MD	Terra Bella Drilling Co. well No. "Miami" 1	1930	798	
22S	27E	26	MD	Hub Oil Co. well No. "Halbert" 1	1925–1926	800	Mariposa slate
22S	27E	27	MD	Cumming Pet., Ltd. well No. "Hastings" 1	1930	1221	Mariposa slate
22S	27E	27	MD	Hub Oil Co. well No. 1	1925–1926	1488	Mariposa slate
22S	27E	27	MD	Hub Oil Co. well No. 2	1925–1926	746	Mariposa slate
22S	27E	27	MD	Terra Bella Irri. Dist. well No. 33	1925–1926	1008	Mariposa slate
22S	27E	34	MD	Alexander, Ford, et al. well No. 1	1931	1000	Mariposa slate
22S	27E	34	MD	Gholson, Fred N. well No. "Chamboy" 1	1935	915	
22S	27E	34	MD	Hallock, William A., well No. 1		1090	
22S	27E	34	MD	Jaques Oil Co. well No. 1	1930	680	Mariposa slate
22S	27E	34	MD	Rayatt Oil Corp well No. "Hinshaw" 1	1930	1085	
22S	27E	34	MD	Roetner Oil Co. well No. 1	1930	1447	
22S	27E	34	MD	Roetner Oil Co. well No. 3	1935	1365	
22S	27E	34	MD	Sheldon & Gholson well No. 1	1935	900	
22S	27E	34	MD	Terra-Bella Drill. Co., Ltd. well No. 1	1930	924	
22S	27E	34	MD	Terra-Bella Drill Co., Ltd. well No. "Keen" 1	1930	1243	Basement
22S	27E	34	MD	Terra-Bella Drill Co., Ltd. well No. "Russling" 1	1930	924	
22S	27E	34	MD	Turk-Campbell Pet. Co. well No. 1		1365	
22S	27E	34	MD	United Kern Pet., Inc., Ltd., well No. 1	1931	1198	
22S	27E	34	MD	United Kern Pet., Inc., Ltd., well No. "Clair" 1	1931	1170	
22S	27E	35	MD	Consolidated Properties well No. "Gardner" 1	1930	1003	Mariposa slate
22S	27E	35	MD	Consolidated Properties well No. 2		912	
22S	27E	35	MD	Terra-Bella Oil Co. well No. "Gardiner" 1		863	
22S	27E	35	MD	Western Oil & Explor. Co. well No. "Gardner" 1	1935	1022	Granite
23S	23E	7	MD	Trico Oil & Gas Co. well No. "Calif.-West." 1	1936	3184	Etchegoin
23S	23E	7	MD	Western Nat. Res. Corp. well No. "Guess" 3	1933	1832	Tulare
23S	23E	22	MD	Pixley Dev. Co. well No. 1	1925–1926	1450	Etchegoin
23S	26E	8	MD	Osborne, P. H., well No. 1	1931	4773	
23S	26E	16	MD	Seaboard Oil Corp. of Del. well No. "Security" 1	1937	4127	Miocene
23S	27E	3	MD	Bowles, Dr., et al., well No. 1	1926	1631	
23S	27E	3	MD	Gholson, Fred N., well No. "Chamboy" 1	1931	1300	
23S	27E	10	MD	Baker-Grover Co. well No. "Baker-Grover" 1	1935	1606	Mariposa slate
23S	27E	10	MD	Baker-Grover Co. well No. "Baker-Grover" 1-A	1935	1030	Mariposa slate
23S	27E	11	MD	Larson, I. H. & Stanford, M. A., well No. 1	1930		
23S	27E	11	MD	Miller & Sullivan well No. 1	1934	1071	Mariposa slate
23S	27E	12	MD	Kabella Oil Co. well No. "H. A. Briggs" 1	1936	800	Jurassic
23S	27E	12	MD	Kabella Oil Co. well No. "H. A. Briggs" 2	1936	903	Jurassic
23S	27E	29	MD	Ducor Drilling Co. well No. 1	1932	4330	Mariposa slate
23S	28E	7	MD	Hagerty & Caine, Trustees, well No. 1	1931	734	
23S	28E	8	MD	Grand View Oil Co. Ltd. well No. 1	1931	100	
23S	28E	8	MD	Jennings Syn. well No. "McMasters" 1	1931	530	Mariposa slate
23S	28E	17	MD	Terra Bella Irri. Dist. well No. 1	1933	442	Tulare
23S	28E	29	MD	Berghofer, Lypps & Le Mohm well No. 1	1931	1442	Slate
23S	28E	31	MD	Griggs & Sumter well No. "May" 1	1937	1500	Basement

VENTURA COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
9N	24W	2	SB	Adams Drill. & Oil Co. well No. 1	Pre-1925	2207	
9N	24W	2	SB	Webfoot Oil Syn. "Webfoot" well		1800	
9N	24W	10	SB	Adams Drill. & Oil Co. well No. 2	Pre-1925	785	Miocene
8N	21W	28	SB	Lockwood Valley Oil Co. well No. 1 NE ¼		600	
7N	23W	17	SB	Ozena Oil Co. well No. 1	1926	3562	
5N	23W	18	SB	Rancho Oils, Inc. well No. "W. F. Battin" 1	1935	2534	
3N	25W	2	SB	Benham Oil Co. well No. 2	Pre-1925	536	
3N	25W	2	SB	Benham Oil Co. well No. 3	Pre-1925	368	
3N	25W	2	SB	Benham Oil Co. well No. 4	Pre-1925		
3N	25W	2	SB	Lancaster-Midway Oil Co. well No. 5	Pre-1925	692	Miocene
2N	21W	20	SB	The Texas Co. "Pierce" well	1937	4053	Modelo
1N	22W	23	SB	The Texas Co. well No. "Eastwood" 1	1929	2665	Miocene volcanics
1N	21W	5	SB	Vaca Oil Exp. Co., Inc. well No. 1		2170	Volcanics
1N	21W	6	SB	El Rio Oils (Canada), Ltd. well No. "El Rio" 1		2625	
1N	21W	13	SB	Pacific Pet. Syn. well No. 1	Pre-1925	200	
1N	21W	14	SB	Ross, S. R., well C-1	1921	200	Miocene
1N	21W	17	SB	Magu Syn., Inc., Ltd. well No. 1	1932	5866	Miocene (?)
1N	20W	18	SB	Ross, A. J., et al., well No. 2	Pre-1925	230	Miocene
1N	20W	22	SB	Calif. Wyo. Oil Prod. well No. 1	1924	740	
1N	20W	24	SB	Sycamore Oil Co. well No. "Hansen" 1	1932	1703	Temblor
1N	19W	24	SB	Triunfo Oil Co. well No. 1	1932	2762	Volcanic
1N	17W	18	SB	Simi Oil Co., Ltd. well No. 1	1932	4898	Temblor
1N	17W	18	SB	Simi Oil Co., Ltd. well No. "Hearst" 2	1932	221	
1N	17W	18	SB	Simi Oil Co., Ltd. well No. "Calabasas" 1	1932	5936	Temblor

YOLO COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
12N	3W	2	MD	Martin, Morton S., well No. 1	1934	570	Cretaceous
12N	3W	15	MD	Swastica Oil Co. well	1923	225	Cretaceous
12N	3W	23	MD	Nigger Heaven Dome Oil & Gas Co. well No. "Lee Bow" 1	1934	6764	Cretaceous
12N	3W	23	MD	Pacific North Oil Co., Getty, George F., Inc. well No. "Guinda" 1		6770	Cretaceous
12N	1W	32	MD	Standard Oil Co. well No. "Peter Cook" 1	1937	5009	Cretaceous
11N	1W	36	MD	San Martinez Oil Co. well No. "E. H. Bemmerley" 1	1926	6221	Cretaceous
10N	1E	27	MD	Yolo Oil Corp. well No. 1	1925	3150	Cretaceous
10N	2W	26	MD	Esparto-Lincoln Oilfields Co. well No. 1	1930	2380	Ione
9N	1E	29	MD	Standard Oil Co. of Calif. well No. "Corcoran" 1			
9N	1E	32	MD	Standard Oil Co. of Calif. well No. "Hooper" 1		5181	Upper Cretaceous
9N	3E	8	MD	Empire Oil & Gas Corp. well No. 1	1938	460	
8N	1W	8	MD	Divide Ridge Oil Co. well No. 1	1925-1926	5003	Cretaceous

YUBA COUNTY

T	R	Sec.	B & M	Name of Company and Well	Yr. Aband. or Last Active	Depth Ft.	Geology at Bottom of Hole
15N	5E	7	MD	Blake, Thomas M., well No. 1			

GEOLOGIC FORMATIONS AND ECONOMIC DEVELOPMENT OF THE OIL AND GAS FIELDS OF CALIFORNIA

Part Four

Glossaries, Bibliography, and Index

Editorial note:

PART FOUR represents the concluding part of Bulletin 118 and refers to all that goes before it. The *Glossary of Geologic Units* includes not only the names of rock formations referred to in this bulletin, but all those described in the geological literature of California. The *Bibliography* is a selected list of published references dealing with features described and cited throughout the four parts of this bulletin. An attempt has been made to prepare a comprehensive *Index*. Folded in a pocket at the end of this bulletin is an *Outline Geologic Map of California Showing Oil and Gas Fields and Drilled Areas*. It is intended to serve as a guide to the reader and as a graphic presentation of the significant regional features relating to exploration for oil and gas in California.

The following chapters are included in PART FOUR:

Chapter XIV

Glossary of the Geologic Units of California

CONTENTS OF CHAPTER XIV

GLOSSARY OF THE GEOLOGIC UNITS OF CALIFORNIA

Compilation Based Largely on the Work of M. Grace Wilmarth * and Alice S. Allen **
Abstracted and Revised by Olaf P. Jenkins ***

OUTLINE OF REPORT

PURPOSE OF THE GLOSSARY

It is the principal purpose of this glossary to give ready reference to names applied to rock formations in California, and to state briefly their usage.

A number of the more widely used of these formation names are shown on the Geologic Legend, Sheet IV, of the Geologic Map of California, scale 1:500,000 (Jenkins, O.P. 38), grouped under the regional cartographic units of that map. In keeping with the original purpose of this bulletin—to serve as a companion piece to the state map—the following glossary has been prepared. It enables anyone interested to find the exact origin and meaning of all these names. The map that accompanies this bulletin, folded in the pocket of Part Four, is a reduced copy of the larger colored Geologic Map of California. The legend shown on it, however, indicates only the major map divisions.

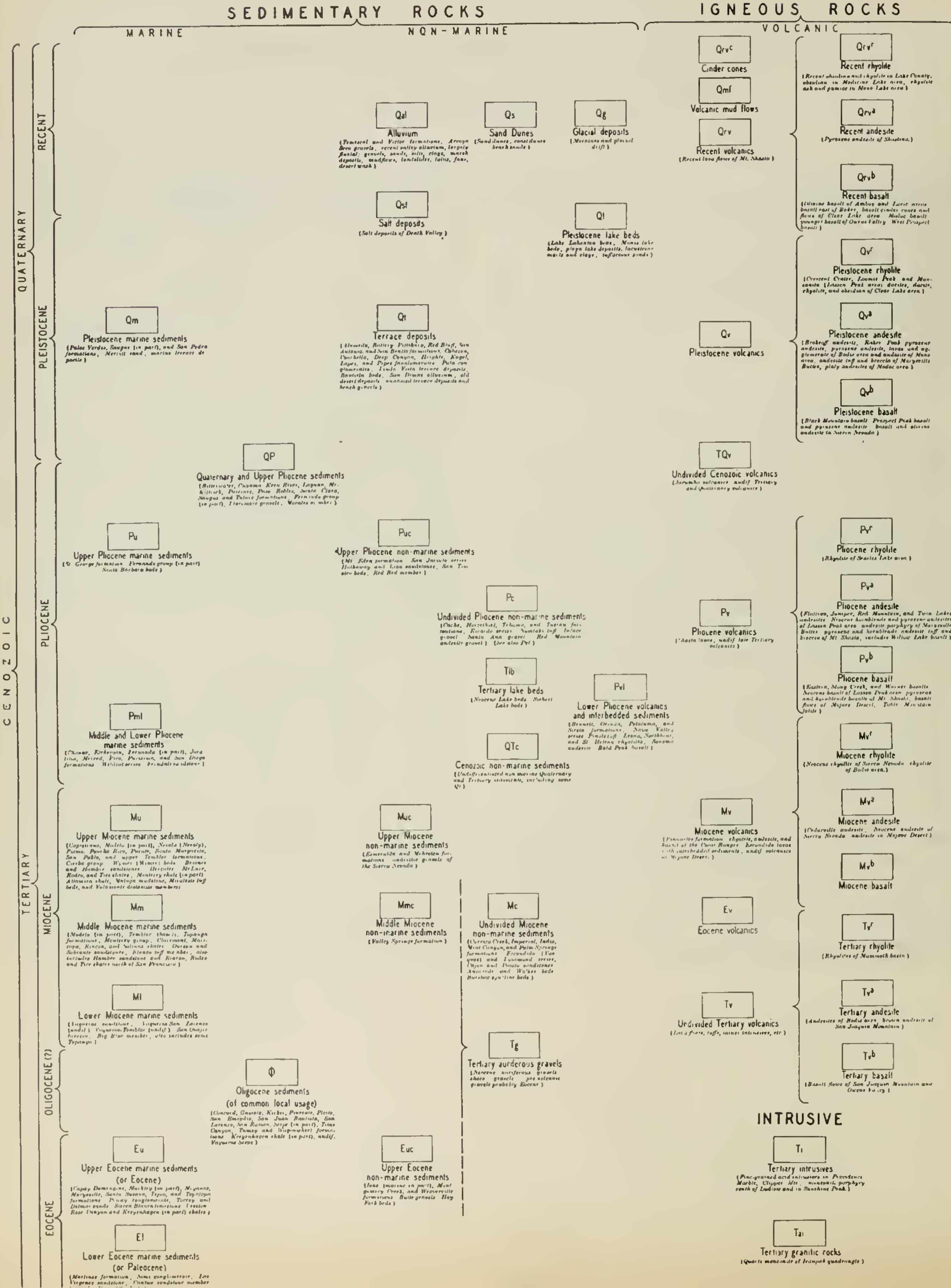
The main legend of the colored Geologic Map of California is reproduced in this report for ready reference. There are two main divisions of the cartographic units: (1) Tertiary and Quaternary, or Cenozoic; and (2) pre-Tertiary, or Mesozoic, Paleozoic, and older. The rocks of the Cenozoic are divided into (1) sedimentary rocks (marine and non-marine), and (2) igneous rocks (volcanic and intrusive). The pre-Tertiary rocks are grouped into (1) sedimentary and metamorphic rocks, and (2) igneous rocks (intrusive and meta-volcanic). In addition to these very generalized lithologic distinctions, the units are systematically arranged according to well-recognized time divisions. Within the boxes shown are symbols which appear on the map itself to serve as guides to the units mapped.

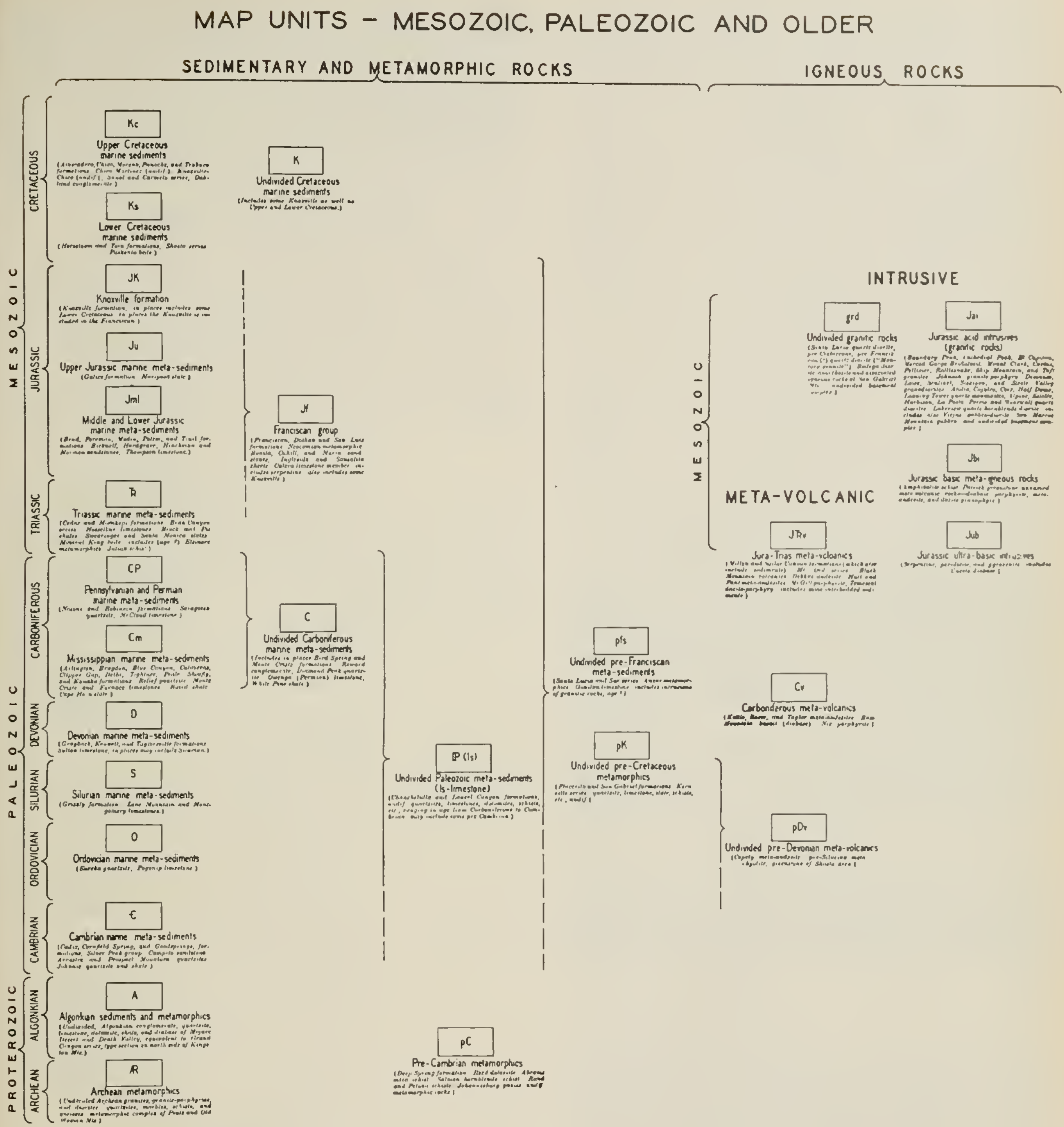
The unique isolated character of California in respect to stratigraphy is responsible for the publication by the United States Geological Survey of Bulletin 826, *Names and Definitions of the Geologic Units of California*, by M. Grace Wilmarth (1931). This publication was accompanied by four excellent correlation charts. These have all been long out of print, and with the steady progress of the science of stratigraphy, many new names have entered the literature. The Survey's Bulletin 896, *Lexicon of Geologic Names of the United States*, by M. Grace Wilmarth (1938), includes many of these new units. The following glossary, though foreshortened as regards descriptive matter, adds still more names to the list; it enables the reader to find literature on all the rock formations of California (whether they are or are not described in this bulletin); it indicates the type locality of each unit; and it endeavors to place the stratigraphic position of each.

As new work is done or old work is revised, new names for rock bodies, for the various divisions in geologic time, and for events in geologic history, are bound to appear. It behooves the geologist, therefore, to know what has been previously recognized and named, so that in coining new names or using old terms, he will create no further confusion. The simplicity of single names is preferred; use of preoccupied names should be avoided (in proposing a new name for a geologic unit it is advisable to consult the Committee on Geologic Names, U. S. Geological Survey, whose files contain those manuscript names that have been reserved, as well as published names); a clear definition, which shows the actual position of the unit within the rest of the rock section, should be given; the type locality should be stated; and mapping of the unit should be required before its definition is published.

* Author of U. S. Geological Survey Bulletins 726, 826, and 896; Secretary of Committee on Geologic Names, U. S. Geological Survey, 1905 to 1937.
** Secretary of Committee on Geologic Names, U. S. Geological Survey.
*** Chief Geologist, California State Division of Mines. Manuscript submitted for publication October 15, 1942.

MAP UNITS – CENOZOIC





FIGS. 283 and 284. Reproduction of "Geologic Legend" (Sheet IV, Geologic Map of California, 1938).

SIGNIFICANCE AND MEANING OF GEOLOGIC UNITS

In the course of making geologic maps from field study, it is necessary to decide what rock bodies should be shown. This decision is primarily controlled by the scale of the base map employed. Each chosen unit or formation is given a name, and its boundaries are delineated on the map.

Ordinarily the characteristic lithologic features of the unit govern its choice. In general, the larger the scale of the map the more differentiation can be made. The unit mapped should represent a deposit of some general continuity, such as a sediment formed under uniform conditions, an igneous mass of one intrusion, or a rock body representing an older regionally metamorphosed formation. In any case there may be wide variation in the petrographic character of the unit.

Lithology, however, is not the only factor that influences the choice of a unit. Relative age is of fundamental importance. Deciphering of geologic structure is one of the means by which relative age is determined. A geologic map should be accompanied by a legend showing the order and sequence of deposition of all the formations mapped, even though these formations may be complexly folded, faulted, eroded, intruded by igneous masses, and in part covered by later sediments.

Fossil remains, if found in sediments, constitute another means of working out sequence. They do more than help in the determination of the age relationships of the rocks in a given area, however, for they tell the relative ages of rocks in widely separated geographic provinces. The study of these regional relationships of fossils has resulted in the recognition of the major geologic time divisions of the earth.

The age of rocks in terms of years is not estimated by means of fossils, but through study of earth processes, such as the time it takes for salt to concentrate in the sea, sediments to be deposited, or radio-active minerals to break down to their end mineral products. On page 90 of this bulletin and Sheet V of the Geologic Map of California, a block diagram is presented which shows geologic ages in terms of estimated years, and salient events that took place in California during each major geologic period. These periods embrace the time represented by all the individual formations found in California, as well as the time intervals when no rock record was left.

It is not the purpose of this bulletin to standardize stratigraphic terms or names of geologic units. An attempt has been made, however, to present a glossary of the names applied to rock units rather than to the divisions or horizons in geologic time; nevertheless, it has been found necessary to define the rock units by referring them to the geologic time during which they were formed.

Schenck and Muller (41) propose that distinction be made between (a) "lithogenetic" terms (group, formation, member, and other smaller actual rock divisions), (b) "time-stratigraphic" terms (system, series, stage, and zone), and (c) "time" terms (era, period, epoch, and age) of broader scope. The material contained in the following glossary consists for the most part of "lithogenetic" units.

The meanings of the stratigraphic terms series, stage, and zone are often confusing in literature. Authors use "series" for group, "stage" for member, and "zone" for member, fossil horizon, or subsurface oil sand. One name is often applied to both the rock units and the time when the rocks were formed. Even names for orogenies have been applied to the rocks which came into being as a result of these mountain-making episodes.

In this glossary, fossil-named zones (for the reason that they are practically unlimited in number) do not appear. Those described in the text of this bulletin, however, are listed in the general index.

GENERAL GEOLOGIC TIME CLASSIFICATION [1]

Era	Period (or System)	Epoch (or Series)
Cenozoic	Quaternary	Recent Pleistocene
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene
Mesozoic	Cretaceous	Upper Cretaceous Lower Cretaceous
	Jurassic	Upper Jurassic Middle Jurassic Lower Jurassic
	Triassic	Upper Triassic Middle Triassic Lower Triassic
Paleozoic	Permian	
	Carboniferous	Pennsylvanian Mississippian
	Devonian	Upper Devonian Middle Devonian Lower Devonian
	Silurian	
	Ordovician	Upper Ordovician Middle Ordovician Lower Ordovician
	Cambrian	Upper Cambrian Middle Cambrian Lower Cambrian
pre-Cambrian: Proterozoic	Algonkian	
	Archean	

[1] For definitions see U. S. Geological Survey Bulletins 769 and 896. Paleocene has only recently been established as the earliest epoch (series) in the Tertiary; Permian has been elevated to the rank of period (system) from its former position as an epoch (series) of the Carboniferous. The terms Archean and Algonkian, which appear on this table and on the 1938 Geologic Map of California are no longer employed in the Survey's general time scale; the rocks corresponding to the Proterozoic era are called pre-Cambrian.

Because of their economic significance, most of the subsurface oil-field zones (with the exception of those bearing fossil names) are listed in the glossary, though not defined. Citations to selected literature and page references to descriptions in this bulletin are given. The zones can be distinguished from other units by the designation "subsurface." The list is not intended to be exhaustive, but it includes most of the important zones.

GEOLOGIC TIME CLASSIFICATIONS

General Classification

Practically all the major time units of the United States, and most of the major time units of the world, are represented in California.

The preceding table, showing these major units, has been prepared from Plate I of the United States Geological Survey Bulletin 769. Definitions of the names in this list have been omitted from the glossary.

Time Stages in the Jurassic and Cretaceous

California stratigraphers frequently refer to European stage names. The tables shown below, which cover the Cretaceous (Muller and Schenck, American Association of Petroleum Geologists meeting at Los Angeles, October 16, 1941) and Jurassic (Muller, S.W. 41) systems have recently been proposed as standards.

JURASSIC SYSTEM

Series		Stages	and Substages
Malm, or Upper Jurassic		Tithonian	Aquilonian Bononian
		Kimmeridgian	
		Oxfordian	
		Callovian	
Dogger, or Middle Jurassic		Bathonian	
		Bajocian	
Lias, or Lower Jurassic	Upper Lias	Toarcian	
	Middle Lias	Pliensbachian	Domerian Carixian
	Lower Lias	Sinemurian	
		Hettangian	

CRETACEOUS SYSTEM

Series	Stages	
Upper Cretaceous	Danian	
	Maestrichtian	
	Senonian	Campanian Santonian Coniacian
	Turonian	
	Cenomanian	
Lower Cretaceous	Albian	
	Aptian	
	Neocomian	Barremian Hauterivian Valanginian Berriasian

Time Stages in the Middle Tertiary of California

In a recent book by R. M. Kleinpell (38) the stratigraphy of the middle Tertiary of California is discussed at length, and important stage names are applied to this part of the geologic section in the State. These stages (from oldest to youngest, Refugian, Zemorrian, Saucesian, Relizian, Luisian, Mohnian, and Delmontian) are not actually rock units, but their use as definite time units is well established in local geologic literature. The reader is referred to Plate IV of this bulletin, where these stages are graphically described in relation to stratigraphic sections measured in the Coast Ranges.

Time Stages in Continental Tertiary

A proposal to standardize the terminology of North American continental (non-marine) Tertiary has recently been published by the Geological Society of America (Wood, H. E. 2nd, et al. 41). Since this work is beyond the scope of the present volume, the reader is referred to the published report.

Glacial Stages of California

The glacial stages of California, as defined by Blackwelder and Matthes, and used in literature, are as follows:

El Portal stage: Pleistocene; Yosemite region; older and more extensive than the Wisconsin glacial stage and younger than Glacier Point stage of glaciation (Matthes, F. E. 29; 30).

Glacier Point glacial stage: Pleistocene; Yosemite region; oldest of three glacial stages of Pleistocene glaciation in Yosemite region (Matthes, F. E. 29; 30).

Lundy glacial epoch: Pleistocene (Iowan glacial stage); east slope of Sierra Nevada; name replaced by Tahoe glacial stage (Blackwelder, E. 30; 31).

McGee glacial stage: Pleistocene (Nebraskan glacial stage); McGee Peak, Mt. Morrison quadrangle, Sierra Nevada; oldest glacial stage on east slope of Sierra Nevada (Blackwelder, E. 30).

Sherwin glacial stage: Pleistocene; east slope of Sierra Nevada, Mt. Morrison quadrangle; younger than McGee glacial stage and older than Tahoe glacial stage; corresponds to Kansan stage (Blackwelder, E. 30; 31).

Tahoe glacial stage: Pleistocene; east slope of Sierra Nevada; next to youngest glacial stage; correlated with Iowan glacial stage (Blackwelder, E. 31).

Tioga glacial stage: Pleistocene; Tioga Pass, Sierra Nevada; youngest glacial stage on east slope of Sierra Nevada (Wisconsin glacial stage) (Blackwelder, E. 31).

Yosemite glacial epoch: Pleistocene; Sierra Nevada; name later replaced with Tioga glacial stage (Blackwelder, E. 30; 31).

Orogenies of California

Episodes of mountain-making in California have had profound effects on the structure and lithologic character of rock formations (see pages 89 to 93 of this bulletin). Recognition of orogenies that have occurred at various times in the geologic history of a region forms an important item in mapping and interpretation. For example, the rocks formed prior to the Nevadan orogeny were, for the most part, metamorphosed to such a degree that they are frequently called the "bedrock series," or "basement complex"; most of the metalliferous mineral deposits of the state are found to have been deposited as a result of the granitic intrusions which accompanied this widespread disturbance. Names used in literature for various orogenies in California are given in the following list.

Cordilleran revolution (replaced in California by Nevadan orogeny): pre-Cretaceous Mesozoic orogeny; included both Sierra Nevada and Coast Ranges (Lawson, A. C. 93; Taliaferro, N. L. 42).

Diablan orogeny: Upper Jurassic (uppermost); Diablo Range, Coast Ranges; diastrophism between the Upper Jurassic and Lower Cretaceous (Taliaferro, N. L. 42). See pages 127, 130, 134, 152.

Jurasside revolution: name applied by A. Knopf to period of folding at end of Jurassic, which affected both Nevada and California (Wilmarth, M. G. 38; Crickmay, C. H. 31; Taliaferro, N. L. 42).

Laramide revolution (orogeny): a period of mountain building and erosion in Rocky Mountain region that began in late Cretaceous time and ended in early Tertiary time; its effect has been recognized in the Ivanpah quadrangle, San Bernardino County, by Hewett (Wilmarth, M. G. 38; Hewett, D. F. 39).

Nevadan orogeny (Nevadian orogeny or revolution): terms applied to diastrophic movements in late Jurassic and early Cretaceous time (Blackwelder, E. 14; Wilmarth, M. G. 38; Jenkins, O. P. 38; Taliaferro, N. L. 42). See pages 107, 130, 134, 151, 152, 184.

Oregonian orogeny: Upper Jurassic (?); California coast; crumpling of strata, accompanied by intrusion of peridotite (Blackwelder, E. 14).

Pasadenan orogeny: Pleistocene; represented by unconformity between lower and upper San Pedro beds (Stille, H. 36; 36a; Reed, R. D. 36). See page 118.

Santa Barbaran orogeny: Pleistocene; southern California; rocks were closely compressed after Pliocene marine sedimentation (Blackwelder, E. 14).

Santa Lucian orogeny: Upper Cretaceous; "The Upper Cretaceous is divisible into two parts separated by a strong orogenic disturbance." See page 131.

ACKNOWLEDMENTS

This glossary has been abstracted from bulletins 896, 826, and 769 of the U. S. Geological Survey (Wilmarth, M. G. 38; 31; 25). Supplementary data have been added by Miss Alice S. Allen. Miss Wilmarth's original work included publications to the end of 1935; Miss Allen's new compilation includes publications from 1936 to the end of 1941. In addition, revisions have been made to conform with more recent local geological research. Page reference is given to reports in this bulletin. Doctors Hubert G. Schenck and Siemon Wm. Muller of Stanford University have kindly read most of this glossary and helped in clearing up a number of important items.

SCOPE AND EXPLANATION OF GLOSSARY

A three-fold classification of the geologic units in this glossary has been made: (a) names in **bold-face** type are accepted and in current use by the U. S. Geological Survey although the age designations for some units are not those adopted by the Geological Survey; (b) names in *italics* have been abandoned or rejected by the U. S. Geological Survey; (c) names in ordinary type have not yet been considered by the Committee on Geologic Names of the U. S. Geological Survey.

Data on the geologic units are briefly summarized in the following manner: (a) name of geologic formation; (b) age of formation; (c) type locality or general location where the formation was first described; (d) stratigraphic or structural position of the formation in the type area; (e) bibliographic citations to original and later selected references listed in the Bibliography, Chapter XV, Part Four, of this bulletin; (f) page references to mention of the formation name in this bulletin.

GLOSSARY

A

Abacherli oil sand (subsurface): see page 363.

Abrams mica schist: Pre-Cambrian (?); Klamath Mountains (Hershey, O.H. 01; Hinds, N.E.A. 32).

Agua Fria slates, limestones, cherts, and tuffs; Lower Mesozoic; Indian Gulch quadrangle, Sierra Nevada; top formation of "Tuolumne group", later called Amador group (Taliaferro, N.L. 32; 42).

Agua sandstone member (of Santos shale): Miocene (lower); Carneros Creek area, Temblor Range; contains Vaqueros fossils (Clark and Clark 35). See pages 248, 251.

Alameda formation: Pleistocene; Berkeley Hills region; unconformably underlies San Antonio formation, and unconformably overlies Campus formation (Lawson, A.C. 14).

Alamitos zone (subsurface): (Soyster and Van Couvering 22a; Collom, R.E. 23a). See page 322, plate V.

Alamo sandstone: Pliocene (?); Mount Diablo area; overlies Neroly formation (Huey, A.S. 37; Condit, C. 38). See pages 191, 201.

Alberhill clay: Paleocene; northern Peninsular Ranges; considered in part correlative of Martinez in age (Sutherland, J.C. 35; Dudley, P.H. 35).

Alderson zone: Lower Cretaceous; in Horsetown group; overlies Mitchell "zone", underlies Hulen beds (Anderson, F.M., this bulletin, p. 184).

Alferitz formation: Miocene (middle); Luisian stage; Devils Den district, San Joaquin Valley; overlies Escudo formation, underlies McLure shale (Van Couvering and Allen, this bulletin, p. 496 et seq.). See page 500.

Alpine quartz diorite: late Jurassic or early Cretaceous; Peninsular Ranges (Miller, W.J. 35).

Altamira shale member (in Monterey shale): Miocene; Palos Verdes Hills, Los Angeles County (Woodring, Bramlette, and Kleinpell 36; Cushman and Goudkoff 38). See pages 222, 224.

Alturas formation: Pliocene; Modoc County; overlies upper Cedarville formation, underlies Warner basalt (Dorf, E. 33; LaMotte, R.S. 36). See page 201.

Amador group (originally named Tuolumne): Jurassic; Cosumnes River, Amador County, Sierra Nevada; grades upward into Mariposa group (Taliaferro, N.L. 42).

Amargosan series: early Tertiary (?); Amargosa Desert and Furnace Canyon (near Death Valley) (Keyes, C.R. 23).

Anaheim zones (subsurface): see page 231, plate V.

Anchor limestone member (of the Monte Cristo limestone): Mississippian (middle); Providence Mountains, San Bernardino County; first described by D.F. Hewett in Nevada (Wilmarth, M.G. 38); described as Anchor limestone (Hazzard, J.C. 37; 38).

Annex zone (subsurface): see plate V.

Antelope shale (subsurface): (Noble, E.B. 40). See pages 248, 249, 251, 252.

Anzar phase (of Santa Lucia series): Anzar Lake, San Benito County; metamorphic phase; relationship of it to Santa Lucia granite and Franciscan chert is not established (Kerr and Schenck 25).

Arcturus zones (subsurface): see page 285.

Arlington formation: Mississippian; northern Sierra Nevada; older than the Shoofly and younger than the Taylorsville (Diller, J.S. 92a; 08). See page 102.

Arlington sand (subsurface): (Kaplow, E.J. 38). See page 544.

Arrastre quartzite: probably Lower Cambrian; San Bernardino County; grades into Furnace limestone above (Vaughan, F.E. 22). See page 99.

Arroyo Hondo shale member (of Lodo formation): Eocene; near Panoche Creek, Fresno County; lies unconformably below Yokut sandstone and above Cantua sandstone member (White, R.T. 38; 40; Vokes, H.E. 39). See pages 188, 189, 196, 247, 248, 250, 487, 592, 595.

Arroyo Seco gravel: Pleistocene; Mokelumne River basin; underlies Victor formation, and unconformably overlies Laguna formation (Piper, Gale, Thomas, and Robinson 39).

Artist Drive formation: Oligocene and Miocene (?); Death Valley region, northern Black Mountains; unconformably underlies Furnace Creek formation (Thayer, T.P., *in* Noble, L.F. 41).

Ashton zones (subsurface): (Collom, R.E. 23a; Gale, H.S. 34). See pages 20, 220, 230, 329, plate V.

Asphalto lake bed: Pliocene; northwestern Kern County (Cooper, J.G. 94). See page 202.

Asuncion group: Upper Cretaceous; central Coast Ranges; unconformably overlies Pacheco group and overlaps on Shasta, Knoxville, Franciscan, and basement complex; on west side of San Joaquin Valley subdivided into Panoche (restricted), Moreno, and Garzas; in southern Santa Lucia Range subdivided into Cantinas sandstone, Godfrey shale, and Piedras Altas formation (Taliaferro, N.L., this bulletin, p. 132). See pages 130, 132, 134, 152, 153, 443, 458.

Atascadero formation: Upper Cretaceous; local representative of the Chico group in San Luis Obispo district; unconformably underlies Vaqueros and overlies Knoxville (Fairbanks, H.W. 04).

Athens zone (subsurface): see plate V.

Atlantic sand (subsurface): see plate V.

Atlas formation: Quaternary; Kern County; ancient alluvium; underlies Tank volcanics (Lawson, A.C. 06).

Atolia quartz monzonite: late Jurassic; Randsburg quadrangle, Kern and San Bernardino Counties; correlative of plutonic rocks of Sierra Nevada (Hulin, C.D. 25).

Auriferous gravels: in a restricted sense, the term refers to the older gravels; in this manner it has been used extensively; Eocene (middle and upper) to Miocene; Sierra Nevada and Klamath Mountains; represented by Weaverville formation, also by Ione formation (Wilmarth, M.G. 38; Allen, V.T. 29; MacGinitie, H.D. 37).

Auriferous slates: term used by Whitney and others for undifferentiated Paleozoic and Mesozoic strata in Sierra Nevada (Smith, J.P. 94).

Auriferous slate series: a descriptive term used in folios and other early reports on Gold Belt region of northern California to include Mariposa slate and Calaveras formation, in contradistinction to Superjacent series, a descriptive term applied to Cretaceous, Tertiary, and Quaternary deposits of the region (Wilmarth, M.G. 38).

Avawatz formation: Pliocene (lower); Avawatz Mountains, San Bernardino County; beds contain fossil vertebrates (Henshaw, P.C. 39). See page 202.

Avenal sandstone: Eocene; south of Coalinga, Kings County; underlies Kreyenhagen shale, overlies Cretaceous (Anderson, F.M. 05; von Estorff, F.E. 30; Clark and Vokes 36). See pages 168, 170, 193, 197, 248, 250, 492, 493, plate III.

B

Bagley andesite: Lower Jurassic, Redding quadrangle, Klamath Mountains; lies between Potem formation above and Modin formation below (Diller, J.S. 06; Hinds, N.E.A. 33).

Baird shale: Mississippian; Redding quadrangle, Klamath Mountains; older than McCloud limestone, younger than Bragdon formation (Fairbanks, H.W. 94; Smith, J.P. 94a; Diller, J.S. 06; Hinds, N.E.A. 33). See page 102.

Baker Canyon member (of Ladd formation) (the name Baker formation was changed to Baker Canyon member); Upper Cretaceous; Santa Ana Mountains, Peninsular Ranges; overlain by Holz member of Ladd formation, underlain by Trabuco formation (Popenoe, W.P. 37; 41; 42; this bulletin, pp. 364, 365, 366).

Balaklala rhyolite: Jurassic (?); Redding quadrangle, Klamath Mountains; Graton proves it to be alaskite porphyry and same as Bully Hill rhyolite; cuts Pit shale (Diller, J.S. 06; Graton, L.C. 10).

Bald Peak basalt: Pliocene; east of Berkeley; top formation of Berkeleyan series (Lawson and Palache 02). See pages 189, 201.

Baldwin zone (subsurface): see pages 233, plate V.

Ballena gravel: Eocene; Peninsular Ranges; perhaps equivalent to Poway conglomerate (Miller, W.J. 35a).

Barlow Ranch beds: Pleistocene; Ventura Basin; overlie the "San Pedro"; unconformably underlie the Hall Canyon (Eaton, J.E., this bulletin, p. 205). See pages 204, 206.

Barrelian series: Cambrian; California (Keyes, C.R. 31).

Barrel Spring formation: Middle Ordovician; Inyo Range; overlies Mazourka formation and underlies Devonian quartzite (Phleger, F.B. Jr. 33).

Barstow formation: Miocene (upper); San Bernardino County; overlies or is a part of the Rosamond series; distinctly older than Ricardo formation; contains vertebrate fossils (Hershey, O.H. 02; Merriam, J.C. 15; 19).

Basement complex (bedrock complex); descriptive term loosely applied to rocks comprising the floor upon which overlying sediments or superjacent rocks rest. See pages 121, 239.

Bass Mountain diabase (Bass Mountain basalt): Mississippian; Redding quadrangle, Klamath Mountains; partly interbedded with upper part of Bragdon formation (Diller, J. S. 06; Hinds, N.E.A. 30; 33; 40).

Battery formation: Pleistocene: Del Norte County; thin marine terrace (Maxson, J.H. 33).

Bautista beds: Pleistocene; San Jacinto quadrangle, Riverside County; contain vertebrate fossils (Frick, C. 21; Fraser, D. McC. 31).

Bay Point formation: Pleistocene; San Diego County; marine terrace deposit (Hertlein and Grant 39). See page 367.

Beal zone (subsurface): (Woodring, Stewart, and Richards 40).

Bean Canyon series (Bean Canyon formation): probably Triassic and Jurassic; Elizabeth Lake quadrangle, Los Angeles and Kern Counties; metamorphic series; no fossils found (Simpson, E.C. 34).

Bear River series: Miocene; Humboldt County; fossiliferous at south fork of Bear River (Stalder, W. 14).

Beck Spring dolomite: pre-Cambrian; Kingston Range, Ivanpah quadrangle; middle formation of Pahrump series; conformably overlies Crystal Spring formation; conformably overlain by Kingston Peak formation (Hewett, D.F. 40).

Bedrock series: a descriptive term used in folios and other early reports on Gold Belt region of northern California to include the Jurassic, Triassic, and Carboniferous formations, in contradistinction to "Superjacent series", which included the Cretaceous, Tertiary, and Quaternary deposits. The term has also been applied to the basement rocks of any region.

Bellavista "stage" (formation): Upper Cretaceous; upper part of Pioneer group; overlies Gaines "stage" (Anderson, F.M., this bulletin, pp. 109, 185).

Bell oil zone (also Bell sand) (subsurface): see pages 343, 344, 346, 380, 383, plate V.

Belridge diatomite: upper Miocene (also referred to as "Reef Ridge equivalent"); lies unconformably below Etchegoin formation, conformably on McLure shale (This bulletin, Wharton, J.B., p. 503; Young, U., p. 522).

Belridge sand (subsurface): (Williams, R.N. Jr. 36). See pages 248, 250.

Belt series: a provincial series of pre-Cambrian sedimentary rocks widely developed in Montana, Idaho, eastern Washington, and British Columbia. In early reports called "Belt formation", "Belt terrane", "Belt beds", and "Belt group" (Wilmarth, M.G. 38).

Bend formation: Middle and Lower Jurassic; Pit River, eastern Klamath Mountains; rests on Cedar formation (Diller, J.S. 92; 95; Fairbanks, H.W. 94; Smith, J.P. 94a).

Berkeley group (Berkeleyan series): Pliocene; Berkeley region; rests on Orinda formation and is overlain by Campus formation (Lawson and Palache 02, Lawson, A.C. 14). See page 201.

Berry conglomerate: Oligocene or Eocene; Junipero Serra quadrangle, Monterey County; overlies The Rocks sandstone, underlies Vaqueros formation (restricted) (Thorup, R.R. 41). See pages 464, 465.

Bicknell sandstone: Upper Jurassic; Taylorsville region, northern Sierra Nevada; overlies Mormon sandstone, and grades into overlying Hinchman sandstone (Diller, J.S. 92a; 08; Crickmay, C.H. 33).

Bicknell tuff: Upper Jurassic; Taylorsville region, northern Sierra Nevada; upper member of Bicknell sandstone (Hyatt, A. 92).

Big Blue serpentinous member (of Temblor formation): Miocene; Big Blue Hills, Coalinga district, Diablo Range; made up of serpentine debris; local deposit (Anderson and Pack 15; Clark, B.L. 35). See pages 117, 141, 189.

Big Glass Mountain complex: Recent; Modoc Lava Bed quadrangle, northern California; siliceous lava (Powers, H.A. 32).

Bird Spring(s) formation: Pennsylvanian; Inyo County; first described by D.F. Hewett in Goodsprings quadrangle, Nevada (Wilmarth, M.G. 38; Hazzard, J.C. 37). See pages 99, 100.

Bishop tuff: Pleistocene; southeast of Mono Lake (Gilbert, C.M. 38).

Bixby zone (subsurface): see page 327, plate V.

Blackhawk breccia: Pleistocene; San Bernardino County; includes Heights fanglomerate (Woodford and Harriss 28).

Black Mountain basalt: late Pliocene or early Pleistocene; western El Paso Range, eastern Kern County; intrusive and extrusive; intrudes Rosamond series and Red Mountain andesite (Baker, C.L. 12; Hulin, C.D. 25). See page 202.

Black Mountain volcanics: probably Upper Triassic or Jurassic; San Diego County; oldest rocks of La Jolla quadrangle; unconformably overlain by Cretaceous beds (Hanna, M.A. 26). See page 367.

Blanca tuff: Miocene; Santa Cruz Island; included in Monterey group; volcanics above and Temblor formation below (Rand, W.W. 31).

Blanco sandstone: Miocene (upper); Chino area, San Bernardino County; underlies Cubierto shale, overlies Papel Blanco shale (Krueger, M.L., this bulletin, page 363).

Bloemer sand (subsurface): (Williams, R.N. Jr. 36). See pages 250, 502, 503.

Blue chert series: Devonian (?); Klamath Mountains; pre-Bragdon; intruded by dioritic and diabasic rocks (Hershey, O.H. 06; Stauffer, C.R. 30).

Blue Canyon formation: Mississippian; Colfax quadrangle, northern Sierra Nevada; includes Duncan chert; underlies Relief quartzite (Lindgren, W. 00; Ferguson and Gannett 29).

"Blue gravels": the Paso Robles formation. See pages 235, 441.

Bodego Bay deposits: Quaternary; Bodega Bay, Marin County (Osmont, V.C. 05).

Bodega diorite: Jurassic (?); (pre-Franciscan); Bodega peninsula, Marin County (Osmont, V.C. 05). See page 622.

Bolinas sandstone: Jurassic (?) Franciscan; Bolinas Bay region, Marin County, near San Francisco (Arnold, R. 02; Lawson, A.C. 03; 14).

Bolsa oil zones (subsurface): (Collom, R.E. 23a; Gale, H.S. 34). See pages 230, 329, plate V.

Bonanza King formation: Middle Cambrian; Providence and Marble Mountains, San Bernardino County; includes Silver King (?) dolomitic member; overlies Cadiz formation and underlies Cornfield Springs formation (Hazzard and Mason 36; Hazzard. J.C. 37; 38). See pages 99, 100.

Bonita sandstone (in Franciscan group): Jurassic; San Francisco region (Arnold, R. 02; Lawson, A.C. 03; 14).

Bonsall tonalite: Jurassic (?); Peninsular Ranges; part of a composite batholith (San Marcos gabbro) which intrudes Triassic metamorphics (Hurlbut, C.S. 35; Miller, F.S. 37).

Bopesta formation: Miocene (upper); northeastern part of Kern County; rests on Kinnick formation (Buwalda, J.P. 34).

Boundary Peak granite: Inyo Range; Pellisier and Boundary Peak granites make up core of Inyo Range (Anderson, G.H. 37).

Bouquet Cañon breccia: probably Miocene; 30 miles north of Los Angeles; may be correlative of San Onofre breccia (Woodford, A.O. 25).

Bragdon formation: Mississippian; Weaverville quadrangle, Klamath Mountains; underlies Baird formation; unconformably overlies Kennett formation (Hershey, O.H. 01; Diller, J.S. 06; Hinds, N.E.A. 33).

Bridalveil granite (also Bridal Veil): late Jurassic or early Cretaceous; Yosemite region (Turner, H.W. 99).

Briones sandstone (in San Pablo group): Miocene; Contra Costa County; includes Hercules shale member; overlies Monterey, underlies Cierbo sandstone (Lawson, A.C. 14; Clark, B.L. 21; 30). See pages 189, 190, 454.

Brock shale: Upper Triassic; Redding quadrangle, Klamath Mountains; overlies Hosselkus limestone; overlain by Modin formation (Diller, J.S. 06). See page 105.

Brokeoff andesite: Cenozoic; Lassen region; *see* Divide Peak andesite and West Prospect basalt (Williams, H. 32; 32a).

Brown zone (subsurface): see pages 230, 322, plate V.

Buckbee oil zone (subsurface): see pages 343, 344, 346, plate V.

Bullion dolomite member (of Monte Cristo limestone); Mississippian; Providence Mountains, San Bernardino County; described as Bullion limestone (Hazzard, J.C. 38); first described by D.F. Hewett in Nevada (Wilmarth, M.G. 38).

Bully Hill rhyolite (Bully Hill volcanics): Jurassic (?); Redding quadrangle, Klamath Mountains; Graton proved this to be intrusive alaskite porphyry and same as Balaklala rhyolite; cuts Pit shale (Diller, J.S. 05; 06; Graton, L.C. 10).

Butano sandstone: Eocene; Santa Cruz Mountains; underlies conformably the San Lorenzo formation (Branner, Newsom, and Arnold 09). See plate III.

Butte gravels: Eocene (middle); Marysville (Sutter) Buttes; overlie white "Ione" sands; overlain by Sutter formation (Williams, H. 29). See pages 109, 611.

Butte "stage" (formation): Upper Cretaceous; in Panoche group; overlies Yolo "stage"; overlain by Joaquin "stage" (Anderson, F.M., this bulletin, p. 185).

Button beds: upper member in Temblor; Miocene; Kern County; first sandy beds below Maricopa shale at Temblor (Anderson, F.M. 05). See pages 116, 248, plate IV.

C

Cabezon fanglomerate: Quaternary; Bear and Holcomb Valleys, San Bernardino Mountains; older than Heights fanglomerate and younger than Coachella fanglomerate (Vaughan, F.E. 22).

Cable formation (or Cable lake beds): Quaternary (?); Kern County; older than Tehachapi formation and younger than Tank volcanics (Lawson, A.C. 06).

Cache formation (formerly Cache Lake beds): early Pleistocene or late Pliocene; Lake County; lies unconformably on Martinez (Becker, G.F. 88; Anderson, C.A. 36). See page 201.

Cactus granite: probably late Jurassic; San Bernardino Mountains (Vaughan, F.E. 22).

Cadiz formation: Middle Cambrian; Providence and Marble Mountains, San Bernardino County; lies above Wood Canyon formation and below Bonanza King formation (Hazzard and Mason 36; Hazzard, J.C. 37). See pages 100, 166.

Cahill sandstone (in Franciscan group); Jurassic (?); San Francisco region; same as San Bruno sandstone (Lawson, A.C. 14).

Cajalco quartz monzonite: late Jurassic (?); Perris block, Riverside County; covers area between Monument Peak and Arlington Mountain (Dudley, P.H. 35).

Calaveras formation (also group): Mississippian (?); Sierra Nevada; used by U. S. Geological Survey in folios of Sierra Nevada for all Paleozoic rocks; underlies Mariposa slates (Turner, H.W. 93; 93a).

Calera limestone member (of Cahill sandstone): Jurassic (?); (in Franciscan group); San Mateo County (Arnold, R. 02; Lawson, A.C. 03; 14).

California sandstone (or San Francisco sandstone): Jurassic (?) and Tertiary (Blake, W.P. 57).

Calitroleum sand (subsurface): (Siegfus, S.S. 39).

Callender zones (subsurface): see pages 230, 318, 319, plate V.

Campito sandstone: Lower Cambrian; Inyo Range; lies uncomformably on Deep Spring formation and grades into Silver Peak group above (Kirk, E. 18).

Camulos formation; Pliocene (middle or upper); Los Angeles and Ventura Counties; probably same as Pico formation (Keyes, C.R. 25). See page 202.

Canal sand (subsurface): (Menken, F.A. 40).

Canoas silt (member of Kreyenhagen): Eocene; Coalinga area; overlies Avenal sandstone, underlies "Kreyenhagen" shale proper (Clark, B.L., this bulletin, p. 189). See page 487.

Cantinas sandstones: Upper Cretaceous; northern Santa Lucia Range; a subdivision of the Asuncion group (Taliaferro, N.L., this bulletin p. 132).

Cantua sandstone member: Eocene; north of Coalinga, Fresno County; middle member of Lodo formation (Anderson and Pack 15; Clark, B.L. 21; 35; Vokes, H.E. 39; White, R.T. 40). See pages 189, 193, 196, 592.

Cantua shale: Oligocene or Eocene; north of Coalinga, Fresno County; same as Kreyenhagen shale (Church, C.C. 30; Hanna, G.D. 30).

Capay formation (stage, shale): Eocene; west of Rumsey Hills, Sacramento Valley; lies on Cretaceous shales (Crook and Kirby 35; Clark, B.L. 35; Anderson and Russell 39). See pages 112, 114, 137, 180, 187, 189, 193, 194, 197, 248, 588, 592, 595, 599, 615.

Cape Horn slate: Mississippian; Colfax quadrangle, Sierra Nevada; overlies Relief quartzite and underlies Delhi formation (Lindgren, W. 00).

Capistrano formation: upper Miocene or Pliocene; Orange County; overlies Monterey shale and is overlain by San Mateo formation (Woodford, A.O. 25).

Careaga formation: Pliocene; Santa Maria district, Santa Barbara County; formerly included in Foxen formation; underlain by restricted Foxen; overlain unconformably by Paso Robles formation (Canfield, C.R. 39; Wissler and Dreyer, this bulletin, p. 235). See pages 201, 235, 237, 238, 431, 434, 435, 437, 439.

Caribou formation: Mississippian; Plumas County; younger than Grizzly formation and older than Spanish formation (Diller, J.S. 92; Smith, J.P. 16a).

Carmelo series: Eocene (?); Carmelo Bay region; overlies Santa Lucia granite; underlies unconformably the Monterey series (Lawson, A.C. 93; Hawley, H.J. 17; Trask, P.D. 26). See page 135.

Carneros sandstone member (sand) (in Temblor); Miocene; Temblor Range, Kern County; included in Temblor sandstone (Cunningham and Barbat 32; Gester and Galloway 33; Packard and Kellogg 34). See pages 200, 248, 250, 251, 503, 504, plate IV.

Carpinteria formation: Pleistocene; Santa Barbara County; contains Pleistocene flora (Chaney and Mason 33).

Carquinez series: Paleocene and Eocene; Carquinez Strait; also spelled "Karquinez" (incorrect) (Arnold, R. 02; Lawson, A.C. 03).

Carrizo formation (Carrizo Creek beds): Pliocene (or Miocene); Imperial and San Diego Counties; G. D. Hanna gave the name "Imperial formation", assigned it to Pliocene; W.P. Woodring divided beds into Palm Spring formation above, and Imperial formation below; U.S. Geological Survey assigns formation to Miocene (Orcutt, C.R. 90; Smith, J.P. 10; Vaughan, T.F. 17; Kew, W.S.W. 14; 20; Hanna, G.D. 26a; Woodring, W.P. 31; Buwalda and Stanton 30). See page 202.

Carson Creek formation: Mesozoic or Paleozoic; Carson Hill, Calaveras County, Sierra Nevada; local name for bedrock series (Moss, F.A. 27).

Cascajo conglomerate member (of San Joaquin formation): Pliocene; Kettleman Hills; basal member of San Joaquin formation (Woodring, Stewart, and Richards 40).

Casmalia red beds (Casmalia gypsiferous shale): Miocene; Santa Maria district; underlie Monterey and younger than Vaqueros formation (Hoots and Herold 35).

Castlebury zone (subsurface): see page 315.

Catalina facies (of Franciscan series): Jurassic (?); Catalina Island; metamorphic facies (Woodford, A.O. 24; 25).

Catalina schist breccia: Miocene (lower ?); southeast end of Catalina Island; doubtful correlative of the San Onofre facies of Temblor formation (Woodford, A.O. 25).

Cathedral Peak granite: late Jurassic or Cretaceous; Yosemite National Park; included in Tuolumne intrusive series, next younger than Half Dome quartz monzonite, and next older than Johnson granite (Calkins, F.C. 30).

"Caving blue shale": see page 252.

Cedar formation: Upper Triassic; Lassen Peak region; includes Hosselkus limestone and Swearinger slate (Diller, J.S. 92; Turner, H.W. 94).

Cedarville series (Cedarville andesite): Miocene; Modoc County; overlain by Alturas formation; divided by LaMotte into upper Cedarville, middle lava layer, and lower Cedarville formation (Russell, R.J. 28; Powers, H.A. 32; LaMotte, R.S. 36).

Centinela gravels: Pleistocene; Baldwin Hills, Los Angeles County (Tieje, A.J. 26).

Cerros shale member (of Lodo formation): Paleocene and Eocene; near Panoche Creek, Fresno County; lower member of Lodo formation (White, R.T. 38; 40). See pages 189, 193, 196, 595.

Chalk Mountain dacite: Recent (?); Lake County; intrudes Cache formation (Anderson, C.A. 36).

Chambless limestone: Lower Cambrian; Providence Mountains, San Bernardino County; described as Chambless (algal) limestone; overlies Kelso shale; underlies Cadiz formation (Hazzard, J.C. 38).

Chanac formation: Pliocene; Tejon Hills, Kern County; equivalent to Tulare, Etchegoin, and Jacalitos formations (Merriam, J.C. 16; Hoots, H.W. 30; Miller and Bloom 37). See pages 202, 240, 241, 243, 244, 245, 483, 559, 562, 563, 564, 565, 566, 568, 569, 570, 573, 574, 577.

Chanchelulla formation: pre-Middle Devonian; Klamath Mountains; includes intrusives, Chanchelulla greenstone and meta-andesite; overlies Abrams schist and Salmon schist; appears to underlie Copley meta-andesite (Hinds, N.E.A. 31; 32; 33).

Chapman zones (shales) (subsurface): see pages 220, 231, 232, 233, 257, 357, 358, 359, plate V.

Chico Creek beds: Upper Cretaceous; Great Valley of California; F.M. Anderson divides the upper part of the Panoche group into the Chico Creek beds and Los Gatos beds (Anderson, F.M. 37).

Chico formation (also group, series): Upper Cretaceous; Chico Creek, Sacramento Valley region; overlies Shasta group (Gabb, W.M. 69; Hinds, N.E.A. 33; Anderson, F.M. 38; Taliaferro, N.L., this bulletin, p. 130). See pages 95, 129, 130, 168, 183, 185, 189, 210, 367, 417, 599, 601, 604, 606, 608, 611, 620, 622.

Chico-Tejon series: a term introduced to include all Upper Cretaceous and Eocene rocks of California (White, C.A. 89).

Chino limestone: upper Paleozoic (?); Crestmore, near Riverside; same as Chino Quarry limestone of J. W. Daly (Woodford, Crippen, and Garner 41).

Chino Quarry quartzite and limestone: Paleozoic (?); Crestmore, Riverside County; the quartzite overlies the limestone; included in Jurupa series (Daly, J.W. 35).

Chubbuck marble member (of Essex series): pre-Cambrian; near Cadiz, San Bernardino County (Hazzard and Dosch 37a).

Church Creek beds: Eo-Oligocene; Lucia quadrangle, Monterey County; bounded above by fault and below by basement rocks (Reiche, P. 37).

Cierbo sandstone (in San Pablo group): Miocene (upper); near Carquinez Strait, Mount Diablo region; lies on Briones and below Neroly (Clark, B.L. 21; 30; Clark and Woodford 27). See pages 189, 190.

Cima sandstone lentil: Cretaceous or Paleocene; Escarpado Canyon, Panoche Hills, Fresno County; occurs in Dos Palos shale member of Moreno shale (Payne, M.B. 41).

Ciocca zone (subsurface): see pages 233, 234, plate V.

Claremont shale (in Monterey group): Miocene (middle); Berkeley Hills; underlies Oursan sandstone and overlies Sobrante sandstone (Lawson, A.C. 14). See page 189, plate III.

Clarke (Clark) oil zone (subsurface): see page 234, plate V.

Clark-Hathaway zone (subsurface): see pages 343, 344, 346.

Clear Creek greenstone: Klamath Mountains region; also called a series, or volcanic series (Hershey, O.H. 01; 03; 04; Diller, J.S. 05).

Clear Lake sediments: Pleistocene; Clear Lake, Lake County; appear to be later than Cache formation (Dall and Harris 92).

Clendenen lime (zone) (subsurface): (Miller and Bloom 37). See page 569.

Clipper Gap formation: Mississippian; Colfax quadrangle, northern Sierra Nevada; overlies Delhi formation (Lindgren, W. 00).

Coachella fanglomerate: Miocene (middle or upper); Riverside County; older than Cabezon fanglomerate; younger than Deep Canyon fanglomerate (Vaughan, F.E. 22).

Coahuila silt: Pleistocene; Imperial County; silts of ancient Lake Coahuila (Hanna, G.D. 26a).

Coalinga beds: Pliocene and Miocene; Coalinga region; restricted definition applied essentially to Santa Margarita formation (Anderson, F.M. 05; 08). See page 202.

Coast complex: Paleozoic (?); pre-Franciscan; northwestern part of Monterey County; same as Sur series (Willis, B. 00).

Coast Range complex: a name that has been applied to the pre-Franciscan rocks of the Coast Ranges (Wilmarth, M.G. 38). See page 121.

Coffin zone (subsurface): see pages 234, 315, 317, plate V.

Coldwater sandstone member (in Tejon formation): Eocene; Los Angeles and Ventura Counties; top member of Tejon formation; overlies Cozy Dell shale, underlies Sespe formation (Kew, W.S.W. 24; Taliaferro, N.L. 24; Kerr and Schenck 28; Clark and Vokes 36). See pages 114, 396, 398, plate III.

Colfax formation: Upper Jurassic; northern Sierra Nevada; upper part of Mariposa slate, as used by U. S. Geological Survey (Smith, J. P. 10; Goranson, R. W. 24).

Combe sandstone: Upper Jurassic; Mount Jura, northern Sierra Nevada; overlies Trail tuffs and conglomerate (Crickmay, C.H. 33). See page 106.

Concord formation: Oligocene; Mount Diablo region; overlies Kirker tuff and underlies or is a part of the Sobrante sandstone (Clark, B.L. 18). See page 189, plate III.

Conejo volcanics: Miocene; western end of Santa Monica Mountains; interbedded in Miocene sediments (Taliaferro, N.L. 24). See page 424.

Contra Costa lake bed: Pliocene; Contra Costa and Alameda Counties (Cooper, J.G. 94). See page 201.

Cooks Canyon agglomerate (formation): Upper Jurassic; Mount Jura, northern Sierra Nevada; underlies Lucky S argillite and overlies "Forman" (Foreman) argillite (Crickmay, C.H. 33). See page 106.

Copley meta-andesite: pre-Middle Devonian; Redding quadrangle, Klamath Mountains; overlain by Kennett limestone (Diller, J.S. 06; Hinds, N.E.A. 31; 32; 33).

Cornfield Springs formation: Middle Cambrian and later (?); Inyo and San Bernardino Counties; overlies Bonanza King formation (Hazzard and Mason 36; Hazzard, J.C. 37; 38). See pages 99, 100.

Corral Hollow shales (member of Franciscan series): Jurassic (?); Corral Hollow, Alameda County; older than Oakridge sandstone (Tolman, C.F. Jr. 15).

Coso formation: Pliocene (upper); Coso Mountains, Inyo County; vertebrate-bearing beds underlying volcanics (Schultz, J.R. 37). See page 202.

Coso granodiorite: late Mesozoic; Darwin district, Inyo County (Kelley, V.C. 37; 38).

Cottonwood beds: Lower Cretaceous; northern Sacramento Valley, Cottonwood district; member in the lower part of the Horsetown group (Anderson, F.M. 38a).

Courtney granite: Mesozoic; Klamath Mountains (Hershey, O.H. 00).

Coyote Mountain clays (in Imperial formation): Pliocene (or lower Miocene); Imperial County; lie above Latrania sands and below Yuha reefs of oyster shells; assigned by G. D. Hanna to the Pliocene, but W.P. Woodring correlates it with his Imperial formation, assigning age of late lower Miocene (Hanna, G.D. 26a; Woodring, W.P. 31). See page 202.

Cozy Dell shale member: Eocene; Ventura County; underlies Coldwater sandstone member and overlies Matilija sandstone member (Kerr and Schenck 28).

Crescent City beds: Pliocene; near wharf at Crescent City, Del Norte County (Diller, J.S. 02). See page 201.

Crescent Crater dacites: Cenozoic; Lassen National Park; *see* West Prospect basalt (Williams, H. 32).

Cruz zone (subsurface): see page 233, plate V.

Crystal Spring formation: pre-Cambrian; Kingston Range, Ivanpah quadrangle; basal formation of Pahrump series; unconformably overlies pre-Cambrian gneissic granite; conformably overlain by Beck Spring dolomite (Hewett, D.F. 40).

Cubierto shale: Miocene (?); Chino area, San Bernardino County; underlies Hunter sandstone and conglomerate, overlies Blanco sandstone of upper Miocene age (Krueger, M.L., this bulletin, p. 363).

Cuesta diabase: San Luis Obispo region; intrusive masses of pre-Chico age (Fairbanks, H.W. 04).

Cuyama formation: Pleistocene or Pliocene; Cuyama Valley, San Luis Obispo and Santa Barbara Counties; lies on Santa Margarita formation, and is overlain by Quaternary terrace gravels (English, W.A. 16).

Cuyamaca basic intrusive: probably pre-Cretaceous; Cuyamaca region, San Diego County; cuts Julian schist and Stonewall quartz diorite (Hudson, F.S. 22; Donnelly, M. 34).

Cypress zones (subsurface): see pages 315, 316, plate V.

D

Daggett lake beds: late Tertiary or Quaternary; Mojave Desert, San Bernardino County; overlie Rosamond; overlain by alluvium (Gardner, D.L. 40).

Darwin limestone: Pennsylvanian; Darwin district, Inyo County (Kelley, V.C. 37; 38).

Darwin quartz diorite: late Mesozoic; Darwin district, Inyo County (Kelley, V.C. 37, 38).

Dawn limestone member (of Monte Cristo limestone): Lower Mississippian; Providence Mountains, San Bernardino County; first described by D.F. Hewett in Nevada (Wilmarth, M.G. 38); described as Dawn limestone (Hazzard, J.C. 38).

Deadman Island beds: Pleistocene; San Pedro, Los Angeles County; lower part of San Pedro formation; later called "Timms Point zone"; Deadman Island has been removed by steam shovels (Smith, J.P. 10; Grant and Gale 31; Clark, A. 31).

Death Valley formation: Paleozoic (?); Panamint Range, Inyo County; overlies Telescope group (Murphy, F. Mac 32).

Deep Canyon fanglomerate: Quaternary; San Bernardino Mountains; older than Coachella fanglomerate and younger than Pipes fanglomerate (Vaughan, F.E. 22).

Deep Spring formation: pre-Cambrian; Inyo Range; underlies conformably the Campito sandstone, and overlies unconformably the Reed dolomite (Kirk, E. 18).

Dekkas andesite: Permian or Triassic; Redding quadrangle; overlies unconformably Nosoni formation, and underlies Bully Hill rhyolite and Pit shale (Diller, J.S. 06; Hinds, N.E.A. 33; Wheeler, H.E. 40).

Del Amo zone (subsurface): (Huguenin, E. 39). See pages 221, 225, 299, 300, plate V.

Delhi formation: Mississippian; northern Sierra Nevada, Colfax quadrangle; overlies Cape Horn slate, and underlies Clipper Gap formation (Lindgren, W. 00).

Delmar sand: Eocene; San Diego County; grades into overlying Torrey sand; lies on "Chico" unconformably; lower member of La Jolla formation (Hanna, M.A. 26; Hertlein and Grant 39). See pages 189, 367.

Descanso granodiorite: late Jurassic or early Cretaceous; Peninsular Ranges; cuts Alpine quartz diorite (Miller, W.J. 35).

DeSoto zone (subsurface): see pages 221, 228, 320, 323, plate V.

Devilwater silt or shale (subsurface): (Bailey, W.C. 39). See pages 248, 249, 503.

Diamond Peak quartzite: Carboniferous; Inyo Range; assigned to Mississippian by Girty, though Kirk found it separated from underlying White Pine shale by 1000 feet of limestone carrying Pennsylvania fossils; first described in Nevada by Hague (Wilmarth, M.G. 38; Kirk, E. 18).

Divide Peak andesite: Cenozoic; Lassen Peak region; units mapped, in downward order, augite andesite, Divide Peak andesite, hypersthene basalt, Brokeoff andesite, Brokeoff andesite (solfatarized), Brokeoff vents, pre-Lassen dacites, Loomis Peak dacites, NE. Lassen dacites, Old Lassen mud flow, dacite tuff, domes, dacite breccias, Lassen 1915 dacite, and Lassen 1914-15 mud flows (Williams, H. 32; 32a).

Domengine formation (Domijean sands): Eocene (middle); north of Coalinga, Diablo Range; at Domengine ranch, overlain by Kreyenhagen shale and underlain by Yokut sandstone (Anderson, F.M. 05; Clark and Stewart 25; Nelson, R.N. 25; Stewart, R.B. 26; Clark and Woodford 27; von Estorff, F.E. 30; Gester and Galloway 33; Clark, B.L. 35; Clark and Vokes 36; White, R.T. 40). See pages 112, 114, 137, 150, 170, 180, 188, 189, 193, 194, 195, 196, 197, 248, 250, 252, 474, 588, 592, 594, 595, 599, plate III.

Dosados member (of Moreno shale): Cretaceous; Escarpado Canyon, Panoche Hills, Fresno County; conformably overlies Panoche formation; underlies Tierra Loma shale member of Moreno (Payne, M.B. 41).

Dos Palos shale member (of Moreno shale): Cretaceous and Paleocene (?); Escarpado Canyon, Panoche Hills, Fresno County; overlies Marca shale member; disconformably underlies Paleocene glauconitic sandstone (Payne, M.B. 41).

Dothan formation: Upper Jurassic; Del Norte County; first described in Oregon by J.S. Diller; name used by Maxson for Franciscan (Wilmarth, M.G. 38; Maxson, J.H. 33; Taliaferro, N.L. 42).

Dry Creek formation: Eocene; Chico quadrangle, Sacramento Valley; above Chico sandstone and conformably underlies Ione formation (Allen, V.T. 29).

Duff zone (subsurface): see pages 576, 577.

Duncan chert: Mississippian; Colfax quadrangle, northern Sierra Nevada; included in Blue Canyon formation (Lindgren, W. 00).

Duncan zone: Lower Cretaceous; lowermost "zone" of Paskenta group; overlain by Sylvester "zone" (Anderson, F.M., this bulletin, page 184).

"Dunns Peak" sandstone: see pages 193, 197.

E

Eastern basalts: Cenozoic; Lassen National Park; lie on Juniper lavas; *see* West Prospect basalt (Williams, H. 32; 32a).

Echo granite: pre-Cambrian (?); San Gabriel Mountains, Los Angeles County (Miller, W.J. 30; 33; 35b).

Eden beds (Mount Eden formation): Pliocene (lower); San Jacinto quadrangle, Riverside County; Fraser suggested name Mount Eden formation, to replace Eden beds, preoccupied (Frick, C. 21; Fraser, D.M. 31). See page 202.

Edison shale: Miocene; east side of San Joaquin Valley; includes Fruitvale shale (Cushman and Goudkoff 38). See pages 241, 243, 244, 483.

Edwin clay: Eocene (?); Jones Butte, Butte County; lowest 8 feet of clay at this locality (Allen, V.T. 29).

Elbe zone (subsurface): see pages 244, 579, 582, 583.

El Capitan granite: Upper Jurassic or Cretaceous; Yosemite National Park; one of the oldest intrusive rocks of Yosemite (Calkins, F.C. 30).

Elder Creek group: Upper Jurassic; Coast Ranges; lowest "group" in Knoxville "series" (Anderson, F.M., this bulletin, page 184).

Elliott zone (subsurface): (Woodring, Stewart, and Richards 40).

Elsinore metamorphic series: Triassic (?); Riverside County; meta-sediments and meta-volcanics, intruded by various plutonic bodies and Temescal dacite porphyry; unconformably overlain by Alberhill clays (Dudley, P.H. 32; 35).

Elsinore zone (subsurface): (Dodd, H.V. 33; Woodring, Stewart, and Richards 40). See page 248.

"Elsmere formation": Pliocene; Elsmere Canyon, southern California; not yet formally described in literature; see p. 202.

Ely Springs dolomite: Upper Ordovician; Inyo County; first described in Nevada by Westgate and Knopf (Wilmarth, M.G. 38); found by Hazzard in Nopah Mountains, Inyo County, between Eureka quartzite below and Silurian above (Hazzard, J.C. 37). See pages 99, 100.

Emery zone (subsurface): see page 348, plate V.

Emigh shale (subsurface): see pages 592, 594.

Erburu zones (subsurface): see page 376.

Escondido series (Vasquez series): Miocene (?); Los Angeles County; Simpson says it is overlain unconformably by Mint Canyon formation; Sharp suggests name Vasquez series to replace it (Hershey, O.H. 02; 02a; Kew, W.S.W. 24; Simpson, E.C. 34; Sharp, R.P. 36).

Escudo formation: Miocene (middle); Relizian stage; Devils Den district, San Joaquin Valley; unconformably overlies Hannah formation, underlies Alferitz formation (Van Couvering and Allen, this bulletin, p. 496 et seq.).

Esmeralda formation (Siebert lake beds): Miocene (upper); Inyo County; Siebert lake beds mapped by S.H.Ball in Inyo County, now same as Esmeralda formation first described by H.W. Turner in Nevada (Wilmarth, M.G. 38; Ball, S.H. 07; Gilbert, C.M. 41).

Essex series: pre-Cambrian; Piute and Old Woman Mountains, San Bernardino County; oldest of three units in the Archean, according to Hazzard and Dosch: Essex series, Fenner granite-gneiss, and Kilbec granite-gneiss (Hazzard and Dosch 37a).

Estelle quartz diorite: late Jurassic (?); Riverside County; pierces the Temescal dacite porphyry (Dudley, P.H. 35).

Etchegoin formation: Pliocene; San Joaquin Valley; lies below San Joaquin formation; U. S. Geological Survey now restricts name Etchegoin formation to include lower two-thirds of formation as originally defined; many geologists treat Etchegoin and Jacalitos as one formation (Anderson, F.M. 05; Nomland, J.O. 16a; Woodring, Stewart, and Richards 34; Arnold and Anderson 08b). See pages 112, 144, 150, 176, 178, 189, 190, 202, 205, 206, 240, 243, 244, 245, 248, 249, 446, 460, 485, 487, 492, 494, 495, 502, 503, 504, 509, 510, 513, 517, 518, 521, 523, 526, 529, 530, 532, 539, 541, 543, 559, 562, 563, 564, 565, 570, 573, 574, 575.

Eureka quartzite: Ordovician (Middle); Inyo County; first described by A. Hague as occurring in Nevada; in Nopah Mountains, J.C. Hazzard describes it as lying between Ely Springs dolomite above and Pogonip (?) dolomite below (Wilmarth, M.G. 38; Hazzard, J.C. 37). See pages 99, 100.

F

Fairhaven sand (subsurface): (Miller, R.H. 38). See pages 562, 564.

Famosa sand (subsurface): see page 573.

Fant meta-andesite: Middle Jurassic; northern Sierra Nevada, Taylorsville region; according to Diller, younger than Hardgrave sandstone, older than Thompson limestone; also called Fant volcanics; Crickmay says reverse stratigraphic position (Diller, J.S. 08; Crickmay, C.H. 33). See page 106.

Farmer zone (subsurface): see plate V.

Felix siltstone (subsurface): (Dodd and Kaplow 33). See pages 248, 250, 251, 492, 493.

Fenner granite gneiss: pre-Cambrian; Piute and Old Woman Mountains, San Bernardino County; younger than Essex series; older than Kilbeck granite gneiss (Hazzard and Dosch 37a).

Fernando group: Pliocene and Pleistocene; Los Angeles and Ventura Counties; lies below Pleistocene terraces and above Modelo formation (Eldridge and Arnold 07; Kew, W.S.W. 24). See pages 202, 322.

Ferndale sandstone: Pliocene (upper); Humboldt County; overlies upper Pico; underlies Wildcat formation (MacGinitie, H.D., this bulletin, page 633).

Flatiron andesites: Cenozoic; Lassen National Park; *see* West Prospect basalt (Williams, H. 32).

Foix oil zone (subsurface): (Collom, R.E. 23a). See pages 232, 343, 344, 346, plate V.

Forbes formation: Upper Cretaceous; west side Sacramento Valley; conformably overlies Guinda formation (Kirby, J.M., this bulletin, p. 601). See pages 602, 603, 606, 608.

Foreman formation: Upper Jurassic; Taylorsville region, northern Sierra Nevada; overlies unconformably the Hinchman sandstone and unconformably overlaps Mormon sandstone, Robinson, and Peale formations; also called the Foreman or Forman argillite (Diller, J.S. 92a; 08; Crickmay, C.H. 33). See page 106.

Foxen formation: Pliocene (middle); Santa Maria district; divided into upper Foxen sand, Foxen foraminite, Foxen diatomite, Lower Foxen sand; underlies Schumann formation and overlies Santa Margarita formation (Porter, W.W. II 32; Reed, R.D. 33; Hoots and Herold 35). See pages 190, 201, 235, 236, 237, 238, 431, 434, 441.

Franciscan formation (group, where subdivided); Upper Jurassic; western California; in San Francisco area, includes Bonita sandstone, Ingleside chert, Marin sandstone, Sausalito chert, Cahil sandstone, Calera limestone member; the intrusive serpentine is not considered part of the formation; considered younger than the Mariposa group by Taliaferro (Lawson, A.C. 95; 95a; 14; Taliaferro, N.L., this bulletin, p. 123). See pages 95, 106, 123, 125, 130, 134, 150, 151, 152, 210, 225, 226, 431, 440, 442, 443, 444, 448, 458, 475, 483, 616, 618, 619, 622, 625, 626, 628, 630, 632, 633, plate V.

Freeman silt member (subsurface): (Kleinpell, R.M. 38). See pages 242, 483, 559, 573, 577, 580.

Freeman-Jewett siltstones (subsurface): see pages 240, 241, 244, 566.

Friant formation: Miocene (?); Friant quadrangle, San Joaquin Valley; unconformably overlaps Ione formation, granitic rocks, and schists; overlain by remnants of basaltic flows (MacDonald, G.A. 41).

Fruitvale shale: Miocene; southeast end of San Joaquin Valley, Mountain View oil field; in the Mountain View field, the upper Miocene is divided into the Santa Margarita sand and Fruitvale shale (Miller and Bloom 37; Cushman and Goudkoff 38). See pages 240, 241, 242, 243, 245, 251, 252, 483, 548, 560, 563, 566, 571, 573, 577.

Funeral fanglomerate: Pliocene (?); overlying borate beds of Death Valley (Keyes, C.R. 23; 23a; Thayer, T.P., *in* Noble, L.F. 41).

Funks formation: Upper Cretaceous; west side Sacramento Valley; conformably overlies Sites formation, conformably underlies Guinda formation (Kirby, J.M., this bulletin, p. 606). See pages 601, 602, 603, 605, 608.

Furnacean series: Miocene (?); borate-bearing beds of Death Valley; younger than Amargosan series (Keyes, C.R. 23; 23a).

Furnace Creek formation: Miocene or Pliocene; Death Valley region, northern Black Mountains; unconformably overlies Artist Drive formation; unconformably underlies Greenwater volcanics (Curry, H.D., *in* Axelrod, D.I. 40; Thayer, T.P., *in* Noble, L.F. 41).

Furnace limestone: Mississippian (?); San Bernardino Mountains; lies below Saragossa quartzite and above Arrastre quartzite (Vaughan, F.E. 22; Woodford and Harriss 28). See page 99.

G

Gabilan limestone: Paleozoic (?) possibly Carboniferous; Coast Ranges; also spelled Gavilan; said to be a member of the Sur series; intruded by granitic rocks; pre-Franciscan (Becker, G. F. 88; Andrews, P. 36).

Gaines stage: Upper Cretaceous; western Shasta County; lower part of Pioneer group (Anderson, F.M. 37). See pages 109, 185.

Galice formation: Upper Jurassic; Smith River, Del Norte County; described first by Diller in Oregon as correlative of Mariposa slate (Wilmarth, M.G. 38; Maxson, J.H. 33; Taliaferro, N.L. 42).

Gallaway beds: Miocene; Point Arena-Fort Ross region, Mendocino County; overlies Skooner Gulch basalt, underlies Point Arena beds (Weaver, C.E., this bulletin, pp. 630, 631, 632).

Garzas sandstone: Upper Cretaceous; Diablo Range; a member of the Moreno shale (Anderson, F.M. 37; Huey, A.S. 37; this bulletin: Taliaferro, N.L., p. 132; Anderson, F.M., p. 185). See pages 109, 132, 134, 185, 186, 588.

Gatchell sand (subsurface): see pages 248, 250, 487, 490.

Gavilan Peak gabbro: Jurassic (?); Val Verde district, Riverside County; intrudes Triassic metamorphic series; apparently older than Trabuco formation and unconformably underlies Alberhill clays; in places is intruded by Val Verde tonalite (Osborn, E.F. 39).

Gaviota formation: Eocene and Oligocene (?); Gaviota Pass, Santa Barbara County; conformably overlies "Tejon" formation and underlies Sespe formation (Effinger, W.L. 35; Schenck and Kleinpell 35; Clark and Vokes 36). See pages 137, 170, 188, 193, 194, plate III.

Genesee Valley limestone and shales: Triassic; Plumas County, northern Sierra Nevada; mapped by Diller as Swearinger slate and Hosselkus limestone (Smith, J.P. 10; Diller, J.S. 08).

Gibson sand (subsurface): see pages 530, 531.

Godfrey shale: Upper Cretaceous; southern Santa Lucia Range; a subdivision of the Asuncion group, (Taliaferro, N.L., this bulletin, p. 132).

Golden Gate formation: Upper Cretaceous; west side Sacramento Valley; overlies Horsetown group, conformably underlies Mills formation (Kirby, J.M., this bulletin, p. 606). See pages 601, 603, 604, 608.

Golden Gate series: Jurassic (?); western California; same as Franciscan formation (Fairbanks, H.W. 95).

Goldman zone (subsurface): (Kaplow, E.J. 38).

Gold Park gabbro-diorite: pre-Cambrian; Twenty-Nine Palms, San Bernardino and Riverside Counties; intrudes metasediments; older than Palms granite (Miller, W.J. 38).

Gosnell zone (subsurface): see pages 202, 388, 389.

Gould shale member (in Monterey shale): Miocene (middle); Chico-Martinez Creek, Kern County; lies between "*Valvulineria californica* zone" and "button bed" (Cunningham and Barbat 32; Barbat, W.F. 32; Gester and Galloway 33; Woodring, Bramlette, and Kleinpell 36). See pages 248, 249, 502, 503, 504, 559, plate IV.

Grapevine conglomerates: early Tertiary; east side of Death Valley, Inyo County; lie beneath Greenwater volcanics; lower formation of Amargosan series (Keyes, C.R. 23, 23a).

Grayback formation: Devonian; Del Norte and Siskiyou Counties; in some respects similar to Kennett formation (Maxson, J.H. 33).

Gredal formation: Eocene (upper); Devils Den district, San Joaquin Valley; overlies Mabury formation, unconformably underlies Point of Rocks formation (Allen and Van Couvering, this bulletin, p. 496 et seq.).

Greeley sand (subsurface): (Musser, E.H. 39). See page 556.

Green Valley formation: Pliocene (lower); SW¼ Sec. 24, T. 1 S., R. 1 W., M.D., Mount Diablo region; stratigraphically higher than Neroly; fossil vertebrate and leaf locality (Condit, C. 38). See pages 189, 191, 201.

Green Valley tonalite: Jurassic (?); Peninsular Ranges; part of the batholith of the San Marcos gabbro (Miller, F.S. 37).

Greenwater volcanics: Miocene or Pliocene; Death Valley, California; unconformable below Redhill sandstone, and unconformable above Grapevine conglomerate (Keyes, C.R. 23; 23a; Thayer, T.P. *in* Noble, L.F. 41).

Grindstone group: Upper Jurassic; Coast Ranges; middle subdivision of Knoxville "series"; underlain by Elder Creek "group"; overlain by Newville "group" (Anderson, F.M., this bulletin, p. 184).

Grit zone (subsurface): see pages 196, 248, 250, 487, 556, 582, 583.

Grizzly formation (or quartzite): Silurian (?) (may be Ordovician); Taylorsville region, northern Sierra Nevada; overlain by Montgomery limestone; rests on meta-rhyolite (Diller, J.S. 92a; 08).

Grizzly Peak andesite: Pliocene; Berkeley Hills; included in Moraga formation; overlain by Siestan formation; rests on rhyolite tuff (Lawson and Palache 02; Lawson, A.C. 14).

Gualala group (series) (*see* Wallala group): Cretaceous; Point Arena—Fort Ross region, Mendocino County; overlies Franciscan, underlies Skooner Gulch basalt (Weaver, C.E., this bulletin, pp. 630, 631).

Guinda formation: Upper Cretaceous; west side Sacramento Valley; conformably overlies Funks formation, conformably underlies Forbes formation (Kirby, J.M., this bulletin, p. 601). See pages 602, 603, 605, 606, 608.

H

Half Dome quartz monzonite: probably Cretaceous; Yosemite National Park; included in Tuolumne intrusive series; younger than Sentinel granodiorite and older than Cathedral Peak granite (Calkins, F.C. 30).

Hall Canyon formation: Pleistocene (lower); Ventura Basin; lies above "San Pedro formation" (restricted) and below Palos Verdes formation (Eaton, J.E. 28a; 31). See pages 204, 205, 206.

Hall City limestone: Carboniferous; Klamath Mountains; not well defined (Diller, J.S. 03).

Hambre sandstone (in Monterey group): Miocene (Mohnian stage); Contra Costa County; underlies Rodeo shale; overlies Tice shale (Lawson, A.C. 14). See page 189.

Hamlin-Broad zone: Lower Cretaceous; uppermost "zone" in Paskenta "group"; underlain by Sylvester "zone" (Anderson, F.M., this bulletin, p. 184).

Hanaupah formation (of Telescope group): Lower Paleozoic (?); Panamint Range, Inyo County; overlies Redlands dolomitic limestone and underlies Death Valley formation (Murphy, F. Mac 32).

Hannah formation: Miocene (lower) (Zemorrian and Saucesian stages); Devils Den district, San Joaquin Valley; unconformably overlies Wagonwheel formation, unconformably underlies Escudo formation (Van Couvering and Allen, this bulletin, p. 496 et seq.).

Harbison quartz diorite: late Jurassic or early Cretaceous; San Diego and Imperial Counties; cuts Alpine quartz diorite (Miller, W.J. 35).

Hardgrave sandstone: Lower Jurassic (Upper Lias); Taylorsville region, northern Sierra Nevada; according to Diller, separated from the overlying Thompson limestone by Fant meta-andesite; called Hardgrave tuff and assigned to the Middle Jurassic by Crickmay who also gives the sequence of this and the adjacent units in the reverse order (Diller, J.S. 92a; 08; Crickmay, C.H. 33). See pages 106, 166.

Harris formation ("Harris Grade"): Miocene (upper) or Pliocene; Santa Maria district (Reed, R.D. 33). See page 201.

Hat Creek basalt: Recent; Hat Creek Valley, north of Lassen Peak (Anderson, C.A. 40).

Hathaway formation: upper Pliocene or lower Quaternary; San Bernardino Mountains; younger than Lion sandstone and older than Pipes fanglomerate (Vaughan, F.E. 22). See page 202.

Hathaway oil zone (subsurface): see page 338, plate V.

Hay Fork beds: Oligocene or Eocene; Trinity County; fossil leaf beds and gravels; correlated with Weaverville formation (Diller, J.S. 02; 03; MacGinitie, H.D. 37).

Headlight porphyry: earliest Cretaceous (probably); Trinity County; applied locally to a granodiorite porphyry (Wilmarth, M.G. 38).

Heights fanglomerite: Quaternary; Banning Heights, San Bernardino Mountains; later included in Blackhawk breccia; overlies Cabezon fanglomerate (Vaughan, F. E. 22; Woodford and Harriss 28).

Herculean shale member (in Monterey group): Miocene; San Pablo region; underlies Quercan sandstone (Weaver, C.E. 09).

Hercules shale member (of Briones sandstone): Miocene (upper); San Pablo Bay region; middle member of Briones sandstone (Lawson, A.C. 14).

Hill zone (subsurface): (Kaplow, E.J. 38).

Hinchman sandstone: Upper Jurassic; Taylorsville region, northern Sierra Nevada; also called tuff and arkose; overlain by Foreman formation; grades into underlying Bicknell sandstone (Diller, J.S. 92a; 08; Crickmay, C.H. 33). See page 106.

Hogan shale (zone) (subsurface): (Miller and Bloom 37).

Hoge zones (subsurface): see plate V.

Holz member (of Ladd formation): Upper Cretaceous; Santa Ana Mountains, Peninsular Ranges; unconformably overlain by Williams formation; underlain by Baker member of Ladd formation (Popenoe, W.P. 37; 42). See pages 364, 366.

Homer quartzite: Triassic (?); southern Sierra Nevada, Tulare County; overlies Lemon Cove schist; probably underlies Three Rivers schist; a subdivision of Kaweah series (Durrell, C. 40).

Hondo shale (subsurface): see pages 485, 487.

Hood oil zone (subsurface): (Miller and Bloom 37).

Horsetown formation: Lower Cretaceous; upper part of the Shasta group; Shasta County; overlies Paskenta formation; underlies Chico formation (White, C.A. 85; Diller and Stanton 94; Anderson, F.M. 38a; this bulletin, p. 184). See pages 108, 124, 129, 130, 134, 168, 183, 184, 606, 616, 619.

Hosselkus limestone: Upper Triassic; Taylorsville and Redding region; overlain by Swearinger slate and unconformably underlain by Robinson formation (Diller, J.S. 92a; 08; Ashley, G.H. 23). See pages 105, 106, 166.

Howard Park zones (subsurface): see plate V.

Hualde zone (subsurface): see pages 351, 354, plate V.

Huckleberry andesites: Cenozoic; northern California (Lassen National Park); occur near Huckleberry Lake (Williams, H. 32).

Hulen beds: Lower Cretaceous; northern Sacramento Valley, Cottonwood district; upper part (member) of the Horsetown formation (Anderson, F.M. 38a; this bulletin, p. 184). See page 108.

Hull agglomerate (also Hull formation): Middle Jurassic; Mount Jura, northern Sierra Nevada; older than Moonshine formation; younger than Hinchman formation (Crickmay, C.H. 33).

Hull meta-andesite: Upper Jurassic; Taylorsville region, northern Sierra Nevada; eruption apparently took place after deposition of Foreman formation (Diller, J.S. 08).

Hunter sandstone and conglomerate: Miocene (?); Chino area, San Bernardino County; underlies Peculiar shale, overlies Cubierto shale (Krueger, M.L., this bulletin, p. 363).

Hunter Valley cherts and tuffs (in Amador group): probably lower Mesozoic; Sierra Nevada; underlie Penyon Blanco agglomerates, and overlie pillow basalts (Taliaferro, N.L. 32; 42).

Hyampom lake beds: Oligocene or Eocene; Trinity County; fossil leaf beds and gravels; correlated with Weaverville formation (Diller, J.S. 02; MacGinitie, H.D. 37).

I

Imperial formation: Pliocene or Miocene (late lower); southern California, Imperial County; Hanna assigns it to the Pliocene, type locality in Alverson Canyon; overlain by Latrania sands; Imperial formation is a substitute for Carrizo Creek beds; Woodring restricted Imperial formation to marine beds, assigning it to late lower Miocene (Hanna, G.D. 26a; Woodring, W.P. 31). See page 202.

Indian conglomerate: Eocene (?); Santa Ynez quadrangle, Santa Barbara County; lies on Cretaceous; overlain by Mono shale (Nelson, R.N. 25a; Keenan, M.F. 32).

Indian Gulch formation, agglomerates, tuffs, sandstones, and conglomerates: Mesozoic; Merced River, and Indian Gulch quadrangle, Sierra Nevada; basal formation of Mariposa group (Taliaferro, N.L. 32).

Indio formation: Pliocene or Miocene (middle or upper); Indio Hills, Riverside County; same as Palm Springs formation; overlies marine Carrizo formation; Hanna assigns it to the Pliocene (Hanna, G.D. 26a; Buwalda and Stanton 30; Woodring, W.P. 31). See page 202.

Ingleside chert (in Franciscan group): Jurassic; San Francisco region; overlain by Bonita sandstone, underlain by Marin sandstone (Lawson, A.C. 14).

Inyoan series: Lower Triassic; Death Valley region; comprises all early Triassic of Nevada (Keyes, C.R. 23; 23a).

Inyo granite: late Jurassic; not defined; probably not intended as a geologic name (Maxson, J.H. 34).

Inyo marble: Lower Cambrian; Inyo Range; caps White Mountain (Hanks, H.G., 86b; Kirk, E. 18).

Inyo series: Middle and Lower Triassic; Inyo Range; a geographic name for these Triassic rocks (Smith, J.P. 10; Ashley, G.H. 23).

Ione formation: Eocene; northern Sierra Nevada, Gold Belt region; also called Ione sandstone; Ione clay rock or tuff of Turner is now called Valley Springs formation of Miocene age; Allen's restricted definition of Ione formation now adopted usage; type locality at Ione; the older auriferous gravels of the Sierra Nevada (not those containing Tertiary volcanic debris) form part of the Ione formation (Lindgren, W. 94; Turner, H.W. 94; Williams, H. 29; Allen, V.T. 29). See pages 112, 114, 137, 150, 193, 592, 594, 611.

Ironside dolomite member: Devonian (?); Providence Mountains, San Bernardino County; first described in Nevada by D.F. Hewett, as member of Sultan limestone (Wilmarth, M.G. 38); lies unconformably above Cornfield Springs formation and unconformably below Mississippian or Devonian limestone; described as Ironside (?) dolomite in Inyo County (Hazzard, J.C. 38).

Isabella granodiorite: late Jurassic (?); Kernville quadrangle, southern Sierra Nevada; younger than gabbro diorite that cuts Kernville series (Miller, W.J. 31).

J

Jacalitos formation: Pliocene (lower); Coalinga region; underlies Etchegoin formation; overlies Reef Ridge shale; some geologists map Etchegoin and Jacalitos as one formation (Arnold and Anderson 08b; Hoots and Herold 35). See pages 145, 146, 176, 189, 190, 202, 240, 243, 245, 248, 249, 467, 492, 500, 513, 562, 563.

Jacumba volcanics: early Quaternary or late Tertiary; southern Peninsular Ranges; rest on Table Mountain formation (Miller, W.J. 35).

Jewett sand and silt (subsurface): (Godde, H.A. 28a; Barbat and Cunningham 32; Diepenbrock, A. 33; 34). See pages 242, 251, 483, 559, 573, 577, 579, 580, 582, 583.

Joaquin "stage": Upper Cretaceous "stage" in Panoche group; overlies Butte "stage"; overlain by Los Gatos "stage" (Anderson, F.M., this bulletin, p. 185). See page 109.

Johannesburg gneiss: pre-Cambrian; Randsburg quadrangle; Kern and San Bernardino Counties; assigned to Archean; believed to unconformably underlie Rand schist (Hulin, C.D. 25).

Johnnie formation: Lower Cambrian; Inyo County; first described by Nolan in Nevada; described by J.C. Hazzard in the Nopah Mountains of Inyo County; lies below Stirling quartzite and above Noonday dolomite (Nolan, T.B. 28; Hazzard, J.C. 37; Noble, L.F. 41). See page 100.

Johnson granite porphyry: late Jurassic or early Cretaceous; Yosemite National Park; youngest of the Tuolumne intrusive series (Calkins, F.C. 30).

Johnson gravels: Tertiary; Taylorsville region, northern Sierra Nevada; later referred to as auriferous gravels (Diller, J.S. 92a).

Jones sand (subsurface): (Gale, H.S. 34). See pages 202, 230, 329, plate V.

Julian schist: Triassic or older; southern Peninsular Ranges, San Diego County; also called Julian group; intruded by granitic rocks; Donnelly assigns it to Juratrias (Merrill, F.J.H. 14; Hudson, F.S. 22; Donnelly, M. 34; Miller, W.J. 35).

June Lake basalt: Pleistocene; June Lake district, east-central Sierra Nevada; extruded between Tahoe and Tioga glacial stages (Putnam, W.C. 40).

Juniper andesites: Cenozoic; Lassen National Park; *see* West Prospect basalt; overlie Willow Lake basalts (Williams, H. 32).

Junipero sandstone: Eocene; Junipero Serra quadrangle, Monterey County; unconformably overlies basement complex; underlies Lucia shale (Thorup, R.R. 41). See page 463.

Jurupa series: Paleozoic (?); Riverside County; oldest rocks of Jurupa Mountains; recrystallized sedimentaries divided into (descending) Sky Blue Quarry limestone, Chino quarry quartzite, and Chino quarry limestone (Daly, J.W. 35).

K

Kagel fanglomerate (or Kaegel fanglomerate): Quaternary; Kagel Canyon, San Gabriel Mountains; overlies Saugus formation unconformably (Hill, M.L. 30).

Kalorama member (of Las Posas formation): Pleistocene; Ventura County; lower member of formation (Pressler, E.D. 29; Bailey, T.L. 35a). See page 202.

Kanaka formation: Mississippian; Oregon Creek to South Yuba, Colfax region; northern Sierra Nevada; underlies Relief quartzite and overlies Tightner formation (Ferguson and Gannett 29).

Kaweah series: Triassic (?); southern Sierra Nevada, Tulare County; subdivided in order of inferred age into Yokohl amphibolite, Lemon Cove schist, Homer quartzite, and Three Rivers schist (Durrell, C. 40).

Keddie formation: Pennsylvanian; Lassen Peak and Taylorsville regions; same as Robinson formation (Diller, J.S. 95).

Kelso shale: Lower Cambrian; Providence Mountains, San Bernardino County; overlies Tough Nut quartzite, underlies Chambless limestone (Hazzard, J.C. 38).

Kennett formation: Middle Devonian; Redding region; underlies the Bragdon formation (Smith, J.P. 94a; Diller, J.S. 06; Stauffer, C.R. 30; Hinds, N.E.A. 33).

Kernco zone (subsurface): (Miller, R.H. 38). See page 564.

Kern River series: Pliocene and Pleistocene; Kern River region, southeast border of San Joaquin Valley; also called group or formation; unconformably overlies Temblor group (Anderson, F.M. 05; 11; Stevens, J.B. 24; Fox, L.S. 29; Diepenbrock, A. 33). See pages 202, 240, 241, 244, 245, 483, 557, 559, 562, 563, 565, 575, 577, 580.

Kernville series: Jurassic or older; Kernville quadrangle; southern Sierra Nevada; metasedimentary series; cut by gabbro-diorite (Miller, W.J. 31).

Kern zones (subsurface): (Kaplow, E.J. 38). See page 544.

Kettleman lake bed: Pleistocene (?); Tulare Lake region; fresh-water deposit (Cooper, J.G. 94). See page 202.

Kettle meta-andesite: Pennsylvanian; Taylorsville region, northern Sierra Nevada; older than Reeve meta-andesite (Diller, J.S. 08).

Kilbeck granite-gneiss: pre-Cambrian; Old Woman Mountains, San Bernardino County; thought to be younger than Fenner gneiss; considered Archean (Hazzard and Dosch 37).

King City formation: Pliocene; Salinas Valley; unconformably overlies basement complex; overlain by Poncho Rico formation; previously referred to Santa Margarita formation (Clark, B.L. 40; this bulletin, p. 190). See page 201.

Kingston Peak formation: pre-Cambrian; Kingston Range, Ivanpah quadrangle; top formation of Pahrump series; conformably overlies Beck Spring dolomite; unconformably overlain by probable Lower Cambrian sedimentary rocks (Hewett, D.F. 40).

Kinnick formation: Miocene (lower); northeast of Monolith, Kern County; underlies Bopesta formation and lies on Witnet formation unconformably (Buwalda, J.P. 34).

Kinsey sand (subsurface): see page 531.

Kirker's Pass beds: Miocene (upper); Mount Diablo region; Kirker's Pass beds with Santa Margarita fauna (Smith, J.P. 10).

Kirker tuff: Oligocene; Mount Diablo region; overlain by Concord formation and underlain by San Ramon formation (Clark, B.L. 18). See pages 137, 189, plate III.

Klamath gravels: Pleistocene; Weaverville and Red Bluff quadrangles; continuous with Red Bluff deposits (Hinds, N.E.A. 33).

Klamath oldland gravels: Pliocene; east of Crescent City; old stream deposits (Maxson, J.H. 33).

Klamath schist series: (or Klamath schists); pre-Cambrian (?); northern California; Klamath Mountains; includes Abrams mica schist and Salmon hornblende schist (Hershey, O.H. 01).

Knoxville formation: Jurassic (uppermost); Knoxville, Lake County; in restricted sense, and at the type locality, is Jurassic; considered to be part of the Franciscan by Taliaferro; Anderson assigns it to below the Paskenta; U. S. Geological Survey considers it to be Jurassic and Lower Cretaceous (White, C.A. 85; Diller and Stanton 94; Anderson, F.M. 32; 33; Taliaferro, N.L., this bulletin, p. 125). See pages 95, 106, 125, 130, 134, 150, 151, 152, 168, 183, 184, 616, 619.

Kraemer zone (subsurface): see pages 221, 231, 232, 234, 357, 358, 359, 360, plate V.

Kreitz zone (subsurface): see plate V.

Kreyenhagen shale: Eocene and Oligocene (?); north and south of Coalinga, Diablo Range; lies conformably above Avenal and Domengine sandstones, and unconformably below Temblor sandstone (Anderson, F.M. 05; Arnold and Anderson 10; Anderson and Pack 15; von Estorff, F.E. 30; Jenkins, O.P. 31; Hanna, G.D. 33; Woodring, Stewart, and Richards 34; Clark and Vokes 36). See pages 112, 113, 114, 115, 137, 150, 170, 172, 178, 182, 189, 193, 194, 195, 196, 197, 248, 250, 252, 483, 485, 487, 492, 573, 592.

L

Ladd formation: Upper Cretaceous; Santa Ana Mountains, Peninsular Ranges; comprised of two members, Holz (upper) and Baker (lower); unconformably overlain by Williams formation; unconformably underlain by Trabuco formation (Popenoe, W.P. 37; 42). See page 366.

Laguna formation: Pliocene (?); Hadselville Creek, Mokelumne River basin; unconformably underlies Arroyo Seco gravel; overlies Mehrten formation (Piper, Gale, Thomas, and Robinson 39). See page 202.

La Habra conglomerate: Pleistocene and upper Pliocene; east of Whittier, south coastal basin; local name for Saugus formation (Eckis, R. 34). See pages 202, 210.

La Jolla formation: Eocene; San Diego County; includes (ascending order) Delmar sand, Torrey sand, and Rose Cañon shale (Clark, B.L. 26; Hanna, M.A. 26; Clark and Vokes 36; Hertlein and Grant 39). See pages 188, 189, 193.

Lake basalt: Pleistocene (?); Modoc lava bed quadrangle, northern California (Powers, H.A. 32; Anderson, C.A. 41).

Lakeview quartz-hornblende diorite: late Jurassic (?); Riverside County; intrudes the Perris quartz diorite (Dudley, P.H. 35).

Lang division: upper Miocene; Los Angeles County; underlies Soledad division and unconformably overlies Mellenia series; Kew considers it upper part of Mint Canyon formation (Hershey, O.H. 02; Kew, W.S.W. 24).

La Posta quartz diorite: late Jurassic or early Cretaceous; La Posta Valley, Peninsular Ranges (Miller, W.J. 35).

Las Posas formation: Pleistocene and upper Pliocene; South Mountain area, Ventura County; divided into Long Canyon member (above), and Kalorama member (below), the latter of which is included in Santa Barbara formation; Las Posas formation overlies the Timms Point formation (Pressler, E.D. 29; Clark, B.L. 30; Grant and Gale 31; Tieje and Cassell 33; Bailey, T.L. 35a). See pages 189, 191, 202, 388.

Lassen dacites: Cenozoic; Lassen region; *see* Divide Peak andesite (Williams, H. 32).

Las Virgenes sandstone: Paleocene; south side of Simi Hills, Ventura County; overlies and grades into Simi conglomerate; underlies and grades into Martinez group (Nelson, R.N. 25).

Latrania sands: Pliocene or Miocene (lower); Imperial County; overlies Imperial formation (Hanna, G.D. 26a); part of Imperial formation (Woodring, W.P. 31). See page 202.

"Lawler tuff": see pages 189, 191.

Leaning Tower quartz monzonite: Upper Jurassic or Lower Cretaceous; Yosemite National Park (Calkins, F.C. 30).

Lehnhardt zone (subsurface): see page 573.

Lemon Cove schist: Triassic (?); southern Sierra Nevada, Tulare County; underlies Homer quartzite; a subdivision of the Kaweah series (Durrell, C. 40).

Leona rhyolite: Pliocene (?); Leona Heights, Alameda County; about same age as Northbrae rhyolite (Lawson, A.C. 14). See page 201.

Lilac argillite: Lower Jurassic; Mount Jura, northern Sierra Nevada; oldest Jurassic rocks of Mount Jura column; rests on Middle Triassic volcanics (Crickmay, C.H. 33). See page 106.

Lillis group (also shale, and formation): Eocene and Oligocene (?); north Coalinga region; originally J.H. Ruckman used Lillis shale group for Domengine sandstone and Kreyenhagen shale (later called by him Oilfields shale); later confusion in nomenclature has led to disuse of the names Lillis shale and Oilfields shale (Merriam, J.C. 15a; Jenkins, O.P. 31; Church, C.C. 31a; Hanna, G.D. 31; 33; Anderson, F.M. 31).

Lindavista terrace material: Quaternary; La Jolla quadrangle, San Diego County; contains boulders derived from Poway conglomerate (Hanna, M.A. 26).

Lion sandstone: Pliocene or Miocene (lower); Lion Canyon, Riverside County; older than Hathaway formation and younger than Potato sandstone; Woodring assigns it to same age as Imperial formation (redefined) (Vaughan, F.E. 22; Woodring, W.P. 31). See page 202.

Little Chief porphyry: Mesozoic (?); Panamint Range, Inyo County; intrudes Telescope group (Murphy, F. Mac 30; 32).

Little Grizzly Creek beds: Pennsylvanian; Taylorsville region, northern Sierra Nevada; same as Robinson formation (Turner, H.W. 94; 94a).

Liveoak member (of Tejon formation): Eocene; north slope of Tehachapi Mountains at south end of San Joaquin Valley; conformably overlies Uvas conglomerate member; conformably underlies Metralla sandstone member (Marks, J.G., this bulletin, p. 535).

Livermore gravel: Pleistocene and Pliocene (upper); Mount Diablo region; rests on Briones (Clark, B.L. 30); younger than Alamo formation (Huey, A.S. 37). See page 201.

Llajas (Las Llajas) formation: Eocene; Simi Valley, Ventura County; Stipp and Tolman divide it into six mappable members (from top to bottom olive silt member, Llajas worn impression shale member, clay shale member, Llajas blue shale member, Llajas silt member, Llajas conglomerate member); overlain by Sespe formation and underlain by Santa Susana formation (McMasters, J.H. 33; Stipp and Tolman 34; Clark and Vokes 36). See pages 170, 172, 189, 193, 195, 196, 418, 419, 422, 423.

Lloyd zone (subsurface): see page 389.

Lodo formation: Paleocene and Eocene; Tumey Hills, near Panoche Creek, Fresno County; overlies Moreno shale, underlies Yokut sandstone; divisible into (lower) Cerros member (middle) Cantua sandstone member, and (upper) Arroyo Hondo member (White, R.T. 38; 40). See pages 188, 189, 193, 195, 196, 197, 247, 250.

Lomita formation: Pliocene (upper); San Pedro Hills, Los Angeles Basin; underlies Timms Point formation and overlies Repetto formation (Grant and Gale 31; Reed, R.D. 31; Grant, U.S. IV 35). See pages 202, 210.

Lone Mountain limestone: Silurian and Upper Ordovician; Inyo County; first described by A. Hague, in Nevada (Wilmarth, M.G. 38); E. Kirk places Lone Mountain limestone above Pogonip limestone in Nevada; mapped by Ball in Inyo County, California (Ball, S.H. 07).

Long Canyon member (of Las Posas formation): Pleistocene or upper Pliocene; Ventura County; upper part of Las Posas formation; underlain by Kalorama member (Pressler, E.D. 29). See page 202.

Loomis Peak dacites: Cenozoic; northern California, Lassen region; *see* Divide Peak andesite (Williams, H. 32).

Lopez fanglomerate: Quaternary; San Gabriel Mountains; overlies Saugus formation unconformably (Hill, M.L. 30).

Los Cerritos beds: Pleistocene; Los Angeles Basin; upper part of San Pedro formation; above Deadman Island beds (Smith, J.P. 10).

Los Gatos beds: Upper Cretaceous; Diablo Range; top formation of Panoche group (Anderson, F.M. 37; this bulletin, p. 185). See page 109.

Los Medanos formation: see pages 189, 191.

Lospe formation: Tertiary; Santa Maria district, Santa Barbara County; unconformably overlies Franciscan; unconformably overlain by Point Sal formation (Wissler and Dreyer, this bulletin, p. 237). See pages 238, 427, 431.

Lowe granodiorite (Mount Lowe granodiorite): late Jurassic or early Cretaceous; San Gabriel Mountains (Miller, W.J. 30; 33; 35b).

Lucia shale: Eocene; Junipero Serra quadrangle, Monterey County; overlies Junipero sandstone; underlies The Rocks sandstone (Thorup, R.R., this bulletin, p. 465.)

Lucky S argillite: Upper Jurassic; Foreman Ravine, Mount Jura, northern Sierra Nevada; underlies Trail tuff and conglomerate and overlies Cooks Canyon agglomerate (Crickmay, C.H. 33). See page 106.

M

Mabury formation: Eocene (middle); Devils Den district, San Joaquin Valley; overlain by Gredal formation (Van Couvering and Allen, this bulletin, p. 496 et seq.).

Machado zone (subsurface): see page 308.

Mahala oil zone (subsurface): see page 363.

Mahala sandstone and conglomerate: Miocene (?); Chino area, San Bernardino County; overlies Peculiar shale (Krueger, M.L., this bulletin, p. 363).

Malaga mudstone member (of Monterey shale): Miocene (upper); Malaga Cove, Palos Verdes Hills region, Los Angeles County; overlies Valmonte diatomite member and underlies Repetto siltstone (Woodring, Bramlette and Kleinpell 36). See pages 218, 222.

Manix lake beds: Pleistocene; Mohave River, San Bernardino County; deposits of extinct Manix Lake (Buwalda, J.P. 14).

Manzanita dacites: Cenozoic; Lassen National Park; *see* West Prospect basalt (Williams, H. 32).

Marca shale member (of Moreno shale): Upper Cretaceous; Escarpado Canyon, Panoche Hills, Fresno County; overlies Tierra Loma shale member; underlies Dos Palos shale member (Payne, M.B. 41).

Maricopa shale: Miocene (upper middle); Midway-Sunset district, Kern County; same as Monterey shale and Salinas shale: originally defined as overlying Vaqueros sandstone of Cuyama Valley and unconformably overlain by Santa Margarita (English, W.A. 16; Pack, R.W. 20; Woodring, Bramlette, and Kleinpell 36). See pages 150, 189, 483, 502, 503, 513, 525, 532, plate III.

Marin sandstone (in Franciscan group): Jurassic; Marin peninsula; described as underlying Ingleside chert and overlying Sausalito chert (Arnold, R. 02; Lawson, A.C. 03; 14).

Mariposa slate: Upper Jurassic; Mariposa County and northern Sierra Nevada; unconformably overlain by the Chico formation; name used extensively in this manner by U. S. Geological Survey; Taliaferro restricted the name Mariposa (group) to the upper part of the sequence and named the lower part the Amador group (Becker, G.F. 85; Taliaferro, N.L. 32; 42). See pages 106, 124, 125, 134, 166, 616.

Markley sandstone: Eocene (upper); Markley Canyon, Mount Diablo region; underlies Kirker formation; contains diatomite of upper Kreyenhagen (Clark, B.L. 18; 31; Bailey, T.L. 31; Jenkins, O.P. 31; Clark and Vokes 36). See pages 113, 137, 182, 189, 193, 196, 197, 252, 588, 592, 595, 599.

Mark West andesite: Pliocene; Sonoma County; underlies Sonoma tuff or included in Sonoma volcanics or group (Osmont, V.C. 05). See page 201.

Martinez formation: Paleocene; vicinity of Martinez; overlies "Chico" formation; underlies "Meganos" formation (Gabb, W.M. 69; Stanton, T.W. 96; Merriam, J.C. 97; Clark and Vokes 36; Clark, B.L., this bulletin, p. 187). See pages 95, 112, 113, 135, 168, 170, 172, 187, 189, 193, 194, 196, 197, 210, 366, 417, 419, 588, 592, 595, 598, 611.

Martinez marine member: Paleocene; south side of Simi Valley, Ventura County; Martinez group is divided into Martinez marine member, Las Virgenes sandstone, and Simi conglomerate (Nelson, R.N. 25).

Martin zone (subsurface): (Miller, R.H. 38). See page 564.

Marvel limestone: Lower Paleozoic (?); Panamint Range, Inyo County; underlies Surprise formation (Murphy, F. Mac 30; 32).

Marysville formation: Eocene; Sutter County; overlies Chico beds and underlies white Ione sands (Williams, H. 29; Anderson and Russell 39; Johnson, H.R., this bulletin, pp. 611, 613).

Masser zone (subsurface): see pages 233, 238, plate V.

Mathis sand (subsurface): see page 231, plate V.

Matilija sandstone member (of Tejon formation): Eocene; Matilija Springs, Ventura County; overlain by Cozy Dell shale member (Kerr and Schenck 28).

Maxwell zones (subsurface): see plate V.

Mazourka formation: Lower Ordovician; Inyo Range; underlies Barrel Spring formation (Phleger, F.B. Jr. 33).

McAdams sand (subsurface): (Woodring, Stewart, and Richards 40). See page 248, plate III.

McCloud limestone (formation, shales): Permian; McCloud River, Redding region, Shasta County; underlies Nosoni formation; overlies Baird shale (Fairbanks, H.W. 94; Smith, J.P. 94a; Hinds, N.E.A. 32). See page 102.

McDonald shale (subsurface): (Cushman and Goudkoff 38). See pages 248, 249, 251, 588.

McGrath zone (subsurface): see pages 220, 327, plate V.

McKanna zone (subsurface): see page 315.

McKittrick breccia (subsurface): see page 249.

McKittrick formation: Pliocene (upper); McKittrick-Sunset district, Kern County; unconformably overlies Monterey and Santa Margarita (?) formation; unconformably overlain by Quaternary (Arnold, R. 09; Arnold and Anderson 10; Arnold and Johnson 10a). See page 202.

McKittrick oil sand (subsurface): see page 249.

McKittrick sands and clays (subsurface): see page 249.

McLure shale member (of Monterey shale): Miocene (upper); McLure Valley, Fresno and Kings Counties; underlies Reef Ridge shale; overlies Temblor formation (Henny, G. 30; Gester and Galloway 33; Barbat and Johnson 34a). See pages 141, 142, 150, 156, 189, 190, 240, 243, 245, 247, 248, 251, 252, 460, 483, 487, 492, 494, 496, 500, 502, 503, 504, 518, 522, 523, 525, 526, 528, 529, 565.

McNally zone (subsurface): see page 231, plate V.

Media shale (member in Temblor): Miocene; San Joaquin Valley; overlies Carneros sandstone and underlies Button bed; included in middle of Temblor (Cunningham and Barbat 32; Gester and Galloway 33). See pages 116, 248, 249, 251, 504, plate IV.

Meekoceras beds: Lower Triassic; the *Meekoceras* zone (as the U. S. Geological Survey designates the beds) has been recognized (by J.P. Smith and others) in Nevada, California, Utah, and Idaho (Smith, J. P. 32; Wilmarth, M.G. 38).

Meganos formation: Eocene (lower); Mount Diablo region, Contra Costa County; overlies Martinez, underlies Markley sandstone (Clark, B.L. 18a; 26; Clark and Stewart 25; Clark and Woodford 27; Clark and Vokes 36). See pages 112, 137, 187, 193, 194, 196, 197, 483, 592, 611.

Mehrten formation: Miocene and Pliocene (?); Mokelumne River basin; underlies Laguna formation; unconformably overlies Valley Springs formation (Piper, Gale, Thomas, and Robinson 39). See pages 202, 588.

Mellenia series: Miocene (upper); southern California; renamed by Kew, Mint Canyon formation (Hershey, O.H. 02; 02a; Kew, W.S.W. 24).

Merced formation: Pliocene; Lake Merced, San Francisco region (Lawson, A.C. 93a; Dorf, E. 33). See pages 174, 176, 191, 201, 205, 206, 543, 621, 622, 625, 626.

Mercy sandstone lentil: Upper Cretaceous; Panoche Hills, Fresno County; occurs in Tierra Loma shale member of Moreno shale (Payne, M.B. 41).

Merritt sand: Pleistocene; Lake Merritt, Oakland; unconformably overlies San Antonio formation; underlies Temescal formation (Lawson, A.C. 14).

Mesa Negra beds (Negra clay): Miocene (?); east of Death Valley, Inyo County (Keyes, C.R. 23).

Metralla sandstone member (of Tejon formation): Eocene; north slope of Tehachapi Mountains, at south end of San Joaquin Valley; conformably overlies Liveoak member; conformably underlies Reed Canyon silt member (Marks, J.G. 41). See page 535.

Meyer zone (subsurface): (Collom, R.E. 23a). See pages 232, 233, 343, 344, 346, plate V.

Middle Park formation (of Telescope group): Lower Paleozoic (?); Panamint Range, Inyo County (Murphy, F. Mac 30; 32).

Miley zone (subsurface): see pages 388, 389.

Milham zone (subsurface): (Woodring, Stewart, and Richards 40).

Millerton formation: Pleistocene; Marin County; unconformably underlies Tomales formation; overlies Merced formation (Dickerson, R.E. 22).

Millett clay: Miocene (?); Inyo County; unconformably underlies Negra clays, overlies Redhill sandstone (Keyes, C.R. 23; 23a).

Mills formation: Upper Cretaceous; west side Sacramento Valley; conformably overlies Golden Gate formation, conformably underlies Sites formation (Kirby, J.M., this bulletin, p. 606). See pages 601, 602, 603, 608.

Milton formation: Jurassic and Triassic; Downieville region, northern Sierra Nevada; older than Mariposa; probably correlative of the Sailor Canyon formation (Turner, H.W. 94; Crickmay, C.H. 31; Clark, S.G. 34).

Mineral King beds: Triassic; 15 miles southwest of Mount Whitney, Tulare County; exposed at old mining camp of Mineral King (Turner, H.W. 94; 94a; Durrell, C. 40; Muller, S.W., *in* Reed, R.D., this bulletin, p. 104).

Mint Canyon formation (Mint Canyon series): Miocene (upper); Los Angeles County; called by Jahns the Mint Canyon series (unconformably overlies Vasquez series, underlies Modelo formation) to include Tick Canyon formation at base; Mint Canyon formation is defined by him as lying unconformably above Tick Canyon formation (Kew, W.S.W. 23; 24; Jahns, R.H. 39). See pages 412, 416.

Miraleste tuff bed (in Monterey shale): Miocene (middle); Agua Negra Canyon, Palos Verdes Hills; lies below top of Altamira shale member (Woodring, Bramlette, and Kleinpell 36). See page 224.

Mitchell zone: Lower Cretaceous; in Horsetown group; overlies Ono "zone"; underlies Alderson "zone" (Anderson, F.M., this bulletin, p. 184).

Modelo formation: Miocene (upper); Ventura County; redefined by Kew: rests on Topanga formation, unconformably overlain by Pico formation (Eldridge and Arnold 07; Kew, W.S.W. 24). See pages 112, 189, 190, 222, 378, 388, 394, 396, 398, 402, 412, 413, plate IV.

Modin formation: Lower Jurassic; Redding quadrangle, Shasta County; lies unconformably on Brock shale; is overlain by Potem formation (Diller, J.S. 06; Hinds, N.E.A. 33).

Modoc basalt: Recent; Modoc Lava-Bed quadrangle; flows and cones; eruption after glaciation (Powers, H.A. 32).

Moenkopi formation: Lower Triassic; Providence Mountains, San Bernardino County; described first by L.F. Ward in Arizona; Hazzard lists it in Providence Mountains section (Hazzard, J.C. 38; Wilmarth, M.G. 38).

Mohave formation (Mojave formation): Tertiary; north slope El Paso Range, between Mojave and Owens Lake; exposed in Red Rock Canyon and about Black Mountain; leaf-bearing beds and lavas (Smith, J.H. 00).

Mohawk lake beds: Miocene (upper); Mohawk Valley, Plumas County; rests on Tertiary volcanics; overlain by alluvium (Turner, H.W. 91; Smith, J.P. 16a).

Mojave formation: see Mohave formation.

Mono Craters obsidian: Pleistocene; June Lake district, east-central Sierra Nevada; later than Tioga moraines (Putnam, W.C. 40).

Mono series (Monoan series): early Cambrian (?); Mono County; said to be older than Prospect Mountain quartzite (Keyes, C.R. 23; 23a).

Mono shale: Eocene or Cretaceous; Santa Ynez quadrangle; Santa Barbara County; lies on Indian conglomerate; overlain by Sierra Blanca limestone (Nelson, R.N. 25a; Keenan, M.F. 32).

Montara granite: Jurassic (?); southern San Francisco peninsula; quartz diorite of pre-Franciscan age (Lawson, A.C. 95; 95a; 14).

Monte Cristo limestone: Mississippian; Inyo County; first described by D.F. Hewett in Goodsprings quadrangle, Nevada; J.C. Hazzard lists Monte Cristo (?) limestone and separates it into upper member and lower member (Wilmarth, M.G. 38; Hazzard, J.C. 37). See pages 99, 100.

Monte de Oro formation: Upper (?) Jurassic; Oroville, Butte County; plant-bearing clay slate; older than the Mariposa group; apparently called Oroville beds by Fontaine and Crickmay (Turner, H.W. 96; Taliaferro, N.L. 42).

Monterey shale (or group): Miocene (upper, middle, and late lower); town of Monterey and widely distributed throughout the Coast Ranges; name applied in many different ways; now generally regarded as older than Santa Margarita formation and younger than Vaqueros (Blake, W.P. 55; Lawson, A.C. 93; 14; Ashley, G.H. 95; Louderback, G.D. 13; Woodring, Bramlette, and Kleinpell 36; Kleinpell, R.M. 38). See pages 112, 117, 150, 178, 180, 189, 190, 210, 222, 236, 237, 238, 372, 374, 380, 384, 402, 427, 429, 435, 437, 439, 440, 441, 448, 450, 452, 453, 467, 479, 554, 580, 621, plates III, IV, V.

Montgomery Creek formation: Eocene; Redding region, Shasta County; overlain by Tuscan and Tehama formations; lies on Chico rocks (Williams, H. 32; Hinds, N.E.A. 33; Anderson and Russell 39).

Montgomery limestone: Silurian (Niagaran); Taylorsville region, northern Sierra Nevada; lies on Grizzly formation; overlain by Taylorsville formation (Diller, J.S. 92a; 08).

Moonshine conglomerate: Middle Jurassic; Mount Jura, northern Sierra Nevada; underlies Hull agglomerate, overlies Mormon sandstone (Crickmay, C.H. 33). See page 106.

Moraga formation: Pliocene (lower); Contra Costa County, Berkeley Hills; underlies Siesta formation, unconformably overlies Merced formation (Lawson, A.C. 14). See pages 189, 191, 201.

Morales member (of Santa Margarita formation): Miocene (upper); Morales Canyon, Cuyama Valley; lies unconformably on Whiterock Bluff shale member, and is unconformably overlain by Cuyama formation (English, W.A. 16).

Moreno formation (also Moreno shale): Upper Cretaceous; Diablo Range; lies conformably on Panoche formation, the lower formation of the "Chico group"; overlain by Cerros shale member of Lodo formation (Anderson and Pack 15; Anderson, F.M. 37; Payne, M.B. 41; Taliaferro, N.L., this bulletin, p. 134; Anderson, F.M., this bulletin, p. 185). See pages 109, 128, 132, 134, 150, 178, 180, 182, 183, 185, 186, 195, 481, 485, 487, 492, 587, 592, 609.

Mormon sandstone: Middle Jurassic; Mormon Station, Taylorsville region; overlies Thompson limestone and is overlain by Moonshine conglomerate (Diller, J.S. 92a; 08; Crickmay, C.H. 33). See page 106.

Morrison sandstone: Middle Jurassic; Trinity and Shasta Counties; said to be misprint for Mormon sandstone (Hershey, O.H. 04).

Mountain Girl conglomerate-quartzite (of Telescope group): Lower Paleozoic; Panamint Range, Inyo County; underlies Wildrose formation and overlies Middle Park formation (Murphy, F. Mac 32).

Mount Clark granite: late Jurassic or early Cretaceous; Yosemite National Park; composes Mount Clark (Calkins, F.C. 30).

Mount Eden formation: Pliocene (lower); San Jacinto quadrangle, Riverside County; Fraser suggested name Mount Eden formation to replace Eden beds, preoccupied; also called Mount Eden Red Beds member (Frick, C. 21; Fraser, D.M. 31). See page 202.

Mount Edgar limestone: Permian; Providence Mountains, San Bernardino County; lies unconformably below Moenkopi formation and unconformably above Providence Mountains limestone (Hazzard, J.C. 38).

Mount Hoffman complex: Pleistocene and Recent (?); Medicine Lake Highland, Siskiyou County (Anderson, C.A. 41).

Mount Lowe granodiorite (Lowe granodiorite): late Jurassic or early Cretaceous; San Gabriel Mountains, Los Angeles County; younger than Mount Wilson quartz diorite (Miller, W.J. 26; 30; 33, 35b).

Mount Wilson quartz diorite: late Jurassic or early Cretaceous; San Gabriel Mountains, Los Angeles County; cut by (Mount) Lowe granodiorite (Miller, W.J. 26; 30; 35b).

Moynier zone (subsurface): see page 309, plate V.

Mud Hill series: Miocene (?) to Pleistocene (?); Mecca, Riverside County; includes Indio and Carrizo formations (Free, E.E. 14; Buwalda and Stanton 30).

"Mud-pit shale": see page 388.

N

Negra clay (Mesa Negra beds): Miocene (?); east of Death Valley, Inyo County (Keyes, C.R. 23; 23a).

Neroly formation (Nerola) (in San Pablo group): Miocene (upper); Mount Diablo region; overlies Cierbo formation (Clark and Woodford 27; Clark, B.L. 30). See pages 172, 189, 190, 454, plate III.

Nevadan series: name applied to a series of late Jurassic intrusives in northern California (Redding, Weaverville, and Red Bluff quadrangles) (Hinds, N.E.A. 33).

Newville group: Upper Jurassic; Coast Ranges; uppermost "group" in Knoxville "series" (Anderson, F.M., this bulletin, p. 184).

Nichols oil zone (subsurface): (Miller and Bloom 37). See page 569.

Nomlaki tuff member (of Tehama and Tuscan formations): Pliocene; Nomlaki Indian Reservation, northern Sacramento Valley; occurs near base of both Tehama and Tuscan formations (Russell and Vander Hoof 31; Anderson and Russell 39). See pages 202, 601.

Noonday dolomite: Lower Cambrian (?); Nopah and Resting Springs Mountains, Inyo County; lies beneath the Johnnie (?) formation; rests unconformably on pre-Cambian, chiefly shales and conglomerates of Algonkian age (Hazzard, J.C. 37). See page 100.

Nopah formation: Upper Cambrian; Nopah Mountains, Inyo County; lies between Pogonip (?) dolomite above and Cornfield Springs formation below (Hazzard, J.C. 37). See pages 99, 100.

Nordhelmer formation: Carboniferous (?); Nordheimer Creek, Klamath Mountains; shattered by intrusive rocks (Hershey, O.H. 06).

Nordstrom oil zone (subsurface): see pages 343, 344, 346, plate V.

Northbrae rhyolite: Pliocene; Berkeley Hills; lies on surface of Franciscan and Cretaceous; overlain by Campus and Orinda formations (Lawson, A.C. 14). See page 201.

North Ridge agglomerate: Upper Jurassic; Mount Jura, northern Sierra Nevada; underlies Foreman argillite and overlies Hinchman arkose (Crickmay, C.H. 33). See page 106.

"Nortonville shale": see pages 189, 193, 196, 197, 248, 592, 594, 595, plate III.

Nosoni formation: Permian; Redding quadrangle, Shasta County; overlies McCloud limestone and underlies Dekkas andesite (Diller, J.S. 06; Hinds, N.E.A. 32; 32a; 33; Wheeler, H.E. 33). See pages 102, 166.

Nozu ("Nazu") sand (zone) (subsurface): (Miller and Bloom 37). See pages 483, 566.

Nutt zone (subsurface): See page 233, plate V.

O

Oakland conglomerate member (of Chico formation): Upper Cretaceous; Berkeley Hills; lies on Knoxville formation (Arnold, R. 02; Lawson, A.C. 03; 14).

Oakridge sandstone (member of the Franciscan series); Jurassic; Corral Hollow, Alameda County; younger than Corral Hollow shales (Tolman, C.F. Jr. 15).

O'Connell oil zone (subsurface): see pages 344, 346, plate V.

Ocoya Creek beds: Miocene (middle); Kern County; of Temblor age (Blake, W.P. 57; Turner, H.W. 94; 94a; Smith, J.P. 10; Anderson, F.M. 11).

O'Dea oil zone (subsurface): (Hoots, H.W. 38). See plate V.

Oilfields shale: *see* Lillis group.

Olcese sand (subsurface): (Diepenbrock, A. 40; Lyons, J.B. 40). See pages 240, 241, 242, 244, 251, 483, 553, 559, 566, 573, 577 580.

Ono zone: Lower Cretaceous; lowermost "zone" in Horsetown group; overlain by Mitchell "zone" (Anderson, F. M., this bulletin, p. 184). See page 108.

Orcutt formation: Pleistocene; Santa Maria district; unconformably overlies Schumann formation (Hoots and Herold 35). See page 235.

Ord Mountain group: Triassic (?); Ord and Kane Mountains, San Bernardino County; divided into an older extrusive unit and a younger intrusive unit. (Gardner, D.L. 40).

Orestimba group: Upper Cretaceous; foothills of Diablo Range; includes Garzas formation and Moreno formation (Anderson, F.M. 38; 40). See page 109.

Orinda formation: (Orindan formation); Pliocene (lower); Berkeley Hills; lies conformably on Pinole tuff; overlain by Moraga formation (Lawson and Palache 02; Lawson, A.C. 14a; Clark, Morse and Bailey 21). See pages 144, 146, 150, 189, 191, 201, 625.

Oro Grande series: Lower Cambrian; San Bernardino County; nearly pure limestone underlain by pure quartzite (Hershey, O.H. 02b).

Oroville beds: Jurassic (Upper?); east side Sacramento Valley, Oroville region; leaf-bearing slates; apparently same as Monte de Oro formation (Fontaine, W.M. 00; Crickmay, C.H. 31).

Osos basalt: Jurassic (?); Los Osos Valley, San Luis Obispo region; antedates Toro formation; related to San Luis formation (Franciscan) (Fairbanks, H.W. 04).

Oursan sandstone (in Monterey group): Miocene (middle); Concord quadrangle, Contra Costa County; underlies Tice shale and overlies Claremont shale (Lawson, A.C. 14). See page 189.

Owenyo limestone: Permian; Inyo Range; unconformably overlain by Lower Triassic shale and unconformably underlain by Reward conglomerate (Kirk, E. 18). See page 105.

P

Pacheco group: Upper Cretaceous; central Coast Ranges; disconformably overlies Horsetown "stage"; disconformably overlain by Asuncion group (Taliaferro, N.L., this bulletin, page 131). See pages 130, 133, 134, 152, 443.

Pacific zone (subsurface): see plate V.

Padelford zone (subsurface): see plate V.

Pahrump series: pre-Cambrian; Kingston Range, Ivanpah quadrangle; lies unconformably on pre-Cambrian granite gneiss; overlain unconformably by probable Lower Cambrian sedimentary rocks; subdivided into (in ascending order) Crystal Spring formation, Beck Spring dolomite, and Kingston Peak formation (Hewett, D.F. 40).

Paicines formation: Pliocene; San Benito County; lies unconformably on Etchegoin formation and is overlain by San Benito gravels (Kerr and Schenck 25). See pages 147, 201.

Pala conglomerate: Pleistocene; Valley of San Luis Rey, San Diego County; valley-fill conglomerate (Ellis and Lee 19).

Palms granite: pre-Cambrian; Twenty-Nine Palms, San Bernardino and Riverside Counties; younger than Gold Park gabbro-diorite (Miller, W.J. 38).

Palm Spring formation: Pliocene or Miocene (middle or upper); Vallecito Creek, Imperial County; overlies Imperial formation in Carrizo Mountain and vicinity (Woodring, W.P. 31). See page 202.

Palos Verdes sand (formation): Pleistocene (upper); Los Angeles County; underlain by Hall Canyon formation (Tieje, A.J. 26; Eaton, J.E. 28a; Woodring, W.P. 32a). See pages 189, 210, 216, 231.

Panamintan series: early Cambrian (?); Panamint Mountains, Inyo County; older than Prospect Mountain quartzite (Keyes, C. R. 23; 23a).

Panamint metamorphic complex: pre-Cambrian and lower Paleozoic (?); Panamint Range, Inyo County; underlies Marvel dolomitic limestone (Murphy, F. Mac 32).

Panoche formation: Upper Cretaceous; Panoche Hills, Fresno County; lies unconformably on Franciscan formation; conformably overlain by Moreno formation (Anderson and Pack 15; Anderson, F.M. 37; 38; this bulletin, p. 185; Taliaferro, N.L., this bulletin p. 134). See pages 109, 130, 132, 134, 185, 186, 481, 487, 543, 587, 598, 614, 615.

Papel Blanco shale: Miocene (upper); Chino area, San Bernardino County; underlies Blanco sandstone, overlies middle Puente (?) (Krueger, M.L., this bulletin, p. 363).

Parker quartz diorite: late Jurassic (?); San Gabriel Mountains; may be facies of (Mount) Lowe granodiorite (Miller, W.J. 35b).

Parker zone (subsurface): see page 564.

Pasadena formation: Miocene; San Gabriel Mountains; flanks San Rafael Hills; rests on San Gabriel plutonic and metamorphic rocks (Arnold and Strong 05).

Paskenta formation (Paskenta group): Lower Cretaceous (Shasta "series"); Tehama County, west side of Sacramento Valley; many California geologists now restrict it to lower part of the Shasta group, lying unconformably on restricted Jurassic Knoxville; U. S. G. S. has not yet adopted this recent interpretation; the former view being that Paskenta is upper part of Knoxville (Anderson, F.M. 02; 32; 38a; this bulletin p. 184; Smith, J.P. 09; 10; Hinds, N.E.A. 33; 34; Clark, B.L. 30). See pages 108, 127, 128, 129, 130, 134, 152, 183, 184, 616, 618, 619, 633.

Paso Robles formation: upper Pliocene and lower Pleistocene; Salinas Valley; lies unconformably on Santa Margarita formation (Fairbanks, H.W. 98). See pages 118, 147, 148, 201, 235, 237, 238, 434, 435, 437, 439, 441, 461, 467, 523.

Pato red member (of Vaqueros formation): Miocene (lower); Cuyama Valley; basal member of Vaqueros or part of Sespe formation (English, W.A. 16; Kew, W.S.W. 19a).

Patrick greenstone: Cretaceous; Del Norte County; intrudes Siskiyou granodiorite (Maxson, J.H. 33).

Patterson zone (subsurface): see plate V.

Paynes Creek basalt: late Pleistocene and or Recent; Chico quadrangle, Sacramento Valley; much later than Red Bluff formation (Hamlin, H. 21; Anderson, C.A. 33).

Peale formation: Mississippian; Taylorsville region, northern Sierra Nevada; overlain by Reeve meta-andesite (Diller, J.S. 08). See page 102.

Peculiar shale: Miocene (?); Chino area, San Bernardino County; overlies Hunter sandstone and conglomerate, underlies Mahala sandstone and conglomerate (Krueger, M.L., this bulletin, p. 363).

Pellisier granite: Inyo Range; batholith which forms core of Inyo Range composed of Pellisier and Boundary Peak granites (Anderson, G.H. 35; 37).

Pelona schist: pre-Cambrian (?); Sierra Pelona, Los Angeles County; identical in lithology to Rand schist; probably Archean (Hershey, O. H. 02a; 02b; 12; Simpson, E.C. 34).

Penyon Blanco agglomerate: probably Lower Mesozoic; Sierra Nevada; included in Tuolumne group; underlies Agua Fria formation and overlies Hunter Valley formation (Taliaferro, N.L. 32).

Perris quartz diorite: late Jurassic (?); Perris block, Riverside County; intrudes the Temescal porphyry (Dudley, P.H. 35).

Pescadero series: Upper Cretaceous, Eocene, Miocene; Santa Cruz Mountains, San Mateo County; underlies Monterey series (Ashley, G.H. 95).

Petaluma formation: Pliocene (lower); Petaluma and Santa Rosa quadrangles (north of San Francisco Bay); divided into upper and lower Petaluma; overlain by Sonoma volcanics (Dickerson, R.E. 22; Bailey and Morse 35). See pages 201, 622, 625, 626, 627.

Pico formation (of Fernando group): Pliocene (upper in part); Pico Canyon, Los Angeles and Ventura Counties; restricted now by U. S. G. S. to upper Pliocene; in Santa Clara and San Fernando Valleys it lies on Modelo formation and below Saugus formation (Clark, B.L. 21; Kew, W.S.W. 23; 24; 32; Eaton, J.E. 26d; Woodring, W.P. 32a; Reed, R.D. 32). See pages 112, 180, 189, 202, 213, 214, 215, 216, 227, 228, 231, 232, 282, 300, 301, 306, 308, 311, 312, 315, 319, 322, 325, 329, 334, 336, 338, 340, 347, 351, 355, 357, 359, 392, 409, 413, 415, 416, 633, plate V.

Piedras Altas formation: Upper Cretaceous; southern Santa Lucia Range; a subdivision of the Asuncion group (Taliaferro, N.L., this bulletin, p. 132.

Pie Knob andesite: Pleistocene; Berkeley Hills; lower part of Campus formation (Lawson and Palache 02).

Pilarcitos sandstone (in Franciscan group): Jurassic (?); San Francisco peninsula; name used locally (Arnold, R. 02; Lawson, A.C. 03; 14).

Pinecate formation: Oligocene (?); 4 miles northwest of San Juan, San Benito County; lies on San Juan Bautista formation; underlies Vaqueros formation (Kerr and Schenck 25). See page 137, plate III.

Pinnacles formation: Miocene (?); Pinnacles National Monument; volcanic breccias and tuffs, chiefly rhyolite; volcanic activity may have extended from middle Miocene into lowermost Pliocene (Andrews, P. 36; Herold, C. L. 37).

Pinole tuff: Pliocene; San Pablo Bay region, Contra Costa County; lies on Neroly formation; lies below and interbedded with basal beds of Orinda formation (Arnold, R. 02; Lawson, A.C. 03; 14). See pages 191, 201, 625.

Pintoan series: Cambrian (?); Riverside County; older than Prospect Mountain quartzite (Keyes, C. R. 23; 23a).

Pinto formation: Pleistocene; Eagle Mountains, Pinto Basin, Riverside County; vertebrate-bearing lake beds and gravels (Scharf, D. 35).

Pinto gneiss: pre-Cambrian; Twenty-Nine Palms, San Bernardino and Riverside Counties (Miller, W.J. 38).

Pioneer group: Upper Cretaceous; west side of Great Valley of California; name of lower part of Panoche formation (Anderson, F.M. 38; this bulletin p. 185). See pages 109, 183, 185, 186.

Pipes fanglomerate: Pliocene (upper) or Quaternary (lower); San Bernardino Mountains; overlain by basalt; younger than Hathaway formation (Vaughan, F. E. 22). See page 202.

Pismo formation: Miocene (upper); Pismo, San Luis Obispo region; underlain by Monterey shale; overlain by Paso Robles formation (Fairbanks, H.W. 04; Clark, B. L. 30). See pages 238, 450.

Pit shale (formerly Pitt shales); Middle and Upper Triassic; Pit River, Shasta County; also called formation and series; underlies Hosselkus limestone; rests on Dekkas andesite; U. S. G. S. does not include Nosoni formation (Fairbanks, H.W. 94; Smith, J.P. 94a; Diller, J.S. 06; Ashley, G. H. 23; Hinds, N.E.A. 33). See page 105.

Plutean series: Pliocene (?); east of Death Valley, Inyo County; includes Negra clays (Keyes, C.R. 23; 23a). See page 202.

Placerita formation: pre-Cambrian (?); Placerita Canyon, San Gabriel Mountains; metasedimentary; may be same as or older than Pelona schist; includes crystalline limestone; intruded by Rubio diorite and Echo granite (Miller, W.J. 35b).

Pleasants member (of Williams formation): Upper Cretaceous; Santa Ana Mountains, Peninsular Ranges; unconformably overlain by Eocene; underlain by Schulz member of Williams formation (Popenoe, W. P. 37; 42). See pages 364, 366.

Pleito formation: Oligocene; Pleito Creek, southern end of San Joaquin Valley, Kern County; overlies San Emigdio formation; unconformably overlain by Monterey group (Wagner and Schilling 23; Clark, B.L. 30). See pages 112, 137, 188, 189, plate III.

Plumas series: Jurassic (Upper, Middle, and Lower); Plumas County, northern Sierra Nevada; includes Hinchman sandstone, Mormon sandstone, and Hardgrave sandstone (Smith, J.P. 10).

Pogonip limestone: Lower Ordovician; Inyo County; first described by C. King in Nevada (Wilmarth, M.G. 38); mapped by S.H. Ball in Inyo County; Hazzard describes it as lying between Eureka quartzite above and Nopah formation below, in the Nopah Mountains, Inyo County (Ball, S.H. 07; Hazzard, J.C. 37). See pages 99, 100.

Pohono granodiorite: late Jurassic or early Cretaceous; Yosemite National Park (Calkins, F.C. 30).

Point Arena beds: Miocene; Point Arena-Fort Ross region, Mendocino County; overlies Gallaway beds (Weaver, C.E., this bulletin, pp. 630, 631, 632).

Point of Rocks sandstone: Eocene; Devils Den, San Joaquin Valley; lies below Kreyenhagen shale and above variegated shale "Tejon" (Reed and Hollister 36; this bulletin, Goudkoff, P.P., p. 250; Van Couvering and Allen, p. 496 et seq.).

Point Sal formation: Miocene (middle) (Relizian stage); Santa Maria Valley, Santa Barbara County; between Monterey (above) and Lospe (below) (Canfield, C.R. 39). See pages 236, 237, 238.

Poncho Rico formation: Pliocene and Miocene (?); Salinas Valley, Monterey County; overlies Santa Margarita formation; underlies Paso Robles formation (Reed, R.D. 25; English, W.A. 19). See pages 190, 201, 467.

Portuguese tuff bed (in Monterey shale): Miocene (middle); Portuguese Canyon, Palos Verdes Hills; top of lower division of Altamira shale member (Woodring, Bramlette, and Kleinpell 36).

Poso Creek sand (subsurface): (Diepenbrock, A. 33).

Potato sandstone: Miocene (probably); San Bernardino Mountains; may be older than Hathaway formation and Santa Ana sandstone (Vaughan, F.E. 22).

Potem formation: Middle and Lower Jurassic; Potem Creek, Redding quadrangle, Klamath Mountains; lies on Modin formation or Bagley andesite (Diller, J.S. 06; Hinds, N.E.A. 33).

Potrero zone (subsurface): see plate V.

Poway conglomerate: Eocene; San Diego County; overlies La Jolla formation (Ellis and Lee 19; Hanna, M.A. 26; Miller, W.J. 35a; Clark and Vokes 36; Stock, C. 37; Hertlein and Grant 39). See pages 112, 113, 114, 193, 195, 367.

Preston diorite: Paleozoic (?); Preston Peak, Siskiyou County; hornblende diorite, intruding Greyback formation, intruded by serpentine and by Siskiyou grandiorite (Maxson, J.H. 33).

Prospect Mountain quartzite: Lower Cambrian; Inyo County; first described by A. Hague in Nevada; mapped by S. H. Ball in Inyo County (Wilmarth, M. G. 38; Ball, S.H. 07).

Prospect Peak basalts: Cenozoic; Lassen National Park; *see* West Prospect basalt (Williams, H. 32).

Providence Mountains limestone: Pennsylvanian; Providence Mountains, San Bernardino County; lies unconformably below Mount Edgar limestone and unconformably above Monte Cristo limestone (Hazzard, J.C. 38).

Puente formation: Miocene (upper and middle); Puente Hills and Los Angeles district; unconformably overlain by Fernando formation; unconformably overlies pre-Cretaceous granite and schist; at Puente Hills, corresponds to Modelo formation; in Los Angeles district, corresponds to Modelo and underlying Topanga; consists of upper Puente shale, Puente sandstone, and lower Puente shale (Eldridge and Arnold 07; Kew, W.S.W. 24). See pages 189, 190, 210, 215, 220, 221, 222, 223, 231, 233, 282, 290, 301, 325, 336, 347, 351, 357, 358, 359, 360, 362, plate V.

Purisima formation: Pliocene; Purisima Creek, San Mateo County; lies unconformably on Monterey shale; top grades into base of Merced formation (Haehl and Arnold 04). See pages 144, 146, 191, 201, 479, 480.

Pyramid Hill sand (subsurface): See pages 251, 483, 559.

Q

Quercan sandstone: Miocene; San Pablo Bay region; top formation of Monterey; overlies Herculean shale member; approximately the same as Briones sandstone (Weaver, C.E. 09).

Quinto "stage": Upper Cretaceous; Contra Costa County, from Los Banos Creek to Brentwood; overlies Moreno "stage"; underlies Garzas "stage" (Anderson, F.M. this bulletin, p. 185). See page 109.

R

Radcliff formation: Lower Paleozoic (?); Panamint Range, Inyo County; overlies Sentinel dolomite; underlies Redlands dolomitic limestone; included in Telescope group (Murphy, F. Mac 30; 32).

Ragged Valley shale member (of Arroyo Hondo formation): Eocene; north of Coalinga; lies beneath the white sandstone member in upper part of Arroyo Hondo formation; called Arroyo Hondo shale member by White (White, R.T. 38; Vokes, H.E. 39).

Rainbow beds: Pliocene or Miocene; Fresno and Kings Counties; included in Coalinga beds (Anderson, F.M. 05). See page 202.

Rainbow series: post-Franciscan (?); Humboldt County; underlies Bear River series (Stalder, W. 14).

Raised Beach formation: Pleistocene; San Pedro and vicinity; beds younger than San Pedro series (Arnold, R. 03).

Raker Peak pyroxene andesites: Cenozoic; Lassen National Park; *see* West Prospect basalt (Williams, H. 32).

Rand schist: pre-Cambrian; Rand Mountains, Kern County; believed to overlie unconformably the Johannesburg gneiss and to underlie unconformably Paleozoic rocks; assigned to Archean (Hulin, C.D. 25).

Ranger oil zone (subsurface): (Hoots, H.W. 38). See pages 225, 304, 305, plate V.

Rattlesnake granite: pre-Cretaceous; San Diego County; intrudes rocks of probable Triassic age (Hudson, F.S. 22; Donnelly, M. 34).

Ravenna plutonic series: pre-Cretaceous; Los Angeles County; lies under Cretaceous shales; probably older than granite series (Hershey, O.H. 02a; 02b).

Red Bluff formation: Pleistocene; Tehama County; unconformably overlies Tuscan tuff (Diller, J.S. 94a; 06; Hershey, O.H. 02a; Hinds, N.E.A. 33; Anderson and Russell 39). See page 599.

Redhill sandstones: Miocene (?); Death Valley region, Inyo County; underlies Millett clay; bottom formation of Furnacean series (Keyes, C.R. 23; 23a).

Redlands limestone (of Telescope group): Lower Paleozoic (?); Panamint Range, Inyo County; underlies Hanaupah formation and overlies Radcliff formation (Murphy, F. Mac 30; 32).

Red Mountain andesite: Miocene (upper) or early Pliocene; Randsburg quadrangle, Kern and San Bernardino Counties; overlies Rosamond series; underlies Black Mountain basalt (Hulin, C.D. 25).

Red Mountain pyroxene basalts: Cenozoic; Lassen National Park (Williams, H. 32).

Red Rock Canyon beds: Pliocene (lower); eastern part of Kern County; same as Ricardo formation (Gilbert, G.K. 75; Fairbanks, H.W. 96a; Merriam, J.C. 19). See page 202.

Redrock Canyon sandstone member (of Santa Margarita formation): Miocene (upper); Cuyama Valley, Kern County; lies unconformably on pre-Monterey rocks; conformably overlain by Whiterock Bluff shale member of Santa Margarita formation (English, W.A. 16).

Red Shale Butte complex: Pleistocene (?); Medicine Lake Highland, Siskiyou County; overlies Warner basalt (Anderson, C.A. 41).

Reed Canyon silt member (of Tejon formation); Eocene; north slope of Tehachapi Mountains at south end of San Joaquin Valley; conformably overlies Metralla sandstone member; unconformably underlies Tecuya formation (Marks, J.G. 41). See page 535.

Reed dolomite: pre-Cambrian; Inyo Range, Inyo County; unconformably underlies Deep Spring formation; underlain by Wyman formation (Kirk, E. 18; Maxson, J.H. 34).

Reeds Creek andesite: Eocene (?); north of Wheatland, Smartsville quadrangle, Sacramento Valley; probably equivalent to Ione (middle Eocene), possibly to Wheatland (upper Eocene or lower Oligocene); rhyolite tuffs lie above Reeds Creek andesite (Clark and Anderson 38).

Reef beds: Miocene; south of Coalinga, San Joaquin Valley; not well-defined formation; part of Temblor beds (Anderson, F.M. 05; 08).

Reef Ridge shale: Miocene (upper) and Pliocene; southern California (Fresno, Kings, and Kern Counties); Siegfus restricts use of name to "caving blue shale" of Kettleman Hills; below Jacalitos sandstone and above McLure shale; transitional, Miocene and Pliocene (Koch, T.W. 33; Gester and Galloway 33; Reed, R.D. 33; Barbat and Johnson 34a; Woodring, Stewart, and Richards 34; Clark, B.L. 35; Hoots and Herold 35; Siegfus, S.S. 39). See pages 180, 188, 189, 240, 243, 248, 249, 483, 487, 492, 494, 495, 502, 503, 504, 518, 519, 521, 526, 528, 529, 530, 559, 563.

Reeve meta-andesite: Pennsylvanian; Taylorsville region, northern Sierra Nevada; grades into Robinson formation; apparently younger than Kettle meta-andesite (Diller, J.S. 08). See page 102.

Relief quartzite: Mississippian; Colfax quadrangle, northern Sierra Nevada; overlies Blue Canyon formation; underlies Cape Horn slate; Ferguson places Tightner and Kanaka formations between Blue Canyon and Relief quartzite (Lindgren, W. 00; Ferguson and Gannett 29; 32).

Rench sand (subsurface): (Diepenbrock, A. 33).

Repetto siltstone (or Repetto formation): Pliocene (lower); Los Angeles region; grades down into uppermost member of Modelo formation; overlain by Pico formation (Reed, R.D. 32; Kew, W.S.W. 32; Woodring, W.P. 32a; Woodring, Bramlette, and Kleinpell 36). See pages 112, 117, 180, 182, 189, 202, 210, 213, 214, 216, 217, 225, 226, 227, 228, 229, 230, 231, 232, 233, 282, 288, 290, 300, 301, 304, 306, 308, 311, 312, 318, 319, 322, 325, 329, 336, 338, 340, 341, 347, 348, 351, 354, 355, 388, 392, 394, 409, 413, 633, 635, plate V.

Republic zone (subsurface): see pages 522, 523, 525.

Reward conglomerate: Pennsylvanian; Inyo Range, Inyo County; unconformably underlies Owenyo limestone and conformably overlies Pennsylvanian limestone and shale (Kirk, E. 18).

Ricardo formation: Pliocene (lower); Kern and San Bernardino Counties; younger than Barstow formation; same as Red Rock Canyon beds (Merriam, J.C. 14; 15; 17; 19). See page 202.

Ridge Route formation: Pliocene (?); Tejon quadrangle, Los Angeles County; overlies Modelo; may be equivalent of the Saugus formation (Clements, T. 37). See page 202.

Rincon shale: Miocene (middle or lower); coastal region from Ventura to Santa Barbara; underlies Modelo formation; overlies Vaqueros formation (or is a part of Vaqueros and Temblor) (Kerr, P.F. 31; Woodring, W.P. 32a; Kew, W.S.W. 32; Kleinpell, R.M. 33). See pages 116, 372, 378, 388, plates III, IV.

Rindge zone (subsurface): see page 308, plate V.

Rio Bravo sand (subsurface): (Hoots, H.W. 38). See pages 245, 553, 556, 560.

Roberts formation: pre-Cambrian; Bishop quadrangle, Inyo Range; underlies Wyman formation; at Wyman Canyon (descending order) Silver Peak group, Campito sandstone, Deep Spring formation, Reed formation, Wyman formation, Roberts formation (Maxson, J.H. 34; Maxson and Anderson 35).

Robinson formation: Permian; Taylorsville region, northern Sierra Nevada; separated from older Peale formation by Reeve meta-andesite; unconformably overlain by Hosselkus limestone; Girty *in* Diller (08), correlates it with Nosoni. (Diller, J.S. 92a; 08). See page 102.

Rodeo shale (in Monterey group): Miocene (middle); Concord quadrangle, Contra Costa County; underlies Briones sandstone; overlies Hambre sandstone (Lawson, A.C. 14). See page 189.

Rosamond series: Miocene (upper and middle?); southeastern Kern County and northern Los Angeles County; overlain by or is part of Barstow formation; older than Ricardo formation; contains basalt flows; overlies granitic rocks (Hershey, OH. 02; 02a; Merriam, J.C. 19; Hulin, C.D. 25; 35; Simpson, E.C. 34).

Rose Canyon shale: Eocene; San Diego County; top member of La Jolla formation (Hanna, M.A. 26; Hertlein and Grant 39). See pages 172, 188, 189, 193, 367, 369.

Round Mountain silt (subsurface): (Diepenbrock, A. 33). See pages 240, 241, 242, 245, 251, 559, 563, 566, 573, 577, 580.

Rowena sand (subsurface): see plate V.

Rubel zone (subsurface): see page 309, plate V.

Rubio diorite and metadiorite: pre-Cambrian (?); San Gabriel Mountains; cuts Placerita formation; is cut by Echo granite (Miller, W.J. 35b).

S

Sacatar quartz diorite: late Paleozoic (?); or Jurassic (?); Kernville quadrangle, southern Sierra Nevada; intrusive into Summit gabbro (Miller and Webb 40).

Sacramento formation: Middle Devonian; Redding region; same as Kennett formation (Smith, J.P. 94a).

Sailor Canyon formation: Lower Jurassic; Colfax region; northern Sierra Nevada; younger than Calaveras formation; older than Mariposa slate (Turner, H.W. 94; Lindgren, W. 00).

St. George formation: Pliocene; Del Norte County; lies unconformably on Dothan; overlain unconformably by Battery formation (Maxson, J.H. 33). See page 201.

St. Helena rhyolite: Pliocene (?); Sonoma County; lies on Sonoma tuff, or included in Sonoma volcanics or group (Osmont, V.C. 05). See page 201.

Salinas shale: Miocene (middle); Salinas Valley; same as Monterey shale at Monterey (English, W.A. 16; 19; Woodring, Bramlette, and Kleinpell 36). See pages 138, 140, 141, 142, 150, 459.

Salmon hornblende schist: pre-Cambrian (?); Trinity and Shasta Counties; together with Abrams schist, comprises Siskiyou terrane; igneous origin, probably intrusive into Abrams mica schist (Hershey, O.H. 01; Hinds, N.E.A. 32; 33).

Salt Creek shale (subsurface) (Goudkoff, P.P. 41). See pages 248, 250, 503.

Salt Lake zone (subsurface): see page 285.

San Antonio formation: Pleistocene; Berkeley Hills, Alameda County; unconformably underlies Merritt sand; unconformably overlies Alameda formation (Lawson, A.C. 14).

San Benito gravels: Pleistocene; San Benito County; unconformably overlie Paicines formation (Lawson, A.C. 93a; Kerr and Schenck 25). See pages 147, 148.

San Bruno sandstone (in Franciscan group): Jurassic; San Francisco region; same as Cahil sandstone (Crandall, R. 07; Lawson, A.C. 14).

Sandholdt formation: Miocene; Junipero Serra quadrangle, Monterey County; overlies Vaqueros formation; underlies Monterey shale (Thorup, R.R. this bulletin, page 466). See pages 464, 465.

San Diego formation: Pliocene (middle); southern California, San Diego region; underlies unconformably Sweitzer formation; overlies unconformably Poway conglomerate (Dall, W.H. 98; Ellis and Lee 19; Woodring, W.P. 32a; Hertlein and Grant 39). See pages 176, 189, 190, 202, 367.

San Dimas formation: Pleistocene (upper); southwestern San Bernardino County; also called "earlier alluvium"; overlain by Recent alluvium (Eckis, R. 28; 34).

San Emedio series: pre-Cambrian (?); Kern County; shown as San Emidio schists (Hershey, O.H. 02a; 02b).

San Emigdio formation: Oligocene; south end of San Joaquin Valley, Kern County; underlies Pleito formation; overlies Tejon formation (Gester, G.C. 17; Wagner and Schilling 23). See pages 137, 188, 189, 553, plate III.

San Francisco sandstone: Jurassic and late Tertiary; San Francisco region; also called San Francisco group; Blake included various sandstones of different ages; Lawson confined the name to rocks which he later called Franciscan (Newberry, J.S. 56; Blake, W.P. 57; Lawson, A.C. 95; 95a; 14).

San Gabriel formation: pre-Cretaceous (pre-Cambrian ?); San Gabriel Mountains; includes Rubio metadiorite and Placerita meta-sediments; cut by Wilson diorite, (Mount) Lowe granodiorite, and Echo granite (Miller, W.J. 35b).

San Jacinto series: Pleistocene and Pliocene; Riverside County; minor sedimentary formation; not adequately defined (Dudley, P.H. 32). See page 202.

San Joaquin formation (clay or clays): Pliocene; San Joaquin Valley; upper third of Etchegoin formation (Anderson, F.M. 05; Woodring, Stewart, and Richards 34). See pages 178, 180, 189, 190, 202, 240, 244, 249, 483, 492, 494, 517, 518, 521, 526, 529, 530, 531, 539, 541, 542, 543, 551, 587.

San Juan Bautista formation: Oligocene; San Benito County; lower formation of San Lorenzo series (Kerr and Schenck 25). See page 137, plate III.

San Lorenzo formation: Oligocene; Santa Cruz Mountains region; underlies and grades into Vaqueros; overlies Butano sandstone; Clark used the name San Lorenzo "series" in a broader sense (Arnold, R. 06a; Branner, Newsom, and Arnold 09; Clark, B.L. 18; 30; Atwill, E.R. 35). See pages 112, 137, 477, 532, plate III.

San Luis formation: Jurassic; San Luis Obispo County; representative of Franciscan formation; unconformably underlies Toro formation; unconformably overlies serpentine and basic igneous rocks (Fairbanks, H.W. 04).

San Marcos (Mountain) gabbro: Jurassic (?); San Diego County; part of a composite batholith which intrudes Triassic schists and quartzites of sedimentary origin, and Jurassic (?) volcanic rocks (Hurlbut, C.S. Jr. 35; Miller, F.S. 37).

San Mateo formation: Pliocene (?); San Mateo creek, northwest corner of San Diego County; overlies Capistrano formation (Woodford, A. O. 25). See page 202.

San Miguel cherts (in Franciscan formation): Jurassic; San Francisco region; later mapped as Ingleside chert, Marin sandstone, and Sausalito chert (Arnold, R. 02; Lawson, A.C. 03; 14).

San Onofre breccia: Miocene (middle); San Diego County; facies of Temblor formation; comprised of slabs of older schists (Ellis and Lee 19; Hanna, M. A. 26; Woodford, A.O. 25). See page 117.

San Pablo formation (where undivided): Miocene (upper); Contra Costa County; also terms San Pablo group or series have been used; (Merriam, J. C. 98; Lawson, A.C. 14; Clark and Arnold 18b; Clark, B.L. 21; 30; Clark and Woodford 27; Trask, P.D. 22). See pages 138, 150, 190, plate III.

San Pedro sand (formation): Pleistocene (lower); Los Angeles County; present U. S. G. S. definition restricts name to lower member of Arnold, while upper member is called Palos Verdes sands (Dall, W.H. 98; Kew, W.S.W. 23; Tieje, A.J. 26; Eaton, J.E. 28a; Grant and Gale 31; Grant, U.S. IV 35; Woodring, W.P. 32a; Bailey, T.L. 35a). See pages 112, 174, 189, 204, 205, 206, 210, 216, 231, 301, 319, 322, 334, 347, 357.

San Pedro schist breccia and sandstone: Miocene or Pliocene; Point Fermin at San Pedro, Los Angeles County; doubtful correlative of San Onofre breccia (Woodford, A.O. 25). See page 202.

San Pedro shales: Paleocene (?) and Cretaceous (?); cliffs north and south of San Pedro Point, San Francisco peninsula; same as formation mapped as "Martinez" by Lawson; name preoccupied (Crandall, R. 07; Lawson, A.C. 14).

San Ramon sandstone: Oligocene: Concord quadrangle, Contra Costa County; overlain by Kirker tuff; overlies Eocene (Clark, B.L. 18; 30; Woodring, W.P. 31; Stewart, R.B. 30). See pages 112, 137, 188, 189, plate III.

Santa Ana limestone: Triassic; west slope of Santa Ana Range, Orange County; locally used name; not well defined (Smith, J. P. 98; Merrill, F.J.H. 14).

Santa Ana sandstone: Pliocene (?); Santa Ana River, San Bernardino Mountains; unconformably overlain by Cabezon fanglomerate (Vaughan, F.E. 22). See page 202.

Santa Barbara formation: Plio-Pleistocene; Santa Barbara County; according to Bailey, it can be divided into an upper *Pecten caurinus* zone and a lower *P. bellus* zone (Smith, J.P. 12; 15; Carson, C.M. 25; Grant and Gale 31; Bailey, T.L. 35a; Woodring, Stewart, and Richards 40). See pages 176, 189, 191, 202, 380.

Santa Clara formation: Plio-Pleistocene; near San Jose Mission, Santa Clara County; contemporaneous with Paso Robles formation; lies on Purisima formation; overlain by Quaternary deposits (Cooper, J.G. 94; Branner, Newsom, and Arnold 09). See pages 147, 150, 201.

Santa Cruz Island formation: Pleistocene; Santa Cruz Island; contains flora related to that of Carpinteria formation (Chaney and Mason 33).

Santa Lucia quartz diorite ("granite"): pre-Cretaceous; Santa Lucia Range; granitic rocks of Santa Lucia Range; cuts Sur series (Lawson, A.C. 93; Trask, P.D. 26; Nickell, F.A. 31; Andrews, P. 36). See pages 121, 150, 456, 463, 467.

Santa Lucia series: pre-Franciscan; Monterey, San Benito, and San Luis Obispo Counties; metamorphic rocks, cut by Santa Lucia quartz diorite; includes Gabilan limestone; same as Sur series, a later name (Willis, B. 00; Smith, J.P. 16a). See page 467.

Santa Margarita sandstone: Miocene (upper); San Luis Obispo County; overlies Monterey shale (Fairbanks, H.W. 04). See pages 112, 117, 138, 140, 141, 142, 150, 156, 172, 189, 190, 236, 237, 238, 240, 241, 243, 244, 245, 249, 372, 374, 380, 388, 402, 441, 442, 446, 448, 450, 452, 459, 460, 467, 483, 487, 518, 529, 532, 562, 563, 565, 566, 568, 670, 633, plate IV.

Santa Maria formation: Pliocene and Pleistocene; Santa Barbara County; same as Fernando formation (Carson, C.M. 25). See page 202.

Santa Monica slate: Triassic (?); Santa Monica Mountains, Los Angeles County; intruded by granite and grandiorite (Hoots, H.W. 31).

Santa Paula formation: lower Pliocene and Miocene (?); Ventura Basin; underlies Pico formation; overlies "Santa Margarita" formation (Eaton, J. E. 26a; 26d; 29; Woodring, W. P. 32a). See pages 202, 388.

Santa Susana formation: Eocene; Ventura County; underlain by Martinez formation; overlain by Llajas formation (Clark, B.L. 24; Nelson, R.N. 25; Cushman and McMasters 36; Clark and Vokes 36). See pages 137, 189, 417, 419.

San Timoteo beds: Pliocene (upper); San Timoteo Canyon, Peninsular Ranges; beds with vertebrate fossils (Frick, C. 21; Eckis, R. 34). See page 202.

Santos shale: Miocene (lower); San Joaquin Valley; included in lower part of Temblor (Gester and Galloway 33; Clark and Clark 35). See pages 248, 251, plate IV.

Saragossa quartzite: probably Carboniferous; San Bernardino Mountains; intruded by granites; grades downward into Furnace limestone (Vaughan, F.E. 22). See page 99.

Saugus formation (in Fernando group): Pliocene (upper); Los Angeles County; lies on Pico unconformably; overlain by terrace deposits (Hershey, O. H. 02; Kew, W.S.W. 23; Eaton, J.E. 28a; 31; Grant and Gale 31; Woodring, W.P. 32a). See pages 112, 118, 189, 202, 388, 409, 410, 413, 415.

Sausalito chert (in Franciscan group): Jurassic; Marin peninsula, north of San Francisco; underlies Marin sandstone; overlies Cahil sandstone (Arnold, R. 02; Lawson, A.C. 03; 14).

Schulz member (of Williams formation): Upper Cretaceous; Santa Ana Mountains, Peninsular Ranges; overlain by Pleasants member of Williams formation; underlain unconformably by Ladd formation (Popenoe, W. P. 37; 42). See pages 364, 366.

Schumann formation: Pleistocene and Pliocene (?); Santa Maria district; unconformably underlies Orcutt formation; overlies upper Foxen sand (Reed, R.D. 33; Hoots and Herold 35). See page 201.

Selover zone (subsurface): see page 325, plate V.

Sentinel dolomite (of Telescope group): Lower Paleozoic (?); Panamint Range, Inyo County; underlies Radcliff formation; overlies Wildrose formation (Murphy, F. Mac 30; 32).

Sentinel granodiorite: late Jurassic or early Cretaceous; Yosemite National Park; oldest known formation of Tuolumne intrusive series (Calkins, F.C. 30).

Sentous zone (subsurface): see page 309, plate V.

Sespe formation: Oligocene and upper Eocene; Ventura County; locally underlies Vaqueros formation; overlies Tejon formation (Watts, W.L. 97; Kew, W.S.W. 24; Clark and Vokes 36). See pages 113, 114, 115, 137, 189, 193, 210, 224, 358, 373, 374, 376, 377, 378, 379, 380, 383, 384, 386, 388, 396, 398, 400, 404, 406, 407, 417, 422, 423, 443, 453, plates III, IV.

Shasta-Chico series: Lower and Upper Cretaceous; California and Oregon; name used by Diller for all known Cretaceous of California including also the so-called Knoxville now known to be Jurassic (Diller, J.S. 93).

Shasta series (group): Lower Cretaceous; California and Oregon; divided into Horsetown formation (above) and Paskenta formation (below) which, in turn, rests on Jurassic Knoxville; (Gabb, W.M. 69; White, C.A. 85; Diller and Stanton 94; Wilmarth, M.G. 38; Anderson, F.M. 38a; Taliaferro, N.L., this bulletin, page 129). See pages 95, 125, 129, 130, 134, 150, 152, 168, 183, 184, 606, 616, 619.

Shoofly formation: Mississippian; Taylorsville region, northern Sierra Nevada; separated from underlying Arlington formation by Taylor meta-andesite (Diller, J.S. 92a; 08). See page 102.

Siebert formation: Miocene (upper); Inyo County; first described in Nevada by Spurr (Wilmarth, M.G. 38); *see* Truckee formation (Ball, S.H. 07).

Sierra Blanca limestone: Eocene; south part of Santa Ynez quadrangle, Santa Barbara County; lies on Mono shale; overlain by Miocene beds (Nelson, R.N. 25a; Keenan, M.F. 32).

Siesta formation: Pliocene; Berkeley Hills; underlies Bald Peak basalt; overlies Moraga formation; middle formation of Berkeley group; also called Siestan formation (Lawson and Palache 02; Lawson, A.C. 14). See pages 146, 189, 191, 201.

Signal Hill beds: see pages 204, 205.

Silver King dolomite member (of Bonanza King formation): Middle Cambrian; San Bernardino Mountains; upper part of Bonanza King formation (Hazzard and Mason 36; Hazzard, J.C. 37).

Silver Peak group: Lower Cambrian; Bishop quadrangle; first described in Nevada by H.W. Turner (Wilmarth, M.G. 38); Maxson describes at Wyman Canyon, Bishop quadrangle; Silver Peak group overlies Campito sandstone (Kirk, E. 18; Maxson, J.H. 34).

Silver Terrace sandstone: Jurassic; San Francisco; part of Franciscan; later mapped as Marin sandstone by Lawson (Crandall, R. 07; Lawson, A.C. 14).

Simi conglomerate: Paleocene; Simi Hills, Ventura County; lies unconformably on "Chico" formation; grades into overlying Las Virgenes sandstone (Nelson, R.N. 25).

Siskiyou granodiorite: Jurassic; Del Norte and Siskiyou Counties; intrudes Preston diorite and serpentine; intruded by Patrick greenstone (Maxson, J.H. 33).

Siskiyou terrane: pre-Cambrian (?); Klamath Mountains; includes Abrams and Salmon formations (Hinds, N.E.A. 32; 33).

Sisquoc formation: Pliocene (lower); Santa Maria district; underlies Foxen formation; unconformably overlies Santa Margarita formation (Porter, W.W. II 32). See pages 201, 236, 237, 238, 429, 430, 431, 434, 435, 437, 439, 441, 442.

Sites formation: Upper Cretaceous; west side Sacramento Valley; conformably underlies Funks formation (Kirby, J.M., this bulletin, p. 606). See pages 601, 602, 603, 605, 608.

Skooner Gulch basalt: Tertiary; Point Arena—Fort Ross region, Mendocino County; overlies Gualala group, underlies Gallaway beds (Weaver, C. E., this bulletin, pp. 630, 631). See pages 629, 632.

Sky Blue limestone: upper Paleozoic (?); Crestmore, near Riverside; same as Sky Blue Quarry limestone of J.W. Daly (Daly, J.W. 35; Woodford, Crippen, and Garner, 41).

Sloan zone (subsurface): see page 315.

Smith sand (subsurface): see page 355.

Sobrante sandstone: Miocene (lower); Contra Costa County; underlies Claremont shale; unconformably overlies Eocene (Lawson, A.C. 14). See page 189.

Soledad division: Miocene (upper); Soledad Canyon, Los Angeles County; upper part of Mint Canyon formation; underlies Saugus formation; overlies Lang division (Hershey, O.H. 02; Kew, W.S.W. 24).

Soledad group: Miocene (lower) or Oligocene; Soledad Pass, Los Angeles County; older than Puente (Jordan, D.S. 19).

Sonoma volcanics: Pliocene; near Petaluma, Sonoma County; Sonoma tuff of Osmont lies on Mark West andesite; Sonoma volcanics, or group, of other authors, include Mark West andesite and St. Helena rhyolite; overlain by Millerton formation; interbedded with Merced group; overlies Petaluma formation (Osmont, V.C. 05; Dickerson, R.E. 22; Bailey and Morse 35). See pages 191, 201, 622, 625, 626.

Sour Dough limestone (of Telescope group): Lower Paleozoic (?); Panamint Range, Inyo County; basal formation of Telescope group; underlies Middle Park formation; overlies Surprise formation (Murphy, F. Mac 30; 32).

Spanish formation: Mississippian; Lassen Peak region; younger than Caribou formation; older than Arlington formation (Diller, J.S. 92).

Steele Valley granodiorite: late Jurassic (?); Steele Valley, Perris-Elsinore area, Riverside County (Dudley, P.H. 35).

Stern zone (subsurface): see page 231, plate V.

Stevens sand (subsurface): (Hoots, H.W. 38). See pages 240, 243, 245, 248, 251, 252, 546, 548, 549, 550, 559, 577.

Stewartsville group; Eocene; Mount Diablo; lies unconformably above Martinez; apparently the same as Meganos (Clark, B.L. 18a).

Stewart Valley limestone: Mississippian; Nopah Range, Inyo County; lies below Monte Cristo (?) limestone and above Sultan dolomite (Hazzard, J.C. 37). See page 99.

Stirling quartzite: Lower Cambrian; Inyo County; first described by T.B. Nolan in Nevada; described by J. C. Hazzard in Nopah Mountains; lies between Wood Canyon formation above and Johnnie (?) formation below (Nolan, T.B. 28; Hazzard, J.C. 37). See page 100.

Stonewall quartz diorite: Jurassic; Cuyamaca region, San Diego County; also called granodiorite by Donnelly (Hudson, F.S. 22; Donnelly, M. 34).

Suisun marble: Quaternary (?); Solano County; travertine (Whitney, J.D. 65).

Sultan limestone (dolomite): Devonian; Inyo County; first described by D. F. Hewett in Goodsprings quadrangle, Nevada (Wilmarth, M.G. 38); Hazzard (37) lists Sultan dolomite Middle Devonian; lies above Silurian (?) and beneath Stewart Valley limestone. See pages 99, 100.

Summit gabbro: late Paleozoic (?) or Jurassic (?); Kernville quadrangle, southern Sierra Nevada; intrusive into Kernville series (Miller and Webb 40).

Superjacent series: a descriptive term used in a titular sense in folios and other early reports on Gold Belt region of northern California, to include Cretaceous, Tertiary, and Quaternary deposits, in contradistinction to Bedrock series, a term applied to underlying Jurassic, Triassic, and Carboniferous formations (Wilmarth, M.G. 38).

Surf zone (subsurface) : see page 230, plate V.

Sur series: pre-Franciscan; Santa Lucia Range, southern Coast Ranges; called Santa Lucia series by J. P. Smith (09); metamorphic rocks, including Gabilan limestone (Trask, P.D. 26; Reiche, P. 37). See pages 121, 150, 456, 463, 467.

Surprise formation: Lower Paleozoic (?); Panamint Range, Inyo County; underlies Sour Dough dolomitic limestone; overlies Marvel dolomitic limestone (Murphy, F.Mac 30; 32).

Sutter formation: Miocene (upper) or Pliocene (lower); Marysville Buttes, Sutter County; overlies Butte gravels (Dickerson, R.E. 16; Williams, H. 29; Anderson and Russell 39). See pages 611, 614, 615.

Swearinger slate: Upper Triassic; Taylorsville region, northern Sierra Nevada; underlain by Hosselkus limestone; lies on Robinson formation; overlapped by Trail formation (Diller, J.S. 92a; 08).

Sweitzer formation: Pliocene or Pleistocene; southwestern San Diego County; unconformably overlies the San Diego formation (Hertlein and Grant 39). See pages 202, 367.

Sycamore Canyon formation: Miocene; Whittier Hills, Los Angeles Basin; lies unconformably on upper Puente member of Puente formation; overlain by Repetto formation (Krueger, M.L. 36). See pages 223, 362.

Sylvester zone: Lower Cretaceous; middle "zone" in Paskenta group; overlies Duncan "zone"; underlies Hamlin-Broad "zone" (Anderson, F.M., this bulletin, page 184).

T

Table Mountain andesite: Cenozoic; Lassen Peak region; volcanic rocks composing Table Mountain, northwest of Lassen Peak (Williams, H. 32).

Table Mountain formation: late Tertiary or early Quaternary; 4 miles northeast of Jacumba, Peninsular Ranges; underlies Jacumba volcanics (Miller, W.J. 35). See page 202.

Taft granite: late Jurassic or early Cretaceous; Yosemite National Park; younger than El Capitan granite (Calkins, F.C. 30).

Tamarack formation: pre-Cretaceous; Klamath Mountains; gabbro in Klamath Mountains (Hershey, O.H. 01).

Tank volcanics: Quaternary (?); Tehachapi Creek, Kern County; older than Cable formation; younger than Atlas formation (Lawson, A.C. 06).

Tassajero formation (Tassajera) : Pliocene or Pleistocene; southwest side of Mount Diablo; type section is crossed by Tassajero creek; called Tassajera lake (?) bed by J.C. Cooper (94); described in Berkeley Hills by B.L. Clark (33). See pages 189, 191, 201.

Taylor meta-andesite: Mississippian; Taylorsville region, northern Sierra Nevada; overlies Arlington formation; underlies Shoofly formation (Diller, J.S. 08). See page 102.

Taylorsville formation (or slates) : Devonian; Taylorsville region, northern Sierra Nevada; lies on Montgomery limestone; older than Arlington formation (Diller, J.S. 92a; 08).

Tecuya beds: Miocene; San Joaquin Valley; also spelled Tecuja; overlain by beds with Vaqueros fossils; lies unconformably on Tejon formation (Stock, C. 20; Clark, B.L. 21; Gester and Galloway 33). See pages 189, 535, 538.

Tegeler zone (subsurface) : see page 573.

Tehachapi formation: Quaternary (?); Tehachapi Creek valley, Kern County; younger than Cable formation (Lawson, A.C. 06).

Tehachapi marble: 9 miles west of Tehachapi, Kern County; brecciated marble in Bright's Valley (Hanks, H.G. 86b).

Tehama formation: Pliocene; northern California, Tehama County; includes Nomlaki tuff member; lies unconformably on Cretaceous; overlain unconformably by Red Bluff formation; Tehama and Tuscan formations interfinger (Russell and Vander Hoof 31; Hinds, N.E.A. 33; Anderson and Russell 39). See pages 202, 588, 599, 601, 604, 605, 609, 619.

Tejon formation: Eocene; south end San Joaquin Valley; in restricted sense, upper part of Eocene (Gabb, W.M. 69; Clark, B.L. 18a; Anderson and Hanna 25; Clark and Vokes 36). See pages 112, 113, 114, 137, 168, 170, 188, 193, 194, 197, 210, 248, 250, 374, 384, 396, 398, 483, 505, 532, 534, 592, plate IV.

Telegraph Hill sandstone (in Franciscan group) : Jurassic; San Francisco; same as Marin sandstone (Crandall, R. 07; Lawson, A.C. 14).

Telescope group: Lower Paleozoic (?); Panamint Range; Inyo County; consists of (descending) : Hanaupah formation, Redlands dolomitic limestone, Radcliff formation, Sentinel dolomite, Wildrose formation, Mountain Girl conglomerate-quartzite, Middle Park formation, and Sour Dough limestone (Murphy, F. Mac 30; 32).

Temblor formation: Miocene (middle); Kern County; near type locality, divided into (descending) members: Button bed sandstone, Media shale, Carneros sandstone, Santos shale, "*Phacoides*" reef, "Barren shale" (Anderson, F.M. 05; 08; 11; Smith, J.P. 10; Anderson and Martin 14; Clark, B.L. 21; 30; Loel and Corey 32; Gester and Galloway 33; Schenck, H.G. 35a; Kleinpell, R.M. 38). See pages 112, 115, 138, 140, 141, 150, 170, 172, 174, 178, 180, 188, 189, 190, 248, 251, 372, 374, 380, 383, 384, 388, 396, 402, 454, 474, 475, 478, 483, 484, 485, 487, 490, 492, 494, 495, 502, 503, 553, 580, 633, plates III, IV.

Temecula Canyon granite: Temecula Canyon, San Diego County; name of a quarried rock (Goodyear, W.A. 90b).

Temescal formation: Recent; Temescal Creek, Alameda County; lies unconformably on Merritt sand (Lawson, A.C. 14).

Temescal porphyry: late Jurassic (?); Temescal Creek, Riverside County; intruded by Virginia norite, gabbro, and Perris quartz diorite (Dudley, P. H. 32; 35).

Ten Section sand (subsurface) : (Menken, F.A. 40).

Tequepis sandstone: Miocene; Santa Ynez River region, Santa Barbara County; top formation of Monterey group; unconformably overlain by Fernando group (Nelson, R.N. 24; 25).

Terminal oil zones (subsurface) : (Hoots, H.W. 38). See pages 220, 225, 304, 305, plate V.

Tesla formation: Eocene; Tesla quadrangle Diablo Range; Capay age (Huey, A.S. 37).

The Rocks sandstone: Eocene; Junipero Serra quadrangle, Monterey County; overlies Lucia shale; underlies Berry conglomerate (Thorup, R.R. 41). See page 465.

Thompson limestone: Middle Jurassic; Taylorsville region, northern Sierra Nevada; according to Diller (92a; 08), overlies Mormon limestone, lies on Fant meta-andesite; but acording to Crickmay (33), Thompson red shale underlies Mormon sandstone, overlies Fant conglomerate. See page 106.

Three Rivers schist: Triassic (?); southern Sierra Nevada, Tulare County; probably overlies Homer quartzite; a subdivision of Kaweah series (Durrell, C. 40).

Tice shale (of Monterey group): Miocene (middle); Concord quadrangle, Contra Costa County; overlies Oursan sandstone; underlies Hambre sandstone (Lawson, A.C. 14). See page 389.

Tick Canyon formation: Miocene; eastern part of Ventura Basin; lower part of Mint Canyon series; unconformably below Mint Canyon formation; unconformably underlain by Vasquez "series" according to R.H. Jahns (39).

Tierra Loma shale member (of Moreno shale): Cretaceous; Escarpado Canyon, Panoche Hills, Fresno County; overlies Dosados sand and shale member; underlies Marca shale member (Payne, M.B. 41).

Tightner formation: Mississippian; Colfax region, northern Sierra Nevada; underlies Kanaka formation (Ferguson and Gannett 29).

Timber Canyon fanglomerate: Pleistocene (upper); Ventura and Los Angeles Basins (Grant and Gale 31).

Timms Point formation: Pliocene (upper); Los Angeles County; name to replace Deadman Island, which no longer exists; underlies San Pedro formation; overlies Lomita formation (Grant and Gale 31; Clark, A. 31; Tieje and Cassell 33; Grant, U.S. IV 35). See pages 202, 210, 325.

Titus Canyon formation: Oligocene (lower); Grapevine and Funeral Mountains, Inyo County; lies on Paleozoic and pre-Paleozoic; unconformably overlain by Miocene (?) conglomerate (Stock and Bode 35).

Todd sand (subsurface) : see page 355.

Tolay volcanics: Pliocene (lower); Petaluma quadrangle, Sonoma County; interbedded with Petaluma shales (Bailey and Morse 35). See pages 201, 627.

Tolenas marble: Cenozoic; Tolenas Springs, Solano County; name applied to quarried aragonite (Watts, W.L. 90).

Tomales Bay deposits: Pleistocene; Marin County; terraces on shores of Tomales Bay (Osmont, V.C. 05).

Tomales formation: Pleistocene (upper); Marin and Sonoma Counties; terrace deposits; lies unconformably on Millerton formation (Dickerson, R.E. 22).

Topanga formation: Miocene; Los Angeles County; overlies Vaqueros formation; overlain by Modelo formation (Kew, W.S.W. 23). See pages 112, 172, 189, 190, 210, 222, 224, 358, 396, 412, 424, plate III.

Topatopa formation: Eocene; Ventura County; underlies Sespe formation; lies on granite (Eldridge and Arnold 07; Kew, W.S.W 24). See pages 377, 378.

Toro formation: Lower Cretaceous or Upper Jurassic; San Luis Obispo region; unconformably underlies "Chico"; overlies Franciscan (Fairbanks, H.W. 04).

Torrey sand: Eocene; San Diego County; middle member of La Jolla formation; overlies Delmar sand; underlies Rose Canyon shale (Hanna, M.A. 26; Hertlein and Grant 39). See pages 189, 367.

Tough Mountain quartzite: Lower Cambrian; Providence Mountains, San Bernardino County; lies below Kelso shale and unconformably above Archean gneiss (Hazzard, J.C. 38).

Trabuco formation: Cretaceous; Santa Ana Mountains, Peninsular Ranges; rests on basement complex; grades into overlying Chico group (Packard, E.L. 16; Eckis, R. 34; Popenoe, W.P. 37). See pages 111, 210, 366, 367.

Tracy gas sand (subsurface) : see page 587.

Trail formation: Lower Jurassic; Taylorsville region, northern Sierra Nevada (Diller, J.S. 92a; 08; Crickmay, C.H. 33). See page 106.

Trampan formation: Miocene (upper); Los Trampas Creek, Contra Costa County (Lawson and Palache 02; Lawson, A.C. 14).

Tres Pinos sandstone: Eocene; Tres Pinos Creek, San Benito County; overlies "Meganos" deposits (Kerr and Schenck 25). Plate III.

Trinity formation: pre-Cretaceous; Klamath Mountains; term applied to the serpentine in Klamath Mountain region (Hershey, O.H. 01).

Truckee formation: Miocene; Lake Tahoe region; fresh-water lake deposits; described by C. King (76, Atlas map V; 78, vol. 1, p. 412) in Nevada and California; name used by U. S. G. S. to include Siebert formation.

Tulare formation: Pleistocene; San Joaquin Valley region; lies on San Joaquin clays (Anderson, F.M. 05). See pages 112, 118, 147, 148, 174, 189, 190, 202, 204, 205, 206, 240, 248, 249, 483, 487, 492, 494, 502, 503, 507, 509, 510, 513, 517, 519, 521, 523, 526, 529, 530, 531, 532, 539, 541, 543, 550.

Tumco formation: probably Paleozoic or older; Tumco Valley, Cargo Muchacho Mountains, Imperial County; arkosite, highly metamorphosed and intruded by granitic rocks (Henshaw, P.C. 42).

Tumey formation: Oligocene; Tumey Gulch, north of Coalinga, Fresno County; unconformably overlies Kreyenhagen shale; overlapped by Temblor; contains *Leda washingtonensis* zone (Atwill, E. R. 35). See pages 137, 189, 193, 196, 248, 250, 251.

Tuolumne group (name replaced by Amador group): Lower Mesozoic; Mariposa and Tuolumne Counties, Sierra Nevada; underlies unconformably the Mariposa group; the Milton and Sailor Canyon formations may be contemporaneous with it (Taliaferro, N. L. 32; 32a; 42).

Tuolumne intrusive series: late Jurassic or early Cretaceous; Yosemite National Park; granitic series including (ascending order of age) Sentinel granodiorite, Half Dome quartz monzonite, Cathedral Peak granite, Johnson granite porphyry formations (Calkins, F.C. 30).

Turf zone (subsurface): See pages 315, 316.

Tuscan tuff: Pliocene; northern California, Lassen Peak quadrangle, Shasta and Tehama Counties; also called Tuscan formation; includes Nomlaki tuff member and interfingers with Tehama formation; lies on Ione formation (Diller, J. S. 95; Hinds, N.E.A. 32; 33; Anderson and Russell 39). See pages 201, 202.

Twin Lakes andesites: Cenozoic; Lassen National Park; *see* West Prospect basalt (Williams, H. 32).

U

Ultra-basic intrusives: Upper Jurassic; Coast Ranges and Sierra Nevada; intrude the Franciscan-Knoxville group of the Coast Ranges; intrude Mariposa group and older rocks of Sierra Nevada (Taliaferro, N.L. 42).

Uvas conglomerate member (of Tejon formation): Eocene; north slope of Tehachapi Mountains at south end of San Joaquin Valley; unconformably overlies basement complex; conformably underlies Liveoak member (Marks, J.G. 41). See page 535.

V

Vacaville shale: Eocene; north-northwest of Vacaville; included in the Capay "stage" (Merriam and Turner 37). See pages 193, 196, 197.

Valley Springs formation: Miocene; Mokelumne River basin; unconformably underlies Mehrten formation; unconformably overlies Ione formation (restricted) (Piper, Gale, Thomas, and Robinson 39). See page 588.

Valmonte diatomite member (of Monterey shale): Miocene (upper); Palos Verdes Hills, Los Angeles Basin; overlies Altamira shale member; underlies Malaga mudstone member (Woodring, Bramlette, and Kleinpell 36). See page 222.

Val Verde tonalite: Jurassic (?); Val Verde district, Riverside County; intrudes Triassic metamorphic series; apparently older than Trabuco formation, and unconformably underlies Alberhill clays; also intrudes the Gavilan Peak gabbro (Wilson, R.W. 37; Osborn, E. F. 39).

Vaqueros sandstone (originally Vaquero sandstone): Miocene (lower); Los Vaqueros Creek, Monterey County, and southern Coast Ranges; contains *Turritella inezana zone.* Overlies Barry conglomerate, underlies Sandholdt formation. (Hamlin, H. 04; Clark, B.L. 30; Loel and Corey 32; Schenck, H.G. 35a; Thorup, R.R. 41). See pages 112, 115, 138, 139, 140, 142, 150, 172, 174, 176, 188, 189, 190, 210, 224, 248, 250, 358, 372, 373, 374, 376, 378, 379, 380, 383, 384, 386, 388, 396, 398, 400, 444, 446, 448, 453, 454, 459, 463, 466, 478, 483, 487, 492, 493, 494, 503, 505, 518, 528, 532, 573, 580, plates III, IV.

Variegated zone (subsurface): see pages 248, 251.

Vasquez series: Miocene (?); 18 miles east of Saugus, Los Angeles County; lies on basement; unconformably overlain by Mint Canyon formation; name suggested to replace Escondido series (Sharp, R.P. 36; Jahns, R.H. 39).

Vedder sand (Vedder silt) (subsurface): (Wilhelm, V.H. 26a; Diepenbrock, A. 33). See pages 240, 241, 242, 244, 483, 546, 556, 559, 563, 566, 573, 577, 579, 580, 582, 583.

Ventura sands, formation, or horizon: Pliocene (upper) and Pleistocene; Ventura County; vaguely defined; may be Saugus formation in part (Carson, C.M. 25; Grant and Gale 31). See page 202.

Vickers-Machado zone (subsurface): see pages 308, 309, plate V.

Victor formation: Pleistocene; Mokelumne River basin; overlies Arroyo Seco gravel (Piper, Gale, Thomas, and Robinson 39).

Viejas gabbro-diorite: late Jurassic or early Cretaceous; southern Peninsular Range; cuts Black Mountain volcanics (Miller, W.J. 35).

Virgen series: Pliocene (?); Virgen Valley and Furnace Canyon, Inyo County (Keyes, C.R. 23a).

Virginia quartz-hypersthene norite: late Jurassic (?); Perris block, Riverside County; intrudes Temescal prophyry (Dudley, P.H. 35).

Vitrefrax formation: probably Paleozoic or older; Vitrefrax and Micatalc Hills; Cargo Muchacho Mountains, Imperial County; quartz-kyanite schist, sericite schist, highly metamorphosed and intruded by granitic rocks (Henshaw, P.C. 42).

Volta formation: Upper Cretaceous; San Joaquin Valley; name listed in table (but not defined) for uppermost "formation" in Orestimba group (Anderson, F.M. *in* Reed, R.D., this bulletin, page 109).

W

Wagonwheel formation: Oligocene (?); Devils Den district, San Joaquin Valley; underlies *Leda* zone, overlies Kreyenhagen shale (Johnson, H.R. 09; Gester and Galloway 33). See pages 248, 249, 250, 483, 500, 503, plate III.

Walker formation (subsurface): (Wilhelm and Saunders 26a; Godde, H.A. 28a; Diepenbrock, A. 33; Miller and Bloom 37). See pages 483, 566, 573, 576, 577, 580, 582.

Walker Ridge shales and sandstones: post-Franciscan (?); Humboldt County; comprise the Rainbow series (Stalder, W. 14).

Walkup clay: Eocene; Chico quadrangle, Sacramento Valley; lies on Cretaceous sandstone (Allen, V. T. 29).

Wallala group (see Gualala): Upper Cretaceous; Fort Ross to Wallala, Mendocino County; originally called Wallala beds; lies on metamorphosed rocks (Becker, G.F. 85; White, C.A. 85a).

Warner basalt: Pliocene; Modoc County; lies on Alturas formation and upper Cederville formation (Russell, R.J. 28; La Motte, R.S. 36).

Wasem zones (subsurface): see page 237, plate V.

Weaverville formation: Oligocene or Eocene; Trinity County, Klamath Mountains; auriferous gravels and fossil plant beds; (Hinds, N.E.A. 33; MacGinitie, H.D. 37).

Webster sand (subsurface): see page 249.

Weitchpec schists: Paleozoic or older; Weitchpec, Humboldt County; may be metamorphosed Paleozoic rocks (Hershey, O.H. 04; 06).

Welcome formation: Eocene (upper); Devils Den district, San Joaquin Valley; overlies Point of Rocks formation, underlies Wagonwheel formation (this bulletin, Van Couvering and Allen, page 496 et seq.).

West Prospect basalt: Cenozoic; Lassen National Park; names of volcanic rocks arranged in downward order on map: West Prospect basalt; Crescent Crater dacites; Manzanita dacites; Prospect Peak basalts; Raker Peak pyroxene andesites; Brokeoff andesites; Eastern basalts; Twin Lakes andesites; Juniper and Flatiron andesites; Willow Lake basalts (Williams, H. 32).

Wharton sand zone (subsurface): (Miller and Bloom 37). See pages 565, 568, 569, 570, 577.

Wheatland formation: Eocene (upper) or Oligocene (lower); Sacramento Valley northeast of Wheatland, Smartsville quadrangle; contains andesitic debris (Clark and Anderson 37a; 38). See page 137, plate III.

Whepley shale (subsurface): (Dodd and Kaplow 33). See pages 248, 250, 492.

White Pine shale: Upper Mississippian; Inyo Range, Inyo County; first described in Nevada by A. Hague (Wilmarth, M.G. 38; Kirk, E. 18).

Whiterock Bluff shale member (of Santa Margarita formation): Miocene (upper); Cuyama Valley; overlies Redrock Canyon sandstone member; unconformably overlain by Morales member, all of Santa Margarita formation (English, W.A. 16).

White Tank monzonite: Jurassic (?); Twenty-Nine Palms, San Bernardino and Riverside Counties; cuts the Gold Park gabbro-diorite, Palms granite, and Pinto gneiss (Miller, W.J. 38).

Wicker oil zone (subsurface): (Miller and Bloom 37). See pages 242, 566.

Widgeon zone (subsurface): (Kaplow, E.J. 38).

Wilbur zone (subsurface): (Soyster and Van Couvering 22a; Gollom, R.E. 23a). See page 322, plate V.

Wildcat series (formation): Pliocene; Humboldt County; extensively developed in coastal region north of Eureka (Lawson, A.C. 94). See pages 191, 201, 633.

Wildrose formation (of Telescope group): Lower Paleozoic (?); Inyo County, Panamint Range; overlies Mountain Girl conglomerate-quartzite; underlies Sentinel dolomite (Murphy, F. Mac 30; 32).

Wildwood limestone: Permian; Hay Fork, Trinity County; limestones with Guadalupian fauna (Smith, J.P. 10).

Williams formation: Upper Cretaceous; Santa Ana Mountains, Peninsular Ranges; comprised of two members, Pleasants (upper), and Schulz (lower); underlain unconformably by Ladd formation; overlain unconformably by Eocene (Popenoe, W.P. 37; 42). See pages 364, 366.

Williams zone (subsurface): see pages 528, 529.

Willis zone: see plate V.

Willow Lake basalts: Cenozoic; Lassen National Park; *see* West Prospect basalt (Williams, H. 32).

Wilmington group: late Pleistocene; Los Angeles Basin; included in lower and upper San Pedro and Los Cerritos stages of Arnold (Hill, R.T. 29).

Wilson diorite: late Jurassic or early Cretaceous; San Gabriel Mountains, Los Angeles County; same as Mount Wilson quartz diorite; cut by (Mount) Lowe granodiorite (Miller, W.J. 26; 30; 35b).

Wilson Ranch beds: Pliocene; Santa Rosa Valley, Sonoma County; believed to be older than St. Helena rhyolite and younger than Sonoma tuff (Osmont, V.C. 05). See page 201.

Wimer beds or formation (Wymer): Miocene (upper); Del Norte County; lie on schists, etc. of plateau (Diller, J.S. 02; Maxson, J.H. 33).

Witnet formation (Whitnet): Tertiary (pre-Miocene); northeast of Monolith, Kern County; overlain unconformably by Kinnick formation (Buwalda, J.P. 34; Axelrod, D.I. 39).

Wonder zone (subsurface): see page 573.

Wood Canyon formation: Lower Cambrian; Inyo County; first described by T. B. Nolan in Nevada; described by J. C. Hazzard in Nopah Mountains; lies between Cadiz formation above and Stirling quartzite below; includes Zabriskie quartzite. (Nolan, T.B. 28; Hazzard, J. C. 37). See pages 99, 100.

World Beater porphyry: pre-Cambrian (?); Panamint Range, Inyo County; age relations not clear (Murphy, F.Mac. 32).

Wright sand (subsurface): see page 231, plate V.

Wyman formation: pre-Cambrian; Bishop quadrangle, Inyo Range; unconformably underlies Reed formation; overlies unconformably Roberts formation (Maxson, J.H. 34).

Wymer beds: see Wimer.

Y

"Yellow gravels": see pages 235, 237, 441.

Yellowpine limestone member (of Monte Cristo limestone): Mississippian; Providence Mountains, San Bernardino County; first described by D. F. Hewett in Nevada; Hazzard described it as Yellow Pine limestone (Wilmarth, M.G. 38; Hazzard, J.C. 38).

Yokohl amphibolite: Triassic (?); southern Sierra Nevada, Tulare County; a subdivision of Kaweah series (Durrell, C. 40).

Yokut sandstone: Eocene; western margin of San Joaquin Valley, Fresno County; overlies Lodo formation; underlies Domengine sandstone; previously referred to Meganos by Clark (21, 26) and Atwill (35), to Domengine by White (38), to Arroyo Hondo by Vokes (39) (White, R.T. 40). See pages 189, 193, 195, 196.

Yolo "stage": Upper Cretaceous; lowermost "stage" in Panoche group; overlain by Butte "stage" (Anderson, F.M., this bulletin p. 185). See page 109.

York-Inglewood zone (subsurface): see pages 315, 317.

Yuha reefs: Pliocene; east end Coyote Mountain, Imperial County; overlain by Coahuila silt; W. P. Woodring (31) includes them in upper part of Imperial formation, which he assigns to lower Miocene (Hanna, G.D. 26). See page 202.

Yunker sand (subsurface): see plate V.

Z

Zabriskie quartzite member (of Wood Canyon formation): Lower Cambrian; Nopah and Resting Springs Mountains, Inyo County; lies as a member within the upper part of Wood Canyon formation (Hazzard, J.C. 37).

Zilch zone (subsurface): see pages 483, 588.

Zins (Zinns) zones (subsurface): see plate V.

Chapter XV

Bibliography

CONTENTS OF CHAPTER XV

LIST OF PUBLICATIONS CITED THROUGHOUT BULLETIN 118

By Elisabeth L. Egenhoff*

Explanation:

This list, arranged alphabetically by authors, is a selected bibliography of subject-matter covered by Bulletin 118, and is drawn from publications issued previous to 1942.

All citations to publications appearing in the four parts of Bulletin 118 may be referred to this assembled work. There are two indexes to this bibliography: the first, by *fields* and *areas*, will be found distributed throughout Part Three as "Citations to Selected References"; the second, by *geologic units*, will be found in Part Four in the "Glossary of Geologic Units of California".

The preliminary work involved in the preparation of both bibliography and indexes was largely done by Miss Corinne Kibler, who was assisted by Miss Lily Paganini.

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In the following list the part of the word used for the abbreviation is in **bold-face** type.

abstract
Academy
Akademie
America(n)
Annales
Annals
Annual
Appendix
Archaeology
Archives
Association

Band
Biography
Boletin
Bulletin
Bureau

California
California, University of
Chemical
Circular
Collection
Commercial
Compressed
Conference
Congres
Congress
Contribution
Contributions from the Department of Geology
Convention

Department
Department of Geological Sciences
Development
Directory
Division

Economic
Editor
Engineering
Engineer(s)
Ethnological
Ethnology

figure
Finance
folio
Foraminiferal

Geographical
Geography
Geological
Geologische
Geologist
Geology

History
Hüttenmännische

illustrated
illustration(s)
including
Industrie
Industry
Information Circular
Institute
Institution
International
Investigations

Journal

Laboratory

Magazine
Mathematical
Memoir
Metallurgical
Metallurgy
Mineral
Minerale
Mines
Mines and Geology, Journal of
Mining
Miscellaneous
Monograph
Monthly
Museum

National
Natural
Naturelles
new series
New York

Occasional

page; pp pages
Paper
Philadelphia
Philosophical

Physical
Physikalisch-Mathematische Klasse
Physiques
plate
Popular
Preussiche
Proceedings
Production
Professional Paper
Publication

Report
Report of Investigations
Research
Resources
Review
Revue
Rundschau

San Francisco
Science
Scientific
Section
Seismological
Sitzungsberichte
Smithsonian
Societe
Society
Southern
State
Supplement
Survey

Technical
Technologists
Technology
Transactions

United States
United States Bureau of Mines
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University

Volume

Washington
Water-Supply Paper

Year Book

Zeitung
Zentralblatt

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00 Mineral production of California for fourteen years. Cal St M Bur, B 22:tabulated sheet (1900) . . . for past fifteen years. B 26:tabulated sheet (1902) . . . for sixteen years. B 29:tabulated sheet (1903) . . . for seventeen years. B 34:tabulated sheet (1904) . . . for eighteen years. B 40:tabulated sheet (1905) . . . for nineteen years. B 43:tabulated sheet (1905) . . . for twenty years. B 48:1906.

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01a The Coalinga oil field, California. Eng M J 71:403-404 (1901)

02 The present condition of the oil industry of California. Eng M J 74:545, 546 (1902)

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Chapter XVI

Index to Bulletin 118

CONTENTS OF CHAPTER XVI

INDEX TO BULLETIN 118

Explanation

This index is to the entire Bulletin 118, "Geologic Formations and Economic Development of the Oil and Gas Fields of California," which is divided into four parts, paged continuously as follows:

Part One, pages 1 to 80
Part Two, pages 81 to 276
Part Three, pages 277 to 664
Part Four, pages 665 to 773

Italics are used throughout this index to indicate (1) scientific names of fossils; (2) titles of articles appearing in Bulletin 118; and (3) page references to the individual reports in Bulletin 118.

The index was prepared by Elisabeth L. Egenhoff, Editorial Assistant, and submitted for publication December 29, 1942.

INDEX

B

C

F

H

K

Lomita

Los Angeles

Q

R

Scalez

Signal

Silicosigmoilina

Stalder

T

Tomales

Tulare

Vaqueros

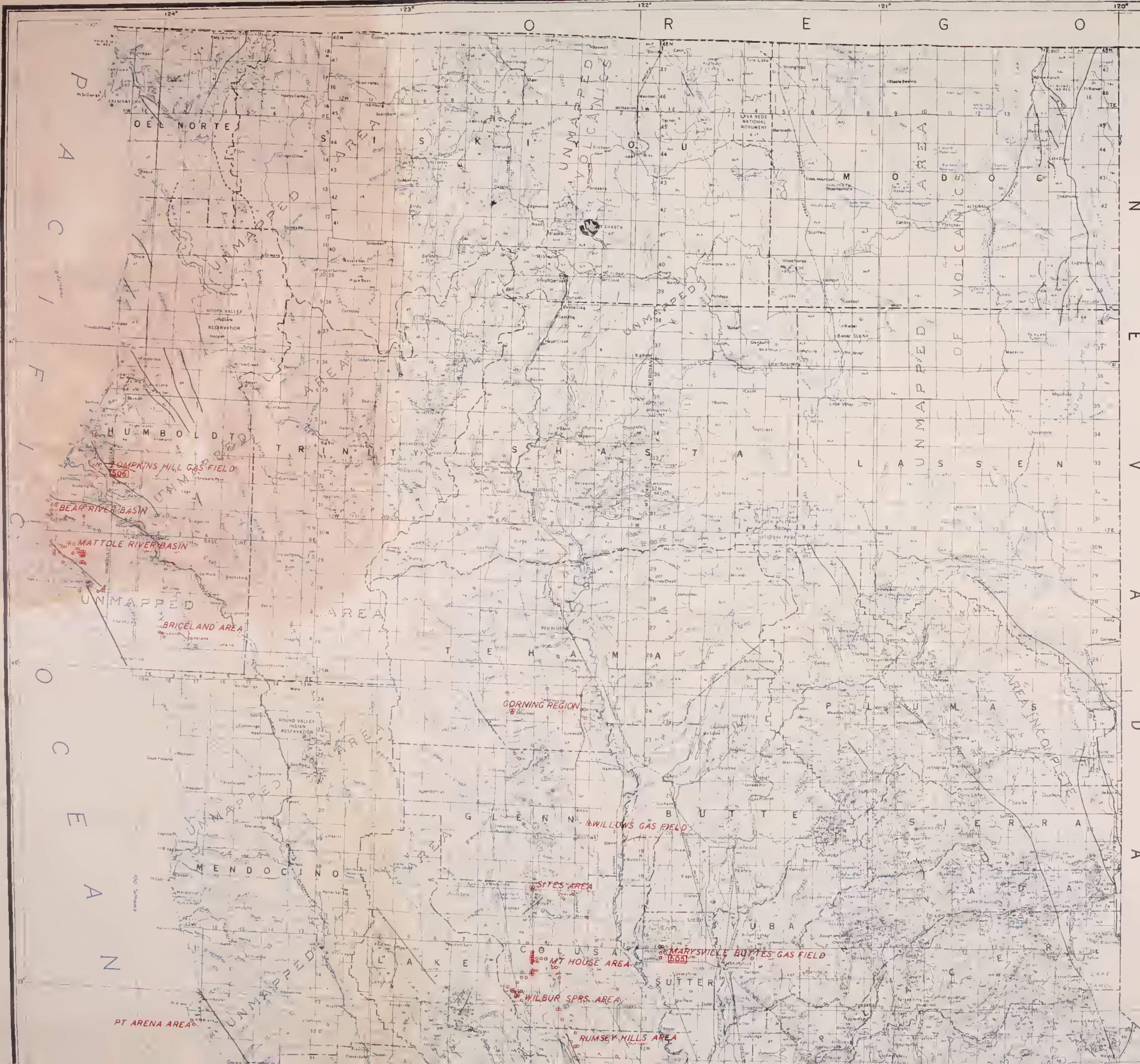
Vosella

o

ERRATA, PARTS ONE AND TWO

Page	*Fig.*	*Line*	
90	41	2	Caption: for "Sheet IV" read "Sheet V".
105	49		Caption: for "Columnar sections of the Triassic of California" read "Columnar section of the Triassic of Nevada".
105	50		Caption: for "Columnar section of the Triassic of Nevada" read "Columnar sections of the Triassic of California".
105	50		For "Hossellcus ls." read "Hosselkus ls."
109			Table 6: for "Gains fm." read "Gaines fm."
112			Table 7: for "Topango" read "Topanga".
122	57		For "Junipero Sierra" read "Junipero Serra".
168	61–17	2, 3	Omit "Loc. 2925 (C.A.S.)".
168	62–2	2	For "61-1" read "62-1".
170	62–11	1	For "Gabb" read "Conrad".
170	62–23	3	For "45°W" read "45°E".
171	62		Read "7" below figure of *Turritella andersoni*, which follows fig. 62-6.
172	63–4	1	For "*tembloris*" read "*temblorensis*".
174	64–6	1	For "Carson" read "Kew".
176	65–18	8	For "lectotype" read "neotype".
177	65		Read "5" below figure of *Clathrodrillia mercedensis* Martin, which follows fig. 65-4.
177	65		Caption: for "(11 to 18)" read "(1 to 18)".
180		49	For "*Bolivina angelica* Church" read "*Bolivina angelina* Church".
181	67		Read "13" below figure of *Rotalia beccarii tepida* Cushman, which follows fig. 67-12.
181	67		Read "21" below figure of *Bolivina obliqua* which follows fig. 67-20.
182		4, 9	After "Cushman" read "and Stewart".
182		68	et seq.: for "From near center . . . . . Upper Cretaceous" read "California, Fresno County, Panoche quadrangle, Sec. 6, T. 15 S., R. 12 E., M. D. Near the center of Sec. 6 in stream bottom of south fork of the main easterly flowing stream, and 2250 feet north and 1725 feet west of southeast corner. Approximately 1100 feet below the Moreno-Lodo contact in the basal portion of the Marca shale member of the Moreno".

Page	*Fig.*	*Line*	
190		22	For "McClure shales" read "McLure shales".
208		4	For "Stratigraphic Formations" read "Stratigraphic Relations".
209		1	For "Stratigraphic Formations" read "Stratigraphic Relations".
212		18	Between "where" and "it", read "in wells".
230		24	For "Miocene Division D" read "Miocene Division C".
230		33	For "correlation" read "correlative".
230		38	For "Tidelands pools" read "Tidelands pool".
231		43	For "Zone 2 about" read "Zone 2 to about". Plate V: for "Ringe zone" read "Rindge zone".
246	98–2, –4, –8, –9, –10		Should be inverted, apertures towards the top.
248	99A		Read "*Globobulimina pacifica*" for "*Globobulumina pacifica*".
249	99B		For "*Uvigerinella obessa*" read "*Uvigerinella obesa*".
249	100		Caption: for "east side" read "west side".
266	106		Title and Legend: for "possible" read "probable".
268		13, 15	For "up-dig" read "up-dip".
271		7	For "stratisgraphic" read "stratigraphic".
276	114, 115		Reverse captions.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GLENN
BUTTE
SIERRA
MENDOCINO
LAKE
COLUSA
YUBA
SUTTER
N E V A D A
UNMAPPED AREA
UNMAPPED VOLCANICS
UNMAPPED AREA OF VOLCANICS
AREA INCOMPLETE
TOMPKINS HILL GAS FIELD
BEAR RIVER BASIN
MATTOLE RIVER BASIN
BRICELAND AREA
CORNING REGION
WILLOWS GAS FIELD
SITES AREA
MT HOUSE AREA
MARYSVILLE BUTTES GAS FIELD
WILBUR SPRS. AREA
PT ARENA AREA
RUMSEY HILLS AREA
LAVA BEDS NATIONAL MONUMENT
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ROUND VALLEY INDIAN RESERVATION
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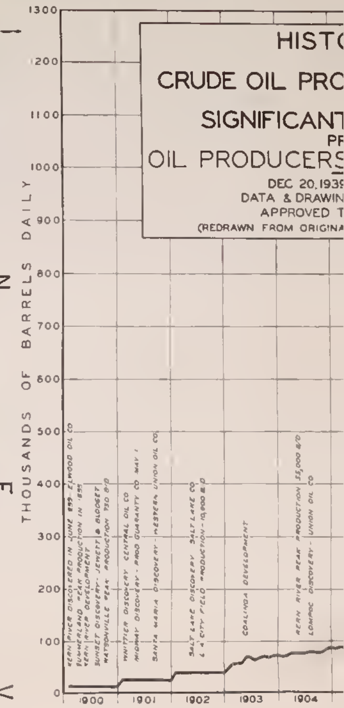
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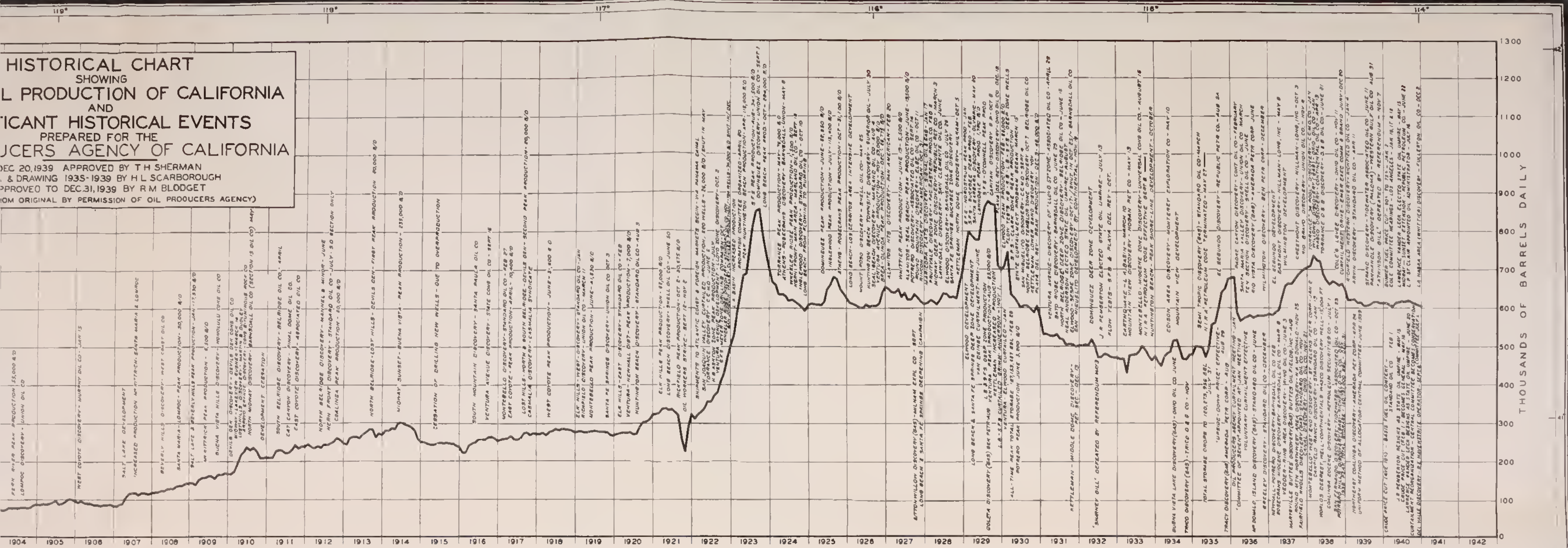


STATE OF CALIFORNIA
EARL WARREN, GOVERNOR

DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, DIRECTOR

DIVISION OF MINES
OLAF P. JENKINS, CHIEF

OUTLINE GEOLOGIC MAP OF CALIFORNIA

SHOWING

OIL AND GAS FIELDS AND DRILLED AREAS

PREPARED UNDER THE DIRECTION OF
OLAF P. JENKINS
GEOLOGIC BRANCH

Scale $\frac{1}{1{,}000{,}000}$
(Approximately 1 inch = 16 miles)

16 0 16 32 48 64 Miles
16 0 16 32 48 64 80 Kilometers

ECONOMIC MINERAL MAP OF CALIFORNIA
No. 2—OIL AND GAS

1941
(REPRINTED IN 1948)

TOTAL PRODUCTIVE ACREAGE (OIL AND GAS)
TOTAL PRODUCTIVE ACREAGE (GAS)

101 SEE INDEX NUMBERS (BOXED) AND LIST FOR NAMES OF FIELDS.

WELLS DRILLED OUTSIDE OF FIELDS AND AREAS MAPPED

ALPHABETICAL INDEX TO OIL AND GAS FIELDS

217 Aliso Canyon (18)
306 Arroyo Grande (19)

214 Bardsdale (17)
407 Belridge (10, 11)
103 Beverly Hills (6)
105 Brea-Olinda (4)
415 Buttonwillow (54)

418 Canal (55)
421 Canfield Ranch (55)
201 Capitan (43)
302 Casmalia (3)
304 Cat Canyon (2)
401 Coalinga (14)
416 Coles Levee (55)
121 Coyote Hills (4)

406 Devils Den (12)
114 Dominguez (29)

402 East Coalinga Extension (14)
430 Edison (48)
410 Elk Hills (15)
107 El Segundo (52)
203 Elwood (40)

504 Fairfield Knolls
426 Fruitvale (49)

202 Goleta (40)
425 Greeley (53)

117 Huntington Beach (26)

111 Inglewood (31)

429 Kern River (13)
404 Kettleman Middle Dome (36)
403 Kettleman North Dome (36)

204 La Goleta (40)
108 Lawndale (52)
301 Lompoc (3)
115 Long Beach (20)
101 Los Angeles City
405 Lost Hills (11)

505 Marysville Buttes
502 McDonald Island
409 McKittrick (9, 10)
205 Mesa (44)
411 Midway (8, 9)
119 Montebello (37)
427 Mountain View (48)
431 Mount Poso (34)

215 Newhall (18)
118 Newport

NUMERICAL INDEX TO OIL AND GAS FIELDS

LOS ANGELES BASIN

101 Los Angeles City
102 Salt Lake (6)
103 Beverly Hills (6)
104 Whittier (38)
105 Brea-Olinda (4)
106 Playa del Rey (42)
107 El Segundo (52)
108 Lawndale (52)
109 Torrance (28)
110 Wilmington (50)
111 Inglewood (31)
112 Potrero (41)
113 Rosecrans (30)
114 Dominguez (29)
115 Long Beach (20)
116 Seal Beach (32)
117 Huntington Beach (26)
118 Newport
119 Montebello (37)
120 Santa Fe Springs (27)
121 Coyote Hills (4)
122 Richfield (46)

VENTURA BASIN AND TRANSVERSE RANGES

201 Capitan (43)
202 Goleta (40)
203 Elwood (40)
204 La Goleta (40)
205 Mesa (44)
206 Summerland
207 Rincon (33)
208 Ventura (16)
209 Ojai (16)
210 Santa Paula (17)
211 Sespe (17)
212 Piru (18)
213 South Mountain (17)
214 Bardsdale (17)
215 Newhall (18)
216 Simi (18)
217 Aliso Canyon (18)

SANTA MARIA BASIN AND SOUTHERN COAST RANGES

301 Lompoc (3)
302 Casmalia (3)
303 Santa Maria (2, 3)
304 Cat Canyon (2)
305 Santa Maria Valley (51)
306 Arroyo Grande (19)
307 Sargent (1)

SAN JOAQUIN VALLEY

SEDIMENTARY ROCKS

CENOZOIC — QUATERNARY — RECENT
- Qs Sand Dunes
- Qal Alluvium
- Qst Salt deposits

PLEISTOCENE
- Qt Terrace deposits
- Qg Glacial deposits
- Ql Pleistocene lake beds
- Qm Pleistocene marine sediments
- QP Quaternary and Upper Pliocene sediments

TERTIARY — PLIOCENE
- Pc Undivided Pliocene non-marine sediments
- Pu Upper Pliocene marine sediments
- Puc Upper Pliocene non-marine sediments
- Pml Middle and Lower Pliocene marine sediments

UNDIVIDED
- Tlb Tertiary lake beds
- QTc Cenozoic non-marine sediments

MIOCENE
- Mc Undivided Miocene non-marine sediments
- Muc Upper Miocene non-marine sediments
- Mmc Middle Miocene non-marine sediments
- Mu Upper Miocene marine sediments
- Mm Middle Miocene marine sediments
- Ml Lower Miocene marine sediments

OLIGOCENE(?)
- Φ Oligocene sediments

- Tg Tertiary auriferous gravels

EOCENE
- Euc Upper Eocene non-marine sediments

IGNEOUS ROCKS

CENOZOIC VOLCANICS — QUATERNARY — RECENT
- Qrv^c Cinder cones
- Qmf Volcanic mud flows
- Qrv Recent volcanics
- Qrv^r Recent rhyolite
- Qrv^a Recent andesite
- Qrv^b Recent basalt

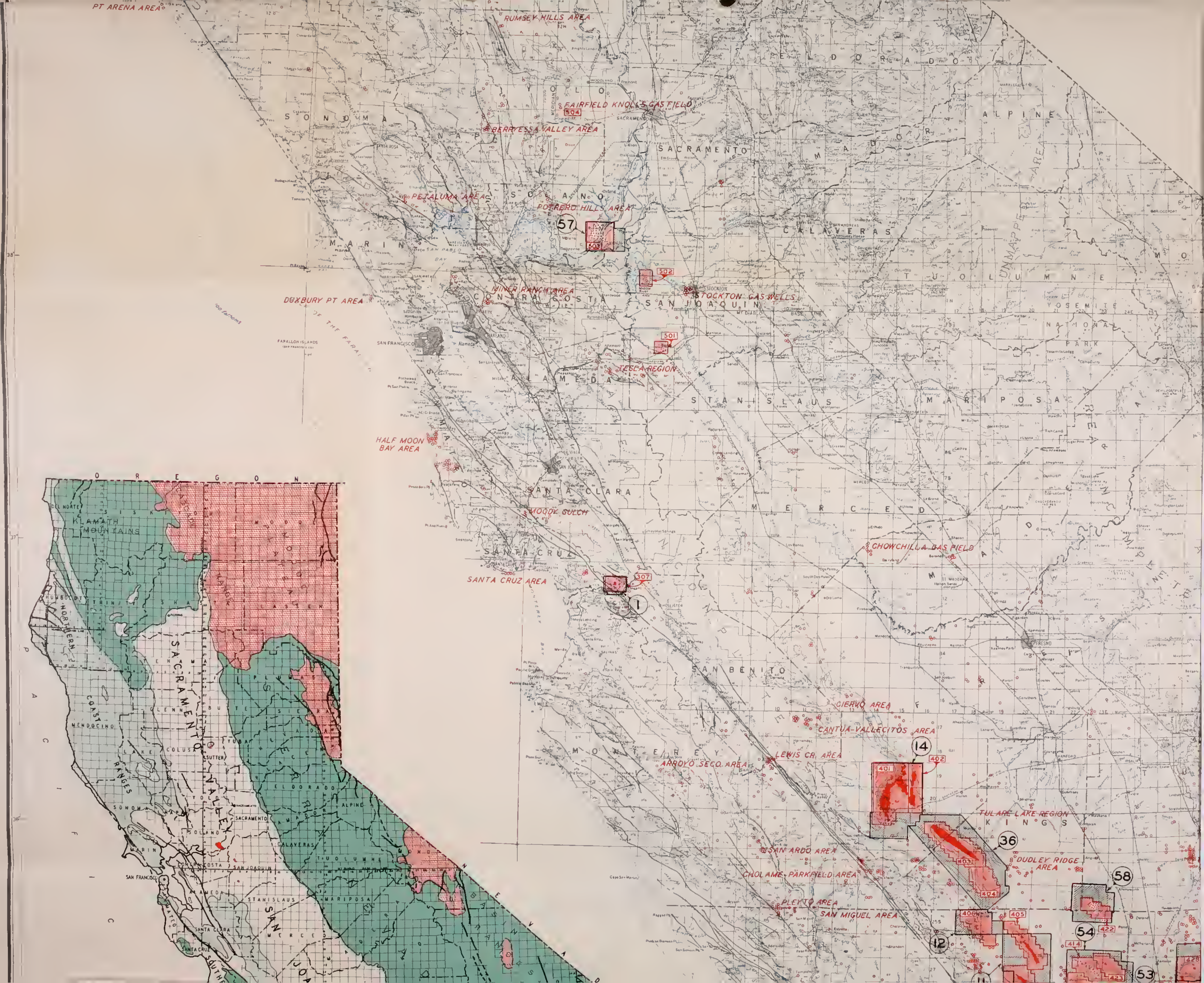
PLEISTOCENE
- Qv Pleistocene volcanics
- Qv^r Pleistocene rhyolite
- Qv^a Pleistocene andesite
- Qv^b Pleistocene basalt
- TQv Undivided Cenozoic volcanics

TERTIARY — PLIOCENE
- Pv Pliocene volcanics
- Pv^r Pliocene rhyolite
- Pv^a Pliocene andesite
- Pv^b Pliocene basalt
- Pvl Lower Pliocene volcanics and interbedded sediments

MIOCENE
- Mv Miocene volcanics
- Mv^r Miocene rhyolite
- Mv^a Miocene andesite
- Mv^b Miocene basalt

EOCENE
- Ev Eocene volcanics

- Tv Undivided Tertiary volcanics
- Tv^r Tertiary rhyolite
- Tv^a Tertiary andesite



PT ARENA AREA
RUMSEY HILLS AREA
FAIRFIELD KNOLLS GAS FIELD
504
BERRYESSA VALLEY AREA
PETALUMA AREA
POTRERO HILLS AREA
57
503
502
STOCKTON GAS WELLS
MINER RANCH AREA
DUXBURY PT AREA
501
TESLA REGION
HALF MOON BAY AREA
MOODY GULCH
CHOWCHILLA GAS FIELD
SANTA CRUZ AREA
307
1
CIERVO AREA
CANTUA-VALLECITOS AREA
14
402
401
LEWIS CR. AREA
ARROYO SECO AREA
TULARE LAKE REGION
36
403
SAN ARDO AREA
DUDLEY RIDGE AREA
CHOLAME-PARKFIELD AREA
404
58
PLEYTO AREA
SAN MIGUEL AREA
406
405
422
54
12
414
53
SONOMA
YOLO
NAPA
SACRAMENTO
EL DORADO
AMADOR
ALPINE
SOLANO
MARIN
CALAVERAS
CONTRA COSTA
SAN JOAQUIN
TUOLUMNE
YOSEMITE NATIONAL PARK
ALAMEDA
STANISLAUS
MARIPOSA
SANTA CLARA
MERCED
SANTA CRUZ
MADERA
SAN BENITO
FRESNO
MONTEREY
KINGS
SAN FRANCISCO
FARALLON ISLANDS
100 fathoms
38°
37°
36°
OREGON
KLAMATH MOUNTAINS
DEL NORTE
HUMBOLDT
TRINITY
SHASTA
MODOC
LASSEN
SACRAMENTO VALLEY
COAST RANGES
MENDOCINO
GLENN
BUTTE
COLUSA
SUTTER
YUBA
LAKE
SONOMA
YOLO
ELDORADO
ALPINE
AMADOR
SOLANO
MARIN
SACRAMENTO
CALAVERAS
SAN JOAQUIN
TUOLUMNE
STANISLAUS
MARIPOSA
SANTA CLARA
MERCED
SANTA CRUZ
SAN FRANCISCO
PACIFIC

101 TOTAL PRODUCTIVE ACREAGE (GAS)

SEE INDEX NUMBERS (BOXED) AND LIST FOR NAMES OF FIELDS.

WELLS DRILLED OUTSIDE OF FIELDS AND AREAS MAPPED BY THE DIVISION OF OIL AND GAS.

MINOR AREAS AND FIELDS ARE INDICATED BY NAME, FOR EXAMPLE: WILLOWS GAS FIELD.

See tabulated list of wells published in BULLETIN 118, GEOLOGIC FORMATIONS AND ECONOMIC DEVELOPMENT OF THE OIL AND GAS FIELDS OF CALIFORNIA.

2 MAPS PREPARED BY THE STATE DIVISION OF OIL AND GAS.

ACKNOWLEDGMENTS

Base and streams after U. S. Geological Survey, 1929, with geologic boundaries and symbols after Geologic Map of California by Olaf P. Jenkins, California State Division of Mines, 1938. Map reduced one half from original scale of 1:500,000.

Data on oil and gas fields and areas, including the names and productive acreage, have been compiled largely from maps of the State Division of Oil and Gas. Locations of wells outside of mapped areas have been secured principally from the records of the Petroleum World and other journals as well as from the publications of the State Division of Oil and Gas and the Division of Mines.

This map has been made to accompany BULLETIN 118, GEOLOGIC FORMATIONS AND ECONOMIC DEVELOPMENT OF THE OIL AND GAS FIELDS OF CALIFORNIA, prepared under the direction of Olaf P. Jenkins, Chief Geologist, Geologic Branch, California State Division of Mines.

CENOZOIC — EOCENE
- Tg — Tertiary auriferous gravels
- Euc — Upper Eocene non-marine sediments
- Eu — Upper Eocene marine sediments
- El — Lower Eocene marine sediments

MESOZOIC — CRETACEOUS
- K — Undivided Cretaceous marine sediments
- Ku — Upper Cretaceous marine sediments
- Kl — Lower Cretaceous marine sediments
- JK — Knoxville formation

MESOZOIC — JURASSIC
- Jf — Franciscan group
- Ju — Upper Jurassic marine meta-sediments
- Jml — Middle and Lower Jurassic marine meta-sediments

TRIASSIC
- Tr — Triassic marine meta-sediments

UNDIVIDED
- pK — Undivided pre-Cretaceous metamorphics
- pfs — Undivided pre-Franciscan meta-sediments
- P (ls) — Undivided Paleozoic meta-sediments (ls limestone)

PALEOZOIC — CARBONIFEROUS
- C — Undivided Carboniferous marine meta-sediments
- CP — Pennsylvanian and Permian marine meta-sediments
- Cm — Mississippian marine meta-sediments

DEVONIAN
- D — Devonian marine meta-sediments

SILURIAN
- S — Silurian marine meta-sediments

ORDOVICIAN
- O — Ordovician marine meta-sediments

CAMBRIAN
- € — Cambrian marine meta-sediments

PROTEROZOIC — PRE CAMBRIAN
- p€ — Pre-Cambrian metamorphics
- A — Algonkian sediments and metamorphics
- Ar — Archean metamorphics

IGNEOUS — TERTIARY
- Tv — Undivided Tertiary volcanics
- Tvr — Tertiary rhyolite
- Tva — Tertiary andesite
- Tvb — Tertiary basalt
- Ti — Tertiary intrusives
- Tgr — Tertiary granitic rocks

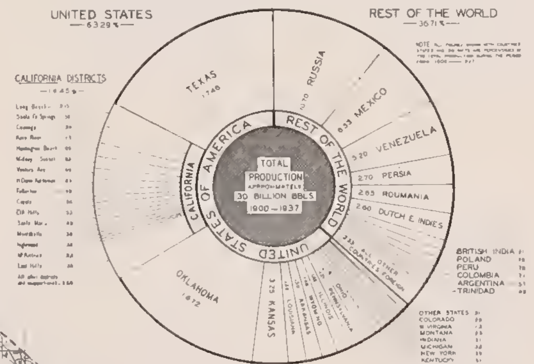
GRANITIC ROCKS LARGELY JURASSIC
- grd — Undivided granitic rocks
- Jai — Jurassic acid intrusives (granitic rocks)
- Jbi — Jurassic basic meta-igneous rocks
- Jub — Jurassic ultra-basic intrusives

META-IGNEOUS — MESOZOIC / PALEOZOIC
- Jkv — Jura-Trias meta-volcanics
- Cv — Carboniferous meta-volcanics
- pDv — Undivided pre-Devonian meta-volcanics

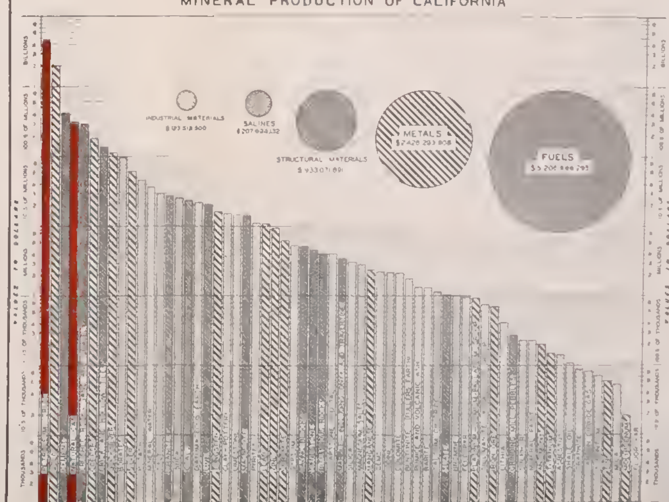
CULTURE
- STATE CAPITAL
- COUNTY SEAT
- LARGE CITY
- TOWN OR VILLAGE
- RAILROAD
- ELECTRIC RAILROAD

GEOLOGIC BOUNDARIES & FAULTS
- FAULT
- GEOLOGIC BOUNDARY & SYMBOL
- GEOLOGIC BOUNDARY UNCERTAIN

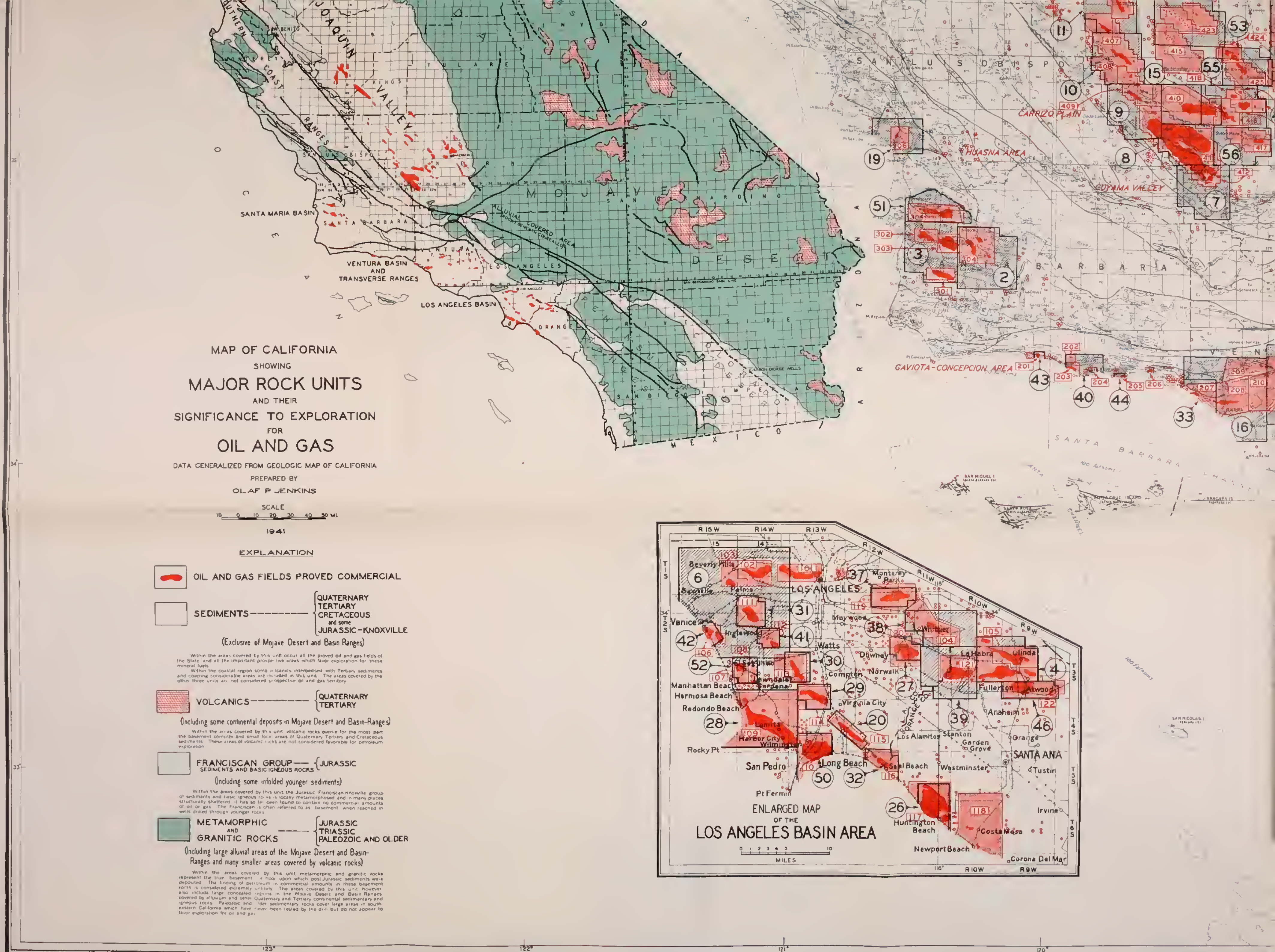

TOTAL WORLD PETROLEUM PRODUCTION
1900—1937
A PERCENTAGE COMPARISON OF MAJOR PRODUCING COUNTRIES WITH PARTICULAR REFERENCE TO CALIFORNIA

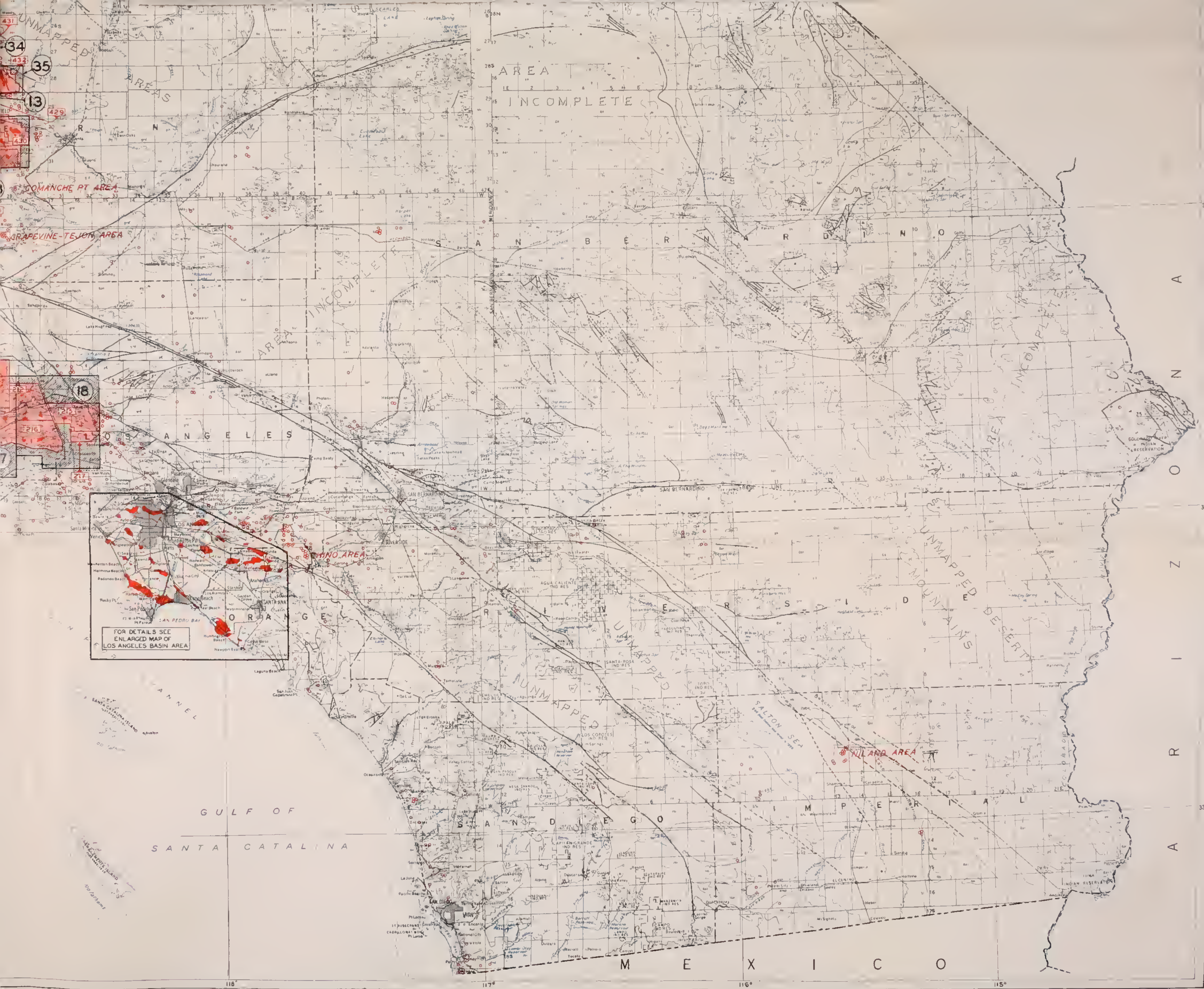


MINERAL PRODUCTION OF CALIFORNIA



TOTALS BY PRODUCTS TO END OF 1937


MAP OF CALIFORNIA
SHOWING
MAJOR ROCK UNITS
AND THEIR
SIGNIFICANCE TO EXPLORATION
FOR
OIL AND GAS
DATA GENERALIZED FROM GEOLOGIC MAP OF CALIFORNIA
PREPARED BY
OLAF P JENKINS
SCALE
10 0 10 20 30 40 50 MI
1941
EXPLANATION
OIL AND GAS FIELDS PROVED COMMERCIAL
SEDIMENTS
QUATERNARY
TERTIARY
CRETACEOUS
and some
JURASSIC-KNOXVILLE
(Exclusive of Mojave Desert and Basin Ranges)
Within the areas covered by this unit occur all the proved oil and gas fields of the State and all the important prospective areas which favor exploration for these mineral fuels.
Within the coastal region some volcanics interbedded with Tertiary sediments and covering considerable areas are included in this unit. The areas covered by the other three units are not considered prospective oil and gas territory.
VOLCANICS
QUATERNARY
TERTIARY
(Including some continental deposits in Mojave Desert and Basin-Ranges)
Within the areas covered by this unit volcanic rocks overlie for the most part the basement complex and small local areas of Quaternary Tertiary and Cretaceous sediments. These areas of volcanic rocks are not considered favorable for petroleum exploration.
FRANCISCAN GROUP
SEDIMENTS AND BASIC IGNEOUS ROCKS
JURASSIC
(Including some infolded younger sediments)
Within the areas covered by this unit the Jurassic Franciscan-Knoxville group of sediments and basic igneous rocks is locally metamorphosed and in many places structurally shattered. It has so far been found to contain no commercial amounts of oil or gas. The Franciscan is often referred to as basement when reached in wells drilled through younger rocks.
METAMORPHIC
AND
GRANITIC ROCKS
JURASSIC
TRIASSIC
PALEOZOIC AND OLDER
(Including large alluvial areas of the Mojave Desert and Basin-Ranges and many smaller areas covered by volcanic rocks)
Within the areas covered by this unit metamorphic and granitic rocks represent the true basement or floor upon which post-Jurassic sediments were deposited. The finding of petroleum in commercial amounts in these basement rocks is considered extremely unlikely. The areas covered by this unit however also include large concealed regions in the Mojave Desert and Basin Ranges covered by alluvium and other Quaternary and Tertiary continental sedimentary and igneous rocks. Paleozoic and older sedimentary rocks cover large areas in southeastern California which have never been tested by the drill but do not appear to favor exploration for oil and gas.
SAN JOAQUIN VALLEY
KINGS
TULARE
COAST RANGES
SANTA MARIA BASIN
SANTA BARBARA
VENTURA BASIN AND TRANSVERSE RANGES
LOS ANGELES BASIN
LOS ANGELES
ORANGE
MOJAVE DESERT
SAN BERNARDINO
RIVERSIDE
SAN DIEGO
IMPERIAL
COLORADO DESERT
PENINSULAR RANGES
ALLUVIAL COVERED AREA
ARIZONA
MEXICO
OCEAN
SAN LUIS OBISPO
CARRIZO PLAIN
HUASNA AREA
CUYAMA VALLEY
GAVIOTA-CONCEPCION AREA
SANTA BARBARA
ENLARGED MAP
OF THE
LOS ANGELES BASIN AREA
MILES
Beverly Hills
Sawtelle
Palms
LOS ANGELES
Monterey Park
Venice
Inglewood
Maywood
Whittier
La Habra
Olinda
Watts
Downey
Norwalk
Compton
Fullerton
Atwood
Manhattan Beach
Hermosa Beach
Redondo Beach
Gardena
Virginia City
Anaheim
Lomita
Harbor City
Wilmington
Los Alamitos
Stanton
Garden Grove
Orange
SANTA ANA
Tustin
Rocky Pt
San Pedro
Long Beach
Seal Beach
Westminster
Pt Fermin
Huntington Beach
Costa Mesa
Irvine
Newport Beach
Corona Del Mar
123°
122°
121°
120°
34°
33°



UNMAPPED AREAS
AREA INCOMPLETE
COMANCHE PT AREA
GRAPEVINE-TEJON AREA
SAN BERNARDINO
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
CHINO AREA
NILAND AREA
UNMAPPED MOUNTAINS
UNMAPPED DESERT
UNMAPPED
SALTON SEA
FOR DETAILS SEE ENLARGED MAP OF LOS ANGELES BASIN AREA
GULF OF SANTA CATALINA
ARIZONA
MEXICO
118°
117°
116°
115°
35
34
33