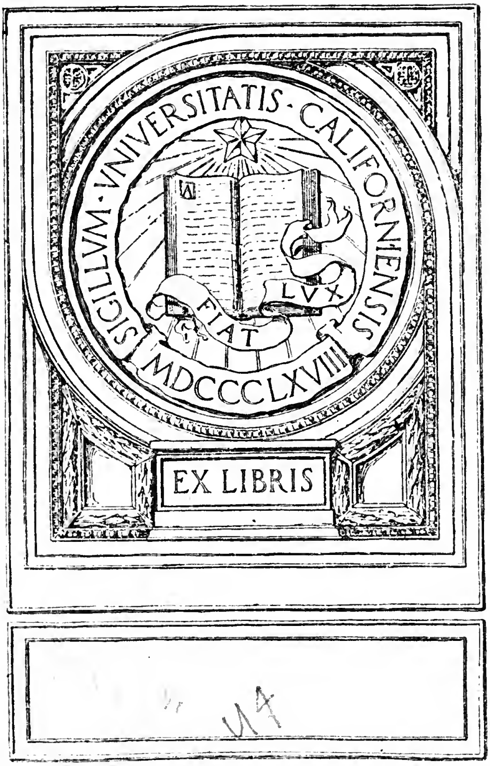

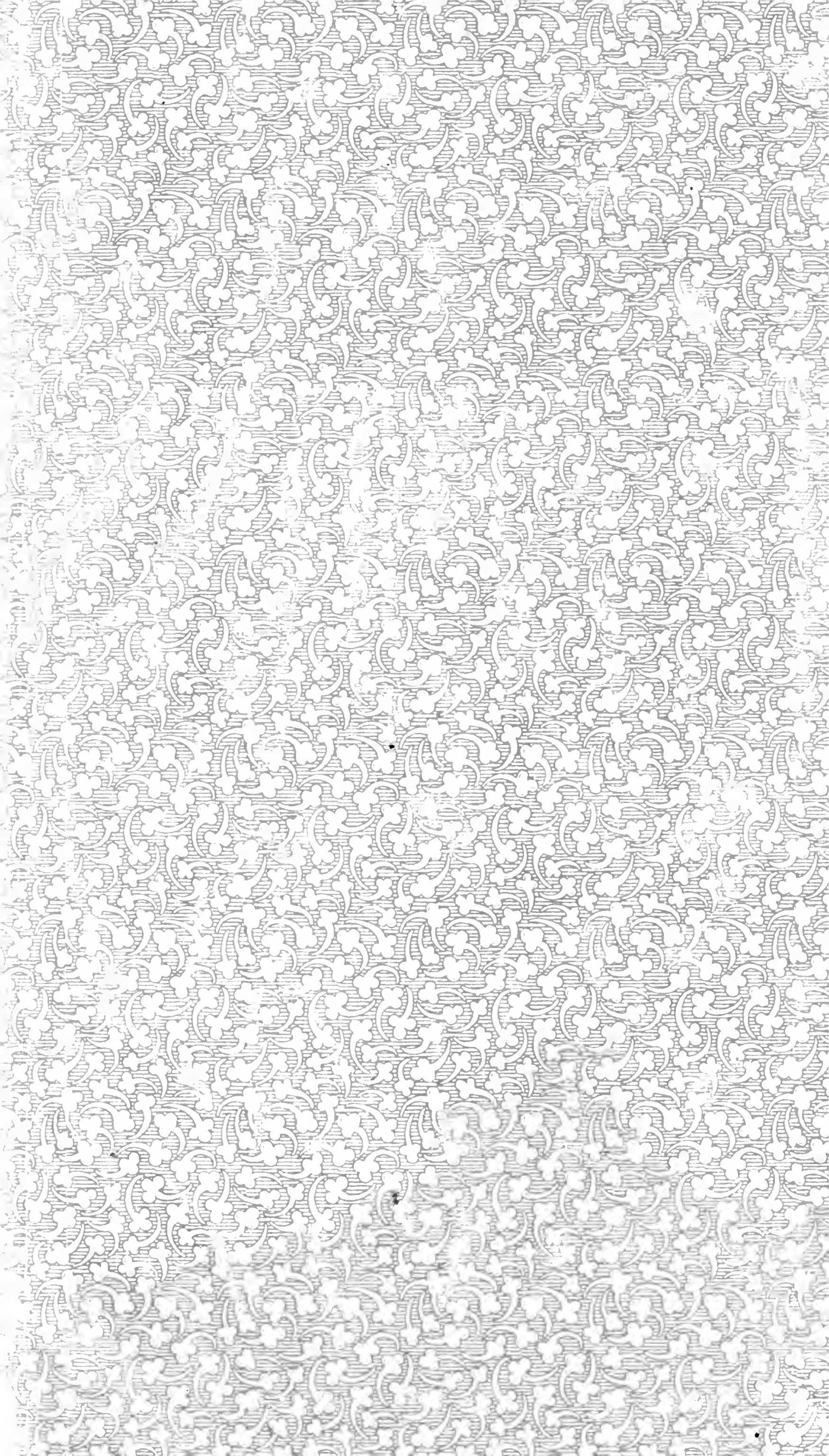

GEOLOGY OF
PETROLEUM

BY

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PREFACE

I have attempted in this volume to present as briefly as is practicable a perspective of the data of the geology of petroleum. The work is based on a series of lectures which for several years past I have offered in courses on economic geology at the University of Minnesota. These lectures have been rewritten and expanded. The material was first prepared some years ago to be included as a chapter in "The Principles of Economic Geology," recently issued. The chapter was so large, however, that to have included it would have defeated some of the purposes of that volume. It was withdrawn and rewritten and is offered here.

This book was prepared to be used as a text for students who wish to acquire some knowledge of the geology of petroleum, especially for those who have already studied the operation of geologic processes and the principles of stratigraphy. I have introduced sections showing the strata of many oil fields and many details of stratigraphy which it will be desirable to omit in classroom work. The best results will probably be obtained by omitting much of the material presented for certain fields and emphasizing that relating to other fields, especially those of which the students already have some general knowledge.

Within the last few years I have had many opportunities to visit the geologic departments of petroleum engineers and corporations and have been impressed with the large amount of carefully prepared data which they possess. I can not hope to add much, if anything, to these data. Nevertheless, by offering a little about many fields I trust I have rendered a service to the profession. This volume is not intended to serve as a handbook of petroleum geology. I have included in it, however, brief sketches of the geology of many oil fields and numerous references to the literature treating them, and I hope it will serve some of the needs of a geologist who is undertaking the study of a field new to him.

I realize that there may be serious omissions and possibly errors in the presentation and discussion of so much material gathered from so many sources. I shall esteem it a favor if anyone whose statements I may have misquoted or misinterpreted will set me right, and if those who have had superior opportunities for study of certain districts will correct any wrong impressions I may have given.

In general I have followed the standard uses of terms. With respect to the use of the term monocline, however, I have departed from the once standard usage and have classed as monoclinal structural features those strata on the flanks of other folds that outcrop and are sealed above the reservoirs. In this usage I have followed many of the highest authorities in the field of petroleum geology. Such a use, I believe, is justified. It is convenient and in many cases it greatly simplifies expression and it is understood by all geologists working in the field of petroleum geology.

I acknowledge my indebtedness to Professors C. R. Stauffer and F. F. Grout and to Messrs. G. M. Schwartz and John Gruner, of the Department of Geology and Mineralogy of the University of Minnesota, and to Mr. Julius Segall and Mr. Frank Notestein, who have read critically sections of the volume; to Prof. J. A. Bownocker who has read the sections on Ohio fields and to Mr. N. O. Barrett who has read the section on Illinois fields; and to Messrs. O. F. Ernster and Karl A. Berg for many services, especially in connection with the preparation of drawings. I have endeavored suitably to acknowledge sources of information by footnote references.

W. H. EMMONS.

UNIVERSITY OF MINNESOTA, MINNEAPOLIS,
December, 1920.

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GEOLOGY
OF
PETROLEUM

CHAPTER I

INTRODUCTION

GENERAL OCCURRENCE OF PETROLEUM

Petroleum, or rock oil, is an inflammable mixture of oily hydrocarbons that exudes from the earth or is pumped up and is used extensively for generating heat, light, and power and for lubricating machinery.

Asphaltum is a solid bitumen, and maltha a semifluid bitumen; both are residues formed by the partial evaporation or inspissation of petroleum.

Natural gas, or rock gas, is an aeriform mixture that is found at or beneath the surface of the earth and is used as an illuminant, for fuel, and for generating power. Natural gas is commonly associated with petroleum.

Petroleum and natural gas are formed by the decomposition of plant and animal remains that have been buried with sediments in the sea. They are almost never found in commercial quantities in igneous rocks, in metamorphosed rocks, or in fresh-water sediments not associated with marine strata. They generally originate in muds, clays, or shales, or much less commonly in marls or limestones. Petroleum and natural gas can not ordinarily accumulate in shales in large amounts, because in such rocks adequate openings are generally not available. As a rule they accumulate in sands or sandstones associated with clays or shales, or in porous limestones. In age the petroleum-bearing strata range from Ordovician to Recent.

Salt water is generally associated with petroleum and is believed to be sea water that filled the pores of the sands when they were laid down in the sea. Waters from oil-bearing strata differ from sea water in concentration and in composition, but there are reasons for supposing that changes have taken place since the original sea water was stored in the rocks. Not all oil-bearing strata are saturated with salt water; some contain very little water, and in at least two fields the oil is floated on water that is practically free from salt.

Where rocks are saturated with petroleum, natural gas, and salt water, the oil is generally found above the water, and as a rule the gas is found above the oil. This rearrangement is due chiefly to gravity.

As a rule the strata that contain petroleum are folded. In some places they are only gently folded; in others they are thrown into sharp folds, the beds dipping 20 to 30 degrees or more. In consolidated rocks, such as shales, sandstones, and limestones, which have been intensely deformed by faulting and close folding, oil is generally not found in large amounts. In unconsolidated series of rocks, such as clays, marls, and sands, large accumulations are known in areas of highly complicated structures. In some regions unconsolidated oil-bearing rocks have been intensely faulted by thrust faults and overturned, yet they still retain large accumulations of petroleum.

Many of the oil fields are on monoclines, on which are developed secondary folds, such as anticlines, synclines, domes, and structural terraces. In rocks that are highly saturated with oil and in beds that dip very gently the oil gathers in domes, if any are available, but accumulation takes place also in very gentle folds and in structural features that are not "closed" (see p. 96), such as plunging anticlines and terraces. In rocks that are less highly saturated with oil in a country containing sharp folds, the accumulation is generally in areas of closed structures, such as domes, or in traps such as are formed where an open fold is crossed by a fault.

Not all reservoirs are porous beds on anticlines. Any body of porous rock sealed above in any manner may under certain conditions supply a reservoir for the accumulation of either petroleum or natural gas.

If the porous strata in areas of folded structure are not saturated with water, oil will descend on the folds until it occupies the flanks of synclines, and if no water is present it tends to move down to the bottoms of the folds. In strata containing openings of unequal size, oil and gas accumulate in the larger openings, the water being drawn by capillary attraction into the smaller ones.

USES

In its crude state petroleum is used extensively for fuel. It has a high evaporating power per unit of weight and is in demand for use under locomotive and marine boilers. The heavy oils are used for fuel more generally than the lighter oils, because as a rule the heavy oil will not yield such valuable products. Heavy oils are used also in the crude state for road dressing, and for making roofing.

In refining petroleum, it is broken up by a process of distillation into many products, including petroleum ether, gasoline, naphtha, kerosene, lubricating oils, vaseline, paraffin wax, and petroleum coke. Each of these materials has a variety of uses. Ether is used in medicine as a cooling agent and for priming internal-combustion engines in cold weather. Gasoline is used as fuel in internal-combustion engines, for cleaning cloth and other substances, and as a solvent of oil and grease. Naphtha is used for approximately the same purposes and much commercial gasoline is a mixture of gasoline and naphtha. Kerosene is used principally for illumination and as a fuel for tractors. Lubricating oils are the heavy viscous products obtained by refining petroleum. They are used for lubricating machinery and when highly refined for medicinal purposes, especially as laxatives. Paraffin wax is used for making candles, for sealing preserved fruits and vegetables, and as a preservative. It is used also for medicinal purposes, especially in the treatment of burns. Petroleum coke is used in metallurgic processes, as a fuel, and for making carbons for batteries and arc lights.

Many petroleum refineries do not produce all the products mentioned. Some "topping plants" distill off the lighter products, such as may be used as fuel for internal-combustion engines, and sell the heavier residues for fuel oil or for road dressing.

Asphalt is formed in nature by the drying up of petroleum, chiefly where it exudes at the surface. It is used for making pavements, roofings, and other building materials. Some oils on refining yield an artificial asphalt that is much like the natural product and is used for similar purposes.

HISTORICAL NOTES

The bitumens were known to the ancients in the earliest historic era. The Bible refers to oil obtained from a rock and to pitch

WORLD'S PRODUCTION OF CRUDE PETROLEUM SINCE 18
(After J. D. Northr

Year	Rumania	United States[a]	Italy	Canada	Russia	Galicia	Japan and Formosa	German
1857...	1,977	....	....	....	....	....	....	....
1858...	3,560	....	....	....	....	....	....	....
1859...	4,349	2,000	....	....	....	....	....	....
1860...	8,542	500,000	36	....	....	....	....	....
1861...	17,279	2,113,609	29	....	....	....	....	....
1862...	23,198	3,056,690	29	11,775	....	....	....	....
1863...	27,943	2,611,309	58	82,814	40,816	....	....	....
1864...	33,013	2,116,109	72	90,000	64,686	....	....	....
1865...	39,017	2,497,700	2,265	110,000	66,542	....	....	....
1866...	42,534	3,597,700	992	175,000	83,052	....	....	....
1867...	50,838	3,347,300	791	190,000	119,917	....	....	....
1868...	55,369	3,646,117	367	200,000	88,327	....	....	....
1869...	58,533	4,215,000	144	220,000	202,308	....	....	....
1870...	83,765	5,260,745	86	250,000	204,618	....	....	....
1871...	90,030	5,205,234	273	269,397	165,129	....	....	....
1872...	91,251	6,293,194	331	308,100	184,391	....	....	....
1873...	104,036	9,893,786	467	365,052	474,379	....	....	....
1874...	103,177	10,926,945	604	168,807	583,751	149,837	....	....
1875...	108,569	8,787,514	813	220,000	697,364	158,522	4,566	....
1876...	111,314	9,132,669	2,891	312,000	1,320,528	164,157	7,708	....
1877...	108,569	13,350,363	2,934	312,000	1,800,720	169,792	9,560	....
1878...	109,300	15,396,868	4,329	312,000	2,400,960	175,420	17,884	....
1879...	110,007	19,914,146	2,891	575,000	2,761,104	214,800	23,457	....
1880...	114,321	26,286,123	2,035	350,000	3,001,200	229,120	25,497	9,3
1881...	121,511	27,661,238	1,237	275,000	3,601,441	286,400	16,751	29,2
1882...	136,610	30,349,897	1,316	275,000	4,537,815	330,076	15,549	58,0
1883...	139,486	23,449,633	1,618	250,000	6,002,401	365,160	20,473	26,7
1884...	210,667	24,218,438	2,855	250,000	10,804,577	408,120	27,923	46,1
1885...	193,411	21,858,785	1,941	250,000	13,924,596	456,400	29,237	41,3
1886...	168,606	28,064,841	1,575	584,061	18,006,407	305,884	37,916	73,8
1887...	181,907	28,283,483	1,496	525,655	18,367,781	343,832	28,645	74,2
1888...	218,576	27,612,025	1,251	695,203	23,048,787	466,537	37,436	84,7
1889...	297,666	35,163,513	1,273	704,690	24,609,407	515,268	52,811	68,2
1890...	383,227	45,823,572	2,998	795,030	28,691,218	659,012	51,420	108,2
1891...	488,201	54,292,655	8,305	755,298	34,573,181	630,730	52,917	108,9
1892...	593,175	50,514,657	18,321	779,753	35,774,504	646,220	68,901	101,4
1893...	535,655	48,341,066	19,069	798,406	40,456,519	692,669	106,384	99,
1894...	507,255	49,344,516	20,552	829,104	36,375,428	949,146	171,744	122,5
1895...	575,200	52,892,276	25,843	726,138	46,140,174	1,452,999	141,310	121,2
1896...	543,348	60,960,361	18,149	726,822	47,220,633	2,443,080	197,082	145,0
1897...	570,886	60,475,516	13,892	709,857	54,399,568	2,226,368	218,559	165,7
1898...	776,238	55,364,233	14,489	758,391	61,609,357	2,376,108	265,389	183,4
1899...	1,425,777	57,070,850	16,121	808,570	65,954,968	2,313,047	536,079	192,2
1900...	1,628,535	63,620,529	12,102	913,498	75,779,417	2,346,505	866,814	358,2
1901...	1,678,320	69,389,194	16,150	756,679	85,168,556	3,251,544	1,110,790	313,6
1902...	2,059,935	88,766,916	18,933	530,624	80,540,044	4,142,159	1,193,038	353,67
1903...	2,763,117	100,461,337	17,876	486,637	75,591,256	5,234,475	1,209,371	445,81
1904...	3,599,026	117,080,960	25,476	552,575	78,536,655	5,947,383	1,419,473	637,4
1905...	4,420,987	134,717,580	44,027	634,095	54,960,270	5,765,317	1,472,804	560,9
1906...	6,378,184	126,493,936	53,577	569,753	58,897,311	5,467,967	1,710,768	578,61
1907...	8,118,207	166,095,335	59,875	788,872	61,850,734	8,455,841	2,001,838	756,63
1908...	8,252,157	178,527,355	50,966	527,987	62,186,447	12,612,295	2,070,145	1,009,27
1909...	9,327,278	183,170,874	42,388	420,755	65,970,350	14,932,799	1,889,563	1,018,83
1910...	9,723,806	209,557,248	50,830	315,895	70,336,574	12,673,688	1,930,661	1,032,52
1911...	11,107,450	220,449,391	74,709	291,096	66,183,691	10,519,270	1,658,903	1,017,04
1912...	12,976,232	222,935,044	53,778	243,336	68,019,208	8,535,174	1,671,405	1,031,05
1913...	13,554,768	248,446,230	47,198	228,080	62,834,356	7,818,130	1,942,009	[b]995,76
1914...	12,826,579	265,762,535	39,849	214,805	67,020,522	[b]5,033,350	2,738,378	[b]995,76
1915...	12,029,913	281,104,104	43,898	215,464	68,548,062	4,158,899	3,118,464	[b]995,76
1916...	[d]10,298,208	300,767,158	50,585	198,123	[d]72,801,110	6,461,706	2,997,178	[b]995,76
1917...	[b]2,681,870	335,315,601	[b]50,334	205,332	[b]69,000,000	[d]5,965,447	2,898,654	[b]995,76
Total..	142,992,465	4,252,644,003	947,289	24,112,529	1,832,583,017	148,459,653	36,065,454	15,952,86
%.....	2.04	60.78	0.02	0.35	26.19	2.12	0.52	0.2

[a] Quantity marketed. [b] Estimated. [c] Includes British Borneo.

y Years and Countries, in Barrels of 42 Gallons
. S. Geological Survey)

ndia	Dutch East Indies	Peru	Mexico	Argentina	Trinidad	Egypt	Other Countries	Total	Year
....	....	......	....	.....	.....	.....	......	1,977	..1857
....	....	......	....	.....	.....	.....	......	3,560	..1858
....	....	......	....	.....	.....	.....	......	6,349	..1859
....	....	......	....	.....	.....	.....	......	508,578	..1860
....	....	......	....	.....	.....	.....	......	2,130,917	..1861
....	....	......	....	.....	.....	.....	......	3,091,692	..1862
....	....	......	....	.....	.....	.....	......	2,762,940	..1863
....	....	......	....	.....	.....	.....	......	2,303,780	..1864
....	....	......	....	.....	.....	.....	......	2,715,524	..1865
....	....	......	....	.....	.....	.....	......	3,899,278	..1866
....	....	......	....	.....	.....	.....	......	3,708,846	..1867
....	....	......	....	.....	.....	.....	......	3,990,180	..1868
....	....	......	....	.....	.....	.....	......	4,695,985	..1869
....	....	......	....	.....	.....	.....	......	5,799,214	..1870
....	....	......	....	.....	.....	.....	......	5,730,063	..1871
....	....	......	....	.....	.....	.....	......	6,877,267	..1872
....	....	......	....	.....	.....	.....	......	10,837,720	..1873
....	....	......	....	.....	.....	.....	......	11,933,121	..1874
....	....	......	....	.....	.....	.....	......	9,977,348	..1875
....	....	......	....	.....	.....	.....	......	11,051,267	..1876
....	....	......	....	.....	.....	.....	......	15,753,938	..1877
....	....	......	....	.....	.....	.....	......	18,416,761	..1878
....	....	......	....	.....	.....	.....	......	23,601,405	..1879
....	....	......	....	.....	.....	.....	......	30,017,606	..1880
....	....	......	....	.....	.....	.....	......	31,992,797	..1881
....	....	......	....	.....	.....	.....	......	35,704,288	..1882
....	....	......	....	.....	.....	.....	......	30,255,479	..1883
....	....	......	....	.....	.....	.....	......	35,968,741	..1884
....	....	......	....	.....	.....	.....	......	36,764,730	..1885
....	....	......	....	.....	.....	.....	......	47,243,154	..1886
....	....	......	....	.....	.....	.....	......	47,807,083	..1887
....	....	......	....	.....	.....	.....	......	52,164,597	..1888
94,250	....	......	....	.....	.....	.....	......	61,507,095	..1889
18,065	....	......	....	.....	.....	.....	......	76,632,838	..1890
90,131	....	......	....	.....	.....	.....	......	91,100,347	..1891
42,284	....	......	....	.....	.....	.....	......	88,739,219	..1892
98,969	600,000	......	....	.....	.....	.....	......	92,038,127	..1893
27,218	688,170	......	....	.....	.....	.....	......	89,335,697	..1894
71,536	1,215,757	......	....	.....	.....	.....	......	103,662,510	..1895
29,979	1,427,132	47,536	....	.....	.....	.....	......	114,159,183	..1896
45,704	2,551,649	70,831	....	.....	.....	.....	......	121,948,575	..1897
42,110	2,964,035	70,905	....	.....	.....	.....	......	124,924,682	..1898
40,971	1,795,961	89,166	....	.....	.....	.....	......	131,143,742	..1899
78,264	2,253,355	274,800	....	.....	.....	.....	......	149,132,116	..1900
30,716	4,013,710	274,800	10,345	.....	.....	.....	[b]20,000	167,434,434	..1901
17,363	2,430,465	286,725	40,200	.....	.....	.....	[b]26,000	182,006,076	..1902
10,259	5,770,056	278,092	75,375	.....	.....	.....	[b]36,000	194,879,669	..1903
85,468	6,508,485	345,834	125,625	.....	.....	.....	[b]40,000	218,204,391	..1904
37,098	7,849,896	447,880	251,250	.....	.....	.....	[b]30,000	215,292,167	..1905
15,803	8,810,657	536,294	502,500	.....	.....	.....	[b]30,000	213,415,360	..1906
44,162	9,982,597	756,226	1,005,000	101	.....	.....	[b]30,000	264,245,419	..1907
47,038	10,283,357	1,011,180	3,932,900	11,472	169	.....	[b]30,000	285,552,746	..1908
76,517	11,041,852	1,316,118	2,713,500	18,431	57,143	.....	[b]20,000	298,616,405	..1909
37,990	11,030,620	1,330,105	3,634,080	20,753	142,857	.....	[b]20,000	327,937,629	..1910
51,203	12,172,949	1,368,274	12,552,798	13,119	285,307	9,150	[b]20,000	344,174,355	..1911
16,672	10,845,624	1,751,143	16,558,215	47,007	436,805	205,905	[b]20,000	352,446,598	..1912
30,149	11,172,294	2,133,261	25,696,291	130,618	503,616	94,635	[b]20,000	383,547,399	..1913
09,792	[c]11,834,802	1,917,802	26,235,403	275,500	643,533	777,038	[b]20,000	403,745,342	..1914
02,674	[c]12,386,800	2,487,251	32,910,508	516,120	[b]750,000	262,208	[b]10,000	427,740,129	..1915
91,137	[c]13,174,399	2,550,645	40,545,712	793,920	928,581	411,000	[b]25,000	461,493,226	..1916
78,843	[c]12,928,955	2,533,417	55,292,770	1,144,737	1,599,455	1,008,750	[e]7,004,973	506,702,902	..1917
62,365	175,103,267	21,878,285	222,082,472	2,974,778	5,347,466	2,768,686	14,599,973	6,996,674,563	..Total
1.40	2.50	0.31	3.18	0.04	0.08	0.04	0.20	....	....%

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stimated in part.

ncludes 19,167 barrels produced in Cuba, 127,743 barrels in Venezuela, and 6,856,063 barrels in Persia.

used for making tight the seams of boats. The Persian fire worshipers had shrines at gas seepages in the Apsheron Peninsula, Russia, and until recent years the followers of Zoroaster made pilgrimages to that region and to Holy Island, nearby, in the Caspian Sea.[1] There are numerous references to the bitumens in Greek and Latin literature. The Romans used petroleum in lamps. The bitumens were obtained at oil seeps or springs or in shallow pits, dug at the surface, into which the oil would flow.

Many place names refer to pitch or oil—for example, Pechelbronn (pitch spring), near Hagenau, Alsace; La Brea (pitch or asphalt), a name used for many places in Spanish countries; the Persian Kir, the Russian Neft, and the Burmese Yenang.

In modern times petroleum has been exploited for more than a century in Alsace,[2] where deep shafts were sunk into the oil-bearing formations. In Burma deep wells were put down by hand, and oil was bailed out of them with buckets. These methods are slow and laborious and because of the gas associated with petroleum are dangerous and frequently result in loss of life. The exploitation of petroleum on a considerable scale began about 1860, when modern drilling practice was introduced. The machinery and technology of drilling were developed largely in the Appalachian region, in the United States, and in the Petrolia region, Lambton County, Ontario, which were among the first regions to be exploited on the modern scale. The "Canadian rig" and "American rig" are widely used throughout the world.

GEOGRAPHIC DISTRIBUTION OF PETROLEUM

On pages 4 and 5 is a table showing the production of petroleum to 1917, inclusive, with the percentage of the whole that each country produced. In order of output the countries rank as follows: United States, Russia, Mexico, Dutch East Indies, Galicia, Rumania, India, Japan, Canada, Peru, Germany, Trinidad, Argentina, Egypt, Italy. Since 1917 no large fields have been discovered or opened except in Persia and Colombia, of which the statistics are not available. Figs. 1 and 2 show the distribution of the oil fields. The United States and Russia together have produced about 87 per cent of the world's petroleum output to 1917.

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[1] Thompson, A. B.: The Oil Fields of Russia, p. 96, London, 1904.

[2] Redwood, Boverton: A Treatise on Petroleum. Vol. 1, p. 48, London, 1913.

North America has produced 64.31 per cent; Europe, including Russia[1], Rumania, Galicia, Germany, and Italy, has produced 30.60 perc ent; Asia and Oceanica, including the Dutch East Indies, India, and Japan, 4.42 per cent; South America, including Peru, Trinidad, and Argentina, 0.43 per cent; and Africa, 0.04 per cent. The Western Hemisphere has produced 64.74 per cent, and the Eastern Hemisphere has produced 35.06 per cent of the total. Australia and Africa, except northern Egypt, are essentially unproductive. The Northern Hemisphere has produced 96.95 per cent, and the Southern Hemisphere, including all of the Dutch East Indies (where some of the oil is found north of the Equator), Peru, and Argentina, has produced 2.85 per cent. It is noteworthy also that 92.29 per cent of the world's production has come from the north temperate zone, and the remaining 7.51 per cent has come from fields south of the Tropic of Cancer. The continents rank in order of output: North America, Europe, Asia, South America, and Africa. The most thoroughly explored countries have been the most productive.

Clapp, who has devoted considerable study to both Asia and South America, states that the South American output will probably rise in the course of a few years to second place; although in his opinion[2] the final rank of the continents by total production, when fully developed, is likely to be as follows: North America, Asia, South America, Europe, Africa. This is a decidedly optimistic view of the future supply of Asia and South America, considering the great production of European Russia and the undeveloped territory on both sides of the Caucasus Mountains and in other parts of Russia in Europe.

In the immediate future Persia and Colombia are likely to become increasingly important as producers of oil, and an increased production is expected from Mexico and Oceanica. Except in the United States there has been very little development of territory far away from areas exhibiting surface indications of oil. Large production may be expected when the same methods of prospecting areas of favorable structure in consolidated rocks that are applied in North America shall be extensively applied in other fields.

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[1] Production of the Emba field, north of Caspian Sea is included with that of European Russia.

[2] Clapp, F. G.: Petroleum Resources of South America. Am. Inst. Min. Eng. *Bull.* 130, p. 1744.

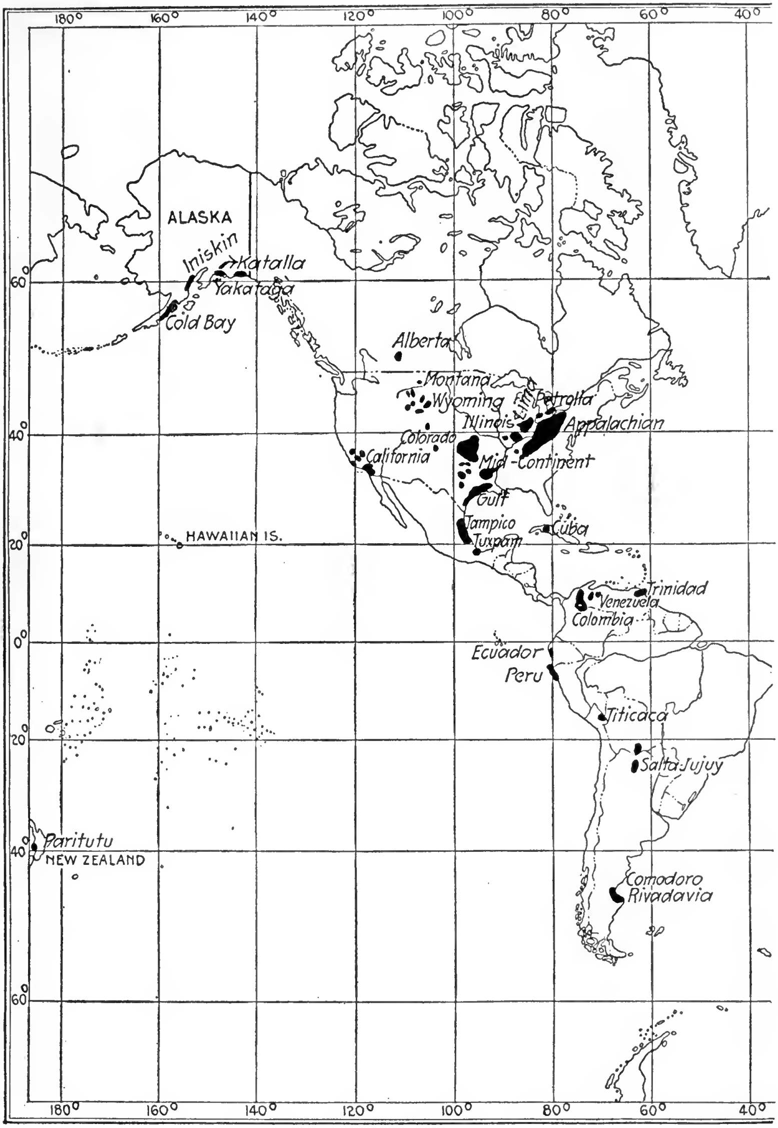

FIG. 1.—Map showing producing oil fields of Western Hemisphere. (*A few prospective fields are shown.*)

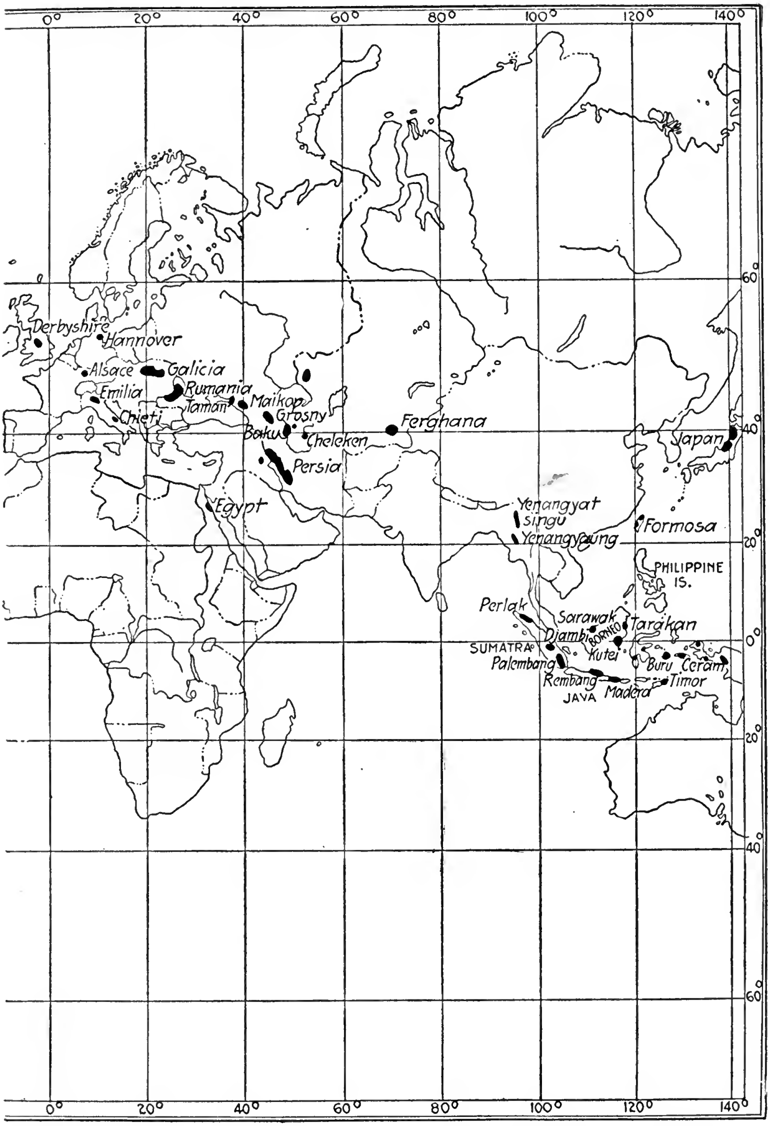

FIG. 2.—Map showing producing oil fields of Eastern Hemisphere. (*A few prospective fields are shown.*)

The United States, by bringing in new fields, has steadily advanced production. It is not expected that as many new fields will be discovered in the future. Probably some will be brought in, new pools on extensions of oil fields will be discovered, and deeper reservoirs will be developed in the producing fields. Nevertheless many investigators who have given most thought to the matter are of the opinion that the United States is not very far from the zenith of its production. As the world's greatest consumer of petroleum and its products the United States must look to foreign fields in the near future, or we must learn to do without some of the things which we have come to regard as necessary.

The world's oil supply has been discussed by Smith,[1] and by White.[2]

White gives an estimate, prepared by geologists of the United States Geological Survey, of the oil remaining in the strata in the United States, January 1, 1919. He states that the quantity available is 6,740,000,000 barrels. At the present rate of consumption this would last the United States about 17 years. White published an estimate of the supplies of the principal countries of the world that are known to contain oil. This estimate, which was prepared by Eugene Stebinger, is stated on page 11. The unused resources of the United States and Alaska are taken as the unit, 1.00, estimated to be 7,000,000,000 barrels.

GEOLOGIC DISTRIBUTION OF PETROLEUM

Kinds of Strata Containing Oil and Gas.—The world's petroleum comes from sedimentary beds, practically all of it from sands, sandstones, conglomerates, and porous limestones and dolomites. The deposits the world over are held in by coverings of shale, clay, or marl.[3] The producing beds almost without exception are marine strata or strata of fresh-water origin that are closely associated with marine strata. The organic material from which the oil is derived finds lodgment in clays and marls when they are deposited, and the oil accumulates in sands and other porous rocks that are associated with the clays and marls. The bodies of strata most

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[1] Smith, G. O.: A Foreign Oil Supply for the United States. Advance Publication No. 157, *Trans.*, Amer. Inst. Min. Eng., February, 1920.

[2] White, David: Petroleum Resources of the World. *Oil and Gas Jour.*, vol. 19, No. 2, pp. 76-82, and vol. 19, No. 3, pp. 54-62, 1920.

[3] Reservoir rocks are discussed on p. 53; cover caps on p. 65.

Oil Resources of Principal Oil Containing Regions of the World.
(Estimate of Eugene Stebinger[a])

COUNTY OR REGION	Relative Value	Millions of Barrels
United States and Alaska	1.00	7,000
Canada	0.14	995
Mexico	0.65	4,525
Northern South America, including Peru	0.82	5,730
Southern South America, including Bolivia	0.51	3,550
Algeria and Egypt	0.13	925
Persia and Mesopotamia	0.83	5,820
Southeastern Russia, southwestern Siberia, and the region of the Caucasus	0.83	5,830
Rumania, Galicia, and western Europe	0.16	1,135
Northern Russia and Saghalien	0.13	925
Japan and Formosa	0.18	1,235
China	0.20	1,375
India	0.14	995
East Indies	0.43	3,015
	6.15	43,055
Total eastern hemisphere	3.03	21,255
Total western hemisphere	3.12	21,800
Total north of equator	5.20	36,400
Total south of equator	0.95	6,655

[a] *Oil and Gas Journal*, vol. 19, No. 3, p. 54, 1920.

common in oil fields are those in which thick shales, clays, or marls alternate with relatively thin sands.

Geologic Age of Strata Producing Petroleum and Gas.—Oil or gas, or both, are found in strata ranging from the Cambrian to the Recent. Large amounts are found in the rocks formed during the Paleozoic, Mesozoic, and Cenozoic eras. All the oil produced in Europe and in Asia is derived from the Cenozoic formations, except a small production in Derbyshire, England, which comes from Paleozoic beds, and a small production in Galicia, Alsace and Hannover where oil is derived from the Mesozoic. In the Eurasian fields the Miocene and Oligocene are the most productive strata, although the Eocene yields considerable oil in Galicia.

In Mexico, Venezuela, and Argentina the principal producing strata are Cretaceous. In Colombia oil is derived from the Cretaceous and the Tertiary. The production of Barbados and most of that of Trinidad are derived from Miocene strata.

In North America large amounts of petroleum are found in strata of Paleozoic, Mesozoic, and Cenozoic age. The Paleozoic strata produce the oils of the Appalachian region, the Illinois field, and the Oklahoma, Kansas, and northern Texas fields. They yield also the oil produced in Canada.

The Cambrian has produced a little gas in New York.

Oil and gas are found in the Trenton limestone (Ordovician) in the Lima-Indiana field of Ohio and Indiana. The Trenton produces some oil also in southeast Illinois and in the Dover West field, just east of Lake St. Clair in Kent County, Ontario. In New York gas is derived from the Trenton.

The Silurian produces a little oil in the Appalachian field. It is the chief source of gas in the Clinton gas field of eastern Ohio, and it yields some gas also in Ontario, west and south of Niagara Falls,

The Devonian yields oil and gas in New York, Pennsylvania. West Virginia, Ohio, Kentucky, Tennessee, Indiana, and Ontario. In Pennsylvania both lower and upper Devonian are productive; in West Virginia the Chemung is barren but the Catskill is productive. In Canada limestone of the Devonian is the chief producing formation. The Devonian limestone has produced oil and gas also in eastern Kentucky.

The Mississippian produces oil in Pennsylvania, West Virginia, Ohio, Kentucky, Illinois, western Indiana, and Texas. In Pennsylvania, West Virginia, Illinois, and northern Texas it is highly productive.

The Pennsylvanian strata produce oil in the Appalachian region and in Illinois. Oil and asphalt are found in Pennsylvanian beds also near Princeton, Indiana. The Pennsylvanian Cherokee shale is the chief oil and gas bearing formation in Kansas and Oklahoma. The Pennsylvanian is productive also in northern Texas. Pennsylvanian rocks carry oil in the San Juan field, Utah. Some oil is found in the Embar (Pennsylvanian and Permian), near Lander, Wyoming.

A little oil is found in the Permian (Red Beds) in Oklahoma, at Virgin City, Utah, and in Pecos Valley, New Mexico.

The Trinity sand (Cretaceous, Comanche) carries oil in the Medill field, Oklahoma, and asphalt in Pike County, Arkansas. At both places it is unconformable above the flexed and eroded Carboniferous beds that are believed to have supplied the oil.

The Upper Cretaceous carries the oil in eastern Texas and northern Louisiana and in the Big Horn Basin, Salt Creek, Big Muddy, and many other fields in Wyoming. A little oil is found in the Graneros (Benton) at Moorcroft, Wyoming, and in the Benton in the Labarge and Spring Valley fields, Wyoming. Oil is found in the Pierre (Upper Cretaceous) in the Shannon field, Wyoming; in fractured Pierre shales at Florence, Colorado; and in a sandstone included in the Pierre in the Boulder field, Colorado. Oil is found in the Mancos (Upper Cretaceous) in the Rangely field, Colorado, and possibly in the Mesaverde (Upper Cretaceous) in the DeBeque field, Colorado. In the McKittrick-Sunset region, California, a little oil appears in the Chico (Cretaceous) shales.

The Tertiary formations are important oil carriers in the Gulf coast fields—for example, Spindletop, Sour Lake, Saratoga, Batson, Dayton, and Humble, all in Texas, and Jennings and Anse La Butte, in Louisiana. In the Wasatch (continental Eocene) asphalt is found in the Uinta Basin of Utah and Colorado, and some oil is found also at Vernal, Utah. In the California fields the principal oil-bearing formations are Eocene (Tejon, Sespe, and Topatopa) and Miocene (Vaqueros, Monterey, Modelo, Puente, Santa Margarita, Fernando, and Jacalitos).

Oil is found also in Pleistocene beds in the Summerland and Puente Hills regions, California. Gas is found in Pleistocene beds of Lake Bonneville, Utah, and asphalt in Salt Lake.

Gum beds and a lubricating oil are found near the base of the glacial drift in Lambton County, Ontario. This oil obviously has escaped from lower beds.

The subjoined tables summarize the data as to the age of the principal reservoirs of oil and gas.

AGE OF PRINCIPAL PETROLEUM RESERVOIRS IN THE UNITED STATES

	New York	Pennsylvania	West Virginia	Ohio	Kentucky	Tennessee	Indiana	Illinois	Missouri	Kansas	Oklahoma	Arkansas	Texas	Louisiana	Wyoming	California
Pleistocene	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+
Pliocene	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+
Miocene	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+
Oligocene	..	..	..	..	..	..	..	..	..	..	..	..	+	+	[a] +	+
Eocene	..	..	..	..	..	..	..	..	..	..	..	..	+	+	..	+
Upper Cretaceous	..	..	..	..	..	..	..	..	..	..	..	+	+	+	+	+
Lower Cretaceous	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..
Jurassic	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Triassic	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Permian	..	..	..	..	..	..	..	..	..	..	+	..	+	..	[b] +	..
Pennsylvanian	..	+	+	+	+	..	+	+	+	+	+	gas	+	..	..	..
Mississippian	..	+	+	+	+	+	+	+	..	..	+	..	+	..	..	..
Devonian	+	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..
Silurian	gas	..	..	+	+	+	+	+	..	..	..	..	..	..	..	..
Ordovician	gas	..	..	+	+	+	+	+	..	..	..	..	..	..	..	..
Cambrian	gas	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

[a] A little oil is found in the White River formation (Oligocene) in the Douglas field.
[b] Embar formation, partly Pennsylvanian

AGE OF PRINCIPAL PETROLEUM RESERVOIRS IN THE CARIBBEAN REGION AND SOUTH AMERICA

	Mexico	Cuba	Haiti	Barbados	Trinidad	Venezuela	Caribbean Colombia	Magdalena and Santander, Colombia	Peru and Ecuador	Argentina and Bolivia
Pleistocene	..	..	..	..	..	..	..	..	..	..
Pliocene	..	..	..	..	[a] +	..	..	..	..	..
Miocene	..	..	..	+	+	..	..	..	{+	..
Oligocene	..	..	..	..	..	..	+	+?	..	..
Eocene	+	..	..	..	..	..	..	+?	⊕	..
Cretaceous	+	..	+?	..	+	+	..	+	..	+
Jurassic	..	+?	..	..	..	..	..	..	..	..

[a] In Trinidad oil exudes from Pliocene strata. It is probably derived in the main from Miocene strata.

Age of Principal Petroleum Reservoirs in the Eastern Hemisphere

	Lower Alsace	Boryslaw, Galicia	Schodnica, Galicia	Rumania	Baku, Russia	Grozny, Russia	Maikop, Russia	Egypt	Burma	Sumatra	Java	Japan	England
Pleistocene	..	..	..	..	..	..	..	..	..	..	..	..	..
Pliocene	..	..	..	[a]+	..	..	..	..	..	+	..	..	..
Miocene	..	+	..	[b]+	+	+	..	+	[c]+	+	+	+	..
Oligocene	[d]+	[e]+	..	+	+	..	[f]+	..	..	..	..	..	..
Eocene	..	..	[g]+	..	..	..	..	..	..	..	..	..	..
Cretaceous	..	..	+	..	..	..	..	+	..	..	..	..	..
Jurassic	..	..	..	..	..	..	..	..	..	..	..	..	..
Triassic	..	..	..	..	..	..	..	..	..	..	..	..	..
Permian	..	..	..	..	..	..	..	..	..	..	..	..	..
Upper Carboniferous	..	..	..	..	..	..	..	..	..	..	..	..	..
Lower Carboniferous	..	..	..	..	..	..	..	..	..	..	..	..	+

[a] Subordinate.

[b] Miocene subdivided into Maeotic, Sarmatian. Tortonian, Helvetian, and Burdigalian; each carries petroleum in places.

[c] Irrawady River fields, include Yenangyaung and Yenangyat-Singu.

[d] In Alsace the principal petroliferous series is lower Oligocene and includes marine and non-marine sediments. A little oil is found in Mesozoic rocks.

[e] The upper Oligocene is the richest petroliferous formation.

[f] Probably upper Oligocene.

[g] Eocene is the most important series.

CHAPTER II

SURFACE INDICATIONS OF PETROLEUM AND MATERIALS ASSOCIATED WITH IT

Indications of oil deposits include oil and the materials that have been formed by the drying of oil—asphaltum, gilsonite, paraffins, maltha, etc.—as well as the common associates of oil, such as bituminous rock, oil shale, burned shale, gas, salt water, and in some regions sulphur and its compounds and acid waters. Mud volcanoes and in some regions mud dikes, indicating the existence of mud volcanoes that have been eroded, are evidence of gas. In places "paraffin dirt" (see page 36) has been found above deposits of oil or gas.

Any indication of oil or gas is to be interpreted in connection with its geologic setting, namely, the rock column, the structure, and the degree of metamorphism shown in associated beds that may be present. The geologic conditions at the surface—the rocks present and their attitude—are indications of what may be expected at depths. These are treated in other chapters.

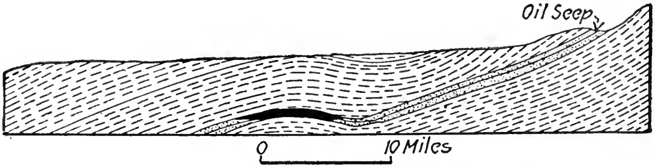

Fig. 3.—Sketch showing oil seeps at outcrop of petroliferous stratum and an accumulation of oil and gas (black) many miles away down the dip from the outcrop.

Distribution.—Oil springs or asphaltites are found in many oil fields and are generally regarded as favorable indications. The springs may exude at outcrops of the oil sands or limestones in which the oil is stored (Fig. 3), or they may exude from fault fissures, joints, or other conduits in beds that cover the oil-bearing stratum. Where oil exudes from the oil-bearing stratum the springs merely indicate that the stratum is petroliferous and that the deposits are being scattered. Petroleum deposits commonly are not situated below the points of issue, but in some regions they

CLASSIFICATION OF HYDROCARBONS AND ALLIED SUBSTANCES

(After Blake, Eldridge, and Others)

CLASSIFICATION OF NATURAL HYDROCARBONS

- Hydrocarbons
  - Gaseous
    - Marsh gas.
    - "Natural gas."
  - Bituminous
    - Fluid
      - Naphtha.
      - Petroleum.
    - Viscous (malthite)
      - Maltha.
      - Mineral tar
      - Brea.
      - Chapapote.
    - Elastic
      - Elaterite (mineral caoutchouc).
      - Wurtzilite.[a]
    - Solid
      - Asphaltite
        - Albertite
        - Impsonite.
        - Grahamite.
        - Nigrite.
        - Uintaite (gilsonite).
      - Coal
        - Lignite.
        - Bituminous coal.
        - Semibituminous coal.
        - Anthracite coal.
  - Resinous
    - Succinite (amber).
    - Copalite.
    - Ambrite, etc.
  - Cereous
    - Ozokerite.
    - Hatchettite, etc.
  - Crystalline
    - Fichtelite.
    - Hartite, etc.

[a] Wurtzilite might perhaps better be classed with the asphaltites.

are down the dip many miles away, at places where the structure is favorable for retaining oil. In southeastern Kansas, southwestern Missouri, and northeastern Oklahoma the Pennsylvanian oil sands that yield prolific supplies farther west in Oklahoma and Kansas are exposed at the surface. Here and there along their outcrops[1]

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[1] ADAMS, G. I., HAWORTH, ERASMUS, and CRANE, W. R.: Economic Geology of the Iola Quadrangle, Kansas. U. S. Geol. Survey *Bull.* 238, p. 16, 1904.

CLASSIFICATION OF NATURAL AND ARTIFICIAL BITUMINOUS COMPOUNDS
(After Eldridge)

Bituminous compounds	Natural	Mixed with limestone ("asphaltic limestone")	Seyssel, Val de Travers, Lobsan, Utah, and other localities
		Mixed with silica and sand ("asphaltic sand").	California, Kentucky, Utah, and other localities. "Bituminous silica."
		Mixed with earthy matter ("asphaltic earth").	Trinidad, Cuba, California, Utah.
		Bituminous schists	Canada, California, Kentucky, Virginia, and other localities.
		Fluid	Thick oils from the evaporation of petroleum.
	Artificial	Viscous	Gas tar. Pitch.
		Solid	Refined Trinidad asphaltic earth. Mastic of asphaltite. Gritted asphaltic mastic. Paving compounds.

and also in the zinc mines of the Joplin region,[1] deposits of bitumen and of partly dried out oil are found in considerable quantities at the base of the Pennsylvanian strata. At Tar Spring, six miles north of Miami, Oklahoma, a heavy bitumen oozes in considerable quantities at the base of the Pennsylvanian. At that horizon the bitumen is so abundant as to interfere with prospecting for metals with the churn drill. These deposits are surface suggestions of the Oklahoma-Kansas oil fields, which lie many miles to the west. Above the oil pools themselves, oil seeps are generally lacking in this region.

Not all petroleum springs, asphaltite deposits, and gas seeps occur at the outcrops of the oil sands or other oil-bearing formations. In some regions these evidences of oil are found at the crests or on the flanks of anticlines, where the oil has seeped through the cover of the reservoir. (See Fig. 4.) Where the hydrocarbons escape through fissures or joint planes, valuable deposits may occur not far away, or even directly below their places of issue. In many

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[1] SIEBENTHAL, C. E.: Origin of the Zinc and Lead Deposits of the Joplin Region, Missouri, Kansas, and Oklahoma. U. S Geol. Survey *Bull.* 606, p. 205, 1915

fields surface evidences of oil are very clearly exposed at or near the tops of structural features that have yielded oil. This is very common where rocks are unconsolidated and is a noteworthy feature of many fields where Tertiary beds are petroliferous. In California, on the Gulf coast, in Alsace, Galicia, Rumania, Baku, Russia, Burma (Yenangyaung and Yenangyat), Java, Sumatra, and elsewhere in Oceanica either asphalt, oil seeps, gas seeps, mud volcanoes, mud dikes, or salt springs appear near or directly above deposits of petroleum. In some of these districts it is clear that oil or gas has issued through fissures at or near the tops of the petroliferous folds.

In North America superficial indications of oil are found in many oil-bearing regions. Oil Spring, in Allegany County, New York, and Oil Creek, in western Pennsylvania, were known before the Appalachian oil field was exploited. At Smith's Ferry,[1] in the Beaver quadrangle, Pennsylvania, the oil floating on the Ohio River was gathered and sold as "Seneca oil" for medicinal purposes. In West Virginia a grahamite dike was worked before the Appalachian field was developed. Burning Springs, West Virginia, is at a gas seep on the Burning Springs-Volcano-Eureka anticline, which has yielded much petroleum. At Oil Springs, Lambton County,[2] Ontario, a liquid extracted from the "gum beds" yielded "gum oil," before the Oil Springs dome was exploited for petroleum. Oil seeps were found upon the Salt Creek dome, and on many other uplifts in Wyoming. An oil spring exists in the Boulder field, Colorado, although it was not this spring that led to drilling. An oil seep issues not far from the productive part of the Florence field, Colorado. Oil seeps or asphalt deposits are present

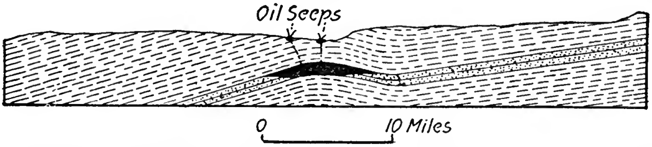

Fig. 4.—Sketch showing oil seeps at crest of fold above oil accumulation (black).

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[1] Woolsey, L. H.: Economic Geology of the Beaver Quadrangle, Pennsylvania. U. S. Geol. Survey *Bull.* 286, p. 76, 1906.

[2] Williams, M. Y.: Oil Fields of Southwestern Ontario. Canada Dept. Mines *Summary Rept.*, 1918, part E, p. 30, 1919.

in the San Juan field, Utah. In the California oil fields asphalt is almost invariably present in large amounts, and oil seeps and tar springs abound. Such evidences are present in the Coalinga, McKittrick, Sunset, Santa Clara, Santa Maria, Summerland, Puente Hills, Los Angeles, and some other fields.

In some fields where oil seeps are lacking gas seeps have led to drilling.

At Findlay, Ohio, gas issuing into cisterns led to the discovery of the field. The Caddo field, Louisiana, was drilled because of the gas bubbling up in Caddo Lake.

In the "salt dome" fields of the Gulf coast, surface indications of oil and gas abound. Because much salt and sulphur are associated with the oil these substances also, when appearing at the surface, are regarded as indications of petroleum. Small mounds rising above the general level of the flat country mark some of the oil districts and have led to drilling. Not all the mounds have proved productive, and not all the districts are on mounds, but practically all the producing pools are marked by the escape of gas. Gas bubbles in water or gas seeps were noted at Spindletop, Sour Lake, Saratoga, Batson, Dayton, and Humble, Texas, and in the Jennings field and at Anse La Butte and Welsh, Louisiana. Sulphur was noted in the soil at Spindletop, and "sour" water at Sour Lake and Saratoga, Texas. At Sour Lake oil and asphalt appeared also, and at Saratoga, oil.

In the Tuxpam-Tampico field, Vera Cruz, Mexico, the rocks dip eastward from the mountains to the coast at low angles. At many places dikes, sills, and stocks of basaltic rocks intrude the sedimentary beds. Most of the surface indications of oil are closely associated with the basalts, and hundreds of them occur throughout the plain. Among the localities where oil seeps are abundant are Panuco, Dos Bocas, Casiano, Tres Hermanos, Ojo de Brea, Chapapotillo, and Monte Grande.[1]

Manjak, a tar formed by the drying of oil, is exploited in Barbados, where it is found at the outcrops of Miocene sandstones and shales. Earth saturated with tar is found at Tarry Gully, near St. Andrew. At the "boiling spring" near St. Andrew inflammable gas issues from a pool of water. Wells sunk in the Miocene of Barbados yielded a little oil.

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[1] Garfias, V. R.: The Effect of Igneous Intrusions on the Accumulation of Oil in Northeastern Mexico. *Jour. Geology*, vol. 20, p. 666, 1912.

Trinidad Island has one of the largest deposits of asphaltum known. Pitch Lake, at La Brea, which lies southwest of San Fernando, is 137 acres in extent and has produced over 2,000,000 tons of asphalt. A heavy viscous asphaltic material rises slowly into the lake. In recent years an oil field of considerable size has been developed not far from La Brea.

In a spring at Pechelbronn, Alsace, was discovered in 1498 an oil which issued with the water and would burn in lamps. In 1735 the outcrop of an oil sand was detected about 500 feet from the spring, and oil was distilled from it in an iron retort. Subsequently this sand was mined from a shaft, and still later this field was developed with shafts and borings.

In Galicia oil was collected at the surface and in shallow wells in the earliest historical era. The Boryslaw-Tustanowice field, the most productive in the country, was noted for its oil springs long before deep exploitation was begun. At Schodnica oil from beds near the surface was produced before deep drilling was attempted. In and around Boryslaw ozokerite deposits were worked before the field was drilled for oil. Most of these deposits were exploited in shallow shafts, but later it was found that they extended to very great depths below the surface.

In Rumania there is a large body of oil-bearing strata, and at many places where they crop out there are clear evidences of petroleum. In the Prahova and Bercu districts numerous pits were dug for catching oil. The mud volcanoes of the Berca and Beciu region are famous. There for about seven miles mud volcanoes, oil seeps and salt springs are closely spaced. In this region at many places oil is obtained from hand-dug shafts.

In the foothills of the Caucasus Mountains in Russia gas and oil seeps are numerous. The Balakhany-Sabunchy-Romany field is an elongated dome where along the main uplift there are mud volcanoes, many of which spout mud, petroleum, gas, and water. Of these the Bog-boga is over 100 feet above the plateau. A short distance from this field is the Surakhany field, where gas was obtained from seeps by the fire worshipers, for use in their temples for 2,500 years. Off the coast of Bibi-Eibat, in Baku Bay, on the Caspian Sea, so much gas rises in the water as to agitate it vigorously, and when lighted on a calm day the gas will burn.[1]

The Grozny field, in the northern foothills of the Caucasus, is

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[1] Thompson, A. B.: Oil-field Development, p. 179. London, 1916.

on an anticline 6½ miles long. The surface indications include oil seeps, and oil was recovered from hand-dug wells before the field was drilled.

The Maikop field, Kuban, Russia, is 300 miles west of Grozny. Here Cretaceous beds are formed in gentle folds and are unconformably overlain by Tertiary beds that dip at low angles. The Tertiary rocks consist of sand and shale, and where they crop out the sands are so highly impregnated with oil that it oozes out when the sand is squeezed in the hand.[1]

Holy Island, in the Caspian Sea off the Apsheron Peninsula, is a faulted dome. According to May,[2] there are ten or twelve mud volcanoes and seeps in the faulted region. Beds of asphalt and small lakes of oil are forming today. Cheleken Island, in the Caspian Sea, is another faulted dome, in which hot salt springs issue and deposits of ozokerite are found in faults. South of the Caucasus, in the Tiflis region, evidences of oil are numerous and have led to the development of a comparatively small oil field. In the Ferghana district, Turkestan, oil seeps abound.

In Egypt, on the coast of the Red Sea near the mouth of the Gulf of Suez, is the mountain known as Gebel Ziet (oil mountain), called by the Romans, Mons Petrolius. Here limestone, gypsum, and clays are impregnated with oil and gas. This material was formerly used for patching boats and wrapping mummies by the Egyptians. Recently a considerable oil field has been developed in this region.

In Mesopotamia, in the region of the lower Euphrates and Tigris, oil seeps are numerous and have furnished material for calking boats and similar purposes since a time long before the Christian era. No considerable oil field has been developed nearer than the Persian field, to the east.

In the Yenangyaung (earth-oil creek) field, Burma, India, on the Irrawady River, oil seeps in Tertiary rocks are numerous, and the Burmese recovered considerable quantities of oil by sinking shallow shafts. Mud dikes are found in the Pegu and Irrawady formations and are supposed to fill the conduits through which mud volcanoes were fed at a time before the mud volcanoes were eroded. Yenangyat (earth-oil place), Burma, is on an elongated dome.

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[1] TRENCH, R. H.: Discussion of paper by A. B. THOMPSON in *Min. and Met. Inst. Trans.*, vol. 20, p. 247, 1911.

[2] *Idem*, p. 248.

Petroleum springs were long ago recognized there, and many of them are approximately at the crest of the fold.

Oil occurs in many islands of the Oceanica group. In Java oil seeps are numerous along the crests of folds which trend parallel to the length of the island. These have led to the development of prolific oil fields. Similar conditions are found in Sumatra and Borneo.

In the Philippine Islands oil and gas seeps are found in seven or eight regions, though no commercial supplies have yet been exploited. At Villaba, at the northwest end of Leyte, considerable quantities of asphaltum occur, probably along a fault which cuts through limestone and sandstone.

In Japan there are many seeps in the oil fields, and shallow wells were formerly dug to collect oil.

In Colombia oil seeps are numerous in many districts. Mud volcanoes are abundant in the Turbaco field of the Caribbean district and in the Tubara field, 20 miles east of Cartagena. One hundred mud volcanoes are said to occur in an area of 3 acres near developed oil wells. Oil is associated with the coal series on the Baudo River and may be seen floating in the Andagueda River, a tributary of the Atrato. In the Magdalena-Santander district there is a large and promising area where oil seeps are common.

In northern Argentina and Bolivia, east of the Andes, oil springs are abundant over a large area. It is believed by some that a large oil field will be developed in this region.

In some fields oil and gas seeps are lacking. The principal oil fields of Illinois show no surface indications, although in one unimportant field a little oil seeped through a deep boring into a coal mine. The Rivadavia field, the principal oil-producing region in Argentina, was discovered by accident in sinking a well for water. The Roma gas field, Queensland, Australia, which is not commercially productive, was discovered by drilling for water.

Oil Seeps.—Oil seeps are evidences that oil exists in the region in which they are found, though in many regions that contain oil seeps considerable drilling has not disclosed commercial supplies—for example, the fields on the northwest coast of Newfoundland, on Gaspe Peninsula, Quebec, and near Albert, New Brunswick. Most of the large oil-producing regions of the world, however, contain oil seeps at one place or another, although numerous individual pools in these regions do not lie below the seeps. Many oil seeps are associated with springs of water. In some there is merely a slight iridescent film or "rainbow" of oil above the water. Such a film resembles somewhat the film of iron oxide that covers some pools of water, and iron oxide films have been mistaken for oil films. The iron oxide film differs from the oil film, however, in that it is brittle and will break if the water is agitated, whereas the oil film will not. In many oil springs the oil on the water forms a considerable layer. At some places it is collected by laying a blanket on the pool. The blanket absorbs the oil and is wrung out and the oil recovered. In other springs the oil is skimmed off.

Oil Spring, in Allegany County, New York, was exploited long before the Appalachian oil field was developed. It was described by Benjamin Silliman[1] in 1833 as follows:

The oil spring or fountain rises in the midst of a marshy mound; it is a muddy and dirty pool, about eighteen feet in diameter, and it is nearly circular. There is no outlet above ground—no stream flowing from it, and it is of course stagnant water, with no other circulation than that which springs from changes of temperature and from the gas and petroleum which are constantly rising through the pool. The water is covered with a thin layer of the petroleum or mineral oil, giving it a foul appearance, as if coated with dirty molasses, having a yellowish-brown color. They collect the petroleum by skimming it like cream from a milk pan. It has then a very foul appearance, like very dirty tar or molasses. Silliman states that cattle like to drink the water of the spring.

When the amount of oil from a well or pool is very small, it is sometimes difficult to ascertain whether or not a steady flow of oil exists. Pools of water contaminated with oil that has been used to lubricate machinery or for other purposes have been mistaken for oil springs. The petroleum of springs is generally heavy, because it has suffered evaporation or oxidation or both, and that of some springs resembles lubricating oil in appearance, but often tests or analyses will show whether the oil of a spring is in the natural state or whether it is a product of refining.

A few oil springs yield commercial supplies of oil. One at Urado, in the Uinta Basin near the Colorado-Utah line, has been opened by a short tunnel and supplies several barrels of high-grade lubricating oil daily from flat-lying sands. Many oil springs in

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[1] SILLIMAN, BENJAMIN: Notice of a Fountain of Petroleum, Called the Oil Spring. *Am. Jour. Sci.*, vol. 23, pp. 97-99, 1833 (*Silliman's Journal*).

Galicia, Rumania, Russia, Burma, Oceanica, and Japan have been exploited by digging trenches, shallow pits, and wells into which the oil can flow. At some places enormous quantities of oil flow out at the surface. At Pitch Lake, Trinidad, enough has issued to make on drying over 3,000,000 tons of asphalt. At Aliat railway station in the trans-Caucasus region, Russia, east of the Caspian Sea, in 1908 and 1909 so much oil issued from fissures that it formed large lakes inundating the railway tracks.[1]

Oil Ponds.—At some places oil has been noted above the surface of the sea, where it has issued from oil springs on the sea bottom. According to Thompson,[2] oil has been observed in the Pacific off the coast near the oil fields of northern Peru. Fenneman[3] mentions oil ponds in the Gulf of Mexico off the coast of Texas, where ships find quiet water during storms. Off Galeata Point, at the southeast corner of Trinidad, submarine eruptions accompanied by discharges of petroleum and pitch are recorded.[4] Holland[5] describes an island off the northwest coast of Borneo that was made by an oil eruption. This island was 210 by 120 feet and was forty feet high. Thompson[6] states that at many localities in the Caribbean Sea off the coast of Mexico vast quantities of oil are periodically ejected, covering the sea for miles.

Solid Bitumens.—Asphaltite is a general term applied to solid asphaltic hydrocarbons. Between oil and asphalt there are all stages, grading from the liquid to the solid state. Many of the solid hydrocarbons have been described and named as distinct species. These include gilsonite, uintaite, elaterite, wurtzilite, albertite, grahamite, and many others.[7] They vary greatly in

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[1] Thompson, A. B.: Oil-field Development. P. 175, 1916.

[2] *Op. cit.*, p. 180.

[3] Fenneman, N. M.: Oil Fields of the Texas-Louisiana Gulf Coastal Plain. U. S. Geol. Survey *Bull* 282, p. 74, 1906.

[4] Thompson, A. B., *op. cit.*, p. 180.

[5] Holland, T. H.: Discussion of paper by A. B. Thompson in *Inst. Min. and Met. Trans.*, vol. 20, p. 233, 1911.

[6] *Op. cit.*, p. 179.

[7] Eldridge, G. H.: The Asphalt and Bituminous Rock Deposits of the United States. U. S. Geol. Survey, *Twenty-second Ann. Rept.*, part 1, p. 220, 1901.

Clarke, F. W.: The Data of Geochemistry, 3d ed. U. S. Geol. Survey *Bull.* 616, p. 719, 1916.

Blake, W. P.: Uintaite, Albertite, Grahamite, and Asphaltum Described and Compared, with Observations on Bitumen and Its Compounds. *Am. Inst. Min. Eng. Trans.*, vol. 18, p. 563, 1890.

composition; most of them are mixtures of hydrocarbons. Ozokerite is largely paraffin and is an important source of that material.

As a rule the asphaltites that are found at the surface contain considerable material other than the hydrocarbons. The asphalt of Pitch Lake, Trinidad, is about one-third sand and clay, one-third water, and one-third bituminous matter. Many asphaltic sands and bituminous limestones carry from 5 to 20 per cent only of bituminous matter (p. 27). Other bitumens are nearly pure, among them the gilsonite dikes of Uinta Basin, Utah, the grahamite dike of Ritchie County, West Virginia, and the ozokerite deposits of Galicia. Bitumens that have been deposited as dikes, especially those deposited as dikes in consolidated rocks, are commonly pure. These are sought for fuels, for making varnishes, and for many other purposes.

Asphalts, as already stated, are formed by the inspissation or drying out of petroleum. They may be regarded as the residual products of natural distillation in which the more volatile fluids are generally scattered. The process is commonly attended by the oxidation of certain constituents, and the oil becomes less readily inflammable.

The drying out of petroleum is undoubtedly by far the most common method of formation of bitumens. Some, however, are found in coal and are believed to be derived from vegetable resins. Others are associated with metallic ores, and it has been suggested by some writers that these have originated at deep sources in connection with volcanic processes. Bitumens are associated with many quicksilver veins of California[1] and elsewhere, and with the vanadium veins of Minasragra, Peru.[2] As a rule the deposits of bitumen in coal and in metalliferous veins are relatively small. Some of the deposits derived from the drying out of petroleum are very large. The great Pitch Lake of Trinidad has been mentioned. At many other places in Trinidad there are enormous deposits of asphalt mingled with the soil. On the mainland in Venezuela the Bermudez deposit of asphalt is of the same order of magnitude. The gilsonite dikes of Utah are extensive. Eldridge estimated the amount in three of them to be 30,674,613 tons. At many places

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[1] Becker, G. F.: Geology of the Quicksilver Deposits of the Pacific Slope. U. S. Geol. Survey *Mon.* 13, pp. 286, 360, 372, 1888.

[2] Hewett, D. F.: Vanadium Deposits in Peru. Am. Inst. Min. Eng. *Trans.*, vol. 40, pp. 279-280, 1910.

in California asphalts cover large areas. In Oklahoma, in Texas, and in Kentucky large deposits of solid bitumens have been exploited. In some other regions deposits of asphalt are small. Where they are formed by leakages from outcropping petroliferous strata they are commonly closely spaced.

Bone Deposits in Asphalt.—In the petroleum-bearing area near Los Angeles, California, enormous deposits of impure asphalt are found at the outcrop of an oil sand and in the wash above the sand. From a pit dug in the asphalt numerous skeletons of animals that lived in comparatively recent times are found. These remains include the skeletons of saber-tooth tigers, deer, and other animals. The deposit is a conglomerate of bones held together by solid or semi-solid bitumen. A little oil exudes in the bottom of the pit. The bones lie closely spaced. Evidently the animals went to a spring to drink water, perhaps somewhat salty, and became immersed in the sticky matter. Hundreds of skeletons have been taken from a small pit.[1] Thompson notes pitch springs in Peru with abundant bones, and he notes the presence of similar deposits in Sviatoi (Holy Island), in the Caspian Sea.

Bituminous Rocks.—Sandstones and limestones at many places are filled with dried or partly dried petroleum. There are all gradations between impure asphalts and bituminous sandstones. The bituminous material in some beds is formed from petroleum that has risen in springs. An example is that of the "gum beds" of Oil Spring, Ontario.[2] In others the bituminous material is that which has remained in the beds after they have been drained of oil. Washburne[3] estimates that 60 per cent of the oil stored in sandstone strata is ordinarily removed from them by wells. Adsorption of oil by sand grains is high, and some of the oil remains even after repeated washings with water. If a saturated sand with 20 per cent porosity is drained and it retains 40 per cent of its oil, the oil would equal 8 per cent of the volume occupied by the sands.

Probably the largest body of bituminous material in the world is the deposit of "tar sands" on the Athabasca River in northern

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[1] Eldridge, G. H., and Arnold, Ralph: The Santa Clara Valley, Puente Hills, and Los Angeles Oil Districts, Southern California. U. S Geol. Survey *Bull.* 309, p. 140, 1907.

[2] Williams, M. Y.: Oil Fields of Southwestern Ontario. Canada Dept. Mines *Summary Rept.*, 1918, part E, p. 34, 1919.

[3] Washburne, C. W.: The Estimation of Oil Reserves. Am. Inst. Min. Eng. *Trans.*, vol. 51, p. 646, 1916.

Alberta, which covers an area variously estimated at 2,000 to 10,000 square miles. The sands are about 200 feet thick and are estimated to contain 14 gallons of oil to the ton.[1] They are of Cretaceous age (Dakota or approximately Dakota) and rest on Devonian limestone. In cracks and joint planes of the Devonian rock pitch has hardened, and Bell[2] states that the petroleum in the sands has passed upward through the Devonian limestone at a remote period.

Many petroliferous strata contain at their outcrops a little residual bituminous matter that is not evident on inspection of the outcrop, although the rock if broken under water may yield an iridescent film of oil.

TEST FOR OIL IN ROCKS

(After Woodruff)

1. Select a representative specimen of rock to be tested. It is generally advisable to obtain several samples as large as one to five pounds each.
2. Break them up, and thoroughly mix the pieces. If the samples consist of sand, mix the sand.
3. Dry the sample on a plate in the sun or over a radiator. Do not dry it over a fire; to do so may drive the oil from the rock or sand.
4. Crush the sample to a powder. Mix the powder. Loose sand does not need to be crushed.
5. Place about a tablespoonful of the sample in a bottle. Pour chloroform or carbon tetrachloride over the sample until it is thoroughly saturated and there is about half a tablespoonful of the liquid above the crushed rock or sand. Cork the bottle, but not too tightly. Shake occasionally for 15 or 20 minutes.
6. Place a white filter paper in a glass funnel over a white dish.
7. Pour the contents of the bottle into the funnel. After the liquid has passed through, place the white dish in a window where the liquid can evaporate.
8. Examine the filter paper. If the rock contains more than a trace of oil, there will be a brown or black ring on the filter paper.
9. After the liquid in the dish has evaporated, examine the remaining substance. It is the petroleum which was in the rock.

Apparatus for Testing

One dinner plate on which to dry specimens.
Some means for crushing rock.
One or more bottles, 4 or 6 ounce size, with corks, in which to treat the rock.

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[1] Bell, E. C.: Geology and History of the Canadian Field. *Oil and Gas Jour. Suppl.*, May, 1919, p. 259.

[2] Bell, Robert: The Tar Sands of the Athabasca River, Canada. Am. Inst. Min. Eng. *Trans.*, vol. 38, p. 838, 1907.

Chloroform or carbon tetrachloride.
One glass funnel 3 or 4 inches in diameter.
Two dozen round filter papers, 6 inches in diameter.
Two or more white dishes.

Bituminous Dikes.—Bituminous dikes are formed where petroleum enters fissures and becomes hardened before it reaches the surface. The process of hardening is brought about by the loss of more volatile constituents and probably in some places by oxidation. Such dikes, during their formation, probably feed gas and oil springs at the surface.

One of the best known bituminous dikes is the albertite dike in New Brunswick. In this region Paleozoic limestone, shale, and sandstone are folded and at some places on edge. The Albert formation, which consists in places of bituminous shales and sands, is probably of Devonian age, although it has been placed by some in the lower Carboniferous. It yields as much as 50 gallons of shale oil to the ton and has been distilled on a commercial scale. Surficial indications of oil are widely distributed in this region. The Albert shale under cover of overlying rocks has been penetrated by the drill and yielded considerable quantities of gas and some oil. The only large albertite dike is that at the Albert

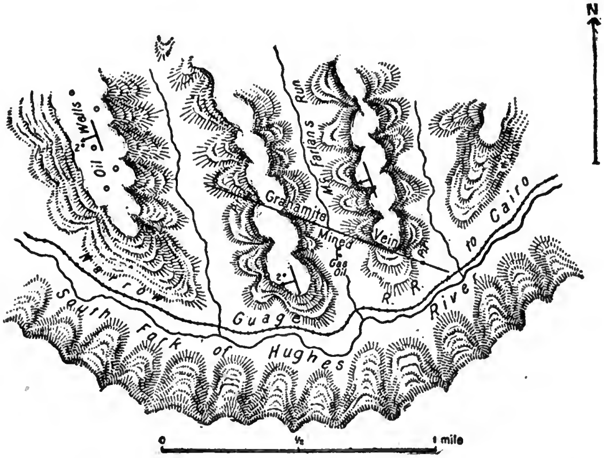

Fig. 5.—Sketch showing grahamite vein in Ritchie County, West Virginia. (*After Eldridge.*)

mine.[1] This dike was worked to depths of 1,100 feet or more and for half a mile along the strike. At places it is 15 feet wide and sends out apophyses into the country rock. It is nearly straight, stands approximately vertical, and follows the general direction of an anticlinal axis. It has yielded over 200,000 tons of albertite.

In Ritchie County, West Virginia, there is a dike of grahamite,[2] much like the albertite dike of Nova Scotia. This dike (Fig. 5) is nearly a mile long and about 5 feet wide for the most part, thinning out to a few inches at the ends. It stands nearly vertical. The fissure that is filled with grahamite, according to Fontaine, is a zone of fracturing, probably one of slight displacement. As noted by White[3] the fissure strikes almost at right angles to the great Burning Springs-Volcano-Eureka anticline, which produces oil west of the deposit. The fissure is supposed to have been made by tension during the formation of the anticline and was filled with petroleum largely from the Cairo sand, which lies at a depth of 1,530 feet[4] and is the main producing rock of this region. The Big Injun sand below, at a depth of 1,652 feet, also may have contributed petroleum. The oil filling the fissure, according to White, was gradually converted by oxidation and other processes into grahamite.

Grahamite dikes are found also in south-central Oklahoma.

In the Uinta Basin, Utah, lower Tertiary beds consisting of shales, sandstones, and limestones of the Wasatch and Green River formations dip northward at low angles toward the Uinta Mountains.[5] The section includes several hundred feet of the Green River oil shales, which on heating will yield large amounts of shale

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[1] Ells, R. W.: The Bituminous or Oil Shales of New Brunswick and Nova Scotia. Part 2, p. 9, Canada Geol. Survey, 1909.

Young, G A.: Twelfth Internat. Geol. Congress Guide Book No. 1, part 2, pp. 366-367, 1913.

Clapp, F. G., and others: Petroleum and Natural Gas Resources of Canada Part 2, p. 50, Canada Dept Mines, Mines, Branch, 1915.

[2] Fontaine, W. M.: Notes on the West Virginia Asphaltum Deposit. *Am. Jour. Sci.*, 3d ser., vol. 6, p. 409, 1873.

[3] White, I. C.: Origin of Grahamite. Geol. Soc. America *Bull.*, vol. 10, p. 278, 1899.

[4] Eldridge, G. H.: The Asphalts and Bituminous Rock Deposits of the United States U. S. Geol. Survey, *Twenty-second Ann. Rept.*, part 1, p. 235, 1901.

[5] Winchester, D. E.: Oil Shales of the Uinta Basin. U. S. Geol. Survey *Bull.* 691, p. 27, 1919.

oil. In this region dike hydrocarbons are developed in great variety. Asphaltic dikes consisting of gilsonite (Fig. 6), elaterite, tabbyite, albertite, wurtzilite, and nigrite are developed and also dikes of paraffin, ozokerite. The asphaltic dikes are found both above and below the oil-shale formation, and the ozokerite dikes below it. The gilsonite dikes are very large and extend for many miles along the strike. Eldridge[1] suggested that the hydrocarbons that filled the dikes were derived from Cretaceous shales and that they came from below under pressure. Winchester[2], however, regards as plausible the hypothesis that the Green River oil shale supplied the material for all the bituminous dikes of the Uinta Basin, as well as the asphaltic material that saturates certain sandstones in the region.

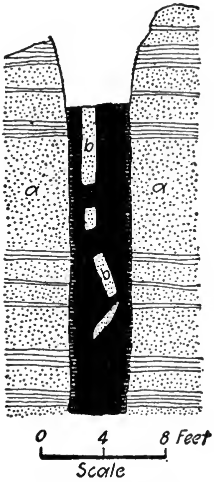

FIG. 6.—Sketch of gilsonite dike, Duchesne Mine, Uinta Basin, Utah. (*After Eldridge.*) The gilsonite is black, *a*, sandstone walls of dike; *b*, fragments of sandstone in dike.

Deposits of solid bitumen in the form of dikes are commonly associated with gas. In the ozokerite mines of Galicia strong currents of air are blown into the galleries to remove the gas and prevent injury to the miners. In the Old Black Dragon gilsonite mine, near Black Dragon station, Utah, no explosives are used, and possession of matches in the mines is prohibited under threat of dismissal. Electric lights only are permitted. A disastrous explosion which caused the death of several men is supposed to have resulted from the striking of a match by a miner in defiance of orders. The fire which ensued melted some of the gilsonite and caused it to run down into the old stopes, so that after the mine was reopened gilsonite was being mined in the same places from which gilsonite had been removed before the explosion.

Ozokerite, or mineral wax, is a native bitumen with a paraffin base. It is essentially paraffin. It is found in Galicia, in England, on Cheleken Island in the Caspian Sea, in the Salt Creek region of Wyoming, and in the Uinta Basin in Utah. It is sup-

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[1] *Op. cit.*, p. 351.
[2] *Op. cit.*, p. 49.

posed to be formed by the drying out of paraffin oil. Considering its origin, its occurrence at depths of nearly 2,000 feet at Boryslaw, Galicia, is noteworthy.[1] (Fig. 7.)

In the Salt Creek region, Wyoming, according to Wegemann,[2] ozokerite is associated with calcite, which fills all fault fissures at the surface. It is produced by the evaporation of oil that has risen in these fissures and long remained in them. The deposits of ozokerite appear to be confined to the dome above the oil pool and are not found in the adjoining synclines, in which shale oil is encountered. This relation is suggested also by the section in Fig. 7.

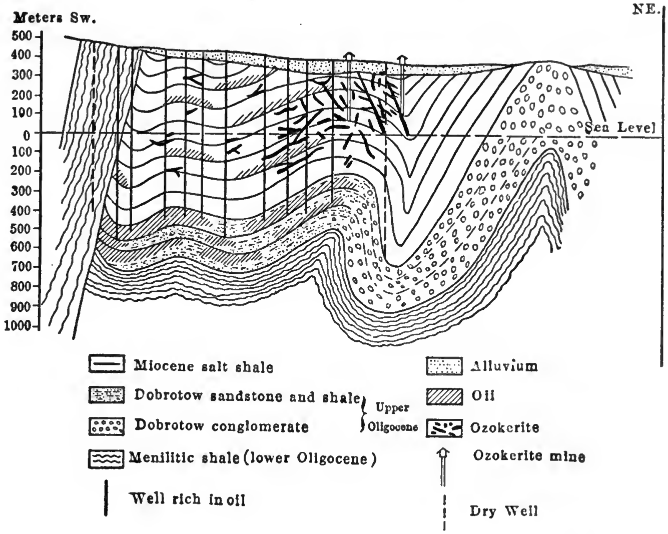

FIG. 7.—Profile through Boryslaw oil field, Galicia, showing ozokerite veins above an anticline. Horizontal and vertical scales are the same. (*After Zuber.*)

Many natural oils carry paraffin in solution. When these issue in wells, owing to relief of pressure and consequent decrease in temperature, some of them deposit paraffin in the bores. Probably some ozokerite dikes are similarly formed where oil escapes through fissures.

[1] ZUBER, RUDOLPH: Die Geologische Verhältnisse von Boryslaw in Ostgalizien. *Zeitschr. prakt. Geologie*, 1904, pp. 41-48.

[2] WEGEMANN, C. H.: The Salt Creek Oil Field, Wyoming. U S. Geol. Survey *Bull.* 670, p. 36, 1911.

Gas Seeps.—Gas accompanies the oil that issues at many oil springs. There are also many gas seeps where no oil issues. Because the gas is colorless and some of it odorless, gas seeps are not so easily recognized as oil seeps. Many of them have been recognized where the gas issues as bubbles in pools of water or by explosions of the gas resulting from accidental ignition. Where the gas is under pressure and the seep is in a sand or soft sandy earth, the movements of the sandy or clay particles may lead to the discovery of gas. The issue of gas under pressure may build up small "pimples," mounds, or mud volcanoes on the surface, which are easily recognized. Where heavy, lethal gases issue in depressions, animals exposed to them are killed, and the remains mark the places of accumulation.

The gases that issue at the surface of the earth include chlorine, nitrogen, carbon dioxide, carbon monoxide sulphurous compounds, methane, and other hydrocarbons. Chlorine, nitrogen, and carbon dioxide have little significance as surficial indications of petroleum. They are not inflammable, and they issue in regions where volcanic processes are active or have recently been active, and elsewhere. Carbon monoxide is not ordinarily abundant in gas seeps, although a little may be present associated with other gases. Carbon monoxide and methane are the "fire damp" of coal mines.

Carbon dioxide, carbon monoxide, and gases other than the hydrocarbon gases are found under many geologic conditions. They are comparatively rare in considerable amounts in association with petroleum, although one or more are present in some petroleum gases, mixed as a rule with much larger quantities of methane. The hydrocarbon gases are commonly associated with oil and are more significant as indications of oil than carbon dioxide and carbon monoxide. Helium is found in some natural gases (p. 82).

The most common constituent of natural gases is methane. Methane gas, however, is not all associated with petroleum deposits. It is "marsh gas," which forms in peat bogs or anywhere that vegetation is decaying. The "will-o'-the-wisp" of the marshes and swamps is burning methane. It occurs in swamp deposits that are buried below glacial lacustrine clays in Minnesota and bordering States. In many fields, however, as stated above, methane is associated with petroleum. Commonly the methane contains also small amounts of other gases. In some fields ethane, propane, and butane are associated with methane. These and heavier hydrocarbon gases are generally regarded as evidence that the gas is petroleum gas—that is, that it is associated with oil—and if the structure of the beds is favorable their presence warrants drilling for oil at a structurally lower point, below the gas reservoir. Some analyses of gases are given below.

Analyses of Gas of Texas and Louisiana Fields
(By Bureau of Mines. From U. S. Geol. Survey *Bull.* 661, p. 239, 1918.)

	1	2	3	4	5	6	7
Carbon dioxide (CO_2)	1.7	Trace	0.0	1.0	7.30	0.2	0.2
Oxygen (O_2)	1.1	0.0	0.0	0.0	0.0	0.1	0.1
Methane (CH_4)	91.9	98.5	96.5	98.5	54.5	52.7	92.4
Nitrogen (N_2)	5.3	1.5	3.5	0.5	38.2	37.8	3.9
Ethane (C_2H_6)	....	....	....	....	....	9.3	3.4
	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Specific gravity determined	0.60	0.56	0.57	0.58	0.79	0.78	0.60
Specific gravity calculated	....	....	0.57	0.57	....	....	0.59
Heating value, in British thermal units, at deg. C.	979	1,052	1,027	1,030	580	755	....

1. Well No. 1 on Mackey lease, near Corsicana, Texas.
2. Well on Anglin lease of Robinson Oil & Gas Co., Mexia-Groesbeck field, Texas. U. S. Geol. Survey *Bull*, 629, p. 102, 1916.
3. Well on L. B. Phillips lease of Southwestern Gas & Electric Co., 10 miles west of Shreveport, Louisiana. Depth 1,000 feet.
4. Edwards well No. 1 of Southern Oil & Gas Co., sec. 23, T. 21 N,. R. 11 W., Caddo field. near Vivian, Louisiana. Depth 1,040 feet.
5. Swamp gas.
6. Beatty well No. 1, Petrolia field, Texas. U. S. Geol. Survey *Bull*, 629, p. 41, 1916.
7. P. H. Youree well No. 3 of Gulf Refining Co. of Louisiana, sec. 33, T. 17 N., R. 14 W., south of Shreveport, Louisiana.

The presence of ethane, propane, and butane in gas is generally regarded as a favorable indication of petroleum, because these substances are found in a great many gases that are associated with oil. Nevertheless, their presence is not an infallible indication. One or more of the hydrocarbon gases heavier than methane were found in a sample of natural gas collected in 1917 in a glacial-lake deposit that is covered with lacustrine clay in southern Minnesota. On the other hand, a gas from the Edwards well (see table above), in the Caddo field, Louisiana,[1] showed on analysis no hydrocarbon except methane, although the sand that yielded the gas contains oil in the same part of the field where the gas sample was taken.

Natural gas carries gasoline vapors much as air carries water vapor. Gas under great pressure is less likely to carry the gasoline vapors than gas under less pressure. When a boring penetrates a reservoir containing oil and gas under great pressure, the gas immediately expands and moves toward the hole, carrying the oil with it. As there is less resistance to the movement of the gas it moves faster and is exhausted first. When the pressure is high the dry gases absorbed in the oil are liberated, but as pressure decreases[2] the wet gases liquified and dissolved in the oil are also released. A dry gas issuing under great pressure is more likely to be associated with oil than a dry gas issuing under low pressure.

Gas, like oil, issues both on land and sea. The seep on the Caspian Sea off Bibi-Eibat has been mentioned. Near Holy Island, also in the Caspian Sea, and off the coast of Peru, as observed by Thompson,[3] gas exuded beneath the sea.

Sulphurous gases and sulphur are associated with many petroleums and in smaller proportions with some natural inflammable gases. The sulphur gases include sulphur dioxide and hydrogen sulphide, both of which are easily detected by their odor. The gases accompanying the oil at Spindletop field, near Beaumont, Texas, were poisonous, possibly owing to the presence of sulphur compounds. These gases deposited sulphur on the Spindletop dome, and it was the occurrence of such deposits that led to the drilling of this field in a search for commercial deposits of sulphur.[4]

Sulphur gases are found at the surface of many of the salt-dome deposits of Texas and Louisiana (p. 365). Because sulphur, hydrogen sulphide, and sulphur dioxide are widely dispersed in nature and occur in places far removed from petroleum deposits, they are generally of uncertain value as indications of oil, although in some small areas their presence is regarded as significant.

[1] MATSON, G. C., and HOPKINS, O. B.: The Corsicana Oil and Gas Field, Texas. U. S. Geol. Survey *Bull.* 661, p. 239, 1918

[2] LEWIS, J. O.: Methods for Increasing the Recovery from Oil Sands. U. S. Bur. Mines *Bull.*, 148, p. 20, 1917.

[3] THOMPSON, A. B.: Oil-field Development. p. 180, London, 1916.

[4] LUCAS, A. F.: Principles and Problems of Oil Prospecting in the Gulf Coast Country (discussion). Am. Inst. Min. Eng. *Trans.*, vol. 59, p. 470, 1917.

Paraffin Dirt.—The so-called paraffin dirt of the Gulf coast oil fields[1] has been considered an indication of the presence of oil and gas, and wells have been brought in on the basis of such evidence. Its association with oil and gas was first pointed out by Lee Hager.

The term "paraffin dirt" has been applied to peaty, clay soils with a peculiar texture, which has been described as "curdy" or "rubbery." When moist, the material breaks much after the fashion of "green" cheese. It is rubbery under compression but does not resemble rubber in tenacity or cohesion. In the field it resembles "art gum." When dry, the material ranges from hard clods to a horny mass.

The moist material ranges in color from dark brown in the specimens rich in organic matter to grayish in specimens containing more inorganic matter. It is readily attacked by molds. It has a characteristic "swampy" or "mucky" odor when wet.

Brokaw analyzed a sample taken 1 mile north of Spanish Lake, St. Martin Parish, Louisiana, near a test well; another near the discovery well in the New Iberia oil field, Iberia Parish; one from Lake Dauterive, St. Martin Parish; and another near the discovery well in St. Martin Parish. He showed that the place of paraffin dirt among the evidences of oil and gas rests on the possibility that it may indicate gas-saturated soils in which gas inhibits oxidation. and obviously such soils are present in the vicinity of gas seeps. It does not necessarily follow that every gas seep is accompanied by paraffin dirt, nor is paraffin dirt an infallible sign of a gas seep. Most "paraffin dirt" probably contains no paraffin.

Mud Volcanoes.—Gas issuing at the surface may carry with it particles of sand and clay which are deposited at the place of issue. Continuation of the process will build up a "pimple," mound, or cone. The process goes on generally in unconsolidated rocks, especially in the presence of water. If the wet clay or mud seals over the place of issue gas accumulates under pressure, and when the pressure is sufficient it blows off the seal with violence, imitating on a small scale the eruption of a volcano. In arid countries these mounds are built to considerable heights. The Bog-Boga mud volcano, in the principal oil district of the Baku region, Russia, is more than 100 feet above the plateau on which it stands and forms one of the high features of the landscape. (See p. 540.)

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[1] Brokaw, A. D.: An Interpretation of the So-called Paraffin Dirt of the Gulf Coast Oil Fields. Am. Inst. Min. Eng. *Bull.* 136, pp. 947-950, 1918.

In many Tertiary oil fields where the rocks are unconsolidated mud volcanoes are numerous. On the Taman and Kertch peninsulas, north of the Black Sea, there are many mud volcanoes, and great streams of mud flow down their sides. Several mud volcanoes are present on the shore of the Caspian Sea southwest of Baku, near the Bibi-Eibat oil field. They are reported also on Cheleken Island, and at Napthun, east of the Caspian Sea. They occur in Rumania (p. 532) and are numerous on the Arakan Islands, off the west coast of Burma, and on Cape Negrais, in southwestern Burma.[1] They are found also in Borneo, Sumatra, Trinidad and Colombia. At many places in Rumania, Russia, Borneo, and Sumatra, they are on anticlines in Tertiary rocks that have yielded oil.

Mud volcanoes, like seeps of oil and gas, have been known to rise from the sea bottom. In 1897 during an earthquake a great mud volcano rose off the Klias peninsula, Borneo. The material ejected formed an island 750 feet long and 420 feet wide. Stigand states[2] that this island was 50 to 60 feet high and eventually became joined to the mainland. Thompson records a volcano near the Arakan Islands, off the coast of Burma, which in 1907 threw out enough muddy material to make an island 1,200 feet long, 600 feet wide, and 20 feet high. The material had a temperature of 148° F.[3] Off Erin, on the south coast of Trinidad, in 1911 masses of hot mud with much gas were thrown out from the sea and formed an island of 2½ acres, 14 feet high. This eruption, according to Thompson, occurred above a submarine anticline.

There are no typical mud volcanoes in the United States. Possibly some of the mounds of the Gulf coast region of Texas and Louisiana have been formed by processes nearly related to those which operate to form mud volcanoes. Features like small mud volcanoes appear at the surface in the Vale region of Oregon and Idaho. In the Caddo district of Louisiana small pimply elevations have been noted, but these, according to Matson, are probably the work of ants.

Somewhat similar in origin to mud volcanoes are the sand heaps that accumulate at the casing heads of some gushers drilled in

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[1] Berghaus, H.: Atlas der Geologie, Gotha, 1892.

[2] Stigand, J A.: Discussion of paper by A. B Thompson in Inst. Min. and Met. *Trans.*, vol. 20, p. 262, London, 1911.

[3] Thompson, A. B.: Oil-field Development. P. 184, 1916

loose sand. At some of the wells in California the engine houses and the lower parts of derricks have been thus completely buried. In some wells in the Sunset field, California, two-thirds of the total yield is sand. One well produced nearly 110,000 cubic feet of sand in two years. Some pumping wells in the North Midway field, California, produce sand at the rate of over 200,000 cubic feet a year.[1]

Describing the sand masses produced by wells in Russia, Thompson[2] says that the oil from fountains is commonly accompanied by an equal bulk of sand, large numbers of stones, and millions of cubic feet of gas which becomes disengaged from the oil on its exit from the tube. A Bibi-Eibat well spouted 10,000 tons of oil and 10,000 tons of sand in a day and in a few weeks yielded 1,700,000 cubic feet (85,000 tons) of sand, which is enough to cover an acre to a depth of nearly 40 feet.

Mud Dikes.—Mud dikes that cut across the strata are found in some oil fields. They are supposed to have filled the vents through which gas issued to form gas seeps or mud volcanoes. Such dikes are found in Burma in the Yenangyat[3] and Yenangyaung fields. What are undoubtedly mud dikes occur in the Huron shales of the gas field around Cleveland, Ohio. Dikes are formed also by clay squeezed into fissures.

Oil Shales.—As oil shales are commonly the original sources of petroleum and gas, their presence is usually regarded as a favorable indication. McCoy[4] says that petroleum shales are always present in the petroliferous series that are exploited in the Oklahoma-Kansas field. From such a shale, under great compression, he extracted a little oil. Winchester[5] suggests the Green River oil shales as sources of the great gilsonite veins and other solid hydrocarbons that are abundant in the Uinta Basin, Utah. Oil is extracted commercially from the oil shales of the West and Mid-

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[1] Kobbe, W. H.: Problems Connected with the Recovery of Petroleum from Unconsolidated Sands. Am. Inst. Min. Eng. *Trans.*, vol. 1, 56, pp. 799-822, 1916.

[2] Thompson, A. B.: The Oil Fields of Russia. Pp. 52-53, London, 1908.

[3] Pascoe, E. H.: The Oil Fields of Burma. India Geol. Survey *Mem.*, vol. 40, part 1, pp. 72-73, 1912.

[4] McCoy, A. W.: Notes on Principles of Oil Accumulation. *Jour. Geology*, vol. 27, pp. 252-262, 1919.

[5] Winchester, D. E.: Oil Shale of the Uinta Basin, Northeastern Utah. U. S. Geol. Survey *Bull.* 691, pp. 27-55, 1919.

lothian districts, Scotland,[1] and elaborate attempts have been made to extract oil profitably from the kerosene shales of New South Wales. Some oil shales approach coal in carbon content and yield 80 to 120 gallons of oil to the ton.[2] The oil shales of the Albert series, at Albert, New Brunswick, which were once exploited for oil, are reported to carry 50 gallons to the ton.

Burnt Shales.—In California the Monterey shale, which according to Arnold has supplied the bulk of the material from which the oil of that region was derived, is burnt red at many places, some of them in the Santa Clara district.[3] The alteration has taken place at depths far below the usual depths of oxidation. In Trinidad red shale is found at many places. This is presumably a clay burnt hard by the oxidation of the petroliferous material it contained. The burnt clay is termed porcelainite.[4] Here, as in California, slow combustion has evidently penetrated to depths beyond those to which air can easily penetrate. Eldridge and Arnold suggest that the changes in California are brought about by spontaneous combustion. At Burnt Hill, Barbados,[5] a bituminous shale by slow combustion has been converted into a hard, bricklike rock. Thompson mentions places on the Yorkshire and Dorsetshire coasts of England where Lias and Kimmeridge bituminous clays, which exude oil, ignite and burn for considerable periods.

Salt-Water Seeps.—Salt water is associated with petroleum in practically every large oil-producing region in the world. (See p. 48.) The only places known to me where oil is associated with water that is fresh or nearly fresh, are in the Rocky Mountain region of the United States, where in several fields the water that floats the oil is evidently mingling with circulating ground water and has been thereby diluted. Salt seeps are found in many oil fields. Many salt licks, or places where animals congregate to lick the salt from the earth or rocks, are formed of drying brine. Where the brine is associated with oil the animals' feet become oil soaked, and it is said that oil seeps have been discovered by men observing

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[1] Steuart, D. R.: The Oil Shales of the Lothians, 2d ed., part 3. Scotland Geol. Survey *Mem.*, 1912.

[2] Thompson, A. B.: Oil-field Development. P. 205, 1916.

[3] Eldridge, G H., and Arnold, Ralph: The Santa Clara Valley Oil District, Southern California. U. S. Geol. Survey *Bull.* 309, p. 22, 1907.

[4] Wall, G. P., and Sawkins, J. G.: Report on the Geology of Trinidad. Part 1, p. 50, West Indian Survey, 1860.

[5] Thompson, A. B : Oil-field Development. P. 195, 1916.

oil on the feet of pigs that had returned to farmhouses from their range. Large quantities of bones are found in some such places. These are evidently the remains of animals that drank at springs which possibly were salty.

Brine and rock salt are among the most widely distributed materials in the earth and occur at many places far removed from oil fields. The presence of salt water may suggest the possibility of petroliferous strata, but it has no certain significance, as many oil pools have been found where no salt springs issue and many salt springs issue at places remote from oil fields.

Sulphur and Sulphur Compounds.—Sulphur or sulphur compounds are found in the petroleum of many fields and in the salt water that is associated with the petroleum. Probably some of the sulphur associated with petroleum has been derived from the plants and bodies of animals that supplied the material from which the oil and gas have been derived. If, as is supposed by many, petroleum bacteria convert organic material to oil and gas, sulphur bacteria, which, like the so-called petroleum bacteria, are anærobic, probably work under similar conditions to convert sulphates to sulphur and its unoxidized compounds. Sea water that is buried with the sediments that yield oil is probably the principal source of the sulphur.

Sulphurous gases have been mentioned (p. 35). Some of them deposit native sulphur and on oxidation yield sulphuric acid. In the Spindletop oil field of the Gulf coast region, sulphur was found in the soil, and the discovery well was drilled as an exploration for sulphur. At Sour Lake, also in the Gulf coast field, acid waters were among the surface indications that led to drilling.

Sulphur and acid waters, like salt and salt water, are widely distributed in the earth. It is only in certain surroundings that they are of interest as indications that suggest of the possible presence of petroleum.

CHAPTER III

OPENINGS IN ROCKS[1]

SIZES OF OPENINGS

Openings may be classified with respect to their size and with respect to their origin. With respect to size, they may be placed in three groups—supercapillary, capillary, and subcapillary.[2]

Supercapillary openings are those in which water obeys the ordinary laws of hydrostatics. For water at ordinary temperatures, tubes with holes more than 0.508 millimeter in diameter or sheet openings more than 0.254 millimeter wide are supercapillary.

Capillary openings are tubes with holes less than 0.508 and greater than 0.0002 millimeter in diameter, or sheet openings between 0.254 and 0.0001 millimeter wide. In these water does not obey the ordinary laws of hydrostatics but is affected by capillary attraction. Water will not circulate so freely in such openings because of the greater friction along the walls. Hot water may move through such openings more readily than cold, however, and under pressure either hot or cold solutions may be forced through capillary openings.

Subcapillary openings include tubes with holes less than 0.0002 millimeter in diameter and sheet openings less than 0.0001 millimeter wide. In these the attraction of the molecules of the solid extends across the open space. Water may enter such openings, but it tends to remain as if fixed to the walls, prohibiting further entrance of solutions. Circulation of solutions at ordinary temperatures through such openings is therefore very slow.

If two rocks have equal amounts of pore space—supercapillary in one and subcapillary in the other—the one with the larger openings will afford more favorable conditions for the movement of fluids. Muds, clays, shales, and rock powders, which contain

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[1] This chapter is an abridgment of a discussion of openings in rocks in an earlier volume by the writer, "The Principles of Economic Geology," New York, 1918.

[2] Daniel, Alfred: A Text-book of the Principles of Physics. P. 315, 1895. Van Hise, C. R.: A Treatise on Metamorphism. U. S. Geol. Survey *Mon.* 47, p. 135, 1904.

exceedingly minute openings, are the great natural barriers to circulation, although, under sufficient pressure, fluids are forced through them.

ORIGIN OF OPENINGS

With respect to their origin, openings in rocks are classified as follows:

Primary Openings:

- Intergranular spaces.
- Bedding planes.
- Vesicular spaces.
- Openings in pumice.
- Miarolitic cavities.
- Submicroscopic spaces.

Secondary Openings:

- Openings formed by solution.
- Shrinkage cracks due to dehydration, cooling, loss of fluids, etc.
- Openings due to force of crystallization.
- Openings due to the thrust of solutions.
- Openings due to the greater earth stresses.

PRIMARY OPENINGS

Intergranular Spaces in Sedimentary Rocks.—The pore spaces in sedimentary rocks constitute a percentage of the volume of the rock ranging from less than 1 up to 25 or even more. According to Buckley,[1] the Dunnville sandstone of Wisconsin has a pore space of 28.28 per cent. Many sandstones have 20 per cent or more. As shown by Slichter,[2] the size of the grains does not determine the amount of pore space: a fine-grained rock may be as porous as a coarse conglomerate. Fig. 8 shows a pile of balls arranged in the most compact manner possible. Fig. 9 shows the spaces between the balls of Fig. 8. It is obvious that if these balls were increased or decreased in size the changes would affect similarly the spaces between them. The amount of space depends principally upon the assortment of grains and the system of pack-

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[1] Buckley, E. R: Building and Ornamental Stones of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey *Bull.* 4, pp. 225, 403, 1898.

[2] Slichter, C. S.: Theoretical Investigation of the Motion of Ground Waters. U. S. Geol. Survey *Nineteenth Ann. Rept.*, part 2, p. 305, 1899.

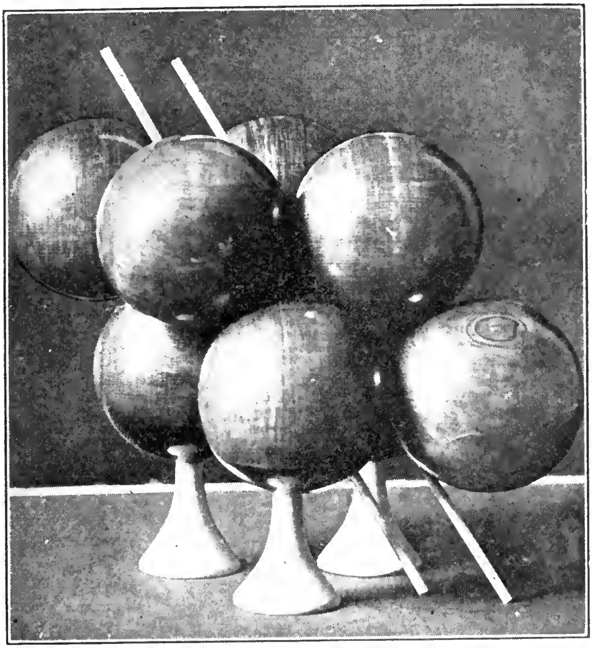

FIG. 8.—Spheres packed in the most compact manner possible. The face angles are 60° and 120°. (*After Slichter.*)

FIG. 9.—Cast showing pore space in a mass of spheres packed in the most compact manner possible. (*After Slichter.*)

ing. If small grains fill in the spaces between large grains, the porosity is obviously diminished. The fact that very fine material will not permit the free movement of fluids is not due to the absence of openings but to the small size of the openings. In rock with subcapillary openings fluids tend to remain fixed to the rock particles. The pore spaces of the more coarsely granular rocks, such as sandstone, are more likely to serve as reservoirs for fluids than those in fine-grained rocks, such as shales. Clay particles are small, and because many are flat they pack closely. Moreover, colloidal matter in clay and shale tends to decrease permeability. Under sufficient pressure, however, fluids will be driven through even clays and shales.

Some sedimentary rocks contain large numbers of fossil shells that are hollow, some beds being made up largely of such shells. The porosity of such a bed may be very great.

Bedding Planes.—Bedding planes are due to the assortment or sizing of material during transportation and deposition. On account of the assortment of grains there is also a different arrangement of the pore spaces in the different beds.[1] Consequently, even in a nearly homogeneous rock the different beds commonly have different degrees of permeability. Fluids moving along the beds may follow the most permeable layer, but fluids moving across them must traverse also the most impermeable layers. Fluids will therefore pass along beds more readily than across them.

Vesicular Spaces.—Magmas generally contain included fluids. When the magmas are erupted and flow out upon the surface, pressure is relieved and the fluids expand and escape as gases. If they expand when the lavas are in a sticky or viscous condition and near the point of solidification the openings due to expansion are preserved. The openings due to expanded gases in lavas, unlike the pores in sandstone, are generally not connected and therefore do not offer continuous passages to fluids.

Openings in Pumice.—Pumices are lavas that contain very large amounts of pore space. The openings are formed in the same manner as vesicles but are generally smaller and much more numerous. Siliceous lavas, such as rhyolites and other acidic rocks, are more viscous than basic lavas, such as basalt or diabase. Rock

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[1] KING, F. H.: Principles and Conditions of the Movements of Ground Water. U. S. Geol. Survey *Nineteenth Ann. Rept.*, part 2, p. 135, 1899.

froth is more generally formed with siliceous material, although both acidic and basic lavas are commonly vesicular. Open spaces in a pumice are not continuous, and the circulation in them is slow. Fragments of pumice placed in water may float for days before the spaces are filled and the water-logged fragments sink. Petroleum deposits in pumice are rare or unknown.

Miarolitic Cavities.—Some igneous rocks and some pegmatites contain small openings which are believed to be spaces formerly occupied by fluids of the rock magma that were unable to escape during the solidification of the rock. Such openings, called miarolitic, are present in rocks that solidified under pressure and are unlike vesicles, although both are due to imprisoned fluids. The walls of miarolitic cavities are usually rough, because they are lined by crystals of the rock. Miarolitic cavities are not known to be seats of accumulations of petroleum.

Submicroscopic Spaces.—The denser rocks, which appear solid, contain nevertheless small amounts of pore space. A granite, which under the microscope has no visible openings, will absorb a small amount of water in the cold. Shales contain numerous openings, but these do not permit the ready passage of fluids because they are largely subcapillary. Under pressure, however, fluids are forced into or through subcapillary openings.

SECONDARY OPENINGS

Openings Formed by Solution.—In soluble rocks like limestones and dolomites large openings may be formed by solution and by removal of rock matter. Solution usually proceeds by enlarging smaller openings, such as joints, bedding planes, or fissures. These openings may become the principal drainage channels of the country, and the solution cavities along them may be developed on an enormous scale. As a rule solution is more active above the water level, but large cavities have been found considerably below the present water level. Where an ancient drainage surface is buried by later strata solution cavities may be found at great depths.

Openings Due to Shrinkage.—Shrinkage may be caused by dolomitization, dehydration, cooling, and other processes. If a fairly pure limestone is changed to dolomite without addition of carbon dioxide a shrinkage of about 12 per cent takes place. The porosity of some dolomites is assumed to be due to shrinkage. Cracks due to shrinkage in drying are common. Cooling cracks are formed soon after the solidification of igneous rocks, before they have cooled to the temperatures of the surrounding rocks.

Openings Due to the Force of Crystallization.—The force which crystallizing matter exerts on the containing walls has been assumed to be sufficient to push the walls apart. If this force so operates it would be supposed that a solution, having once gained entrance to a fissure, however narrow, could enlarge the fissure while it was being filled. This process does not produce open spaces but is assumed to widen those already formed. Becker and Day[1] performed experiments to ascertain the strength of such a force and found it to be of the same order as the crushing strength of crystals. They say: "It is manifest that we here have to deal with a force of great geological importance. If quartz, during crystallization, exerts a pressure on the sides of a vein which is of the same order of magnitude which it offers to crushing, then this force is also of the same order of magnitude as the resistance of the wall rocks, and it thus becomes possible that * * * veins have actually been widened to an important extent, perhaps as much as 100 per cent or even more, by pressure due to this cause."

Dunn[2] considers the force of crystallization as an agent that has operated in expanding the openings of quartz-filled reefs of Bendigo, Victoria. The hypothesis appears, however, to be of limited application, if not untenable for many deposits. Very commonly veins show numerous vugs, and it is improbable that crystals, where they could grow freely into open spaces, would thrust aside great masses of rock. Moreover, the crystals themselves are generally not distorted. They do not show that their own growth was affected by such enormous pressures as are demanded by this hypothesis.

Harris[3] has appealed to this force in an hypothesis which he proposed to account for the salt domes of the Gulf coast region, and many investigators working in that region have accepted his

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[1] Becker, G. F., and Day, A. L.: The Linear Force of Growing Crystals. Washington Acad. Sci. *Proc.*, vol. 7, pp. 282-288, 1905.

[2] Dunn, E. J.: Report on the Bendigo Gold Field, Victoria. P. 25, Dept. of Mines, 1896.

[3] Harris, G. D.: Oil and Gas in Louisiana, With a Brief Summary of Their Occurrence in Adjacent States. U. S. Geol. Survey *Bull.* 429, p. 8, 1910.

hypothesis. The puzzling genesis of the salt domes, however, should be regarded as a problem that is only in process of solution (p. 372).

Openings Due to Greater Stresses.—The openings that are due to the greater stresses attending the deformation of the earth are the seats of the larger number of the world's metalliferous deposits. Such openings, however, are less significant in connection with the origin of the bitumens. Many dikes of ozokerite, gilsonite, and other bitumens have formed by the drying out of petroleum in great fractures. Few metalliferous veins filling openings in rocks are longer or wider than the great gilsonite dikes of the Uinta Basin, Utah. In some regions that yield petroleum fissures and zones of fracturing have served as passages between the strata in which the petroleum and gas originated and the strata in which they accumulated. In a few regions the fissures in rocks serve as the petroleum and gas reservoirs.

CHAPTER IV

ASSOCIATION OF PETROLEUM AND SALT WATER

Salt water is associated with petroleum in practically all the large oil-producing regions in the world and in nearly all prolific oil pools in these regions (Fig. 10.) In the Appalachian oil fields salt water generally saturates the petroliferous strata below the Catskill formation and also some of the petroliferous strata above the Catskill. The Catskill itself is not saturated. This series is of terrestrial origin. According to Reeves,[1] in places the pore space in the Catskill sands is filled with air. The sediments had evidently dried out before they were submerged in the sea. This series, which embraces the Venango oil sand group, is very prolific in southwestern Pennsylvania. In the Venango group the oil is found in synclines. (See p. 212.)

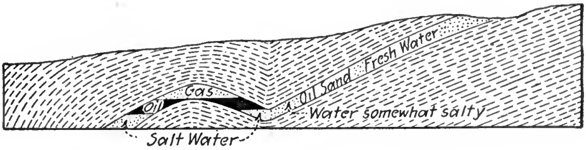

Fig. 10.—Sketch showing a common relationship of oil, gas, salt water, water somewhat salty, and fresh water. The circulation of fresh ground water sweeps out the brine near the surface and dilutes it in depth.

In the Ohio portion of the Appalachian field the Pennsylvanian and Mississippian strata carry salt water. In the Clinton gas field the Big lime (Silurian), which lies a short distance above the "Clinton" sand, is soaked with brine. Near Bremen, Fairfield County, a very light oil is found in the Clinton in a small pool that appears to be free from water.[2] From this fact Bownocker concludes that the oil is in shallow basins rather than on the slopes of anticlines. It seems probable that the oil is perched in this basin and that gas rather than brine may be found in the Clinton below.

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[1] Reeves, Frank: Absence of Water in Sandstones of the Appalachian Oil Fields. Econ. Geology, vol. 12, pp. 254-278, 1917.

[2] Bownocker, J. A.: Petroleum in Ohio and Indiana. Geol. Soc. America *Bull.*, vol. 28, p. 672, 1917.

the pool. This occurrence of oil free from water, according to Bownocker, is unusual in Ohio.

In the Lima-Indiana field, where oil and gas are found in the Trenton limestone, salt water rises to nearly equal altitudes. In the Irvine field, eastern Kentucky,[1] salt water is associated with the oil, some wells yielding considerable quantities. In the Wayne County and McCreary County fields,[2] in southern Kentucky, oil is found in Paleozoic rocks. Where the oil lies in synclines the rocks do not contain water. Salt water is present in the Spurrier region, Tennessee.

In Lambton County, Ontario, the petroliferous strata carry salt water. The Dundee (Corniferous) formation in southern Michigan contains brine.[3]

In Illinois petroleum is found chiefly in the lower part of the Pennsylvanian and upper part of the Mississippian rocks, in both of which it is associated with much salt water. As stated by Kay[4] in the bottom of the Illinois basin and well up on its sides the Pottsville rocks are saturated with salt water.

In the Oklahoma-Kansas field salt water is associated with the oil, and in the western part of the field the sands are saturated and the oil and water are under considerable pressure. In the Red River field of southern Oklahoma and northern Texas, and in the Ranger field of Texas the petroliferous rocks are saturated with brine.

In the fields of northern Louisiana and eastern Texas, where oil is obtained from the Upper Cretaceous beds, salt water is present in the producing members. The Woodbine sand yields oil and gas in Louisiana and at South Bosque, Texas. At both places it carries brine. At Corsicana, Texas, where the Woodbine is barren, it yields water that is only slightly saline. The Blossom sand at Caddo, Louisiana, carries oil and salt water. The Nacatoch sand is saturated with brine in the Caddo field. The Taylor marl

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[1] Shaw, E. W.: The Irvine Oil Field, Estill County, Kentucky. U. S. Geol. Survey *Bull.* 661, p. 149, 1918.

[2] Pemberton, J. R.: A Résumé of the Past Year's Development in Kentucky From a Geologic Standpoint. Am. Assoc. Pet. Geol. *Bull.*, vol. 2, pp. 38-53, 1918.

[3] Smith, R. A.: The Occurrence of Oil and Gas in Michigan. Michigan Geol. and Biol. Survey Pub. 14, Geol. ser. 11, p. 27, 1914.

[4] Kay, F. H.: Oil Fields of Illinois. Geol. Soc. America *Bull.*, vol. 28, p. 657, 1917.

carries salt water at Thrall, Texas. Salt water and salt are associated with petroleum in the salt-dome field of Texas and Louisiana.

In the West, also, salt water is associated with petroleum in nearly every large field. It is present in all the producing fields of Wyoming except in the Grass Creek anticline of the Big Horn Basin and some neighboring anticlines, where the oil is floated on a water that is only slightly salty or feebly alkaline. In this region, as stated by Hewett and Lupton,[1] there has probably been accession of surface water to the beds from the outcrops. In the Salt Creek field the oil is floated on brine. Recently, however, a well sunk near a fault, on the west border of this field, yielded comparatively fresh water. In the Pecos Valley, New Mexico, a heavy black oil is associated with water that rises copiously into artesian wells. The water carries a considerable concentration of salts in some wells but very little salt in others.[2] In California the petroleum is associated with brine.

In Mexico great quantities of salt water are encountered in the petroleum-bearing strata. The Dos Bocas well, after spouting oil heavily for 58 days, began to discharge hot salt water, yielding 1,500,000 barrels a day.

In the Boryslaw region, Galicia, oil occurs in the Miocene salt shale and Saliferous clays, and in Rumania in the Saliferous clays. In Rumania oil is associated with salt water and some with salt. In the Berca and Becieu fields[3] salt efflorescences accompany oil seeps and mud volcanoes above the producing anticlines.

In the Baku field, Russia, all the deep waters are brines. At Holy Island salt water issues in the oil fields. In Egypt salt and salt water are closely associated with the petroliferous beds. In the Irrawady River field, Burma, the oil is floated on salt water. Noteworthy features of the water of Yenangyaung, as indicated by analyses reported by Pascoe, are the large amount of carbonates and the absence or low content of sulphates.

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[1] Hewett, D. F., and Lupton, C. T.: Anticlines in the Southern Part of the Big Horn Basin, Wyoming. U. S. Geol. Survey *Bull.* 656, pp. 46, 156, 1917.

[2] Fisher, C. A.: Geology and Underground Waters of the Roswell Artesian Basin, New Mexico. U. S. Geol. Survey Water-Supply *Paper* 158, 1906.

[3] Preiswerk, H.: Ueber den Geologischen Bau der Region der Schlammvulkane und Oelfelder von Berca und Becieu bei Buzen in Rumanien. Zeitschr. prakt. Geologie, 1912, pp. 86-95.

The waters of the oil fields of California were investigated by Rogers[1]. The water-bearing sands are generally encountered above, below, and, in many places, in the oil measures. The water in many of the sands is under high pressure. Some of the ground waters are as salty as ocean water, but others are fresh. This difference is believed to be the result of difference in freedom of circulation, which is controlled by the structure. Where the structure prevents circulation the ground water is salty, but where it does not and circulation is relatively free, surface water has entered the beds and replaced much of the strong chloride water originally present. Ground water near the surface and near the outcrops of the beds is comparatively fresh, but the content of chloride generally increases with depth. The deeper waters trapped in structural troughs, like the Midway syncline, closely resemble ocean water in most respects and are believed to be only slightly altered sea water. The surface waters and shallow ground waters and also the deeper ground waters outside the oil fields on the west side of San Joaquin Valley contain sulphate. In the oil fields, however, the content of sulphate decreases with depth, and ground waters near and in the oil measures are practically free from sulphate. This decrease in sulphate is attended by a corresponding increase in carbonate, and in districts in which chloride is not abundant the waters near the oil measures are nearly pure carbonate waters. Where chloride is the predominating acid radical, even in the shallower waters, carbonate is unimportant, and the chief change with depth is the disappearance of the sulphate. The amount of sulphide in the deeper waters is roughly proportional to the amount of sulphate in the waters directly above them, or nearer the surface. Calcium and magnesium predominate in many of the surface waters, but sodium and potassium greatly predominate in the deeper waters. Most of the waters associated with the oil are therefore variously proportioned mixtures of solutions of alkaline carbonates and chlorides, the proportion of carbonate depending chiefly on the extent to which meteoric water is able to enter at the outcrop.

When gases under high pressure are released they expand and the salt solution, carried as spray, becomes cooler and deposits salts by evaporation of water in their reservoir rocks and in casings

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[1] Rogers, G. S.: Chemical Relations of the Oil-field Waters in San Joaquin Valley, California. U. S. Geol. Survey *Bull.* 653, p. 113, 1917.

of wells. Mills and Wells[1] state that waters associated with petroleum undergo deep-seated concentration, brought about by their evaporation into moving and expanding gas. During this concentration there is a definite order of change in the relative proportions of the dissolved constituents in the waters. Carbon dioxide and other gases are lost from solution. Calcium, magnesium, and iron separate from solution as carbonates, and under favorable conditions sodium and minor proportions of calcium and magnesium separate as chlorides—a process similar to the salting up of gas wells. A further separation of the dissolved constituents, more particularly of calcium, magnesium, iron, sodium, barium, strontium, carbonate, and silica, is brought about when waters from different beds and having different properties of reaction become mixed. The ratio of calcium to chlorine in the waters increases and the ratio of sodium to chlorine decreases with the concentration. Mills and Wells state that concentration by natural processes is brought about much as it is in wells, the gas pressure being gradually relieved by leakage of reservoirs where gas escapes in seeps at the surface, or into other strata containing gas at a lower pressure.

[1] MILLS, R. V. A., and WELLS, R. C.: The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas. U. S. Geol. Survey *Bull.* 693, pp. 1-103, 1919.

CHAPTER V

RESERVOIR ROCKS AND COVERING STRATA

RESERVOIR ROCKS

General Character.—The reservoirs that contain oil and gas are the pore spaces in sands, sandstones, and sandy marls and the pores, solution cavities, and fissures in limestones, dolomites, and other sedimentary rocks. Oil is found in fissures in indurated shale and in fissures in igneous rock, but such occurrences are comparatively rare.

In Pennsylvania and West Virginia, altogether, there are thirty-seven reservoir strata,[1] of which thirty-five are sands and sandstones, one a conglomerate, and one a limestone. The limestone is the Greenbrier, of Mississippian age.

Of the eight principal reservoir strata in Ohio[2] seven are sands and one, the Trenton, is limestone.

In Indiana[2] the Huron sandstone, the Jeffersonville or "Corniferous" limestone, and the Trenton limestone are the chief reservoir strata.

In Kentucky the principal reservoir stratum is the Jeffersonville or "Corniferous" limestone, although oil or gas or both are found also in many sands, and a small production is derived from limestones below the Devonian.

In the Spurrier and Riverton districts, Tennessee, the oil is derived from Ordovician limestone. In the Glenmary district it is obtained probably from an oolitic limestone.[3]

In the Fayette gas field of Alabama[4] gas is derived from sands.

In Michigan[5] oil is derived from the Dundee limestone.

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[1] Fuller, M. L.: Appalachian Oil Field. Geol. Soc. America *Bull.*, vol. 28. p. 633, 1917.

[2] Bownocker, J. A.: Petroleum in Ohio and Indiana. Geol. Soc. America *Bull.*, vol. 28, pp. 667-676, 1917.

[3] Glenn, L. C.: Recent Oil Development of Glenmary, Scott County, Tennessee: Resources of Tennessee. Vol. 7, p. 40, 1917.

[4] Munn, M. J.: The Fayette Gas Field, Alabama. U. S. Geol. *Bull.* 471, p. 38, 1912.

[5] Smith, R. A.: The Occurrence of Oil and Gas in Michigan. Michigan Geol. and Biol. Survey *Pub.* 14, Geol. ser. 11, pp. 1-281, 1914.

In Illinois[1] in the principal producing district there are seven reservoir strata. All of them are sands or sandstones except the so-called McClosky sand, which is an oolitic limestone, and the Trenton dolomite.

In the Oklahoma-Kansas field the chief reservoir strata are sands. In Oklahoma, as shown by Aurin,[2] there are more than 40 producing strata, of which all but two are sands. The Oologah, or Big lime and the Oswego or Fort Scott limestone, of the Pennsylvanian, at places form reservoirs. Gardner[3] states that 90 per cent of the Oklahoma production has been derived from a single sand, the Bartlesville.

In the Arkansas gas field near Fort Smith,[4] and in the oil field south of Kansas City, Missouri,[5] the reservoir strata are sandstones.

In the Red River district of southern Oklahoma and northern Texas the reservoir rocks are sandstones. In the Ranger and neighboring districts the principal reservoir strata are sandstone. In the Ranger and Caddo fields one reservoir horizon is at a contact between limestone and shale. In the Balcones fault region of Texas and in the northern Louisiana fields[6] the chief reservoir strata are sands, although in some districts the Austin (Annona) chalk carries gas and a heavy oil, and at Thrall oil is found in a tuff included in the Taylor marl.[7] In the Gulf coast region of Texas and Louisiana oil and gas are found in porous fractured limestone and in sands.

In the principal oil fields of Wyoming oil and gas are found in sands. On the Shoshone anticline, however, oil is derived from

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[1] Kay, F. H.: Oil Fields of Illinois. Geol. Soc. America *Bull.*, vol. 28, p. 657, 1917.

[2] Aurin, F.: Correlation of the Oil Sands of Oklahoma. Oklahoma Geol. Survey Circ. 7, pp. 1-16, chart, 1917.

[3] Gardner, J. A.: Mid-Continent Geology. *Oil and Gas Jour. Suppl.*, May, p. 7. 1919,

[4] Smith, C. D.: Structure of the Fort Smith-Poteau Gas Field, Arkansas and Oklahoma. U. S. Geol. Survey *Bull.* 541, p. 23, 1914.

[5] Wilson, M. E.: Oil and Gas Possibilities in the Belton Area, Missouri. Missouri Bur. Geology and Mines, 1918.

[6] Matson, G. C., and Hopkins, O. B.: The Corsicana Oil and Gas Field, Texas. U. S. Geol. Survey *Bull.* 661, p. 217, 1918.

[7] Udden, J. A., and Bybee, H. P.: The Thrall Oil Field. Univ. of Texas *Bull.* 66, p. 39, 1916.

limestones. A small part of the oil produced at Salt Creek[1] comes from fractures in shale.

In the Florence district, Colorado,[2] oil is found in fissures in shales. In the fields of western Colorado and in Utah the oil and gas are in sandy strata.

In California fields[3] the reservoirs are sands and conglomerates.

In Middlesex counties the principal producing area of Lambton and the Ontario field, the oil and gas are in Devonian limestone.[4] In Dover West, Kent County, some oil has been derived from the Trenton limestone, and near Niagara Falls gas is derived from the Clinton sand. In the foothill region of the Canadian Rockies gas is derived from sand.

In the Tampico region of Mexico the principal reservoir rock is limestone, although some oil is derived from sands above it. In Trinidad oil is derived from sands. In the coastal fields of Peru and Ecuador the oil is in sandstone. In the Comodoro Rivadavia field, Argentina, the reservoir is a coarse pebbly sandstone.

In Derbyshire, England, oil is found in limestone. In Alsace the oil is almost exclusively confined to sandstones that are included in marl beds.[5] In the Boryslaw field, Galicia, according to Zuber,[6] the oil and gas are in flaggy sandstone in the Saliferous formation, and in conglomerates and sandstones in the Dobrotow formation, which is the richest in oil. In the Schodnica field the Eocene oil is in thick sandstone lenses and the Cretaceous oils are in sandstone lenses covered by shales or saline clays. In Rumanian fields[7] the oil reservoirs are sands, sandstones, conglomerates, and probably

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[1] WEGEMANN, C. H.: The Salt Creek Oil Field, Wyoming. U. S. Geol. Survey *Bull.* 670, p. 36, 1917.

[2] WASHBURNE, C. W.: The Florence Oil Field, Colorado. U. S. Geol. Survey *Bull.* 381, p. 522, 1910.

[3] ARNOLD, RALPH, and GARFIAS, V. R.: Geology and Technology of the California Oil Fields. Am. Inst. Min. Eng. *Bull.* 87, p. 405, 1914.

[4] WILLIAMS, M. Y.: Oil Fields of Southwestern Ontario. Canada Dept. Mines *Summary Rept.*, 1918, part E, pp. 30-42, 1919.

[5] VON WERVEKE, L.: Vorkommen, Gewinnen und Entstehung des Erdöls in Unter-Elsass. Zeitschr. prakt. Geologie, 1895, pp. 97-114.

[6] ZUBER, RUDOLPH: Die geologischen Verhältnisse von Boryslav in Ostgalizien: Zeitschr. prakt. Geologie, 1904, pp. 41-48.

[7] PREISWERK, H.: Ueber den Geologischen Bau der Region der Schlammvulcane und Oelfelden von Berca und Becieu in Rumanien. Zeitschr. prakt. Geologie, 1912, pp. 86-95.

volcanic tuffs. The reservoirs of the Baku field,[1] Russia, are sands of unusual thickness. In the Grozny field[1] they are sands and sandstones. In the Maikop field[2] the oil is found in loose sands. At Holy Island the oil is in sand.

The reservoir rocks of the Irrawady River fields[3] in Burma are sands. In Japan the reservoirs are sandstones and volcanic tuffs.

It is noteworthy that the reservoir rocks in most oil fields are sands and sandstones. Among the exceptions are the Trenton limestone in Ohio, Indiana, and Ontario; the Devonian limestone in Ontario, Michigan, Indiana, and Kentucky; the Greenbrier limestone in Pennsylvania and West Virginia; the McClosky "sand" in Illinois; the Oologah and Oswego limestones in Oklahoma; the Annona chalk of Louisiana and Texas; the limestone cap rock above the salt plugs in the Gulf coast region; the Embar limestone of Wyoming fields; the Tamasopa limestone of Mexican fields; the Mountain limestone in England; and the oil-bearing limestone of the Suez field, Egypt.

The sandstones differ greatly as to size of grain. In several fields oil or gas or both are found in conglomerates—for example, the Sharon conglomerate (Pottsville) of the Pennsylvania-West Virginia region. The Vaqueros formation of the Coalinga district and the McKittrick formation of the McKittrick district, California, yield oil in part from conglomerates. The reservoir of the Comodoro Rivadavia district, Argentina, is a coarse pebbly sand. In Rumania and Galicia some of the reservoirs are conglomerates. In the Galician fields the Dobrotow formation, which is very rich in oil, consists in part of conglomerates.

At many places oil is found in or near igneous rocks, but under conditions which indicate that it migrated from sedimentary strata near by. In three fields the productive reservoirs are igneous bodies, but in each of these fields associated sediments cover the igneous bodies and in each the igneous bodies are, in part at least, tuffs, breccias, or volcanic ash and sand.

Many occurrences of bitumen in porous igneous rocks are known.

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[1] Adiassevich, A.: Oil Fields of Russia. Am. Inst. Min. Eng. *Trans.*, vol. 48, p. 613, 1914.

[2] Trench, R. H.: The Relationship of Structure and Petrology to the Occurrence of Petroleum. (Discussion of a paper by A. B. Thompson.) Am. Inst. Min. and Met. *Trans.*, vol. 20, p. 247, 1911.

[3] Pascoe, E. H.: The Oil Fields of Burma. India Geol. Survey *Mem.*, vol. 40, part 1, pp. 55-100, 1912.

One at Tar Point, Gaspe, Quebec, is noted by Logan.[1] Clapp[2] mentions a vesicular basalt from Colorado in which the oil was shown by David T. Day to be sealed by calcite. Washburne[3] describes a porous basalt containing oil from the Johnson ranch, western Lane County, Oregon. These examples could be multiplied. It is noteworthy that none of them give evidence of petroleum originating in the igneous body and that none of them are of much commercial importance.

In Cuba, at many places, small amounts of petroleum have been obtained from fractured serpentine. DeGolyer[4] states that the oil probably originated in Jurassic or other sedimentary rocks, and then seeped into the serpentine from them.

The Thrall field, Williamson County, Texas, contains wells that were gushers. The petroleum reservoir[5] is a vesicular, soft green basic igneous rock, in the Taylor marl. It lies at a depth of about 850 feet. The top of the igneous body is arched, so that it has a closure of at least 125 feet. (See p. 343.) The rock is brecciated, and Larsen, who examined specimens microscopically, states that some of them appear to be tuff. The oil is probably derived from the Taylor marl. It is red in color and, like that derived from the Taylor marl in the Corsicana field, Texas, has a paraffin base. It is heavier, however, than the Corsicana oil.

In the Furbero district, Mexico,[6] igneous rocks including basalt, dolerite, basalt-gabbro, volcanic ash and sands, are covered by the Mendez shale and possibly by other strata which are indurated near the igneous mass. The sedimentary rocks above form an anticline. Petroleum has accumulated in openings in the igneous rocks and in the Mendez shale. DeGolyer states that the petroleum probably originated in the Tamasopa (Cretaceous) beds.

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[1] Logan, Sir William: Geology of Canada. Pp. 405-789, 1863.

[2] Clapp, F. G.: Revision of the Structural Classification of Petroleum and Natural Gas Fields. Geol. Soc. America *Bull.*, vol. 28, p. 592, 1917.

[3] Washburne, C. W.: Geology and Oil Prospects in Northeastern Oregon. U. S. Geol. Survey *Bull.* 590, p. 100, 1914.

[4] DeGolyer, E.: The Geology of Cuban Petroleum Deposits. Assoc. Am. Pet. Geol. *Bull.* 2, pp. 133-167, 1917.

[5] Udden, J. A., and Bybee, H. P.: The Thrall Oil Field. Texas Univ. *Bull.* 66, 1916.

[6] DeGolyer, E.: The Furbero Oil Field, Mexico. Am. Inst. Min. Eng. *Bull.* 105, pp. 1899-1911, 1915.

At Copper Mountain, in the Wind River Basin, Wyoming,[1] pre-Cambrian granite forms the base of a dome. Paleozoic and later strata dip away from the granite on three sides of the dome. On the fourth side are Tertiary strata, nearly flat-lying. The granite is fractured and faulted, and in it, in shafts and tunnels, a heavy asphaltic oil and asphaltum are encountered. The oil, according to Trumbull, was once accumulated in the Embar (Carboniferous) beds, which elsewhere contain a heavy oil and which, with a thick series of Paleozoic and Cretaceous rocks, have been eroded from the dome. The oil may have migrated laterally as the strata were tilted, or even laterally and upward into the lower rocks, which had been raised to great altitudes near the center of the dome.

Petroleum is found in small amounts in metamorphosed rocks. The occurrence at Furbero, Mexico, has been mentioned. A little petroleum is found also in a gneiss in the Santa Clara district, California.[2] In the Controller Bay region, Alaska,[3] oil seeps from schists were noted, and in the Copper Mountain region, Wyoming,[4] bitumen is found in a hornblendic rock and also in the granite. None of these accumulations are important sources.

Mineral Composition of Reservoir Rocks.—The sands that form the reservoirs of sandy strata range from fine sands to the pebbles of conglomerate. Few data are available regarding the mineral character of sands as shown by microscopic study. Most petroliferous sands consist mainly of quartz, but in some, feldspar, mica, and chlorite are present. Pyrite is often abundant. Some petroliferous sands contain fragments of heavy residual minerals such as magnetite, garnet, ilmenite, amphibole, and monozite. Recently the method of identifying sands by microscopic study of the minerals present has been used by operating companies. Such study is expected to add much to the data available concerning the mineral character of sands.

Many minerals, on altering, yield clay. The fine particles of kaolin and the colloidal matter that is present in many clays tend to seal openings between the original mineral particles. Many of

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[1] Trumbull, L. W.: Petroleum in Granite. Wyoming State Geologist's Office *Bull.* 1, Sci. ser., pp. 1-16, 1916.

[2] Eldridge, G. H.: The Santa Clara Valley Oil District, Southern California. U. S. Geol. Survey *Bull.* 309, p. 5, 1907.

[3] Martin, G. C.: Geology and Mineral Resources of the Controller Bay Region, Alaska. U. S. Geol. Survey *Bull.* 335, p. 42, 1908.

[4] Trumbull, L. W.: *op. cit.*, p. 9.

the ferromagnesian minerals form clay readily on weathering. These are more abundant, in general, in basic rocks than in acidic rocks like granites. Sands derived from basic rocks are generally less porous than sands derived from acidic rocks. Woodruff[1] states that certain sands of Cuba are derived largely from gabbro fragments and that they have altered partly to clay, which fills the pores and limits their capacity. It is noteworthy, however, that fragments of limburgite, a rather basic rock, are found in the Thrall field, Texas,[2] and that basic igneous rocks, in part tuffs and volcanic sands, constitute part of the reservoir at Furbero, Mexico.[3]

The porous limestones that form reservoirs include dolomites and also limestones that are not high in magnesium. The Trenton limestone of the Lima-Indiana oil field is in the main a dolomite, and Orton maintained that its porosity and ability to hold oil are due to dolomitization. He showed by analyses that the dolomitized portion of the formation is productive and that where it is barren it is low in magnesia.[4] Phinney,[5] who investigated the Indiana field after Orton's conclusions had been published, states that the cavities of the Trenton are due "to loss of substance and not to substitution." He believed that the formation is commonly hard and uniform in texture and compact between the irregular ramifying cavities and pores interspersed through it. The Greenbrier limestone, in which some of the oil of the Appalachian region is found, is at many places non-magnesian. The Devonian limestone, of the oil-bearing region of Ontario, is somewhat dolomitic, and the Devonian of eastern Kentucky is dolomitic in the Irvine field, where it constitutes the reservoir rock. The Tamasopa limestone of the Mexican fields is said to be, in part at least, of low magnesia content.

Capacities of Reservoir Rocks.—The amount of petroleum and

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[1] Woodruff, E. G.: Petroliferous Provinces. Am. Inst. Min. Eng. *Bull.* 150, p. 909, 1919.

[2] Udden, J. A., and Bybee, H. P.: The Thrall Oil Field. Texas Univ. *Bull.* 66, p. 39, 1916.

[3] DeGolyer, E.: The Furbero Oil Field, Mexico. Am. Inst. Min. Eng. *Bull.* 105, pp. 1899-1911, 1915.

[4] Orton, E.: The Trenton Limestone as a Source of Petroleum and Natural Gas in Ohio and Indiana. U. S. Geol. Survey *Eighth Ann. Rept.*, part 2, p. 583, 1889.

[5] Phinney, A. J.: Natural-gas Field of Indiana. U. S. Geol. Survey *Eleventh Ann. Rept.*, part 1, p. 617, 1891.

natural gas a reservoir will hold depends upon its size and its porosity. The porosity of a fractured rock varies greatly because of differences in size and irregular spacing of fractures. Porous sands, on the other hand, are comparatively regular, although many of them show considerable differences also. The most porous sands are those that are made of comparatively uniform grains and free from clay. Cementation by silica, lime carbonate, iron oxide, or other substance will decrease porosity. An experienced driller can generally estimate the porosity of a sand by its "feel." If it is loose and free from cement and clay particles, its porosity is likely to be high. Other tests include touching it with the tongue or blowing through it to ascertain porosity. Chemical tests will reveal any trace of oil (p. 28). The amount of lime carbonate is easily estimated by treatment with acid.

Outcrops of a loose-textured, porous sandstone will show rounded forms of sugary texture. A good example is the St. Peter sandstone found at Minneapolis and at many other places in the Mississippi Valley. Under proper conditions this sand would afford a good reservoir for oil accumulation. Unfortunately, the conditions other than porosity are unfavorable. If a sand is cemented by silica its outcrop shows the customary jagged forms of quartzite. Surfaces here and there may be worn smooth and polished by wind erosion.

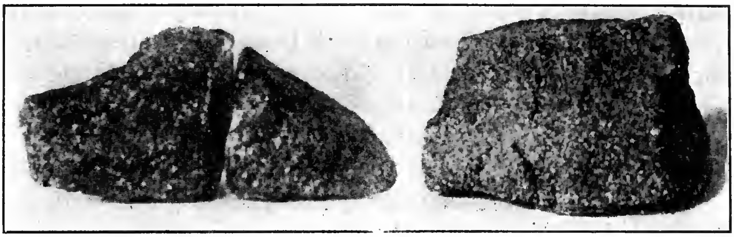
The porosity of a sand does not depend upon size of grain; a fine sand may have pore space less than, equal to, or greater than a coarse one. Uniformity of grains, shape of grains, and arrangement or system of packing affect porosity. If spheres of uniform size are packed in the closest possible manner (see Figs. 8 and 9) the pore space between them is 25.95 per cent by volume.[1] If the spheres are of different sizes the pore space is less, because the small particles fill the spaces between the large ones. If the particles are of irregular or angular shape the porosity may be greater or less than that of a system of uniform spheres, but if the material is highly angular, with no flat particles, the porosity is likely to be greater. Fig. 11 shows porous sands.

[1] Slichter, C. S.: Theoretical Investigation of the Motion of Ground Water. U. S. Geol. Survey *Nineteenth Ann. Rept.*, part 2, p. 310, 1899.

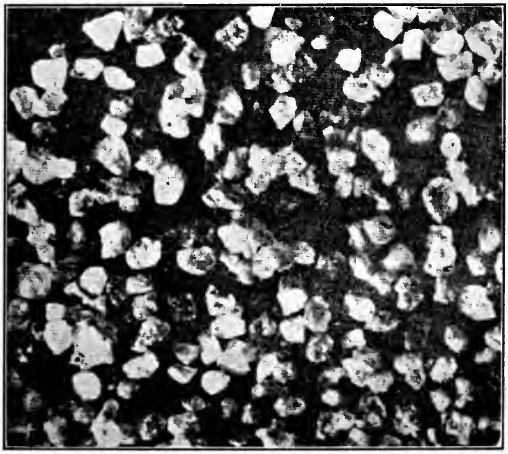
King, F. H.: Conditions and Movements of Underground Water. *Idem*, pp. 209-215.

Lewis, J. O.: Methods for Increasing the Recovery From Oil Sands. U. S. Bur. Mines *Bull.* 148, pp. 16-20, 1917.

Buckley[1] states that the Dunville sandstone of Wisconsin has a pore space of 28.28 per cent. A specimen of the Wall Creek sand, which is the principal petroleum-bearing stratum in the Salt Creek field, Wyoming, collected by Wegemann in the Powder River field, just west of Salt Creek, under tests made by C. E. Van Orstrand, showed a porosity of 25.8 per cent.[2] Another specimen, somewhat shaly, taken near the base of the formation, has a porosity of 20.4 per cent, and a thin layer of calcareous sandstone showed only 7.6



(A) Hoing sand, Colmar field, Illinois. (B) Producing sand of the Cushing field.



(C) Grains of sand from sandstone shown in B, magnified

Fig. 11.—Photographs of oil sand. (*From A. W. Lauer, Econ. Geology.*)

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[1] Buckley, E. R.: Building and Ornamental Stones of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey *Bull.* 4, pp. 225, 403, 1898.

[2] Wegemann, C. H.: The Salt Creek Oil Field, Wyoming. U. S. Geol. Survey *Bull.* 670, p. 27.

per cent. The average porosity of the Wall Creek sand as indicated from the three determinations is 17.9 per cent. The effective porosity, however, is less than that, for, as noted by Wegemann, some of the intergranular spaces are sealed and cut off from other spaces by impervious material, so that oil can not enter them. The Shannon sand of Salt Creek has a porosity of 26.7 per cent.

Van Orstrand made tests of the porosity of the Nacatoch sand member of the Navarro formation, which carries the great gas deposits of the Mexia-Groesbeck field, Texas.[1] The results ranged from 16.6 to 34.2 per cent, and the average was 25.5 per cent. The sand in this field is uniformly porous, according to Matson. The pressure, which was originally 276 pounds to the square inch, was probably enough to force the gas into minute pores. The oil and gas bearing sandstone of Petrolia, Texas, tested by Van Orstrand,[2] showed a porosity ranging from 18.5 to 27 per cent.

Fragments of the third sand at Oil City, Pennsylvania, were tested by Carll,[3] who estimated them to be capable of absorbing 7 to 10 per cent of their bulk without pressure and probably 12.5 per cent under pressure. Gardner[4] estimated the porosity of the Bartlesville sand of Oklahoma to be 20 per cent. The porosity of some of the sands of Baku, Russia, according to Thompson,[5] is 25 per cent or more.

Sandstones such as are used for building are not much less porous than some oil sandstones. Buckley found the average porosity of 32 Wisconsin sandstones[6] to be 15.89 per cent and of six Missouri sandstones[7] to be 17.74 per cent. The average of six building stones of Ohio, according to Bownocker,[8] is 16.63 per cent. Three

[1] Matson, G. C.: Gas Prospects South and Southeast of Dallas, Texas. U. S. Geol. Survey *Bull.* 629, p. 87, 1916.

[2] Shaw, E. W.: Gas in the Area North and West of Fort Worth, Texas. U. S. Geol. Survey *Bull.* 629, p. 36, 1916.

[3] Carll, J. F.: The Geology of the Oil Regions of Warren, Venango, Clarion, and Billings Counties, Pennsylvania. Second Geol. Survey, vol. 3, p. 251, 1880.

[4] Gardner, J. H.: Mid-Continent Geology. *Oil and Gas Jour. Suppl.*, May, 1919, p. 7.

[5] Thompson, A. B.: The Oil Fields of Russia. P. 45, London, 1904.

[6] Buckley, E. R.: Building and Ornamental Stones of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey *Bull.* 4, Econ. ser. 2, p. 402, 1898.

[7] Buckley, E. R.: The Quarry Industry of Missouri. Missouri Geology and Mines, vol. 2, 2d ser., p. 317, 1904.

[8] Bownocker, J. A.: Building Stones of Ohio. Ohio Geol. Survey *Bull.* 18, 4th ser., p. 77, 1915.

determinations of building stones of Washington, made by Shedd,[1] showed an average porosity of 13.7 per cent.

The size of the grains of a sand does not appear to limit its porosity. Some of the productive sands of the Duke-Knowles pool in Texas have very fine grains. In many parts of the Sunset-Midway field, California, according to Pack,[2] more than 80 per cent of the oil sands are smaller than 200 mesh. Of five samples of oil sands from Russian fields treated by Thompson,[3] nearly all of the material passed through a screen measuring 80 meshes to the inch and all of one sample passed through one measuring 200 meshes to the inch.

Clay particles between sand grains greatly reduce porosity. The small clay particles fill the pores and some clay is in a jelly-like colloidal state which is relatively impervious.

Sands grade into muds and sandstones into shales. Muds and shales are made up principally of very fine sand grains and clay. Very thin sands in thick series of shales are likely to be filled with clay and impervious to oil and water. Some of the sands of the Cretaceous shale and sand series that is productive in Wyoming are barren at places in northern Montana, where the thickness of the sands decreases. Sands that were laid down far out from shore lines are commonly less porous than sands deposited near shore.

The estimation of production by utilizing saturation as a factor has been worked out by Washburne.[4] He estimates that the porosity of sand ranges from 0 to 20 per cent and notes that field determinations of surface samples generally show lower porosity than those of buried sands, probably because near the surface calcium carbonate is deposited in some of the openings. In one determination the deep sands showed one-fourth greater porosity than the same sand at the surface. Washburne estimates for two samples 60 and 75 per cent saturation, the volumetric remainder, 40 and 25 per cent, respectively, being assigned to gases and water. The amount of oil extracted is, according to Washburne, 60 to 80

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[1] Shedd, Solon: Building and Ornamental Stones of Washington. Washington Geol. Survey *Ann. Rept.*, 1902, vol. 2, pp. 134-136, 1903.

[2] Pack, R. W.: The Sunset-Midway Oil Field, California. U. S. Geol. Survey *Prof. Paper* 116, p. 000, 1920.

[3] Thompson, A. B.: Oil Field Development. P. 107, 1916.

[4] Washburne, C. W.: Estimation of Oil Reserves. Am. Inst. Min. Eng. *Trans.*, vol. 51, p. 645, 1915.

per cent, the higher figure for gas-rich oils, in sands pumped to a vacuum. Heavy asphaltic oils may yield considerably less.

The porosity of porous limestones can not be so readily estimated because the pores in limestone are more diverse in size and not so regularly spaced. Enlarged sections of the Trenton limestone showing the nature of the pores are illustrated in Fig. 12, after Orton.[1] The porosity of some limestones is very great. The Trenton limestone and the Tamasopa limestone of the Tampico region are among the most productive oil-bearing strata known. The Spindletop, a prolific dome in Texas, derived its oil from a porous limestone.

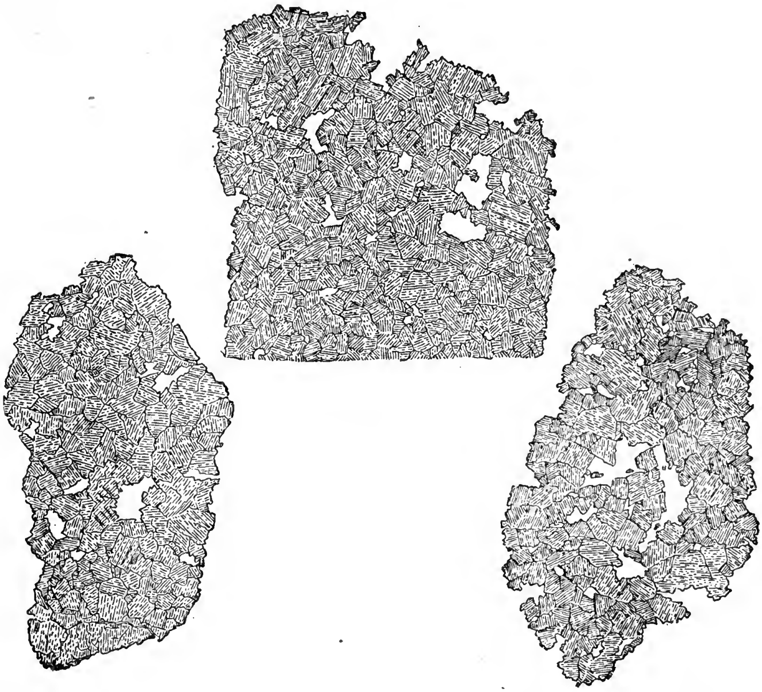

FIG. 12.—Enlarged sections of Trenton limestone showing nature of pores. (*After Orton.*)

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[1] ORTON, EDWARD: The Trenton Limestone as a Source of Petroleum and Inflammable Gas in Ohio and Indiana. U. S. Geol. Survey *Eighth Ann. Rept.*, part 2, pp. 475-662, 1889.

COVERINGS OF RESERVOIRS

Kinds of Covering Strata.—Nearly all the strata that form petroliferous reservoirs are covered by argillaceous rocks. Paleozoic reservoirs are generally covered by shales; Mesozoic reservoirs by shales, clays, or marls; Cenozoic reservoirs by clays or marls, or, where the strata have become indurated, by shales.

In the Appalachian field of the United States the covering strata are shales. In the fields of southwestern Ontario the strata that cover the petroleum-bearing limestone are soft shales or "soap rock." In Ohio, Indiana, and Illinois the reservoir rocks generally are covered by shale. In the Colmar field, Illinois, the Hoing sand lies as patches on eroded shale and is covered by the Niagara limestone. In Kentucky and Tennessee the reservoirs are covered by shale, but in parts of these States the covering shales are thin and some of the reservoirs are not effectively sealed.

The covering strata in all the Kansas, Oklahoma and northern Texas fields are shales. In the Balcones fault region of Texas the reservoirs are covered by clays and marls. In the northern Louisiana fields the covering strata are clays. In the Gulf coast region of Texas and Louisiana the covering strata are clays, muds, and "gumbo."

In the Rocky Mountain fields the covering strata are shales, except in the Douglas field, Wyoming, where a little oil in the White River formation is found in sandstone below clays. In California fields the covering strata are shales and clays.

In the Tampico field, Mexico, the deposits in the Tamasopa limestone are covered by shales and clays. The petroliferous strata of Trinidad are covered by clays. In Peru the beds covering the oil strata are shales.

In Alsace the petroliferous sandstones, according to Von Werveke, are covered by marls. In the Boryslaw field, Galicia, the gas and oil-bearing sandstones of the Saliferous formation are covered by clay, shale, or marl. The sands and conglomerates of the Dobrotow (upper Oligocene) are covered by shales. In the Schodnica field the principal petroliferous members are thick sandstone lenses in clay. In the Rumanian fields the oil and gas are in sandstones and conglomerates covered by marls, clays, and shales. In the Baku fields, Russia, the oil is found in sands covered by clays and marls. In the Grozny field the sands and argillaceous cap rock are said to be more indurated. At Maikop, Russia, the reservoir is sand covered by shale. At Holy Island the reservoir is a sand covered by clay. In the Burma fields the oil sands are covered by clay. In Java the oil sands are covered by clay and clayey marls. In Japan the reservoirs, which consist of sandstone and tuff, are covered by shale.

Thickness of Covering Strata.—The thickness of the covering that is necessary to retain a petroleum deposit depends upon the gas pressure that exists in the deposit. If the covering is a soft, pliable rock that will not fracture it is more effective than an indurated, brittle or jointed rock. Most of the large petroleum deposits developed are relatively deep. They are held down by adequate covers of clays or shales that fracture with difficulty and close the fractures that are made in them. Some oil fields, however, are developed very near the surface. The Drake well at Titusville, Pennsylvania, encountered oil at a depth of only 69 feet and yielded oil at the rate of 25 barrels daily. Flowing wells have been brought in less than 100 feet below the surface. A well-known shallow oil field is the one in Lambton and Middlesex Counties, southwestern Ontario (Fig. 13). The producing stratum is the porous limestone, which is covered by about 400 feet of shales, limestone, and glacial drift. The shales are soft and very pliable and are referred to by the drillers as "soapstone." Flowing wells shooting high in the air and producing from 3,000 to 6,000 barrels a day each were obtained in this field. The efficiency of the thin covering is due probably to the nature of the rocks, the limestone layers giving strength to the whole and the soft shales sealing any opening that may have formed.

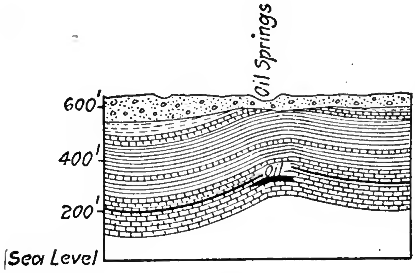

Fig. 13.—Section of Oil Springs dome, Ontario, showing thin cover cap holding in oil under high gas pressure. The vertical scale is greatly exaggerated. (Based on sketch by Williams.)

The Llewellyn well, 100 feet deep, which flowed oil at the rate of 1,000 to 2,000 barrels a day, was opened in the early sixties on the Eureka Springs anticline in West Virginia.[1]

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[1] Fuller, M. L.: Appalachian Oil Field. Geol. Soc. America *Bull.*, vol. 28, p. 623, 1917.

TYPICAL RECORD OF A WELL IN OIL SPRINGS POOL, LAMBTON COUNTY, ONTARIO

	Feet
Pleistocene:	
Surface	0– 60
Hamilton:	
Upper limestone	60– 95
Upper "soapstone"	95–196
Middle limestone	196–223
Lower "soapstone" (salt water at 252 feet)	223–330
Onondaga:	
Lower limestone (oil at 370 feet)	330–370

Shallow wells encounter oil in the Irvine district, Kentucky, where a porous limestone forms the reservoir. It is overlain by the black shale of the Chattanooga formation (Upper Devonian). This shale is higher in the geologic column than the Hamilton, which is the covering of the "Corniferous" limestone in Ontario. It is also more brittle, although where sufficiently thick it supplies a good cap rock. In this region wells only 80 or 90 feet deep sunk in the shales and penetrating the limestone have obtained oil. Unlike the oil in the Ontario field, however, it was not under a high gas pressure.[1]

Oil was found at comparatively shallow depths in the eastern part of the Kansas-Oklahoma field, and also at Brownwood and Strawn, Texas. In these regions where the oil-bearing strata are shallow in general the pressures and the initial production are low. In the great Mid-Continent gusher fields the coverings are in general comparatively thick.

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[1] SHAW, E. W.: The Irvine Oil Field, Estill County, Kentucky. U. S. Geol. Survey *Bull.* 661, p. 145, 1918.

CHAPTER VI

SOME PROPERTIES OF PETROLEUM AND GAS

Color.—Most crude oils are opaque except in very thin bodies. As a rule the color of thin layers in light passed through them is brown, although some oils are red and others yellow. The light oil obtained in the Calgary field, Alberta, is a pale lemon-yellow. A little white oil has been found in the Los Angeles field, California, and considerable quantities of pale straw-colored or "white" oil are recovered in the Surakhany field[1] in the Baku region, Russia. White oils are supposed to result from the natural filtration of petroleum through clay. Sumatra, according to Thompson,[2] yields large quantities of volatile crude oil having the color of port wine.

By reflected light most crude oils have a greenish cast. Some, however, are yellow or black, or of the same color as when seen in transmitted light. The greenish cast of crude oil in reflected light frequently serves to distinguish it from some products of refining, which have a bluish fluorescence.[3]

Odor.—Oils from different fields have different and fairly constant odors. The Pennsylvania oils smell like gasoline. California oils, which have less odor, smell like coal tar. Some East Indian oils smell like oil of cedar. The Lima-Indiana oil has the disagreeable odors of sulphur compounds.

The odors of oils have been used to assist in ascertaining their origin. According to Clapp,[4] in order to determine the characteristic odor of an oil, samples should be prepared in narrow bottles, stoppered, half filled with the oil. The oil is shaken vigorously so as to impart its odor to the air above the oil in the bottle, and if this gives the odor of hydrogen sulphide, a strong solution of caustic potash is added and the oil shaken until the odor of sulphide

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[1] THOMPSON, A. B.: The Oil Fields of Russia. P. 94, London, 1904.

[2] THOMPSON, A. B.: Oil-field Development. P. 278, 1916.

[3] CLAPP, F. G.: Petroleum and Natural Gas Resources of Canada. Vol. 1, p. 45, Canada Dept. Mines, 1914, Mines Branch.

[4] CLAPP, F. G., *op. cit.*, p. 47.

of hydrogen disappears. Many California oils, shaken with caustic potash solution will give an odor of pyridine. In a second sample the odor should be noted after similar treatment with dilute sulphuric acid.

DENSITY

The value of an oil in a general way is suggested by its weight, or specific gravity. As a rule light oils will yield larger proportions of the more valuable products, such as gasoline and kerosene. The heavier products are used in the main for fuel and for road dressing and are lower priced. If, however, the heavy oil contains considerable paraffin wax or materials that can be used for lubricants it may bring a higher price than light oil. The highest-priced oils are natural lubricating oils. These are comparatively rare and are generally produced from shallow wells of small yield.

The specific gravity of an oil is its weight divided by that of the weight of the same volume of distilled water, taken as 1.000. By this standard oils range in weight from 0.780 or less to 1.000.

In foreign countries the decimal specific-gravity scale is extensively used, but in the United States the Baumé scale is used almost exclusively. That is an arbitrary scale in which the weight of water is placed at 10°, the degrees increase as the weight of the liquid decreases. Thus, the lighter an oil the higher the number on the Baumé scale. The United States Bureau of Standards uses the following formula[1] for converting degrees Baumé into the decimal standard:

$$°\text{Baumé} = \frac{140}{\text{Specific gravity of liquid}} - 130$$

The density is taken at 60° F.

On p. 70 is a table to be used for converting readings from one scale to the other and from pounds per gallon, barrel, or cubic foot to either scale. Gravity determinations are made by weighing a known volume of the oil either in a large container or on an assay balance in a small weighing bottle, or by placing the hydrometer in the oil and reading off the scale.

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[1] Used for liquids lighter than water.

EQUIVALENTS OF BAUMÉ SCALE AND SPECIFIC GRAVITY
(After Payne and Stroud)

Deg. Bé.	Specific Gravity	Weight, Pounds			Deg. Bé.	Specific Gravity	Weight, Pounds		
		Per Gallon	Per Barrel	Per Cubic Foot			Per Gallon	Per Barrel	Per Cubic Foot
10	1.0000	8.328	349.79	62.301	36	0.8434	7.024	295.02	52.545
11	0.9929	8.269	347.31	61.859	37	0.8383	6.982	293.23	52.227
12	0.9859	8.211	344.86	61.422	38	0.8333	6.940	291.48	51.915
13	0.9790	8.153	342.45	60.993	39	0.8284	6.899	289.77	51.610
14	0.9722	8.097	340.07	60.569	40	0.8235	6.858	288.05	51.305
15	0.9655	8.041	3.3772	60.152	41	0.8187	6.818	286.38	51.006
16	0.9589	7.986	335.42	59.740	42	0.8140	6.779	284.73	50.713
17	0.9524	7.932	333.14	59.335	43	0.8092	6.739	283.05	50.414
18	0.9459	7.878	330.87	58.931	44	0.8046	6.701	281.44	50.127
19	0.9396	7.825	328.67	58.538	45	0.8000	6.663	279.83	49.841
20	0.9533	7.773	326.46	58.145	46	0.7955	6.623	278.26	49.560
21	0.9272	7.722	324.33	57.765	47	0.7910	6.588	276.68	49.280
22	0.9211	7.671	322.19	57.385	48	0.7865	6.550	275.11	48.999
23	0.9150	7.620	320.06	57.005	49	0.7821	6.514	273.57	48.726
24	0.9091	7.571	317.99	56.637	50	0.7778	6.478	272.07	48.458
25	0.9032	7.522	315.93	56.270	51	0.7735	6.442	270.56	48.189
26	0.8974	7.474	313.90	55.909	52	0.7692	6.406	269.06	47.922
27	0.8917	7.426	311.91	55.554	53	0.7650	6.371	267.59	47.660
28	0.8861	7.379	309.95	55.205	54	0.7609	6.337	266.16	47.405
29	0.8805	7.339	307.99	54.856	55	0.7568	6.303	26.472	47.149
30	0.8750	7.287	306.07	54.513	56	0.7527	6.269	263.29	46.894
31	0.8696	7.242	304.18	54.177	57	0.7487	6.235	261.89	46.644
32	0.8642	7.197	302.29	53.840	58	0.7447	6.202	260.49	46.395
33	0.8589	7.153	300.44	53.510	59	0.7407	6.169	259.09	46.146
34	0.8537	7.110	298.62	53.186	60	0.7368	6.136	257.73	45.903
35	0.8485	7.066	296.80	52.862	61	0.7330	6.105	256.40	45.667

Oil expands with increase in temperature. The coefficients of expansion of certain oils are shown in the following table:

COEFFICIENTS OF EXPANSION OF SOME OILS
(After Hoefer)

Origin	Density × 1,000 at		Coefficient of Expansion × 100,000
	0 Deg. C.	50 Deg. C.	
West Virginia (Burning Spring)	841	808	81
Pennsylvania (Oil Creek)	816	784	82
Canada	870	851	44
Burma	892	861	72
Russia (Baku)	954	920	71
Eastern Galicia	870	836	81
Western Galicia	855	852	77
Rumania (Ploiesti)	862	829	80
Italy (Parma, Neviano de Rossi)	809	772	96
Hanover (Oberg)	944	914	66
Alsace (Pechelbronn)	912	880	73
France (St. Gabian)	894	861	69
Zante	952	921	67

Viscosity.—The viscosity of oil varies with its specific gravity. It is measured by ascertaining the time it takes a given amount of the oil to flow through a small opening in a viscosimeter. The instruments used are the Engler viscosimeter and the Saybolt viscosimeter. A unit often used is the Engler unit, obtained by dividing the time of the outflow of 200 cubic centimeters of the oil by the time of outflow of the same quantity of water at 20° C.

The determinations are of interest especially to pipe-line companies and all others who transport oil through pipes. Some oils are so thick that it is found practicable to heat them to decrease their viscosity. The lubricating properties of oils are closely related to their viscosity.

Composition of Petroleum.—Petroleums are mixtures of compounds of carbon and hydrogen, generally with impurities consisting of sulphur compounds and nitrogen compounds. Hydrocarbons of the following series have been discovered in petroleum.[1]

C_nH_{2n+2} C_nH_{2n-6}
C_nH_{2n} C_nH_{2n-8}
C_nH_{2n-2} C_nH_{2n-10}
C_nH_{2n-4} C_nH_{2n-12}

[1] HOEFER, H.: Das Erdöl. P. 54, 1906.

The compounds most frequently appearing, according to Hoefer, belong to the first or paraffin series, the second or olefine series, and the fifth or aromatic (benzene) series. Of these the paraffins are much the most abundant in both natural gas and petroleum. The sulphur compounds in oil are mentioned on page 85, and the nitrogen compounds on page 82.

PARAFFINS FROM PETROLEUM[a]

Name	Formula	Melting Point	Boiling Point
1. Gaseous:		Deg. C.	Deg. C.
Methane	CH_4	−184	−164
Ethane	C_2H_6	−172.1	− 84.1
Propane	C_3H_8	− 45	− 45.0
Butane	C_4H_{10}	....	+ 1
2. Liquid:			
Pentane	C_5H_{12}	....	36.3
Hexane	C_6H_{14}	....	69
Heptane	C_7H_{16}	....	98
Octane	C_8H_{18}	....	125.8
Nonane	C_9H_{20}	− 51	150
Decane	$C_{10}H_{22}$	− 31	173
Endecane	$C_{11}H_{24}$	− 26	195
Dodecane	$C_{12}H_{26}$	− 12	214
Tridecane	$C_{13}H_{28}$	− 6	234
Tetradecane	$C_{14}H_{30}$	+ 4	252
Pentadecane	$C_{15}H_{32}$	− 10	270
Hexadecane	$C_{16}H_{34}$	18	287
Heptadecane	$C_{17}H_{36}$	22	303
3. Solid:			
Octodecane	$C_{18}H_{38}$	28	317
Eicosane	$C_{20}H_{42}$	37	....
Tricosane	$C_{23}H_{48}$	48	....
Tetracosane	$C_{24}H_{50}$	50–51	....
Pentacosane	$C_{25}H_{52}$	53–54	....
Hexacosane	$C_{26}H_{54}$	55–56	....
Octocosane	$C_{28}H_{58}$	60	....
Nonocosane	$C_{29}H_{60}$	62–63	....
Hentriacontane	$C_{31}H_{64}$	66	....
Dotriacontane	$C_{32}H_{66}$	67–68	....
Tetratriacontane	$C_{34}H_{70}$	71–72	....
Pentatriacontane	$C_{35}H_{72}$	76	....

[a] After HOEFER, H.: *Op. cit.*, pp. 58-59, with additions and changes.

Oils are commonly classified as those with asphaltic base and those with paraffin base. Asphaltic oils are those that yield on distillation a dark asphaltic residue. Paraffin oils on distillation yield light-colored paraffins that do not dissolve in the solvents that dissolve asphalts. Oils that contain paraffin are more easily refined than those that contain asphalt. In general asphaltic oils sell at a lower price than paraffin oils. Many oils, including most mid-continent and Rocky Mountain oils, contain both asphalt and paraffin.

In ordinary work oil is analyzed to ascertain what fractions may be obtained from it by distillation, rather than exactly what chemical compounds are present. The standard method of analysis, known as Engler's method, has been recommended by the Third International Petroleum Congress. This method is described by Day[1] as follows. One hundred cubic centimeters of the crude oil, measured at 60° F., is delivered by a pipette into a distilling bulb holding about 125 cubic centimeters. The thermometer used is a nitrogen thermometer, reading to 550° C. The condenser tube, as prescribed by Engler, is 75 centimeters long and has an inclination of 75° from the horizontal. The point of initial boiling is taken when the first drop of oil falls from the condenser tube into the receiving flask. To avoid loss by evaporation the condenser tube is ground to fit into the graduated receiving flask, which is provided with a stopcock to draw off the oil at 150° C. and again at 300° C. The fraction between the initial boiling point and 150° C. (302° F.) constituting the gasoline fraction, and the fraction between 150° and 300° C. (572° F.), constituting the kerosene fraction, are examined for specific gravity. The residuum is weighed as soon as cool; then its specific gravity is taken in the usual way and the volume calculated. The total thus obtained for the different fractions includes the sum of all determinations.

[1] Day, D. T.: The Production of Petroleum in 1913. U. S. Geol. Survey Mineral Resources, 1913, part 2, p. 1123, 1914.

ANALYSES OF PETROLEUMS[a]

LOCATION	Depth of Well, Feet	PHYSICAL PROPERTIES			
		GRAVITY AT 60 DEG. F.		Color	Odor
		Specific	Baumé		
1 Petrolia, Ontario, Lambton County	......	0.8580	33.0	....	....
2 Venango County, Pennsylvania	......	0.8820	28.7	Dark brown	....
3 Petroleum, Allen County, Kentucky	810	0.8490	34.9	Brown	Like Pennsylvania oil
4 Parkersburg, Wood County, West Virginia	350	0.8750	30.0	Dark green	Like Pennsylvania oil
5 Bremen pool, Fairfield County, Ohio	2,462	0.7848	48.4	Medium green	Like Pennsylvania oil
6 Northwestern Ohio—Trenton limestone	......	0.8284	39.0	....	....
7 Lawrence County, Illinois	1,700	0.8289	38.9	Dark green	Sulphur
8 Terre Haute, Vigo County, Indiana	......	0.8790	29.3	....	....
9 Chanute pool, Allen County, Kansas	751	0.8647	31.9	Dark green	....
10 Glenn pool, Creek County, Oklahoma	1,500	0.8459	35.5	Black	....
11 Sour Lake pool, Hardin County, Texas	1,020	0.9352	19.7	Dark green	Sulphur
12 Caddo pool, Marion County, Texas	±2,300	0.8065	43.6	Brown	Like Pennsylvania oil
13 Coalinga, Fresno County, California	......	0.9590	16.0	....	....
14 Kern River, Kern County, California	......	0.9673	14.7	Black	....
15 Zorritos, Peru	......	0.8480	35.0	Dark brown	....
16 Baku Russia	......	0.8800	29.0	....	....
17 Rumania	......	0.8460	35.0	....	....

[a] In the preparation of this table I have used data compiled by F. G. CLAPP.

1. REDWOOD, BOVERTON: Treatise on Petroleum. Vol. 1, p. 228.
2. HENRY, J. T.: History of Petroleum. B. Silliman, analyst.
3, 4, 5, 7, 11, 12. DAY, D. T.: U. S. Geol. Survey Mineral Resources, 1909, part 2.
6. ORTON, EDWARD: U. S. Geol. Survey *Eighth Ann. Rept.*, part 2, 1889.
8. Indiana Dept. Geology and Nat. Resources. W. A. Noyes, analyst.

Composition of Natural Gas.—Natural gas is associated with practically all petroleums. It rises to the higher points of reservoirs, and it is absorbed in the oil. Under the high pressures that exist in some fields considerable quantities are absorbed. Expansion of gas pushes the oil out of the interstices of the rocks and causes it to flow in wells. It is the gas pressure that causes wells to spout oil and salt water. Even in wells that are pumped, the gas generally forces the oil to the boring.

ANALYSES OF PETROLEUMS[a]

DISTILLATION BY ENGLER'S METHOD, BY VOLUME							Sulphur, per Cent	Paraffin, per Cent	Asphalt, per Cent	Water, per Cent	UNSATURATED HYDROCARBONS, PER CENT	
To 150 Deg. C.		150 Deg.-300 Deg. C.		Residuum		Total Cubic Centimeters						
Cubic Centimeters	Specific Gravity	Cubic Centimeters	Specific Gravity	Cubic Centimeters	Specific Gravity						Crude	150 Deg.-300 Deg.
2.50	...	57.50	...	[a]40.00	...	100.00	...	...	...	...	...	....
8.55	...	42.78	...	48.67	...	100.00	...	...	...	...	...	....
12.50	0.7373	41.00	0.8144	45.30	0.9162	98.80	...	3.65	2.10	Trace	18.8	7.0
...	...	16.00	0.8356	82.40	0.8872	98.40	...	...	...	Much	21.6	5.0
15.00	0.7036	40.00	0.7698	42.00	0.8557	97.00	...	8.33	...	None	11.6	4.0
15.00	...	33.00	...	51.46	...	...	0.54	...	...	...	...	....
12.00	0.7230	35.00	0.7874	49.20	0.9067	96.20	...	4.31	...	Trace	...	...
...	...	39.60	0.8254	60.40	...	100.00	0.72	...	...	...	...	....
5.00	0.7350	36.00	0.7993	57.80	0.9223	98.80	...	4.25	1.23	...	...	....
8.50	0.7566	42.00	0.8001	49.90	0.9032	100.40	...	6.98	0.45	...	...	....
...	...	23.00	0.8750	76.70	0.9569	99.70	...	...	...	...	59.6	11.0
6.00	0.7305	50.50	0.7646	42.90	0.8739	99.40	...	7.02	...	...	12.8	5.0
...	...	14.50	...	85.50	...	100.00	...	...	9.50	...	...	....
1.00	...	28.99	...	71.01	...	100.00	0.95	...	21.25	...	...	....
25.00	...	28.50	...	17.00	...	...	...	...	31.00	...	...	....
		35.00										
0.63	0.7620	37.28	...	62.09	...	100.00	...	...	...	...	...	....
10.00	...	81.88	...	5.89	...	97.77	...	2.23	...	...	...	....

9, 10. DAY, D. T.: U. S. Geol. Survey *Mineral Resources*, 1909, part 2.

13. U. S. Geol. Survey, from card reporting production.

14. Am. Chem. Soc. *Jour.*, vol. 25. Edmond O'Neil, Univ. California, analyst.

15. U. S. Geol. Survey Mineral Resources, 1909, part 2. American Analysis & Chemical Co., analyst.

16, 17. REDWOOD, BOVERTON, *op. cit.*, p. 225.

Although practically all oils are associated with inflammable gas, there are at many places issues of gas that are not associated with oil. The gas that forms in swamps and marshes has been mentioned (p. 33). In Minnesota, in sands below glacial clay, gas is found in quantities sufficient for lighting houses and under a pressure as great as 12 pounds to the square inch. Swamp gas is generally methane or "marsh gas." Analyses of natural gases are shown in the accompanying tables.[1] Properties of some of the lighter hydrocarbons are given in the table following the analyses.

ANALYSES OF NATURAL GAS (Table Prepared by F. E. Carter)

	Methane (CH_4)	Ethane (C_2H_6)	Carbon Dioxide (CO_2)	Oxygen (O_2)	Nitrogen (N_2)	Other Gases	Authority
Ontario	92.6	....	0.3	0.3	3.6	H_2, 2.2; CO, 0.5; H_2S, 0.2; C_2H_4, 0.3	Tassarts[a]
Vancouver, British Columbia	....	93.6	0.1	....	6.3		Phillips[b]
Calgary, Alberta	91.6	....	....	0.2	8.2		Carter[c]
United States:							
Wyoming	81.7	17.4	0.2	....	0.7		Burrell[d]
Pennsylvania	92.6	....	0.3	....	7.1		Phillips[e]
New York	90.1	....	0.4	Trace	9.5		Phillips[f]
Cleveland, Ohio	93.5	....	0.2	....	6.3		Phillips
Indiana	77.4	14.2	0.7	....	6.6	C_2H_4, 0.9; He, 0.2	Cady and McFarland[g]
Kansas	90.6	....	1.0	0.6	7.1	C_2H_4, 0.2; CO, 0.5	Do.
California	83.7	....	6.7	2.8	6.3	C_2H_4, 0.2; CO, .3	Do.
Russia:							
Ssurachany	94.0	....	4.0	0.4	0.6	C_2H_4, 1.0	V. Herr[h]
Bibi-Eibat	86.3	2.8	10.0	0.2	0.7		Do.
Baku	91.2	1.3	1.8	1.2	4.5		Do.
Galicia:							
Tustanowice	86.5	....	....	1.0	3.8	Heavy hydrocarbons, 8.7	Grusciewicz and Hausmann[i]
Hungary:							
Seibenburgen	91.0	....	0.2	0.3	1.4	Heavy hydrocarbons, 1.1; unstated, 6.0	Zeller[k]
Kissarmas	99.0	....	....	0.4	0.2	H_2, 0.4	Czako[l]

[a] Exploit du Petrol, 1908, p. 302.
[b] Am. Chem. *Jour.*, vol. 16, p. 416, 1894.
[c] Fuel-testing Division, Mines Branch, Ottawa.
[d] Bur. Mines Tech. *Paper* 57.
[e] Am. Chem. *Jour.* vol. 16, p. 416, 1894.
[f] Chem. *Centralblatt*, 1887, p. 1524.
[g] *Jour.* Am. Chem. Soc., vol. 29, p. 1523, 1907.
[h] Trudy, 1908.
[i] Petroleum, vol. 6, p. 2245, 1911.
[k] Petroleum, 1906, p. 297.
[l] *Jour.* Gasbeleuchtung, December, 1911.

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[1] See also CADY, H. P., and MCFARLAND, D. F.: Chemical Composition of Gas. Kansas Geol. Survey, vol. 9, pp. 228-302, 1908.

ANALYSES OF NATURAL GAS[a]

Oil Field	County	State	CO_2	O_2	N_2	Total Paraffins	Total	CH_4	C_2H_6	Gross Heating Value per Cubic Foot at 0° C. and 760 Millimeters Pressure	Specific Gravity (air = 1)
										B.t.u.	
Santa Maria.	Santa Barbara	California	15.5	0.2	1.4	82.9	100.0	62.7	20.2	1,044	0.81
Torrey......	Ventura	California	6.8	0.0	3.4	89.8	100.0	54.2	35.6	1,240	0.81
Coalinga....	Fresno	California	11.1	0.0	0.9	88.0	100.0	88.0	0.0	937	0.66
McKittrick..	Kings	California	30.4	0.0	2.4	67.2	100.0	66.2	1.0	724	0.85
West Los Angeles...	Los Angeles	California	1.0	0.1	5.2	93.7	100.0	91.0	2.7	1,019	0.60
Sunset......	Kings	California	10.5	0.0	1.8	87.7	100.0	87.7	0.0	934	0.66
Fullerton....	Orange	California	1.7	0.0	2.1	96.2	100.0	86.7	9.5	1,100	0.63
Kern River..	Kern	California	6.5	0.0	1.2	92.3	100.0	84.3	8.0	1,047	0.66
	Clarion	Pennsylvania	0.0	0.0	1.1	98.8	100.0	96.4	2.5	1,073	0.57
	Forest	Do.	0.0	0.0	1.0	99.0	100.0	70.8	28.2	1,279	0.70
	Clarion	Do.	0.0	0.0	1.7	98.3	100.0	80.5	17.8	1,189	0.65
	Butler	Do.	0.0	0.0	0.9	99.1	100.0	53.3	45.8	1,420	0.78
	Armstrong	Do.	0.05	0.0	1.45	98.5	100.0	81.6	16.9	1,184	0.64
Hogshooter..	Osage	Oklahoma	1.1	0.0	4.6	94.3	100.0	94.3	0.0	1,004	0.58
	Creek	Oklahoma	2.4	0.0	1.8	95.8	100.0	64.1	31.7	1,273	0.74
	Barren	Kentucky	2.5	0.0	1.3	93.3	[b]100.0	23.6	69.7	1,548	0.91
	Barren	Kentucky	2.6	0.0	5.1	92.3	[c]100.0	44.1	48.2	1,367	0.84
	Grand	Utah	3.6	0.0	5.6	90.8	100.0	90.8	0 0	967	0.61
	Grand	Utah	3.5	0.0	6.5	90.0	100.0	90.0	0.0	959	0.62

[a] Bur. Mines *Bull.* 88, p. 21, 1915.

[b] H_2S, 2.9 per cent.

[c] H_2S, 0.1 per cent.

The recovery of gasoline from natural gas has become an important industry. By one method the gasoline is recovered by condensation of the gas; by another it is recovered by absorption of the gasoline when the gas is passed through a heavy oil. The gasoline is in great demand for mixing with low-grade naphtha. In 1911 176 plants in nine States produced 7,425,839 gallons of gasoline from natural gas. In 1917, only six years later, 886 plants in 12 States produced 217,884,104 gallons. Prior to 1916 the greater portion of the gasoline recovered from natural gas was obtained by methods involving compression and condensation. Since 1913, however, a steadily increasing proportion of the annual output of natural-gas gasoline has been recovered by the absorption process. The development of this process that followed work done by G. M. Sabolt has extended the scope of the natural gas gasoline industry to include types of natural gas containing too little gasoline to warrant their successful treatment by compression methods.[1] Some gasoline is recovered also from "drips" in pipe lines that carry gas.

PROPERTIES OF SEVEN PARAFFIN HYDROCARBONS[a]

Hydrocarbon	Formula	Boiling Point[b]	Specific Gravity (at 0° C. and 760 Mm.; Air=1)	Weight of 1 Liter	Heating Value per Cubic Foot at 0° C. and 760 Mm.[c]	Illuminating Value	Calculated Volume of Gas (at 60° F. and 30 Inches Pressure) from 1 Gallon	Theoretical Volume of Air Necessary to Burn 1 Cubic Foot of Gas
		C.		Grams	B.t.u.	British Candle-power		Cu.Ft.
Methane	CH_4	-164^{d}	0.554	0.7159	1,065	[e]5.0	......	9.57
Ethane	C_2H_6	-84.1^{d}	1.049	1.3567	1,861	[h]35.0	53	16.72
Propane	C_3H_8	-45^{d}	1.520	1.9660	2,654	[h]53.9	45	23.92
Butane	C_4H_{10}	1.0^{d}	2.004	2.594	3,447	....	37	31.10
Pentane	C_5H_{12}	36.4^{k}	....	....	4,250	....	31	38.28
Hexane	C_6H_{14}	68.9^{k}	....	....	5,012	....	27	....
Heptane	C_7H_{16}	98.4^{k}	....	....	....	....	....	....

[a] Bur. Mines *Bull.* 88, 1915.

[b] HOLLEMAN, A. F.: Organic Chemistry, edited by A. J. Walker. P. 41, 1910.

[c] LANDOLT and BÖRNSTEIN: Physikalisch-chemische Tabellen, 3d ed. Pp. 416, 425, 1905. (J. Thomsen.)

[d] Gas at ordinary temperature.

[e] WRIGHT, L. T.: Illuminating Power of Methane. Chem. Soc. *Jour.*, vol. 47, p. 200, 1885.

[f] LANDOLT and BÖRNSTEIN: Physikalisch-chemische Tabellen, 3d ed. P. 185, 1905. (Dewar.)

[g] *Idem.* (Olzewski.)

[h] FRANKLAND, P.: Illuminating Power of Methane. *Jour.* Chem. Soc., vol. 47, 1885, p. 235.

[i] LANDOLT and BÖRNSTEIN: *op. cit.*, p. 182. (Dewar.)

[k] Liquid at ordinary temperature.

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[1] NORTHROP, J. D.: Gasoline from Natural Gas. U. S. Geol. Survey Mineral Resources, 1917, part 2, p. 1115, 1919.

NATURAL-GAS GASOLINE MARKETED IN THE UNITED STATES IN 1917[a]

State	Number of Operators	Plants		Gasoline Produced			Estimated Volume of Gas Treated	Average Yield of Gasoline per Thousand Cubic Feet of Gas
		Number	Daily Capacity	Quantity	Value	Price per Gallon		
			Gallons	Gallons		Cents	M Cu. Ft.	Gallons
Oklahoma....	167	234	492,436	115,123,424	21,541,905	18.71	84,719,941	1.359
West Virginia.	128	188	135,663	32,668,647	6,511,813	19.93	167,771,351	0.195
California....	45	49	99,761	28,817,604	4,438,022	15.40	45,351,247	0.635
Pennsylvania.	287	251	59,164	13,826,250	2,778,098	20.01	49,487,056	0.279
Texas........	10	11	32,550	6,920,405	1,149,441	16.61	12,677,216	0.546
Ohio........	49	61	25,137	5,439,560	1,051,376	19.33	30,062,141	0.181
Louisiana....	15	20	20,118	4,979,754	814,747	16.36	2,233,511	2.229
Illinois......	33	55	17,392	4,934,009	866,033	17.55	2,685,895	1.837
Kentucky....	5	5	13,400	3,818,209	763,186	19.99	24,915,946	0.153
Kansas......	4	6	4,642	1,174,980	241,219	20.53	9,315,339	0.126
New York.... Colorado.....	7	6	2,122	181,262	33,116	18.27	68,154	2.659
	750	886	902,385	217,884,104	40,188,956	18.45	429,287,797	0.508

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[a] U. S. Geol. Survey Mineral Resources, 1917, part 2, p. 1119, 1919.

CHAPTER VII

ORIGIN OF PETROLEUM AND NATURAL GAS

The theories of the origin of petroleum and inflammable natural gas are separated into two groups, which may be called the inorganic and the organic.

INORGANIC THEORIES

The theory that oil has been formed by inorganic processes has, in one form or another, been advocated by many chemists. (Their theses assume that waters or gases within the earth, acting on chemical compounds, generate the hydrocarbons which accumulate near the surface at favorable places.) This theory is attractive because it suggests processes by which oil may be continuously forming, the supplies being replenished in part as they are used. Notwithstanding its attractiveness the theory of inorganic origin has not been accepted by many geologists because of the insuperable difficulties which it encounters in the field. Petroleum reservoirs are generally tightly sealed. The rocks that have been nearest the interior of the earth, the igneous rocks and crystalline schists, are nearly everywhere barren of oil. The geologic settings of accumulations of petroleum offer the extreme antithesis to those of deposits of metals other than iron, which in the main are found near the centers of volcanism.

Berthelot[1] showed that carbon dioxide at high temperatures can react on free alkaline metals, which some have supposed the interior of the earth contains, and can yield acetylene, which would break down, forming higher hydrocarbons. He showed that acetylene heated to high temperatures yields benzine.

Mendelief[2] suggested that iron carbides are present in the interior of the earth, and that underground water coming into contact with these compounds yields hydrocarbons. This theory was sup-

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[1] Berthelot, P. E. M.: Sur l'Origine des Carbures et des Combustibles Minéraux. Compt. Rend., vol. 62, pp. 949-951, 1866.

[2] Mendelief, D.: Enstehung und Vorkommen des Mineralöls. Abstract by G. Wagner. Deutsch. Chem. Gesell. Ber., vol. 10, p. 229, 1877.

ported by Moissan[1] and others, who produced hydrocarbons from iron carbides.

These and other inorganic theories have been advanced. Becker[2] attempted to show a relation between areas of magnetic deflection due to the presence of iron carbides and oil fields. The improbability of his hypothesis has been pointed out by Tarr.[3] Coste[4] has defended the inorganic theory, but most of his assumptions are unsubstantiated.

Nitrogen is found in many samples of natural gas and petroleum. Nitrogen exists also in some mines that exploit deposits of the metals that have been formed in comparatively late geologic time and that are associated generically with igneous rocks.[5] It has been suggested that nitrogen found in natural gas is of deep-seated origin. This element, however, is widely distributed in nature and takes part in many biochemical processes. Mabery[6] found that samples of petroleum collected from widely separated regions all contained nitrogen compounds. It is present as pyridine and quinoline bases and their derivatives, and Mabery states that the association and composition of these substances are such that they could have originated only in plant and animal remains.

Inspection of Mabery's analyses with respect to the depth of the oil pools from which the samples came, shows the noteworthy fact that the deepest oils do not contain the most nitrogen, nor are those found nearest the surface much lower in nitrogen than those that are found in the deeper measures. The Paleozoic oils, which have probably been more deeply buried than those of later age, do not contain as much nitrogen as the Cretaceous and Tertiary oils. Of the oils Mabery analyzed, 13 are from Paleozoic and 8 from Tertiary and Cretaceous fields. The average nitrogen content of the

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[1] MOISSAN, H.: Sur la Formation des Carbures d'Hydrogène Gazeux et Liquides par l'Action de l'eau sur les Carbures Métalliques. Compt. Rend., vol. 122, pp. 1462-1467, 1896.

[2] BECKER, G. F.: Relations Between Local Magnetic Disturbances and the Genesis of Petroleum. U. S. Geol. Survey *Bull.* 401, pp. 1-24, 1909.

[3] TARR, W. A.: The Lack of Association of the Irregularities of the Lines of Magnetic Declination and the Petroleum Fields. Econ. Geology, vol. 7, pp. 647-661, 1912.

[4] COSTE, EUGENE: The Volcanic Origin of Oil. Am. Inst. Min. Eng. *Trans.*, vol. 35, pp. 288-297, 1905.

[5] EMMONS, W. H.: The Principles of Economic Geology. P. 285, 1918.

[6] MABERY, C. F.: The Genesis of Petroleum as Revealed by Its Nitrogen Constituents. Am. Chem. Soc. *Jour.*, vol. 41, No. 10, pp. 1690-1697, 1919.

Paleozoic oils is 0.061 per cent; that of the later oils, 0.104 per cent. These relations suggest that nitrogen compounds in petroleum break up with age, the nitrogen accumulating in gas associated with the petroleum.

NITROGEN CONTENT OF OILS[a]

PALEOZOIC OILS

No.	Locality	Rock Strata	Depth, Feet	Nitrogen, per Cent
1	Dudley, Ohio	Berea grit	1,400	0.027
2	Emlenton, Pennsylvania.	Rosenberg sand	1,240	0.0136
3	Malta, Ohio	First Cow Run sand	38	0.039
4	Corning, Ohio	Berea grit	1,150	0.410
5	Marietta, Ohio	Goose Run sand	150	0.016
6	Newport, Ohio	Berea grit	1,170	0.024
7	Cabin Creek, West Virginia	Berea grit	2,700	0.029
8	Titusville, Pennsylvania	Third sand	1,200	[b]0.014
9	Emlenton, Pennsylvania.	Third sand	1,080	0.0115
11	Bartlesville, Oklahoma	....	......	0.074
13	Mahoning Valley, Ohio	Pure quartz sand	150	0.049
14	Mecca, Ohio	Sand	150	0.054
20	Morris, Kansas	....	1,125	0.035

TERTIARY AND CRETACEOUS OILS

No.	Locality	Rock Strata	Depth, Feet	Nitrogen, per Cent
10	Humble field, Texas, medium	Sand	2,750	0.058
12	Vinton, Louisiana	....	2,750	0.067
15	Sour Lake, Texas	Sand	1,300	0.067
16	Beaumont, Texas	Sand	1,000	0.023
17	Jennings, Louisiana	Sand	2,000	0.480
18	Caddo, Louisiana	Sand	2,200	0.050
19	Humblefield, Texas, light.	....	950-1,300	0.015
21	Baku, Russia	Sand	......	0.071

[a] MABERY, C. F., *op cit.*, p. 1693. I have taken the liberty to rearrange Mabery's table.—W.H.E.

[b] Average of two determinations.

In some gases from the oil fields of the Mid-Continent region helium[1] is present with methane and nitrogen. Its presence has

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[1] CADY, H. P. and MCFARLANE, D. F.: Chemical Composition of Gas. Kansas Geol. Survey, vol. 9, pp. 228-302, 1908.

suggested to some investigators a deep-seated source of the gas and the oil associated with it. Little is known of the geologic occurrences of helium. The high molecular velocity of this light element renders plausible the hypothesis that it departs from the planet, and if so it was once more abundant in the earth than it is today.

ORGANIC THEORIES

The theory that petroleum is generated by natural distillation under geothermal and dynamic influences from organic matter buried in sediments was first suggested by Newberry[1] and by Orton.[2] Laboratory experiments that support this theory include those of Warren and Storer,[3] who prepared a calcium soap from menhaden oil which on distillation yielded a mixture of hydrocarbons like kerosene. Engler[4] distilled directly from menhaden oil the paraffins from pentane to nonane. Day[5] obtained by distilling a mixture of fresh herring and pine wood a product that yielded on redistillation a residue like gilsonite, and by distilling herring alone he obtained one like elaterite.

Clarke[6] mentions calculations made by Szajnocha which show that the annual catch of herring on the northeast coast of Germany could yield in 2,560 years as much oil as Galicia has produced.

Engler[7] obtained hydrocarbons by the distillation of vegetable oils. The theory that oil is derived principally from animal remains was supported by Engler[8] and by Hoefer[9], both well known for their investigations of the origin of petroleum.

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[1] Newberry, J. S.: Devonian System. Ohio Geol. Survey, vol. 1, p. 160, 1873.

[2] Orton, Edward: The Origin and Accumulation of Petroleum and Natural Gas. Ohio Geol. Survey, vol. 6, p. 74, 1888.

[3] Warren, C. M., and Storer, F. H.: Examination of a Hydrocarbon Naphtha Obtained from the Products of the Destructive Distillation of Lime Soap. Acad. Arts and Sci. Mem., 2d ser., vol. 9, p. 177, 1867.

[4] Engler, C.: Zur Bildung des Erdöls. Deutsch. Chem. Gesell. Ber., vol. 21, p. 1816, 1918.

[5] Day, W. C.: The Laboratory Production of Asphalts from Animal and Vegetable Materials. Am. Chem. *Jour.*, vol. 21, pp. 478-199, 1899.

[6] Clarke, F. W.: The Data of Geochemistry, 3d ed. U. S. Geol. Survey *Bull.* 616, p. 730, 1916. (The original paper is not accessible to me.)

[7] Engler, C.: Cong. Internat. du Pétrole, Paris, 1900, p. 20.

[8] Engler, C.: Zur Geschicte des Bildung des Erdöls. Deutsch. Chem. Gesell. Ber., vol. 33, pp. 7-21, 1900.

[9] Hoefer, H.: Das Erdöl, p. 219, 1906.

These experiments show that compounds like those found in petroleum may be derived from either animal or vegetable matter.

A theory that is accepted by many investigators today is that there are two stages[1] in the formation of petroleum from organic material. In one biochemical processes predominate; in the other geochemical or dynamochemical processes. Petroleum is believed to be derived from remains of plants, especially from those of low orders yielding waxy, fatty, gelatinous, or resinous substances, and from animal matter. The organic matter was deposited on the sea bottom in estuaries or not far from shore and in lakes. Through the action of anærobic bacteria it is changed, the cellulose probably being altered to other compounds and the waxes and fats set free. That plants of low orders, when distilled, can yield petroleum was demonstrated by Renault.[2] Prominence is given to such plants in the contributions by Dalton, White, and Winchester, mentioned elsewhere.

The probability that bacterial action plays a part in the reaction that yields petroleum was brought forward by Morrey.[3] That the source of the material is principally muds and shales is evident from the association of shales and clays with oil-bearing strata.

The anærobic bacteria are active probably as soon as the mud containing organic material is deposited. Any oily matter which they set free could accumulate even on the sea bottom, for fine particles of clay surround globules of oil and sink them[4] or hold them below water. Oil will not float long on water that is even slightly turbid. That is often shown on the Mississippi River near the Hennepin Avenue Bridge at Union Station, Minneapolis. Frequently oil is passed into the river from industrial operations. It covers the water for a few hundred feet along the river below the

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[1] DALTON, W. H.: On the Origin of Petroleum. Econ. Geology, vol. 4, pp. 603-631, 1909.

WHITE, DAVID: Some Relations in Origin Between Coal and Petroleum. Washington Acad. Sci. *Jour.*, vol. 5, pp. 189-212, 1915. Late Theories Regarding the Origin of Oil. Geol. Soc. America *Bull.*, vol. 28, pp. 727-734, 1917.

[2] RENAULT, B.: Houille et Bacteriaces. Soc. Hist. Nat. Autun. *Bull.*, vol. 9, pp. 475-500, 1896; Compt. Rend., vol. 117, p. 593, 1893.

[3] MORREY, C. B., and ORTON, EDWARD: Origin of Oil and Gas. Ohio Geol. Survey *Bull.* 1, p. 313, 1903.

[4] STUART, MURRAY: The Sedimentary Deposition of Oil. India Geol. Survey Rec., vol. 40, pp. 320-333, 1910.

bridge and disappears downstream. After they have sunk the oil the clay particles can hold it down permanently, and it will accumulate at the bottom of the water.

There are few data showing the depth at which bacterial action takes place in buried sediments. Sulphur bacteria, which break up sulphates, probably live very near the sea bottom. Murray and Irvine[1] show that sea water associated with the muds from the sea bottom contain less than half as much sulphate radicle as normal sea water. Shaw[2] states that anærobic bacteria have been reported to be present at depths of 20 feet in bogs.

Some processes that either generate oil from the strata or accumulate it are active for a long time after the burial of the deposits. This conclusion is warranted by the fact that oil accumulates under pressure in reservoirs on monoclines that have been sealed long after burial, either by faults, by dikes, or by later impermeable strata that are deposited above them unconformably. The oil that had formed before the top of the reservoir became sealed would have been expelled if it had been under water pressure or gas pressure at that time.

The anærobic bacteria that are supposed to effect the decomposition of cellulose in buried strata presumably work best in the presence of salt water. This is suggested by the fact that practically all productive petroleum deposits are found in marine strata or in beds closely associated with marine strata. Coal deposits, on the other hand, are formed principally in fresh water, and the beds most closely associated with them are in the main nonmarine.

The sulphur bacillus (*Bacillus sulphurens*) and the petroleum bacillus (*Micrococcus petroli*) probably work together. Both are anærobic. Sea water that has been buried is depleted of sulphates (p. 51), and some of it carries hydrogen sulphide. Native sulphur is often found in marine strata. Sulphur bacteria take oxygen from sulphates and set sulphur free.

Sulphur, or its compounds, is found in the petroleum of most fields, although in some fields it is present in very small amounts. It is abundant in the oils of the Lima-Indiana field, where it occurs as methyl sulphide $(CH_3)_2S$. Other sulphides of the paraffin

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[1] Murray, J., and Irvine, R.: On the Chemical Changes in the Composition of Sea Water. Roy. Soc. Edin. *Trans.*, vol. 37, pp. 481-57, 1895.

[2] Shaw, E. W.: The Rôle and Fate of Connate Water in Oil and Gas Sands (discussion). Am. Inst. Min. Eng. *Trans.*, vol. 51, p. 606, 1915

series have been identified.[1] Sulphur compounds have been identified in Canadian oils, and free sulphur occurs in a Texas oil. The sulphur in oils is probably derived from bodies of plants and animals, many of which contain sulphur, as well as from sea water.

Because practically all important accumulations of oil are in or near marine strata it is supposed that organic matter buried in the sea may be more readily converted into oil than organic matter buried in fresh water. Nevertheless, oil shales such as are supposed to have supplied some of the materials for the generation of petroleum are not all marine. The Green River oil shales contain remains of fresh-water shells.[2] Winchester suggests as probable the hypothesis that these shales were the sources of the great bitumen dikes and asphaltic sandstones that are present in rocks below and above them in the Uinta Basin.

In California several of the formations associated with the oil measures are diatomaceous. One of these formations, the Monterey shale, is made up almost entirely of diatom tests. It is more than 2,000 feet thick and is present in nearly every important field. The oil has accumulated in sandstones associated with the shale. As shown by Arnold[3] and his associates, the sandy members are generally barren except where diatomaceous shales are present.

Diatoms are free-moving vegetable organisms. They dwell in the sea and also in fresh waters. The larger number of species are marine. These live near the sea bottom and on free-floating plants, in the main of the plankton. Diatoms have siliceous tests made of two valves that fit together as a pill-box fits into its cover. They contain protoplasm much like that found in other algal cells, with chlorophyl, colored brown by diatomin. Their abundance, the composition stated, and their constant association with

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[1] Mabery, C. F., and Smith, A. W.: Sulphur Compounds in Ohio Petroleum. Am. Chem. *Jour.*, vol. 13, pp. 233-243, 1891.

[2] Winchester, D. E.: Oil Shale of the Uinta Basin, Northeastern Utah. U. S. Geol. Survey *Bull.* 691, pp. 26-50, 1919. Schuchert states that some of the shale deposits may be of saline lakes. Amer. Inst. Min. Eng. *Bull.* 155, p. 3060, 1919.

Prof. Chas. Schuchert suggests that the lake in which the Green River was deposited may have been salt at one time. Written communication.

[3] Arnold, Ralph, and Anderson, Robert: Geology and Oil Deposits of the Coalinga District, California. U. S. Geol. Survey *Bull.* 398, 1910.

Arnold, Ralph, and Johnson, H. R.: Preliminary Report on the McKittrick Oil Region. U. S. Geol. Survey *Bull.* 406, 1910.

oil-bearing strata in California have led Arnold to regard the dia toms as the principal sources of California oil and gas.

It has been suggested that "kerogen," the oil-yielding substance of oil shale is the product resulting from bacterial action on organic matter.[1] This substance is assumed by some to represent a common intermediate product, which may later, by dynamic metamorphism, be transformed to oil and gas.

Practically every body of oil-bearing strata in the world includes a considerable thickness of shales or clays, or of marls and clays. These rocks not only furnish the impermeable covers necessary to prevent the escape of oil or gas, but in general they supply the organic matter from which the oil and gas are derived. As a rule the oil and gas are found in sands or sandstones associated with shales or clays, or in fractured limestones or dolomites. In a great many districts the producing strata consist of great thicknesses of shales or clays, containing several relatively thin beds of sand. Such a body of strata is commonly formed near shore, under delta conditions, or offshore in water only moderately deep. Deep-sea conditions are presumably less favorable for the deposition of such beds. Twenhofel states that black hydrocarbonaceous shale may form in water so shallow that it is but a step to land conditions. In Esthonia, on the Baltic, there are a number of localities along the shores in which deposits of black shale are now forming.[2]

It is characteristic of a great many petroliferous regions that the strata change within short distances both laterally and vertically. Such changes are noteworthy in the oil fields of Burma, in the Apsheron region of the Caucasus, Russia, in the Appalachian oil fields, in Oklahoma, in California, and elsewhere. In some of the Burma fields one well section may differ greatly from that of a well a few rods away. Such abrupt changes in sediments are characteristic of near-shore conditions. In other fields, like those of Indiana, the strata are persistent, and sections of wells started at the same geologic horizon will resemble each other closely. All these data indicate that oil-bearing sediments form most abundantly in shallow water and to a less extent in deep water though not at abyssal depths.

[1] Steuart, D. R.: The Chemistry of Oil Shale; The Oil Shales of the Lothians. 2d ed., part 3, p. 164, Scotland Geol. Survey *Mem.*, 1912.

[2] Twenhofel, W. H: Notes on Black Shale in the Making. *Am. Jour. Sci.*, 4th ser., vol. 40, pp. 272-280, 1915.

While practically all of the petroliferous deposits of the world are associated with marine strata, it is possible that some have formed in saline lakes. Schuchert states that "kerogen" may be formed in saline lakes, probably in those only that are not over 4 per cent salt.[1]

ASSOCIATION OF PETROLIFEROUS STRATA AND COAL

It has been suggested[2] that oil is derived from the materials that form coal. "Coal oil" and kerosene distilled from petroleum are nearly related with respect to their physical properties. Pictet and Bouvier distilled from a coal from Montrambert, Loire, a tar in which they found $C_{10}H_{20}$ and $C_{11}H_{22}$, hydrocarbons identical with some separated from petroleums.

Coal has been formed in the main from vegetable matter deposited in fresh water. If vegetable matter deposited in fresh water can yield oil, a close association of coal deposits and of oil deposits would be expected. Methane gas is commonly associated with coals, and it is reasonable to suppose that heavier hydrocarbons also might be derived from coal-forming materials. They are formed when coke is made from coal. If there is a close generic relation between the formation of coals and the formation of oils, one should expect frequently to find oil-soaked coals and coal measures impregnated with oil, and also coal or lignite in the oil measures. The great coal-producing strata of the earth generally are not the oil-producing strata. Many of the oil-producing strata are nevertheless lignitic or closely associated with highly lignitic beds—more generally in Europe and Asia than in North America.

The oil-bearing series of Alsace, near Schwabweiler, passes into thin upper Oligocene sandstones, which alternate with coal seams 20 inches thick or less.[3] Carbonized plant remains are found in petroliferous saliferous sandstones in the Oligocene of the Bory-

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[1] Schuchert, Charles: Petroliferous Provinces. Discussion of a paper by E. G. Woodruff. Am. Inst. Min. Eng. *Bull.*, 155, pp. 3059-3060, 1919.

[2] Cunningham-Craig, E. H.: Origin of Oil and Shale. Royal Soc. Edinburgh *Proc.*, vol. 36, pp. 44-86, 1916.

Pictet, A. and Bouvier, M.: Ueber die Distillation der Steinkohle Unter Vermindertem Druck. *Deutsch. Chem. Gesell. Ber.*, 1913, pp. 33-42.

[3] Von Werveke, L.: Die Entstehung der Unterelsaessischen Erdoelager erlautert an der Schichtenfolge im Oligocaen. *Phil. Gesell. Elsass-Lothringen*, Mitt., Band 4, Heft 5, pp. 697-721, 1913.

slaw field of Galicia,[1] and also in the upper *Inoceramus* (Cretaceous) petroliferous beds of the Schodnica field. In Rumania, beds of lignite are found in the Pontian (Pliocene) in which petroleum also is present, possibly, however, as a result of infiltration from lower beds. The Burdigalian (Miocene) petroliferous sandstones of Rumania carry also beds of lignite. Coal fragments occur in the Pegu (Miocene) beds, which yield oil in the principal fields of Burma.[2] Some of the coal beds of Sumatra are petroliferous.

At Roma, Queensland, Australia, gas occurs in Jura-Trias rocks consisting of sandstones, shales, and thin coal seams.[3] Plant remains are found in the petroliferous rocks of Trinidad.[4]

In North America oil, coal, and lignite are geologically not so closely spaced, although many of the great oil fields are not far from the great fields of coal and lignite. The coal fields of the Appalachian region are mainly within the area bearing oil, but the principal oil-producing beds are below the coal-producing beds and separated from them by hundreds of feet of shales. The Ordovician and Devonian oils of Ohio, Indiana, Kentucky, Michigan, and Ontario are not closely associated with coals. The coal basin of Michigan lies above the Devonian strata. The coal measures of the Michigan coal basin possibly joined those of the Appalachian coal basin before the country was denuded by erosion. This, however, is uncertain. The Ohio-Indiana oil region was once probably overlain by coal.

In Illinois much oil is found in the coal series, but generally at geologic horizons below those of the coal. In the northeastern Oklahoma oil fields coal beds are found in the Pennsylvanian oil measures associated with the oil sands. In the Pawhuska quadrangle, as noted by Heald,[5] the upper Pennsylvanian rocks contain layers with marine fossils but are accompanied by some thin lenticular beds of coal and beds of clean, fine-grained swamp clays with plant remains that indicate swamp or land condi-

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[1] Zuber, Rudolf: Die Geologischen Verhältnisse von Boryslaw in Ostgalizien. *Zeitschr. Prakt. Geologie*, 1904, pp. 41-48.

[2] Pascoe, E. H.: The Oil Fields of Burma. India Geol. Survey *Mem.*, vol. 40, p. 234, 1912.

[3] Cameron, W. E.: Report on the Significance of a Flow of Gas in the Roma No. 2 Bore. Queensland Geol. Survey *Pub.*, 247, 1915.

[4] Cunningham-Craig, E. H.: Oil Finding, p. 13, London, 1914.

[5] Heald, K. C.: Geologic Structure of the Northwestern Part of the Pawhuska Quadrangle, Oklahoma. U. S. Geol. Survey *Bull.* 691, p. 61, 1919.

tions. Ripple marks, worm trails, mud cracks, and footprints of quadrupeds in some of the sandstones show that the materials forming the beds were laid down on tidal flats, flood plains, or other low places where they were not submerged at all times or where the water was very shallow. Some of the oil sands of northern Texas are in coal-bearing formations. In northern Louisiana oil sands are associated with lignitiferous strata. In Wyoming the principal oil measures are older than the Laramie coal-bearing formation and younger than the Dakota, which in places carries plant remains. In California there are no coal measures comparable to the oil measures. It is improbable that lignite has contributed any considerable portion of the materials from which the California oils were derived.

In brief, the organic materials that have formed coals and lignites may have contributed fractions that have accumulated as deposits of petroleum and gas. It is improbable, however, that the principal coal deposits have formed from the materials that have contributed the principal petroleum deposits. This is shown at many places by the presence of barren sands between the oil sands and coal beds. There are probably in all fields, moreover, other sources of organic matter adequate to have supplied petroleum.

ACCUMULATION OF PETROLEUM IN BEDS FORMED UNDER ARID CONDITIONS

Many petroliferous strata are closely associated with red beds, salt, and gypsum—strata that are assumed to have formed under arid conditions. This association is noteworthy, for arid conditions generally are not favorable to the accumulation of organic remains. Salt and gypsum in the main are formed in arms of the sea or precipitated in closed basins, such as do not exist in moist climates. Most marine organisms, moreover, will perish in salt solutions that are highly concentrated.

Not all red beds are associated with salt and gypsum. Red beds alone are not proof that the conditions were arid when they were formed. Many of the deserts of today are not conspicuously red. On the other hand, red beds are now being deposited as sediments at some places in moist regions.[1]

The red shales that are closely associated with many oil-bearing

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[1] Tomlinson, C. W.: The Origin of Red Beds. *Jour. Geology,* vol. 24, pp. 238-253, 1916.

series may have become red in part after the shales were deposited. Red oxide of iron may be formed from hydrated iron oxide by the dehydrating action of salt solutions,[1] just as anhydrite is formed from gypsum. This action may be brought about in a saturated solution of sodium chloride at a temperature not above 150° C. Concentrated salt solutions are common in oil fields.[2]

The association of oil deposits in many regions with beds formed under arid conditions is probably due in part to the porosity of sands formed under such conditions. In arid climates weathering is largely mechanical rather than chemical. The sands are likely to be clean and free from clay particles. Moreover, the wind-blown sands are commonly porous, because the wind sorts the quartz grains and clay particles. A desert sand, with round grains, free from clay, submerged and covered by marine organic clays, marls, or muds would afford an excellent reservoir for the accumulation of oil.

In the Appalachian region red sediments are closely associated with many of the oil and gas bearing beds. The Catskill series contains a considerable amount of red shale. Red shales of the Mauch Chunk inclose petroliferous beds. In places the "Clinton" sand of Ohio is red. In Illinois red shales are found in the Chester (Mississippian), which is oil bearing. In the Mid-Continent oil field red shales are associated with some of the productive sands. In the Appalachian region salt and gypsum are found in the Salina, which, however, is not intimately associated with the strata that yield the petroleum.

In some fields in Europe the petroliferous beds are associated closely with land sediments formed under arid conditions. In Alsace the petroliferous series consists in part of red marl, anhydrite, gypsum, and pyrite lenses. In some parts of the district coal seams are present. As stated by Von Werveke, the series is part marine and part non-marine. The conditions when it was laid down changed from marine to non-marine, terrestrial, and arid. Although the oil-bearing beds are associated with the arid land sediments, where anhydrite is present there is no oil in the sands.

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[1] Daubrèe, A.: Etudes et Expériences Synthétiques sur le Metamorphisme. *Annales des Mines,* 5th ser., vol. 16, p. 411, 1859; Smithsonian Inst. *Annual Rept.,* 1861, p. 270.

[2] Mills, R. V. A., and Wells, R. C.: The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas. U. S. Geol. Survey *Bull.* 693, p. 24, 1919.

In Galicia the Sarmatian strata (Miocene) consist of limestone, sandstone, sands, clays, and shales, with gypsiferous and saliferous clays in the lower part of the section. The Sarmatian Salifère is the oil-bearing series in the Boryslaw-Tustanowice field. In Rumania gypsum is found in the Tortonian and Helvetian of the Miocene. Both of these formations carry petroleum. The Sarmatian also carries petroleum in Rumania and is one of the petroliferous series of the Baku fields, Russia, where it is gypsiferous.

In Egypt, Miocene strata yield oil along the west coast of the Gulf of Suez. As stated by Hume, the oil-bearing strata are associated with great thicknesses of salt and gypsum beds.

In the Yenangyaung and Yenangyat-Singu fields, Burma, the oil-bearing series is the Pegu formation, of Miocene age, which is associated with red beds.

These associations are significant, yet practically all the oil-bearing series that contain beds formed under arid conditions include also, associated with red beds, or with red beds, salt, and gypsum, bodies of marine strata containing organic matter or remains of organic bodies, adequate to supply material for the formation of petroleum. Strata formed under arid conditions doubtless supply the favorable reservoirs rather than the sources of organic matter that yields petroleum.

TEMPERATURES OF OIL FIELDS

Temperatures increase with depths in the earth, in general at the rate of about 1° F. for 60 or 70 feet. Many observations have been made in mines and wells, and the results differ widely owing to differences in local conditions, such as ventilation in mines, the structure of the rocks, and the nearness to watercourses of points where observations have been taken. Temperatures are higher in some oil fields than elsewhere at similar depths. Koenigsberger and Muehlberg[1] have suggested that temperature gradients may be used in prospecting for oil. The differences in the gradients of oil fields are so great, however, that the value of their conclusions is somewhat problematic. Nevertheless, so far as is indicated by

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[1] Koenigsberger, Joh.: Normale und anormale Werte der Geothermischen Tiefenstufe. Centralbl. Mineralogie *Jahrbuch*, 1905, pp. 673-679.

Koenigsberger, Joh. and Mühlberg, Max: On the Measurements of the Increase of Temperature in Bore Holes. Inst. Min. Eng. (England) *Trans.*, vol. 39, pp. 617-644, 1910; Ueber Messungen der Geothermischen Tiefenstufe. *Neues Jahrb.*, Beilage Band 31, pp. 107-157, 1911.

data now available, the temperatures in oil fields are generally above normal. Rogers[1] has recently investigated this problem and has found a high gradient in the Sunset-Midway district, California.

Many factors affect the accuracy of observations of temperatures in borings and of fluids that are encountered in them. Expanding gases cool the fluids, and temperatures change somewhat as the fluids rise. These factors are discussed by Rogers.[2] So far as is indicated by data now available, temperatures generally increase more rapidly in Cretaceous and Tertiary oil fields than they do in older ones. That is not true everywhere, however, for the gradient in certain Rumanian fields, where the oils are found only in Tertiary strata, are lower than in the Bartlesville field, Oklahoma, where oil is derived from Pennsylvanian strata. The data available are not sufficient for generalization, although they indicate an attractive problem for study.

There is little exact data indicating the temperatures that formerly existed in oil fields. Some of the Sunset-Midway oils of California are over 120° F. and, according to Pack,[3] were probably hotter at times of migration.

Willis[4] states that the lowest strata of the Appalachian geosyncline when deeply buried probably had a temperature of about 200° C.

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[1] Rogers, G. S.: The Sunset-Midway Oil Field, California, part 2. U. S. Geol. Survey *Prof. Paper* 117, pp. 37-42, 1919.

[2] *Op. cit.*, pp. 42-43.

[3] Pack, R. W.: The Sunset-Midway Oil Field, California. U. S. Geol. Survey *Prof. Paper* 116, p. 74, 1920.

[4] Willis, Bailey: Geologic Distillation of Petroleum. *Bull. Amer. Inst. Min. Eng.* No. 157. sec. 10, pp. 1-7, 1920.

GEOTHERMAL GRADIENT IN OIL FIELDS AND IN OTHER REGIONS[a]

	Depth of Well	Temperature at Bottom	Depth per Degree of Increase in Temperature	Remarks	Observer
	Feet	Deg. F.	Feet		
Oil fields:					
Sunset-Midway, California	1,470-3,870	97-131	41.0	Based on average of corrected temperature of water in 9 wells in western part of field	Rogers
Bartlesville, Oklahoma	1,275	84	51.0	Oil well	Woodruff[b]
Batson, Texas	1,100	101	34.5	Oil and water well	Fenneman[c]
Florence, Colorado	......	......	44.0	Based on average temperature of oil produced by many wells	Washburne[d]
Findlay, Ohio	3,000	82.1	95.8	Precise measurements	Johnston[e]
Wheeling, West Virginia	4,462	110.15	75.2	Precise measurements in dry hole	Hallock[f]
Vera Cruz, Mexico	2,276	122.9	48.6	Furbero oil field	Mühlberg[g]
Pechelbronn, Alsace	1,692	......	25.3-38.3	Asphaltic shale oil	Branca[h]
Campina, Rumania	2,726	99.3	54.7	Dry hole	Tanasescu[i]
Lucaceşti-Zemes, Rumania	1,575	70.7	69.8	Oil and water well	Tanasescu[i]
Bibi-Eibat, Apsheron Peninsula, Russia	2,695	114.5	47.7	Thermometer submerged for 11 hours in oil well	Goloubjatnikov[j]
Samarinda, Borneo	2,214	......	51.0	Oil well producing light paraffin oil	Mühlberg[g]
Echigo, Japan	2,381	118.6	39.2	....	Kawamura[k]
Other districts:					
Bay City, Michigan	3,455	97.0	68.5	....	Lane[l]
Charleston, South Carolina	2,001	99.7	57.5	Temperature of outflowing water	Knapp[m]
Ames, Iowa	2,100	63.4	129.6	Precise measurements	Beyer[n]
Maris, Holland	4,265	138	50.5	Precise measurements	Beyer[o]
Schladebach, Germany	5,630	133.9	67.2	Precise measurements	Dunker[p]
Paruschowitz, Germany	6,427	156.7	62.1	Precise measurements	Henrich[q]

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[a] ROGERS, G. S.: The Sunset-Midway Oil Field, California, part 2. U. S. Geol. Survey *Prof. Paper* 117, p. 41, 1919.

[b] Personally communicated by N. H. DARTON.

[c] FENNEMAN, N. M.: Oil Fields of the Texas-Louisiana Gulf Coastal Plain. U. S. Geol. Survey *Bull.* 282, p. 56, 1906.

[d] WASHBURNE, C. W.: The Florence Oil Field, Colorado. U. S. Geol. Survey *Bull.* 381, p. 530, 1910.

[e] JOHNSTON, JOHN, and ADAMS, L. H.: On the Measurement of Temperatures in Bore Holes. *Econ. Geology*, vol. 11, p. 741, 1916.

[f] HALLOCK, WILLIAM: Deep Well at Wheeling, West Virginia. *Am. Jour. Sci.*, 3d ser., vol. 43, pp. 234-236, 1892; School of Mine *Quart.*, vol. 18, pp. 148-153, 1897.

[g] Konigsberger, J., and Mühlberg, M.: On Measurements of the Increase of Temperature in Bore Holes.. Inst. Min. Eng. (England) *Trans.*, vol. 39, pp. 617-644, 1910

[h] Branca, W.: Ver. Naturkunde in Württemberg Jahreshefte, 1897, p. 42.

[i] Tanasescu, I.: Etudés Préliminaries sur le Régime Thermique. Inst. Geol. Romanei *Annarul*, vol. 5, iasc. 1a, p. 111, 1912.

[j] Goloubjatnikov, D.: Observations Géothermiques a Bibi-Eibat et Sourakhany (in Russian). Com. Géol. Mém., nouv. sér., livr. 141, p. 32, 1916. The observation cited is close to the average of several hundred careful measurements. The average gradient in the neighboring Sourakhany field is 44.5.

[k] Kawamura: On the Geothermic Gradient in the Echigo Oil Fields, Japan (in Japanese). Geol. Soc. Tokio *Jour.*, vol. 19, pp. 179-185, 222-227, 1912.

[l] Lane, A. C.: The Geothermal Gradient in Michigan. *Am. Jour. Sci.*, 4th ser., vol. 9, p. 435, 1900.

[m] Stephenson, L. W.: A Deep Well at Charleston, South Carolina. U. S. Geol. Survey *Prof. Paper* 90, p. 70, 1915.

[n] Beyer, S. W.: Iowa Agricultural College Water Supply, pp. 13-14, Ames, 1897.

[o] Temperatur-Metingen in Diepe Boorgaten. *Ryksopsporing van Delfstoffen Jaarverslag*, 1912, pp. 27-28.

[p] Dunker, E.: Ueber die Temperatur-Beobachtungen im Bohrloche zu Schladebach. *Neues Jahrb.*, 1889, Band 1, pp. 29-47.

[q] Henrich, F.: Ueber die Temperaturverhältnisse in dem Bohrloch Paruschowitz V. *Zeitschr. prakt. Geologie.* vol. 12, pp. 316-320, 1904.

CHAPTER VIII

MAPS AND LOGS

STRUCTURAL CONTOUR MAPS

Structural contour maps are used extensively in mapping oil fields. They show approximately, by contours, the position of a bed or horizon over the entire area mapped, and one familiar with their use may picture the structure from them at a glance. As a rule it is not possible to map a bed or horizon over a large folded area. At some places it may be removed by erosion; at others it may be concealed. Its outcrops are mapped and their elevations noted at many places, with the dip and strike (Fig. 14). Its positions in wells are also recorded. Where it has been removed by erosion any bed below it that is now exposed is noted, and the former position of the bed to be mapped is estimated from its distance above the exposed bed in the geologic column as determined within or near the area.

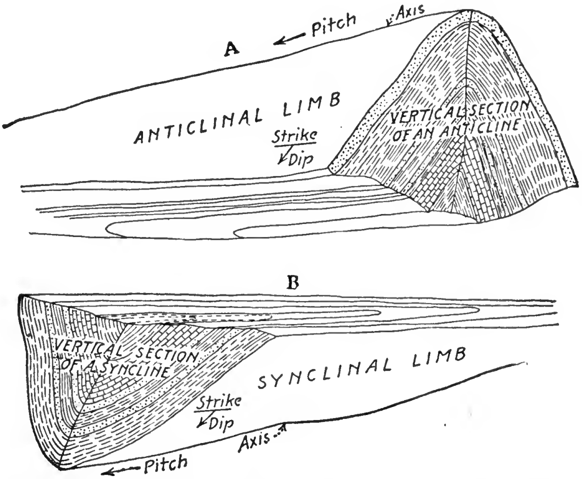

FIG. 14.—Sketches showing parts of folds. (*After Willis.*)

If the structure is domatic the contours will "close," or pass all the way around the dome. Such a fold is called a "closed fold."

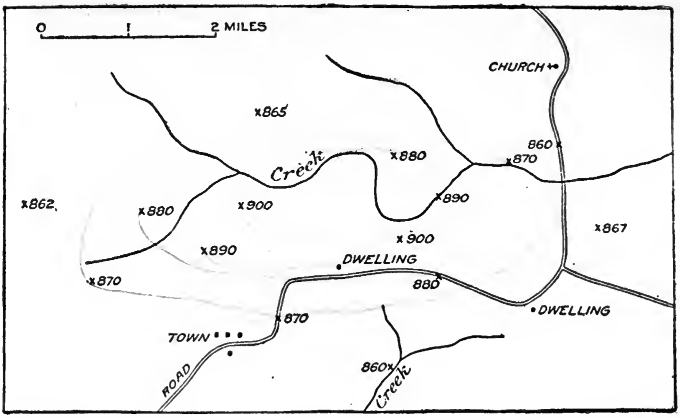

FIG. 15.—Sketch map showing elevation of the same stratum at different points, marked by crosses. (*After Gardner.*)

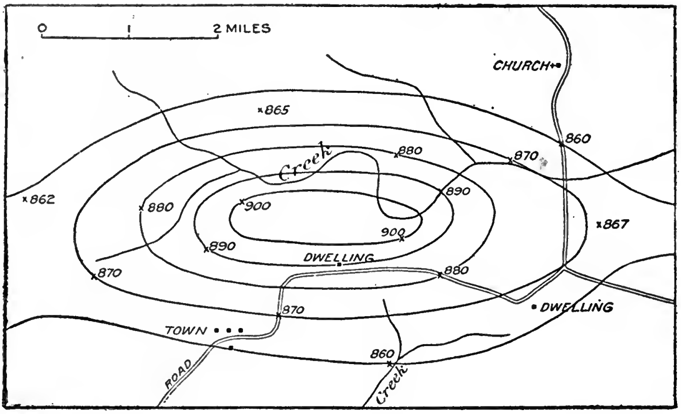

FIG. 16.—Sketch map showing elevations of same stratum at different points marked by crosses as in Fig. 15. The structure contours are drawn connecting points of equal elevation, thus outlining an elongated dome. (*After Gardner.*)

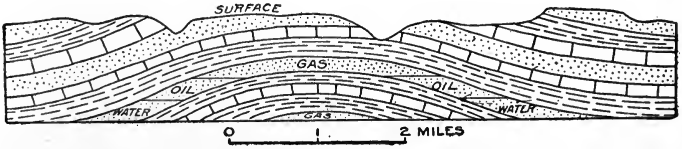

FIG. 17.—Lengthwise section of elongated dome shown in Fig. 16, vertical scale greatly exaggerated. (*After Gardner.*)

Fig. 15 is a sketch showing elevations of the same stratum or horizon at different places. Fig. 16 is a sketch of the same area

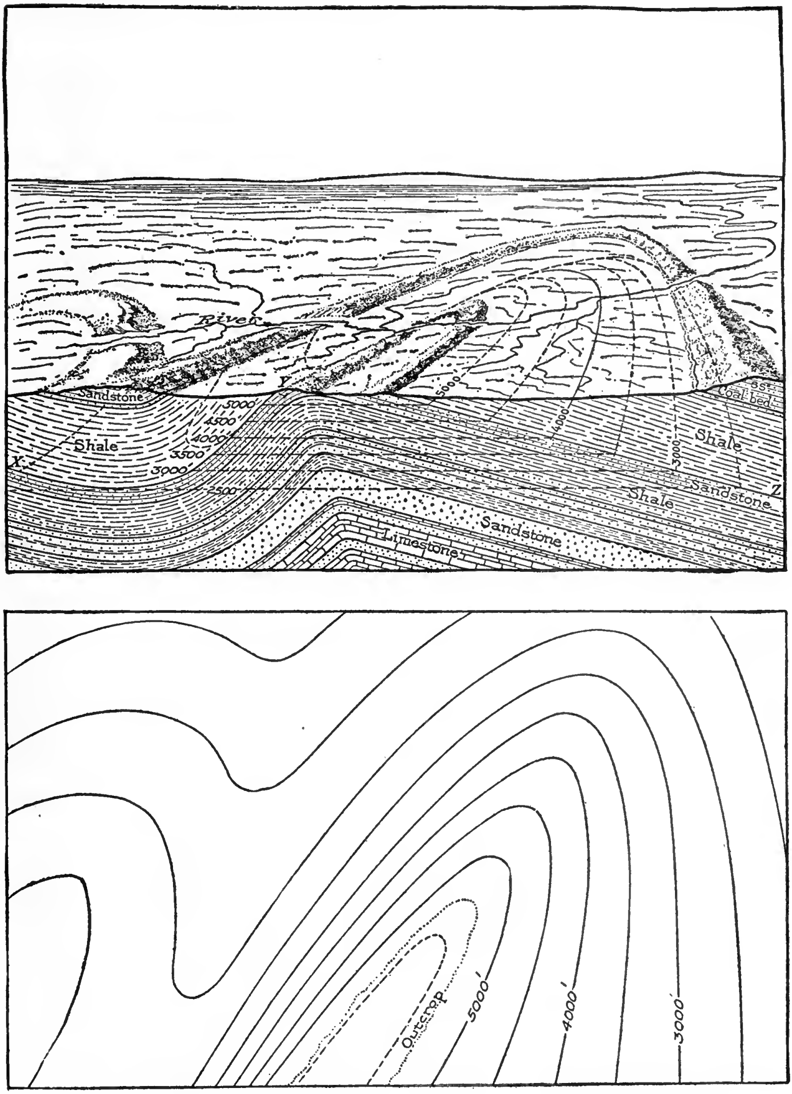

Fig. 18.—Cross section and sketch of an anticline illustrating the use of structure contours (*above.*) Structure contour map of the same anticline is shown below. The structure contours are drawn on the top of sandstone X Y Z. (*After Hewett and Lupton.*)

with structural contours drawn to connect points of equal elevation. It outlines an elongated dome, or anticline, with at least 30 feet of closure. Fig. 17 is a lengthwise section of the anticline, in which the vertical scale is greatly exaggerated.

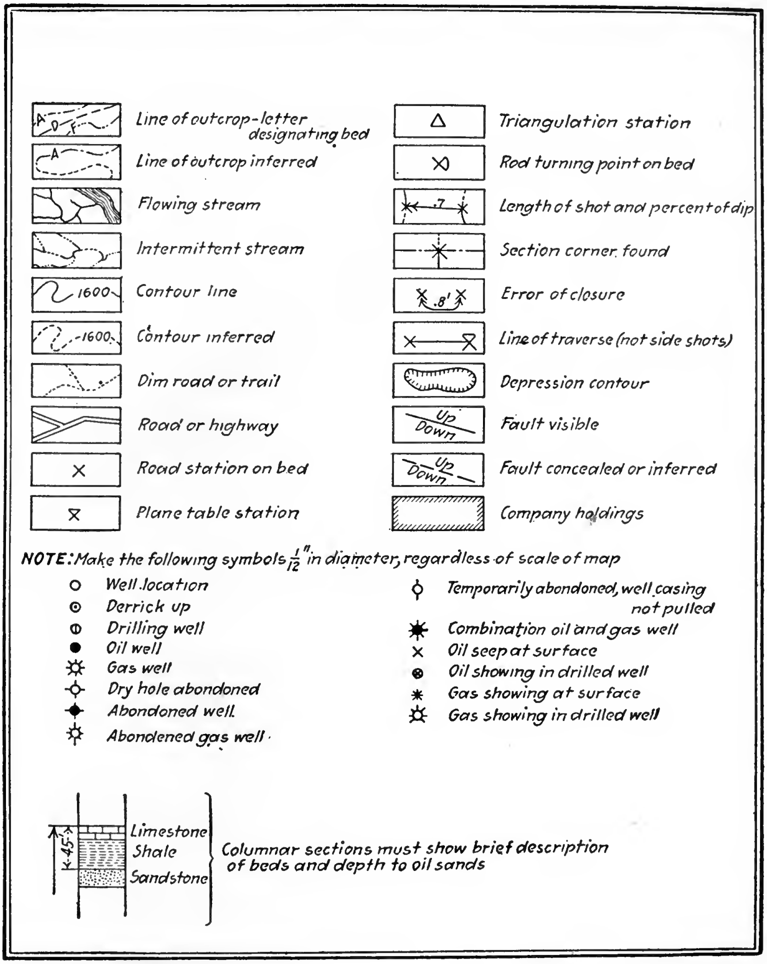

FIG. 19.—Symbols commonly used on field maps. (*After Woodruff.*)

In ordinary mapping of beds having complicated structure it is not regarded good practice to use a vertical scale on the cross section that is different from the horizontal scale, because it gives a distorted picture of the structure. For mapping flat-lying rocks, however, this practice is necessary. In some fields the folds are so low that they can not be shown on a true scale. If a contour map is used to depict the structure, together with the section, the amount of exaggeration is instantly apparent.

In some fields the relation of oil and gas accumulations to structure is very close. On the presence of a closure of 30 feet may depend the localization of 30 feet of sand saturated with oil or gas.

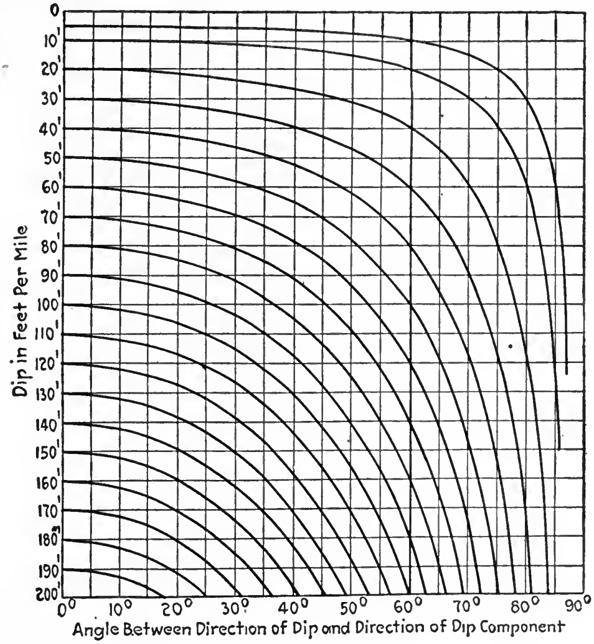

FIG. 20.—Chart for determining the amount of true dip, when components are known, on lines oblique to line of dip. Horizontal lines represent true dip, curved lines represent dip components. (*After Lahee.*)

The mapping is done as accurately as is possible, with instruments of precision.

Small domes like that shown in Fig. 16 are typically developed in the oil fields of Oklahoma and Kansas. In fields in mountainous countries the structural features are larger and the dips steeper. Fig. 18 shows a sketch and cross section of an anticline, with a contour map.

It is desirable that as far as practicable the same symbols be used on different maps. Fig. 19 is a chart prepared by E. G. Woodruff, showing symbols that are commonly used.

When the true direction of dip of a bed and the differences in elevations of the bed in different wells are known, it is frequently desirable to determine the amount of dip. Fig. 20 is a chart prepared by F. H. Lahee for this purpose. Suppose two well logs show a difference in elevation of a certain bed amounting to 30 feet to a mile in a direction N. 40° E. The true dip is known to be N. 80° E. The angle between the true dip and the dip component is 40°. The intersection of the vertical line marked "40°" with the curve marked "30'" indicates that the amount of the true dip between the two wells is about 40 feet to the mile.

In many fields, formations above the oil-bearing strata have the forms of flat-lying wedges, or are tabular bodies thicker at some places than at others, varying irregularly. To show these variations the convergence sheet is used. Such sheets are frequently made on transparent paper or cloth and placed above the map. The depth of the oil sand may then be readily estimated where the out-cropping horizons and elevation are accurately plotted. In the Appalachian region the Devonian rocks increase gradually from Ohio eastward. The rate of increase is shown by the parallel lines in Fig. 101, after I. C. White. These lines show the convergence of the strata from east to west. The convergence sheet is used in drawing structural contours on the key bed, or on the oil-bearing stratum.

WELL LOGS

Well logs are utilized when they are accessible. In fields covered with mantle rock these supply most of the detailed information. Some companies provide for samples to be taken, at regular intervals, from the holes, but as a rule the written well records only are accessible. That is particularly true in the United States where most fields are developed by two or more companies, and where, generally, there is a courteous interchange of such data. The driller's log depends principally upon the erudition of the driller and his previous experience. He often carries the names of rocks encountered in one district to another perhaps far removed, and in different surroundings. The rocks encountered with the cable or impact drill may be recorded differently when encountered with the rotary drill which progresses by abrasion.

A "hard rock" is generally one that is hard to make progress in.

If the cable system is used, a stratum of gypsum might be classed as a hard rock because it is elastic and not readily broken by blows, whereas a hard, brittle limestone which is easily drilled would be classed as "soft." The gypsum would be classed as soft if the rotary system is used, because it is readily cut, whereas the limestone which resists abrasion would be hard.[1]

"Slates" are reported in most logs of wells that are driven through argillaceous rocks that are more consolidated than clays or soft shales. Oil sands are rocks that contain oil, whether sands, sandstones, limestones, or dolomites.

With the rotary drill, a formation is "sticky" which cuts in large pieces that adhere to the bit and drill pipe. A formation that is sticky with the rotary is usually sticky with the cable tools. On the other hand, formations are encountered in which the cable tools stick, owing either to the elasticity of the formation or to the fact that the drilled-up particles do not mix readily with the water in the hole and settle so quickly as to stick the bit. These formations might not appear sticky to the rotary driller.

The term "sandy" may be used accurately by the cable-tool driller. He obtains samples of the formation through which he passes, of sufficient size to determine the relative amount of sand to clay or sand to shale in any formation. In the case of the rotary drill, this term is misleading. The rotary well is drilled with the aid of a "mud" of varying density. It is usually a mixture of clay, sand, and water. It often contains as high as 40 to 50 per cent sand. As stated by Knapp, any change in the density of the mud changes its capacity to carry sand. Even a small shower falling on the slush pit will change the density enough to cause some of the suspended sand to be precipitated. These properties of the mud lead to error in the observation of the formation. If a clay formation containing a moderate amount of sand is encountered while drilling in a mud low in sand content, the mud will absorb most of the sand, which will not settle out in the overflow ditch and its presence in the formation will not be noted, if not felt by the action of the bit in drilling. If, some time later, the mud is thinned by adding water this sand will appear in the overflow and may be attributed to a formation many feet below the one from which it actually originated.

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[1] KNAPP, A.: Rock Classification from the Oil-driller's Standpoint. *Mining and Metallurgy*, sec. 26, No. 158, pp. 1-6, February, 1920.

The so-called "jigging" action of the rising column of mud on the sand or cuttings also leads to misinterpretation. The deeper the drill, the finer the sand in cuttings brought to the surface by mud. As stated by Knapp, the coarser particles are pounded into the walls of the well or broken.

A change in the speed of pumping the mud also causes a change in the amount and size of the cuttings that appear at the surface. Thus, in the case of the rotary, "sandy" may have little or no meaning when applied to a formation. The term sandy is often used in contradistinction to sticky. A formation that drills easily and is not sticky is often recorded as sandy because sand tends to decrease stickiness.

A wet specimen, fresh from the hole, has a different color from the same specimen dried. Many specimens, when dried, bleach. Many of them air slack or oxidize. The terms light and dark should be used only for the extremes. They are, in general, relative. A sample of wet shale examined under an electric light might appear darker than in daylight. The terms indicating shades are more definite than light and dark, and are recommended by Knapp.

Clay is readily recognized by the "feel of the bit" while drilling with either cable tools or rotary. To some drillers all clay is gumbo while to others gumbo is only sticky clay. Some clays have the property of cutting in large pieces but do not adhere excessively to the bit and drill pipe and are designated as "tough."

Free, uncemented sand is easily recognized by the feel of the tools in both systems of drilling. "Packed sand" is a sand that is slightly cemented with some soft, easily-broken cementing material, such as calcium carbonate. It cuts, when drilled with a rotary, with much the same feeling as when cutting crayon with a knife. The cementing material is dissolved or broken before reaching the surface, so that the driller finds only sand in the overflow. A microscopic examination of sands from the overflow often shows cementing material to be present when not suspected by the action of the bit.

A quicksand is one that caves or sticks the tools; a heaving sand is one that rises in the bore. A "shell" may be the test of an organism or a thin layer of any kind of sedimentary rock.

Rock Classification (After Knapp)

General Class	Rotary-drillers' Term	Use in Rotary System	Cable-drillers' Term	Use in Cable-tool System	Technical Equivalent
Sands................	Sand	Any uncemented sand.	Sand	Any uncemented sand; also many slightly cemented sands or very porous formations.	Sand
	Water sand	Sands, the samples of which appear clean and bright. Sands tested and found to produce water.	Water sand	Sands producing water.	Sand
	Quicksand	Sands that cave and settle rapidly.	Quicksand	Sands that cave and settle rapidly.	Sand
	Heaving sand	Sands that cave and are forced up the hole.	Heaving sand	Sands that cave and are forced up the hole.	Sand
	Oil sand	Sands or other porous formations containing oil.	Oil sand	Sand or other porous formations containing oil.	Oil sand
	Gas sand	Sands or other porous formations containing gas.	Gas sand	Sand or other porous formations containing gas.	Gas sand
Gravel, boulders........	Gravel	Any formation having the feel of gravel while drilling.	Gravel	Correctly used.	Gravel
	Boulders	Large loose pieces of any formation.	Boulders	Correctly used.	Boulders
Clay, shale............	Clay	Clay or soft shale; usually not sticky.	Clay	Correctly used.	Clay, or sandy clay
	Gumbo	Soft, sticky clay.	Gumbo	Soft, sticky clay.	Clay
	Shale	Formations having parallel bedding.	Shale	Consolidated clays.	Shale
Consolidated formations.	Rock	Any consolidated formation.	Rock	Term not used.	Rock
	Gas rock	Any rock formation containing gas.	Gas rock	Term not used.	Rock
	Chalk rock	Applied to light-colored chalk only.	Chalk rock	Correctly used.	Chalk
	Sand rock sandstone	Terms used interchangeably for all cemented formation.	Sandstone	Correctly used.	Sandstone
	Packed sand	Loosely cemented sand.	Packed sand	Correctly used.	Sandstone
	Shell	Thin layer of hard material.	Shell	Thin layer of hard material.	Rock
	Shell rock	Any consolidated formation containing fossil shells.	Rock with shells	Formation containing shells.	Rock with shells
	Flint or flinty rock	Any very brittle rock.	Flint or flinty rock	Correctly used.	Flint
	Limestone	Limestone, also hard shale.	Limestone	Correctly used.	Limestone.
	Lignite	All fossil wood.	Lignite	Correctly used.	Lignite or fossil wood
	Gypsum	Correctly used when recognized also reported as limestone or shale or sticky gumbo.	Gypsum	Correctly used.	Gypsum
Miscellaneous..........	Shells	Fossil shells	Shells	Fossil shells.	Fossil shells

CHAPTER IX

ACCUMULATION OF PETROLEUM

Water, oil, and gas in porous strata tend to arrange themselves in accordance with their density—the oil above the water and the gas above the oil (Fig. 21). In folded rocks that are saturated with water, oil, and gas, the oil and gas rise to the crests of the upfolds, or anticlines, and the water is found on the flanks of the anticlines and in synclines. If the rocks are dry the oil is found low on the folds or in synclines. If some water is present, the oil floats on the water and will be found low on the anticlines, its position depending on the amount of water present. On monoclines that are sealed the oil rises above the water, and the gas above the oil.

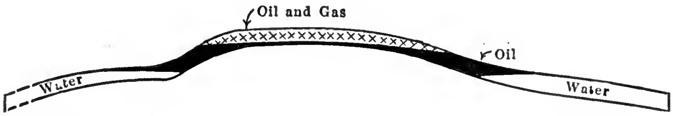

Fig. 21.—Section through Bartlesville sand, Cushing field, Oklahoma. (*After Beal.*)

THE ANTICLINAL THEORY

The theory of gravitational arrangement according to density is generally referred to as the anticlinal theory or the structural theory. This theory was formulated as a result of work in the Appalachian field of the United States and in the Ontario field. It is doubtful, however, whether the theory meets so many difficulties in any other large oil field in the world, as in the Appalachian region, where many of the sands are not saturated with water. In these sands the oil is found far down on the flanks of the anticlines and in synclines. At some places, especially in the well-known fields in Pennsylvania near Pittsburgh, these sands are very productive, and it was natural that the theory should have met a lack of enthusiasm where pronounced exceptions to it were so prominently displayed.

The fact that oil and gas and water will separate by gravity was first noted in America[1] by Andrews[2] and by Hunt.[3] Andrews had studied the Burning Springs-Volcano anticline of West Virginia, and Hunt the Petrolia and Oil Springs domes of Lambton County, Ontario. In these localities the segregation of oil and its accumulation at the tops of domes is very marked. (See Figs. 13 and 26.)

Alexander Winchell and J. S. Newberry gave the theory a more definite form. Winchell[4] based his conclusions chiefly on the relations he had observed in Ontario, and Newberry[5] on the areas in western Pennsylvania, West Virginia, and eastern Ohio. In the years immediately following these discussions the theory made little progress. The fields of Pennsylvania were then being developed, and in these fields many of the accumulations are in synclines. Lesley[6] and his associates of the Pennsylvania Geological Survey opposed the anticlinal theory. The theory was discredited in many quarters, because so many exceptions to it had been found. I. C. White[7] revived it, worked out many problems nearly related to it, and was probably the first investigator to use it in a practical way.

Orton agreed with White as to his main contention and soon after the discovery of oil in the Trenton fields of Ohio and Indiana made a survey of the fields and found that accumulations were on or near anticlinal axes and on terraces, or "arrested anti-

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[1] ENGLER and HOEFER state that Oldham recognized a connection between the anticline and oil accumulation at Yenangyaung in 1855 (*Das Erdoel*, Band 2, p. 18).

[2] ANDREWS, E. B.: Rock Oil, Its Relations and Distribution. *Am. Jour. Sci.*, 2d ser., vol. 32, pp. 85-91, 1861.

[3] HUNT, T. S.: Notes on the Geology of Petroleum or Rock Oil. Canadian *Naturalist*, vol. 6, pp. 241-255, 1861.

[4] WINCHELL, ALEXANDER: On the Oil Formation in Michigan and Elsewhere. *Am. Jour. Sci.*, 2d ser., vol. 39, p. 352, 1865; Something About Petroleum, in Sketches of Creation, Harper & Brother, 1870; also notes in appendix about initial production of Ontario wells.

[5] NEWBERRY, J. S.: Devonian System. Ohio Geol. Survey, vol. 1, p. 160, 1873.

[6] LESLEY, J. P.: Geology of the Pittsburgh Coal Region. Am. Inst. Min. Eng. *Trans.*, vol. 14, pp. 654-655, 1886.

ASHBURNER, C. A.: The Production and Exhaustion of the Oil Regions of Pennsylvania and New York. Am. Inst. Min. Eng. *Trans.*, vol. 14, pp. 419-428, 1886; The Geology of Natural Gas. *Idem*, p. 434.

[7] WHITE, I. C.: The Geology of Natural Gas. *Science*, vol. 6, June 26, 1885; Petroleum and Natural Gas. West Virginia Geol. Survey, vol. A, pp. 48-64, 1904 (a reprint and amplification of the first paper).

clines," where there was a flattening of the northward dip of the strata.[1] Later Orton published a monograph on the Lima-Indiana field.[2] In this paper he amplified his former discoveries and presented a map,[3] which is probably the first contour map drawn for the purpose of showing structure in an oil field. This report marks a decided advance in geologic methods applied to mapping the structure of oil fields. It was followed by a series of brilliant papers by men engaged in the survey of the Appalachian oil region by the United States and Pennsylvania geological surveys. under the direction of Campbell. These reports and the structural contour maps accompanying them have shown that oil and gas occur at the tops of structural uplifts in saturated rocks and lower in unsaturated rocks. Woolsey[4] in 1906 noted that the oil was found high in anticlines where the beds contain water and in the hollows of synclines where they do not. F. G. Clapp[5] and Stone and Clapp[6] investigated further the occurrence and relations of oil, gas, and water in unsaturated synclines. Griswold and Munn[7] in 1907 made a detailed report on a large area in southwestern Pennsylvania in which the oil in the saturated rocks, the Big Injun sand and beds above it was found in the higher parts of anticlines, and that in the unsaturated rocks, the Squaw sand and those below it, on the flanks of anticlines and in synclines. (See Fig. 63.) They suggested the hypothesis that the unsaturated rocks had formerly been saturated and partly drained. Later Reeves[8] reviewed the problem and noted that the unsaturated

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[1] ORTON, EDWARD: The Origin and Accumulation of Petroleum and Natural Gas. Ohio Geol. Survey, vol. 6, p. 94, 1888.

[2] ORTON, EDWARD: The Trenton Limestone as a Source of Petroleum and Inflammable Gas in Ohio and Indiana. U. S. Geol. Survey *Eighth Ann. Rept.*, part 2, pp. 475-662, 1889.

[3] *Idem*, pl. 55, opp. p. 548.

[4] WOOLSEY, L. H.: Economic Geology of the Beaver Quadrangle, Pennsylvania. U. S. Geol. Survey *Bull.* 286, p. 81, 1906.

[5] CLAPP, F. G.: Economic Geology of the Amity Quadrangle, Pennsylvania. U. S. Geol. Survey *Bull.* 300, pp. 1-145, 1907.

[6] STONE, R. W., and CLAPP, F. G.: Oil and Gas of Greene County, Pennsylvania. U. S. Geol. Survey *Bull.* 304, pp. 79-82, 1907.

[7] GRISWOLD, W. T. and MUNN, M. J.: Geology of the Steubenville, Burgettstown, and Claysville Quadrangles, Ohio, West Virginia, and Pennsylvania. U. S. Geol. Survey *Bull.* 318, 1907.

[8] REEVES, FRANK: The Absence of Water in Certain Sandstones of Appalachian Oil Fields. *Econ. Geology*, vol. 12, pp. 354-378, 1917.

rocks in the Catskill of the Devonian are a fresh-water or terriginous series that was probably dry when buried below the sea. He recorded great flows of salt water from deep wells below the Devonian, opposing suggestions made earlier that the Catskill rocks had dried out after being buried.

During the development of the California oil fields, Arnold and his associates worked out the structural details of accumulations. They found that the principal oil pools are on anticlines and monoclines sealed with asphalt or by faults.[1]

Later the structural relations in the Illinois fields were found to accord with the gravitational theory. The accumulations of the Kansas, Oklahoma, Texas, Louisiana and Wyoming fields were found to be in accord with it except where the rocks are dry. Some of the deposits are found in sealed monoclines or terraces, but the gravitational arrangement[2] is in general clearly expressed. Nearly every governmental report on an oil field in any country that has been published in recent years discusses the relations of the accumulation to structure. These relations are treated elsewhere (pp. 120-169).

The differences in the surface tension of oil and water cause them to separate, the oil and gas occupying the large spaces and the water the smaller ones. This segregation, as pointed out by Washburne,[3] attends gravitational separation, and its influence has been noted in many fields (p. 112).

The theory of gravitational separation of gas, oil, and water is demonstrated in so many fields, so widely separated, and under so many different conditions that additional proof is not required to substantiate it. The gas is above, and with the oil, and generally both are above salt water. This arrangement is modified by capil-

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[1] Arnold, Ralph and Anderson, Robert: Geology and Oil Resources of the Coalinga District, California. U. S. Geol. Survey *Bull.* 398, pp. 1-354, 1910.

Arnold, Ralph and Johnson, H. R.: Preliminary Report on the McKittrick-Sunset Oil Region, Kern and San Luis Obispo Counties, California. U. S. Geol. Survey *Bull.* 406, pp. 1-225, 1910.

Eldridge, G. H., and Arnold, Ralph: The Santa Clara Valley, Puente Hills, and Los Angeles Districts, Southern California. U. S. Geol. Survey *Bull.* 309, pp. 1-266, 1907.

[2] Clapp, F. G.: Revision of the Structural Classification of Petroleum and Natural Gas Fields. Geol. Soc. America *Bull.*, vol. 28, pp. 553-602, 1916.

[3] Washburne, C. W.: The Capillary Concentration of Gas and Oil. Am. Inst. Min. Eng. *Bull.* 93, pp. 2365-2378, 1914.

lary attraction. Where there are great differences in the sizes of the openings that constitute the reservoirs, the water clings tenaciously to the smaller openings, and the larger ones are filled with oil and gas. To some, however, this theory appears inadequate. In many fields the line between water and oil is not level. The amount of oil that can be removed from a reservoir is estimated to be 10 to 75 per cent[1] of that originally contained. In some porous sandstones so much oil remains that after drying they contain from 4 to 8 per cent or more of bitumen. Originally the oil sands must have contained much less than 4 per cent, for in many fields the expanses of the "dry" oil sands are at least 20 times as great as the producing areas. The unproductive parts of the oil sands, moreover, are either essentially barren of oil or contain much less than the parts that have been drained by man. Evidently nature's process of accumulating an oil pool is more efficient than man's process of draining it.

Various theories have been proposed as corallaries to the anticlinal theory. Of these the hydromotive theory of Munn is perhaps the best known.[2] He suggests that bodies of water in motion carry the oil with them. If the water moved downward or laterally it could carry the oil with it, and the oil carried down would tend to float into any higher structural features it encountered and accumulate in them. The higher folds would serve as oil traps raised above the passageways of water and oil. If, in depths below the higher folds the sands were for any reason impermeable, the downward flow would turn to a horizontal course and larger volumes of water might pass below the oil trap, giving greater opportunities for segregation.

Johnston[3] suggests that the oil is carried through the sands as films on globules of gas. Daly[4] appeals to pressures generated as a result of diastrophic movement. These methods of segregation probably assist gravitational separation to some extent.

There is reason to suppose that the temperatures of the oil

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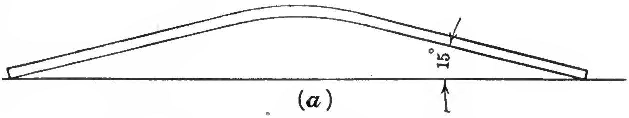
[1] LEWIS, J. O.: Methods for Increasing the Recovery from Oil Sands. U. S. Bur. Mines *Bull.* 148, pp. 25-28, 1917.

[2] MUNN, M. J.: The Anticlinal and Hydraulic Theories of Oil Accumulation. *Econ. Geology,* vol. 4, pp. 509-529, 1909.

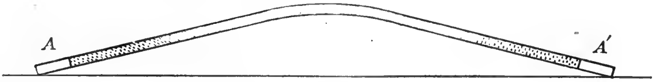
[3] JOHNSTON, R. W.: The Accumulation of Oil and Gas in Sandstone. *Science,* new ser., vol. 35, pp. 458-459, 1912.

[4] DALY, MARCEL: Water Surfaces in the Oil Fields. Am. Inst. Min. Eng. *Trans.,* vol. 59, pp. 557-563, 1918.

measures have, in general, been higher than they are now. The water ejected from the Dos Bocas well in Mexico, was hot. The temperatures of muds ejected from a mud volcano off the coast of Burma was 148° F. In many fields[1] there is reason to suppose that temperatures in the oil sands have been as high as 70° C. Oil loses viscosity with increase of temperature and would be less readily adsorbed by grains of sand. At depths of 6,000 feet some oils would be no more viscous than water. If a vessel is filled with sand that is saturated with oil, and the bottom is perforated so that all the oil that can be removed by gravity will drain out,

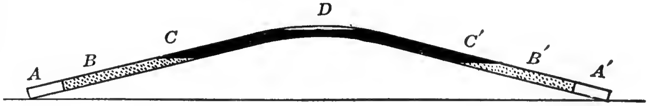


(*a*)
Glass tube bent to represent anticline.



(*b*)

Glass tube filled with oil sand and sea water, acidified with acetic acid. Ground dolomite was introduced at A and A′.



(*c*)

Same as 22*b*, after 48 hours. AA′ is dolomite; BB′ sea water in sand; CC′ segregation of oil in sand; D accumulation of gas in sand.

FIG. 22.—Experiment illustrating accumulation of oil and gas in sand.

much oil will remain in the sand. If air is blown through the sand, more oil will be removed. If water, hot water, and superheated water, are successively passed through, additional oil will be carried out with each. The water of oil fields is probably rarely as hot as steam, but efficiency to overcome adhesion is aided, doubtless, by high temperature. Oil will absorb more gas than water, and the gas makes it lighter and assists accumulation. An increase of temperature of only 50° C. will decrease the density of

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[1] WASHBURNE, C. W.: The Rôle and Fate of Connate Water in Oil Sands. Am. Inst. Min. Eng. *Trans.*, vol. 51, p. 607, 1915.

oil appreciably, increasing the difference in weight between oil and water.

A series of experiments has recently been made in the geological department of the University of Minnesota, in which gas was introduced into an oil-soaked sand in a closed system. Tubes about six feet long, were bent to form anticlines of which the limbs had slopes of about 15 degrees. (Fig. 22*a*.) These were filled with sand which had been mixed with oil. The amount of oil introduced was only that which adhered to the sand, the excess having been drained away. This was charged, together with sea water which had been made slightly acid with acetic acid. The tube was completely filled with the mixture and allowed to remain a considerable period, as shown by Fig. 22*b*. No segregation took place except locally, where the oil gathered into small drops. Subsequently small amounts of dolomitic limestone were introduced at each end of the tube (Fig. 22*b*; A, A′). After forty-eight hours a considerable segregation of oil, gas, and water had taken place. (Fig. 22*c*). The gas occupied the highest part of the tube (D), and rested on oil (C, C′), which in turn rested on salt water (B, B′)[1]. The space occupied by the gas represents air spaces which it was not possible to eliminate in charging the water and the oil soaked sand in the tube, together with the space made available by the gas pressure forcing liquids into small cracks of the sand.

The method of segregation is due principally to gravity. Gravity, however, will not operate in the absence of gas, because adhesion is great enough to hold the oil tightly to the sand. The gas generated presses on both oil and water, but the oil being lighter is pushed up farther and rides above the water. It is clear that the oil is not carried by the gas as films on gas bubbles, because the amount of oil is much greater than would be required to form films. A small amount of gas seems to be as effective as a large amount, provided the pressure is sufficient. That the pressure is effective, rather than the movement of the gas, is clear from additional experiments. The system, with acid and dolomite, was set up exactly as is shown in Fig. 22*c*, but the tube was arranged to represent a syncline rather than an anticline. The gas rose on either limb, near the end of the tube, the oil below the gas, and water segregated below the oil. A terrace was set up, the tube being bent so

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[1] Thiel, G. A.: Gas an Important Factor in Oil Occurrence. Eng. and Min. *Jour.*, vol. 109, p. 888, 1920.

that two arms sloped approximately 15°. Between the two arms the tube was level, as it was also at the upper end. After being charged with oil soaked sand, acidified sea water and dolomite, the oil rose to the first level of the terrace and remained several days. Subsequently it moved up the higher inclined arm to the flat portion of the tube. There was a strong tendency for the maximum accumulation to remain in the flat part of the tube nearest the bent limb.

In other experiments gasoline or ether was used instead of acid and dolomite. On warming the system similar results were obtained.

SEGREGATION OF OIL AND WATER DUE TO DIFFERENCES IN THEIR SURFACE TENSION

Surface tension is the tension of a liquid by virtue of which it acts as an elastic enveloping membrane, tending always to contract to the minimum area.[1] It is best exemplified in films freed from liquid masses, as in soap bubbles, and in the formation of drops. It is commonly explained as due to the fact that while molecules in the interior of the liquid are attracted in all directions, and are thus in equilibrium, those on the surface have no neighbors outside to balance the attraction of those within and are consequently acted upon by a resultant force tending toward the interior.

Capillary Constants of the Paraffin Series[a]

Substance (Normal)	Temperature, Deg. C.	Surface Tension[b]	Substance (Normal)	Temperature, Deg. C.	Surface Tension[b]
C_5H_{12}	11.0	16.0	$C_{11}H_{24}$	14.0	26.4
C_6H_{14}	11.0	20.0	$C_{12}H_{26}$	12.8	27.2
C_7H_{16}	12.0	23.5	$C_{13}H_{28}$	14.0	27.9
C_7H_{16}	12.0	23.4	$C_{14}H_{30}$	13.0	28.7
C_8H_{18}	11.0	24.3	$C_{15}H_{32}$	13.3	29.4
C_9H_{20}	14.0	24.9	$C_{16}H_{34}$	14.0	29.8
$C_{10}H_{22}$	13.0	25.8			

[a] Compiled by C. W. Washburne.
[b] Dynes per centimeter.

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[1] Standard Dictionary.

As a result of surface tension, water and oil will be drawn into small openings of capillary size, regardless of the force of gravity. Examples are the movements of water into a sponge or the rise of oil in a lamp wick. The surface tension of a water-air surface is about 75.6 dynes per centimeter at 0° C. and 72.8 dynes at 20° C. Washburne[1] states that the surface tension of salt water such as is found in oil fields is 79 dynes per centimeter. Washburne found also that Pennsylvania crude oil (specific gravity 0.852) had a tension of 24 dynes at 20° C.[2]

As water has about three times the surface tension of crude oil, capillary action must exert about three times as much pull upon it. The amount of the capillary pull varies inversely as the diameter of a pore. Hence the constant tendency of capillarity is to draw water rather than oil into the finest openings, displacing the gas and oil in them. Gas can not be drawn into capillary openings

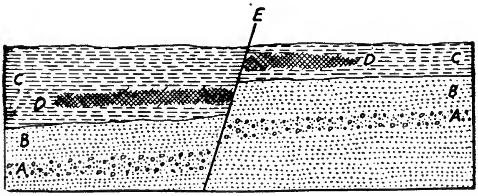

Fig. 23A.—Diagram illustrating apparatus used in experiment to show movement of oil from oil-soaked mud to coarse sand. (*After McCoy.*)

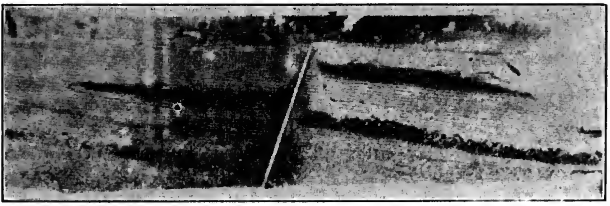

Fig. 23B.—View of apparatus illustrated in Fig. 23A, showing accumulation of oil in coarse sand after movement from oil-soaked mud. (*After McCoy.*)

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[1] Washburne, C. W.: The Capillary Concentration of Gas and Oil. Am. Inst. Min. Eng. *Trans.*, vol. 50, pp. 829-842, 1914.

[2] The movements of oil and water in quartz sand, due to differences in surface tension, are probably similar to movements in contact with glass. In clayey containers the results may be quantitatively different. Exact data are not available.

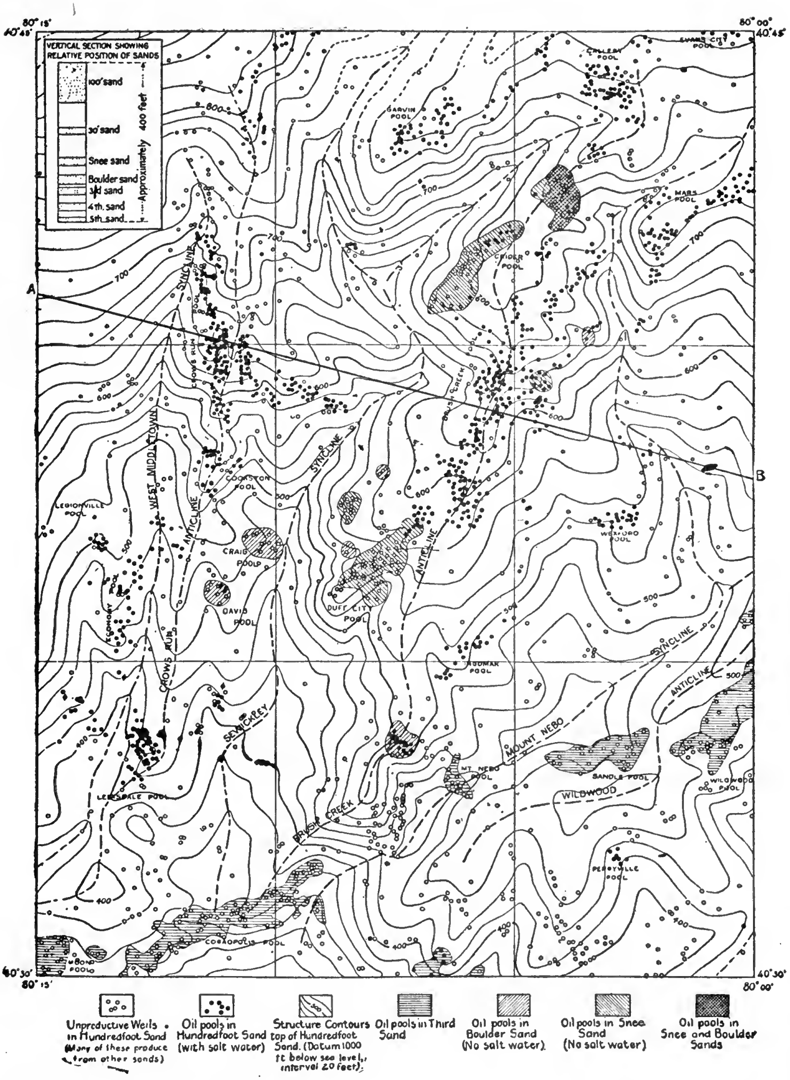


Fig. 24.—Map showing oil wells in Sewickley quadrangle, Pennsylvania. (*After Munn.*)

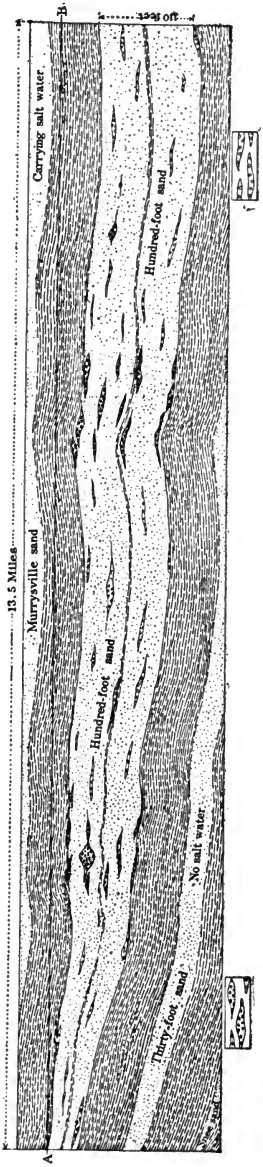
by surface tension, hence water can force it out of the fine pores without any resistance. Therefore, as stated by Washburne,[1] gas is the most quickly and completely gathered in the largest

[1] *Op. cit.*, p. 832.

openings available. Capillarity, moreover, resists the movement of water from fine to large pores more than it resists the movement of oil and gas from them. Thus water will enter fine capillaries about three times as readily as oil, and it encounters about three times as much capillary resistance in leaving them. Consequently oil and gas are concentrated in the largest openings, as the largest openings have the least capillary power.

Capillary action is not exerted in supercapillary openings. (See p. 41.) As water is most readily removed from such openings by capillary action in the surrounding material they are most readily filled with oil and gas.

Capillary attractions decrease with increase of temperature and therefore with increase of depth. With an increase of 1° C. per 30 meters in depth, capillary action loses half its force at a depth of about 5,000 meters. As heat increases more rapidly downward in many oil fields than the normal increase, it is probable, according to Washburne, that capillary force decreases one-half at depths of 3,000 or 4,000 meters. Moreover, the surface tensions of all but the lightest hydrocarbons decrease much less rapidly than that of water for each increment of temperature, so that the surface tension of water does not have such great excess over that of oil at these depths. Hence it is



Soft, conglomeratic sandstone lenses containing neither oil nor gas.

Soft conglomeratic sandstone lenses (pay streaks) containing oil, gas and salt water.

FIG. 25.—Section of Hundred-foot sand in Sewickley quadrangle, Pennsylvania, along line A-B in Fig. 24. (*After Munn.*)

probable that the capillary concentration of oil and gas must all be effected within 4,000 or 5,000 meters of the ground surface. Oil in deeper strata must remain diffused in the shales, if that was its original distribution, unless it was concentrated in the sands at some former period when the strata concerned were closer to the surface.

If oil-soaked mud is placed near water-soaked sand the oil will move to the sand. McCoy[1] placed in a glass box a water-soaked sand bed (B, Fig. 23A) in which was a layer of coarser sand (A). Above the sand was placed water-soaked mud (C), containing a layer of oil-soaked mud (D). Two series of these beds at different levels were separated by a celluloid sheet (E), representing a fault. Within one hour after removal of the sheet, oil began to collect in the layer of the sand having the largest pores, and it continued to do so for several hours until the porous sand was nearly filled on each side of the plane representing the fault (Fig. 23B). Water, by capillary action, had partly replaced the oil in the oil-soaked mud.

In the Sewickley quadrangle, near Pittsburgh, Pennsylvania,[2] oil is produced from the Catskill sands (Devonian) and from the Hundred-foot sand, near or above the top of the Devonian. The Hundred-foot sand is from 30 to 125 feet thick and is saturated with salt water. The sand is of medium grain and porosity and contains lenses of coarse sandstone and conglomerate which are much more porous than the surrounding sand. The porous lenses are a mile long, more or less, and a few feet thick. Practically all the oil is concentrated in them. The country is thrown into very gentle folds, and nearly all the lenses or "pay streaks" that contain oil are in the higher parts of the anticlines. The oil is associated with gas under pressure and with salt water. Down the dip and in synclines the pay streaks generally carry water only. Some of the wells have flowed as much as 2,000 barrels of oil a day. This area is shown in the accompanying map (Fig. 24). The section in Fig. 25 illustrates the occurrence of oil on anticlines in the pay streaks. The pools lower on the flanks of anticlines and in synclines in the sands below the Hundred-foot sand (Fig. 24) are noteworthy.

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[1] McCoy, A. W.: Notes on Principles of Oil Accumulation. *Jour. Geol.*, vol. 27, pp. 252-262, 1919.

[2] Munn, M. J.: Studies in the Anticlinal Theory of Oil and Gas Accumulation. *Econ. Geology*, vol. 4, pp. 141-157, 1909.

FRACTIONATION OF PETROLEUM IN CLAY

It has been suggested that some white oils and some very light oils have been formed by the fractionation of petroleum that has passed through clay. When oil is mixed with fuller's earth and then displaced with water about two-thirds of the oil will pass out and one-third of the oil will remain in the earth. As shown by Day[1] and his associates, oil passing through a dry fine clay (fuller's earth) loses its sulphur compounds, unsaturated compounds, and heavier components more readily than its lighter ones.

When petroleum is allowed to rise in a tube packed with dry fuller's earth, the fraction at the top of the tube is lighter than the one at the bottom. When water is added to fuller's earth that contains petroleum, the oil which is displaced first differs in specific gravity from that which is displaced afterward, when more water is added. The paraffin hydrocarbons tend to collect in the lightest fraction at the top of the tube, and the unsaturated hydrocarbons at the bottom.

[1] Day, D. T.: Experiments on the Diffusion of Crude Petroleum Through Fuller's Earth. *Science*, new ser., vol. 17, pp. 1007-1008, 1903.

Gilpin, J. E., and Cram, M. P.: The Fractionation of Crude Petroleum by Capillary Diffusion. U. S. Geol. Survey *Bull.* 365, pp. 1-33, 1908.

Gilpin, J. E., and Bransky, O. E.: The Diffusion of Crude Petroleum Through Fuller's Earth, with Notes on Its Geologic Significance. U. S. Geol. Survey *Bull.* 475, pp. 1-50, 1911.

SALIENT FEATURES OF CERTAIN OIL FIELDS

Field	Reservoir Rocks		Cover	Principal Structural Features	Surface Indications of Oil or its Associates
	Age	Kind[a]			
Appalachian	Pennsylvanian to Devonian	Sandstone and limestone	Shale	Anticlines, terraces, and dry synclines	Oil and gas seeps, grahamite
Ohio-Indiana	Ordovician	Porous dolomite	Shale	Half domes and terraces on Cincinnati anticline, domes	Gas seeps at Findlay, Ohio
Illinois	Pennsylvanian and Mississippian, Ordovician	Sandstone and porous oolitic limestone, limestone	Shale	LaSalle anticline and minor flexures	Oil seeps rare or lacking
Northeast Oklahoma and Kansas	Pennsylvanian[b]	Sandstone, limestone	Shale	Anticlines, domes, half domes, and terraces	Asphalt to east, where oil-bearing strata crop out
North Central Texas	Pennsylvanian and Mississippian	Sandstone	Shale	Arched monocline	Rare
Gulf Coast (salines)	Miocene and Eocene; some in Cretaceous	Porous dolomitic limestone and sandstone	Clay or shale	Domes (salt)	Mounds, acid waters, salt water, sulphur, gas, "paraffin dirt"
Sabine, Louisiana and Texas	Upper Cretaceous	Sandstone, limestone	Clay	Domes	Gas seeps, etc.
Rocky Mountains, Wyoming-Colorado	Cretaceous and Carboniferous	Sandstone	Shale	Domes are typical; fracture zone at Florence, Colorado; fault traps	Some tar springs and gas seeps
California	Late Tertiary, mainly Miocene to Cretaceous	Sandstone	Shale and clay	Anticlines, domes, plunging anticlines, overturns, monoclines, fault zones, fault traps, etc.	Asphalt, brea, tar springs, etc.

[a] Rocks designated sandstone in tables, include also sands.

[b] Recently some oil has been found in Mississippian.

SALIENT FEATURES OF CERTAIN OIL FIELDS—*Concluded*

Field	Reservoir Rocks		Cover	Principal Structural Features	Surface Indications of Oil or its Associates
	Age	Kind[a]			
Tampico, Mexico	Basal Tertiary and Cretaceous	Limestone and sands	Shale	Anticlines, domes, and disturbances near igneous rocks	Oil seeps, asphaltum
Trinidad	Tertiary and Cretaceous	Sandstone	Clay	Anticlines	Asphalt, oil, and gas seeps
Venezuela	Tertiary and Cretaceous	Sandstone	Clay shale	Anticlines	Asphalt, oil seeps
Colombia	Tertiary and Cretaceous	Sandstone	Clay shale	Anticlines	Asphalt, mud volcanoes, oil seeps
Rivadavia, Argentina	Upper Cretaceous	Sandstone, coarse, pebbly	Shale	Flat, minor anticlines	None
Lower Alsace	Oligocene	Sandstone	Marl	Faulted monoclines	Pitch springs, asphalt
Boryslaw, Galicia	Miocene and Oligocene	Sandstone	Clay and shale	Anticlines, synclines	Oil seeps, ozokerite
Schodnica, Galicia	Eocene, Cretaceous	Sandstone, conglomerate	Clay and shale	Anticlines, synclines	Oil seeps
Rumania	Pliocene, Miocene, and Oligocene	Sandstone, conglomerates	Clays, shales	Anticlines, fault traps	Mud volcanoes, oil seeps, gas seeps
Baku, Russia	Miocene and Oligocene	Sandstone	Clays, marls	Anticlines, monoclines	Oil seeps, mud volcanoes, gas seeps
Grozny, Russia	Miocene	Sandstone	Clays, shales	Anticlines	Oil seeps, gas seeps
Maikop, Russia	Oligocene	Sandstone	Shale	Unconformity	Oil seeps, asphalt
Egypt	Miocene and Cretaceous	Sandstone	.. ..	Anticlines in part	Oil seeps, asphalt
Burma	Miocene	Sandstone	Clay	Anticlines	Oil seeps, gas seeps
Sumatra	Miocene	Sandstone	Clays, shales	Anticlines	Oil seeps, mud volcanoes
Java	Miocene	Sandstone	Clay marls	Anticlines	Oil seeps, etc.
Japan	Tertiary	Sandstone and tuff	Shale	Anticlines	Oil seeps, etc.

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[a] Rocks designated sandstone in tables, include also sands.

CHAPTER X

STRUCTURAL FEATURES OF OIL AND GAS RESERVOIRS

RESERVOIRS IN ANTICLINES AND DOMES

Occurrence.—In accordance with the gravitational theory of accumulation, where reservoir rocks are saturated with salt water, oil will rise above the water and gas above the oil. On a fully developed, regular structural dome the normal arrangement would be a circular area of gas wells surrounded by a belt of oil wells, which in turn is surrounded by an area containing salt-water wells only. This ideal arrangement is not the most common one in oil fields, because most structural features are irregular in form, and oil sands rarely have uniform porosity. Gas and oil, moreover, in many petroleum fields occur together and will issue simultaneously from wells drilled on the tops of folds. In many folds the water is not clearly segregated from the oil. Many wells yield mixtures, some of them emulsions of oil and water. Size of pores also influences segregation (p. 112). There is, nevertheless, in almost every great oil field in the world a distinct segregation of oil and gas in the higher parts of the uplifts.

In the Appalachian oil field of North America oil and gas are generally accumulated in anticlines except in terrestrial rocks, the sands of which are not saturated with water. The Venango group of southwestern Pennsylvania is a prolific series of dry or partly dry sands in which much of the oil is found in synclines. In the Carboniferous strata above the Venango group the oil is found in saturated rocks and accumulates near the tops of the anticlines. In the Volcano anticline of West Virginia the oil has accumulated near the crest of a dome (Fig. 26). In the Lima-Indiana field of Ohio and Indiana, where oil is found in the Trenton limestone, the accumulation lies below or near a broad anticlinal axis that extends northward from the vicinity of Cincinnati and branches, one end trending toward the south end of Lake Michigan, and the other toward the west end of Lake Erie. In Ohio the best yield is obtained below the arch and on terraces; in Indiana it is found on the north side of the arch, where the rocks dip northeast. The east branch of the axis of the Cincinnati anticline becomes essentially

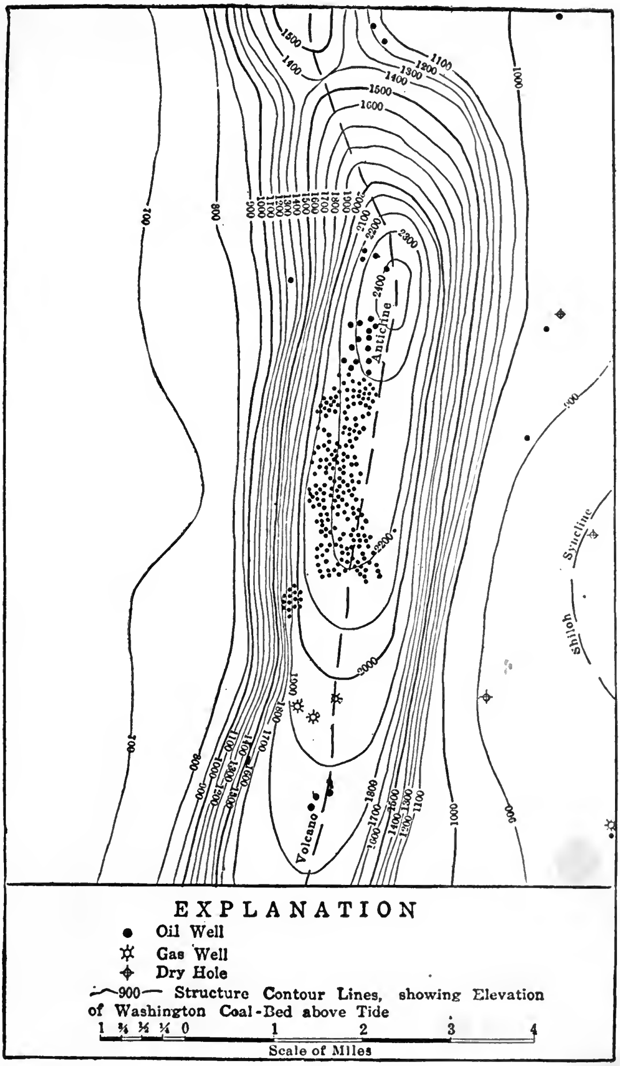

FIG. 26.—Contour map of a part of the Volcano anticline, Wood, Richie. Wirt and Pleasants Counties, West Virginia. Contour interval 100 feet. (*After White, Grimsley and Hennen, West Virginia Geol. Survey.*)

flat north of Lake Erie, in the region of Lake St. Clair. North of Lake St. Clair, however, an axis may be traced northeastward to the Petrolia dome, in Lambton County, Ontario. Practically all the oil produced in Canada has come from Lambton and Middlesex Counties, Ontario, where at Petrolia, at Oil Springs, and in Mosa Township the oil has accumulated in well-defined domes.

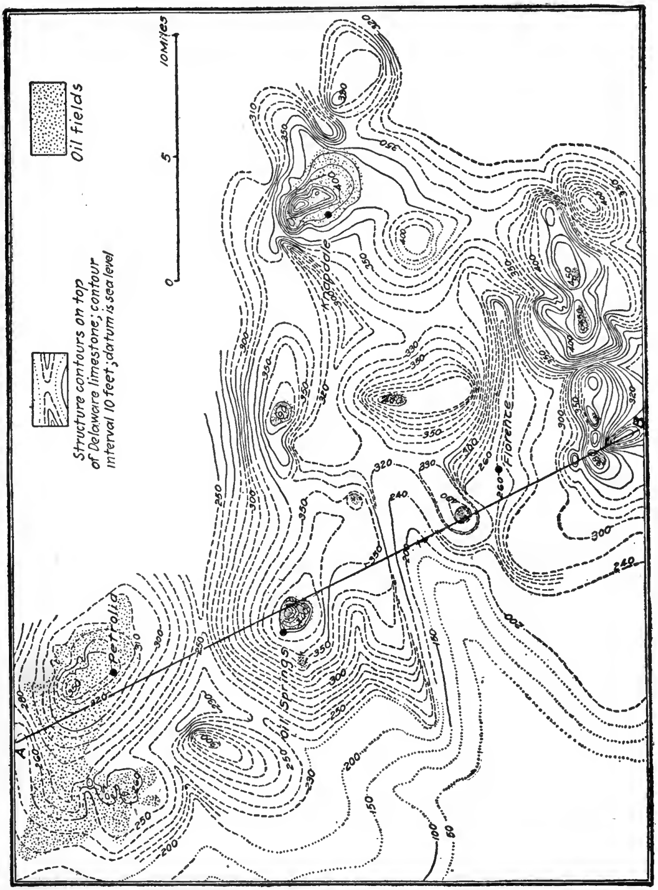

Fig. 27.—Sketch showing structure of principal oil region of Lambton County, Ontario. (*After Williams.*)

In this district a subordinate amount of oil has been found also on anticlinal noses on the flanks of the domes. (Figs. 27, 28).

Classification of Oil and Gas Reservoirs

A. Elevated structural features.

1. Anticlines and domes: Appalachian fields and Lima-Indiana in part, southwestern Ontario, Illinois, Mid-Continent field, Wyoming, California, Gulf coast; Mexico (domes near intrusives); Trinidad; Colombia, Galicia; Rumania; Baku, Grozny, Sviatoi, and Cheleken, Russia; Burma; Oceanica; Japan.

2. Monoclines sealed by
   - (*a*) Overlying and underlying shales, joining above reservoirs: Appalachian fields, in Pennsylvania, West Virginia, and Ohio, in part, some Mid-Continent fields.
   - (*b*) Faulting: Los Angeles, California; Benigadi, Russia; Rumania and Galicia in part.
   - (*c*) Local cementation of reservoir rock: Glenn pool, Oklahoma; probably many others.
   - (*d*) Asphalt: Coalinga and McKittrick-Midway-Sunset fields, California in part.
   - (*e*) Unconformities: Maikop Russia, Douglas, Wyoming.
   - (*f*) Igneous intrusions: Tuxpam-Tampico field, Vera Cruz, Mexico.

B. Flat-lying beds.

1. Aclines including oil sands: Comodoro Rivadavia(?), Argentina (in part); New Plymouth, Paritutu, New Zealand.
2. **Flat-lying lenses.**
3. Terraces: Pennsylvania, Ohio-Indiana, districts in eastern part of Kansas-Oklahoma field in part.

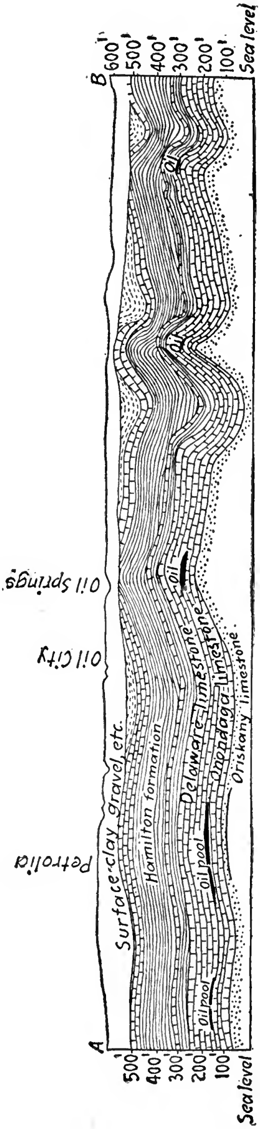

FIG. 28.—Cross-section of Petrolia and Oil Springs oil fields, Lambton County, Ontario, along line A B, of Fig. 27. Vertical scale is much exaggerated. (*Redrawn from a section by Williams.*)

C. Depressed structural features.
  1. Synclines and basins: Catskill sands in Pennsylvania and West Virginia; some parts of fields of California and Galicia; unimportant districts of Rocky Mountain fields.

D Fissures.
  1. In shales: Florence, Colorado; part of Salt Creek, Wyoming; part of Cleveland, Ohio.
  2. In schists: Small occurrences of Santa Clara, California and Alaska.
  3. In igneous rocks: Cuba; part of Furbero, Mexico.

E. Combinations of two or more structural features named above: Numerous fields.

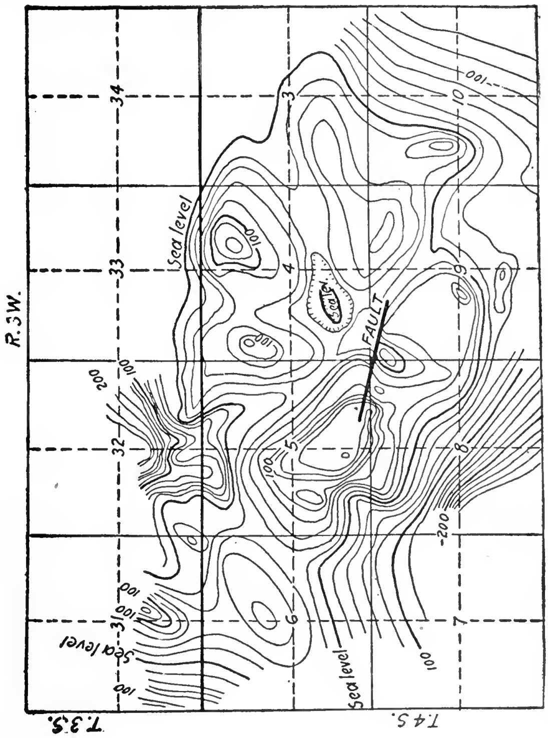

FIG. 29.—Structure map of Healdton field, Oklahoma. Contour interval 20 feet. (*After Wegeman and Heald.*)

In Kentucky the principal producing fields are on anticlines; these include Irvine, Campton, Station, and Cannel City.

In Illinois the principal producing wells are along the La Salle anticline, especially in domes that are on and near the crest of the anticline in Lawrence, Crawford, Clark, and Cumberland Counties. In the southwestern part of the State oil is found in

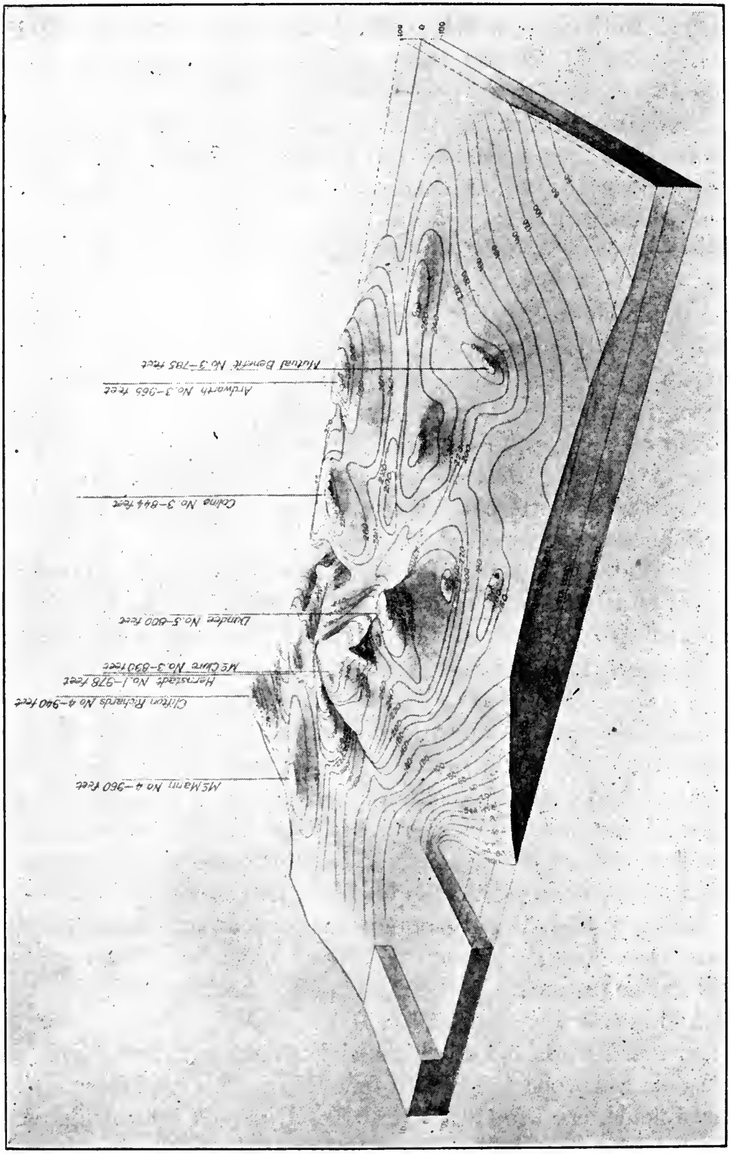

FIG. 30.—Stereogram of the Healdton oil field, Oklahoma. (*After Wegeman and Heald.*)

small pools at or near the crests of domes in Sandoval, Marion County, in Carlinville, Macoupin County, and in Greenville, Bond County. In the Carlyle field, Clinton County, the beds are practically horizontal. Within short distances they dip away from the field or become tight.

In many districts in the Oklahoma-Kansas region the oil and gas are clearly segregated at the tops of anticlines and domes. These include the accumulations of the Cushing, Ponca City, Garber, Augusta, Eldorado, and many other fields. East of a north-south line through Tulsa, Oklahoma, the rocks are less highly saturated and some of the pools are on structural terraces. Some are on comparatively regular monoclines. In the Bartlesville field, Oklahoma, which has been highly productive, the monoclinal dip is nearly uniform at many places. Where it is not the oil is concentrated on slight upwarps of the undulatory strata. In the Iola field of Kansas the anticlinal structure is barely perceptible, although, according to Orton, it may be measured over very broad arcs. In the western part of the Kansas field the oil pools are on anticlines and domes.

In the Red River district, south of the Arbuckle Mountains, in southern Oklahoma and northern Texas, oil or gas or both have accumulated in domes or anticlines in the Healdton (Figs. 29, 30), Fox, Graham, Loco, and Duncan fields. In Texas the Petrolia field is a dome; the Electra and Burkburnett pools are probably anticlinal deposits in areas complicated by faulting. In the Ranger and neighboring districts the oil pools are on the Great Bend arch, below small anticlinal noses that are generally without recognized closure at the surface. It is thought by some investigators that the amplitudes of these folds increase with depth, and there is some evidence that the folds are also closed in depth. In the Corsicana field, Texas, some of the pools are on an essentially regular monocline that shows no closed folds, but others are on domes on the monocline. The Mexia-Groesbeck gas field and the Thrall oil field are on domes.

In northern Louisiana oil or gas or both are found on domes in the Caddo, Shreveport, De Soto-Red River, Pelican, Homer, and Monroe fields. In the Homer and Red River-De Soto fields pronounced faults are found near the crests of the producing domes. On the Gulf coast in Texas and Louisiana oil is found in many salt domes, which are believed to lie along axes of faulting and flexing.

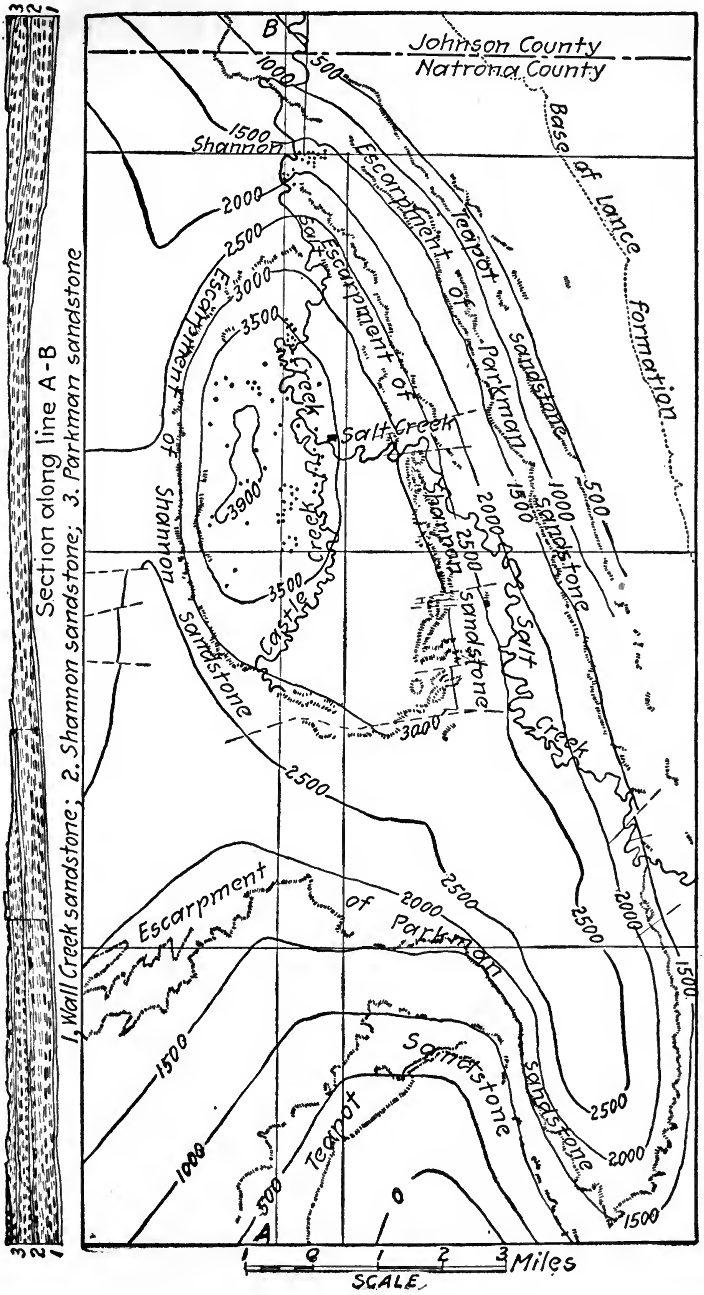

FIG. 31.—Structure map of the Salt Creek oil field, including the Shannon Pool and Teapot dome, Natrona County, Wyoming. Structure contours show elevations of Wall Creek sandstone above sea level. (*After Wegeman.*)]

In the Rocky Mountain fields all the oil in the principal producing districts is derived from deposits lying on domes and anticlines. In Wyoming, which produces about 97 per cent of the oil and gas from the Rocky Mountain fields, more than 98 per cent of the output (1917) is derived from fields having closed structure. Of these fields about 15 produce oil, and several others produce gas only. All the elevated closed folds are domes except one or possibly two. In one of these the oil is accumulated in a fault trap formed by an anticline plunging away from a fault. In the Salt Creek field (Fig. 31), which is the most productive in Wyoming, oil occurs on a dome. On this dome and west of it oil is derived from fissures in shale. In the Shannon field, north of the Salt Creek field, a little oil has been obtained from a small half dome or nose. In the Spring Valley district, Uinta County, in the southwest corner of the State, a few thousand barrels have been obtained from wells sunk in a syncline.

In the Boulder district, Colorado, oil is derived from thin sands in a shale and probably from fissures in the shale also. In the northern extension of this district flowing wells were brought in on an anticline.

In California the oil-bearing rocks are generally saturated and the oil and gas are found on uplifts. The Coalinga[1] field is divided into two parts, the Eastside and Westside. On the Westside the oil has accumulated on a monocline where at the outcrop the oil sands are cemented with asphalt. On the Eastside the oil is concentrated below the Coalinga anticline. In the Lost Hills district, Kern County, about 50 miles southeast of the Coalinga district, oil is accumulated on the extension of the Coalinga anticline.[2] The Midway district, on the northeast flank of the Temblor Range, is on a monocline on which two subsidiary folds are developed. These folds have undulating crests, and the best yield, according to Arnold and Johnson, is obtained on or near the nodes of the crests.[3] In the McKittrick field oil is found in anticlines and in synclines, the rocks being overturned, and on monoclines

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[1] Arnold, Ralph, and Anderson, Robert: Geology and Oil Resources of the Coalinga District, California. U. S. Geol. Survey *Bull.* 398, pp. 1-354, 1910.

[2] Arnold, Ralph and Garfias, V. R.: Geology and Technology of the California Oil Fields. Am. Inst. Min. Eng. *Bull.* 87, p. 422, 1914.

[3] Arnold, R., and Johnson, H. R.: Preliminary Report on the McKittrick-Sunset Oil Region. U. S. Geol. Survey *Bull.* 406, p. 165, 1910.

where the beds are healed by asphalt. The Kern River field, in Kern County, 4 miles north of Bakersfield, is on a low dome on a general monocline, superimposed on which are minor folds that control accumulation.[1] The Santa Clara district, in Ventura and Los Angeles Counties, is structurally dominated by an overturned anticline. In this field the structure is exceedingly complicated. One part of the field is situated in a syncline. A few wells have encountered some oil in schists. In the Santa Maria field oil is accumulated principally on anticlines.[2] In the Summerland field, a small district near shore and below the Pacific Ocean, the relation of accumulation to structure is not clear. In the Los Angeles field oil is accumulated near the crest of an anticline andin amonocline developed on its limb where the oil-bearing strata crop out (Fig. 182, p. 465). In part of the field the oil appears to be sealed in by the faulting of shales against the reservoir rock. In the Puente Hills district the oil is found on anticlines and on monoclines sealed by faults.[3]

In foreign fields nearly all the petroleum and natural gas is found in the elevated parts of structures.

Southwestern Ontario has supplied most of the petroleum discovered in Canada. The oil is obtained mainly from clearly defined domes, although a little has been obtained from open anticlines and on monoclines.[4]

In Mexico all the large wells are located where the structure is anticlinal or domical[5] and the rock shows pronounced fractures, usually in the regions of basaltic intrusives. In the Furbero district,[6] at the south end of the oil region, oil is found in an indurated and shattered shale above an igneous sill. In Trinidad oil is found on anticlines.

All the oil produced in Europe, Asia, and Africa comes from

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[1] Arnold, Ralph, and Garfias, V. R., *op. cit.*, p. 436.

[2] Arnold, Ralph, and Anderson, Robert: Preliminary Report on the Santa Maria Oil District.. U. S. Geol. Survey *Bull.* 317, p. 30, 1907.

[3] Eldridge, G. H.: The Puente Hills Oil District, Southern California. U. S. Geol. Survey *Bull.* 309, p. 102.

[4] Williams, M. Y.: Oil Fields of Southwestern Ontario. Canada Dept. Mines, *Summary Rept.*, 1918, part E, pp. 30-42, 1919.

[5] Huntley, L. H.: The Mexican Oil Fields. Am. Inst. Min. Eng. *Bull.* 105, p. 2092, 1915.

[6] De Golyer, E. L.: The Furbero Oil Field, Mexico. Am. Inst. Min. Eng. *Bull.* 105, pp. 1899-1911, 1915.

strata later than Paleozoic, except in Derbyshire, England, where oil has accumulated in a dome in rocks of Paleozoic age. With this exception the oil-bearing strata are all of Mesozoic and of Tertiary age, much the greater part being of the Tertiary.

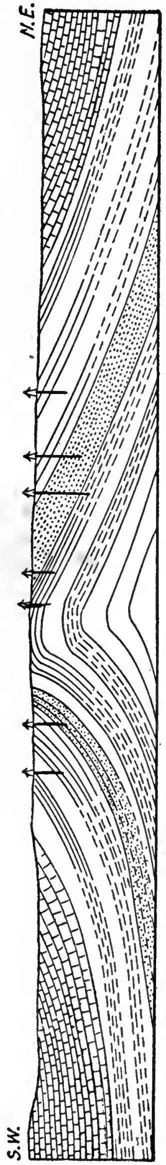

FIG. 32.—Section of western part of the Balakhany oil field and part of Zabrat oil field near Baku, Russia. (*After Barbot de Marni.*)

In Alsace oil is found in lenses of sands completely inclosed in marls, on monoclines, or sealed up the dip by marls coming together. Some of the lenses are faulted against impervious beds up the dip.

In the Boryslaw field, Galicia, where the petroliferous beds are found among strata that are closely folded and faulted along overthrusts, the accumulations occur in anticlines and also in gentle synclines between them. The Tustanowice field is on a monocline. In the Opaka-Schodnica-Urcyz field, in a block between two profound faults, as shown by Zuber, oil is produced from anticlines, synclines, and monoclines. In western Galicia, which includes the Potak, Rogi, Rowne, Krosus and other fields, the oil is generally concentrated in domes and anticlines.

In Rumania the bulk of the output comes from anticlines, salt domes, and monoclines sealed by faults.

In Baku, Russia, the oil is derived from anticlines and from monoclines on their flanks. The principal structural features are probably domes or irregular closed folds and monoclinal lenses (Fig. 32.) In the Holy Island and Cheleken fields oil is derived from quaquaversal uplifts. The Grozny field is on an anticline crossed by faults. The Maikop field is on a monocline sealed at an unconformity.

In Burma the petroleum is derived from anticlines, especially from the high places on their undulating

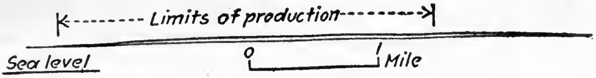

FIG. 33.—Section of Dropright dome, Cushing field, Oklahoma. Vertical and horizontal scale are the same. Shows curvature of Pawhuska limestone from northwest corner of section 5, to northwest corner of section 27 T. 8. N., R. 7. E. (*Data from Beal.*)

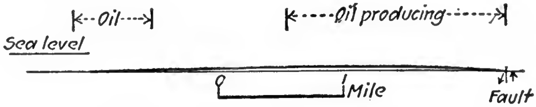

FIG. 34.—Section of De Soto-Red River field, Louisiana. Vertical and horizontal scale are the same. Shows curvature of Nacotosh sand from northwest corner of section 14 to fault in section 23. T. 13 N. R. 11 W. (*Data from Matson and Hopkins.*)

FIG. 35.—Section of Thrall field, Texas. Vertical and horizontal scale are the same. Shows curvature of oil-bearing rock. (*Data from Udden and Bybee.*)

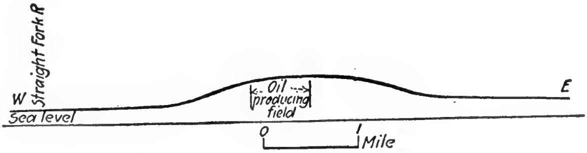

FIG. 36.—Section of Volcano anticline, West Virginia. Shows curvature of Washington coal bed from Straight Fork Creek through town of Volcano to Goose Creek. Vertical and horizontal scale are the same. (*Data from Hennen, West Virginia Geol. Survey.*)

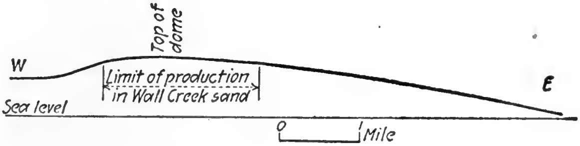

FIG. 37.—Section of Salt Creek dome, Natrona County, Wyoming. Shows curvature of Wall Creek sand from southwest corner of section 27, T. 40 N. R. 79 W. to southwest corner of section 26, T. 40 N. R. 78 W. Vertical and horizontal scale are the same. (*Data from Wegeman, U. S. Geol. Survey.*)

crests. The fields of Oceanica and Japan that have been described are on anticlines.

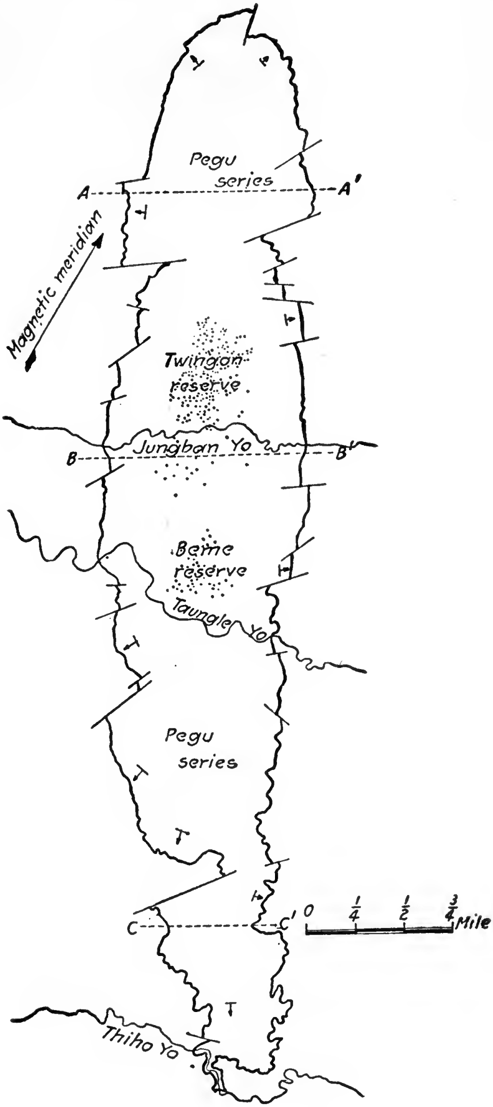

FIG. 38.—Sketch plan of Yenangyaung oil field, Burma. The heavy black line is the red bed at the base of the Irrawadian formation. (*After Pascoe.*) For sections along *AA′*, *BB′* and *CC′*, see Fig. 39.

Amplitudes of Anticlinal Folds That Form Reservoirs.—The domes and anticlines on which oil and gas accumulate differ much as to size and elevation. In Kansas, Oklahoma, and Texas productive fields are developed where the closure is less than twenty feet and the dips are as low as 30 feet to the mile. The anticline of the Iola field of Kansas, according to Orton, rises 50 feet in 8 miles.[1] The closure in the steepest part of the Eldorado field, Kansas, is more than 100 feet, and in Augusta, Kansas, it is approximately the same. Many productive folds are larger. Fig. 33 is a section, true to scale, of the Cushing field, Oklahoma. Fig. 34 is a similar section, of the DeSoto-Red River field, Louisiana. Fig. 35 is a section of the Thrall field, Texas. A section of the Volcano anticline of West Virginia is shown in Fig. 36, and one of the Salt Creek dome of Wyoming in Fig. 37.

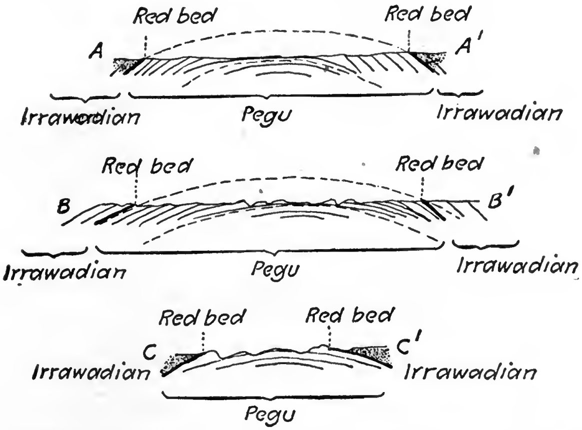

FIG. 39.—Sections through Yenangyaung oil field, Burma, along lines *AA'* *BB'* and *CC'* in Fig. 38. (*After Pascoe.*)

Shapes of Anticlines That Form Reservoirs.—Some anticlines and domes that yield oil are fairly symmetrical—for example, the Yenangyaung dome of the IrrawadyRiver region of Burma (Figs. 38, 39); the anticline at Bibi-Eibat, Russia; and the Volcano dome, Ritchie County, West Virginia. Other domes are unsymmetrical—for example, the Grass Creek dome and the Salt Creek dome, Wyoming, and the Oil Springs dome, Ontario. The axial planes

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[1] ORTON, EDWARD: Geological Structure of the Iola Gas Field. Geol. Soc. America *Bull.*, vol. 10, p. 104, 1911.

of some domes and anticlines are steeply overturned, as in the Yenangyat-Singu field, Burma; the Campina field, Rumania; the Boryslaw field, Galicia; and the Grozny field, in the Caucasus region (Fig. 40).

Oil and gas are found in overturned folds whose axial planes lie at low angles. In some of the California fields (Fig. 64, p. 155) the strata are so closely folded as to form isoclines, and a well may penetrate the same formation twice. Such folds producing oil are apparently confined to fields that contain unconsolidated or partly consolidated beds. Deformation so intense in thoroughly consolidated rocks would generally result in scattering the oil and gas.

Origin of Anticlines That Form Reservoirs.—Anticlines and domes in general are formed by compressive stresses operating on the earth's crust. Many of them are small mountain folds formed when the larger mountain axes were elevated. This is indicated by their positions on monoclines that dip away from mountain ranges. Some of the subordinate folds are 100 miles or more from the controlling major mountain axes.

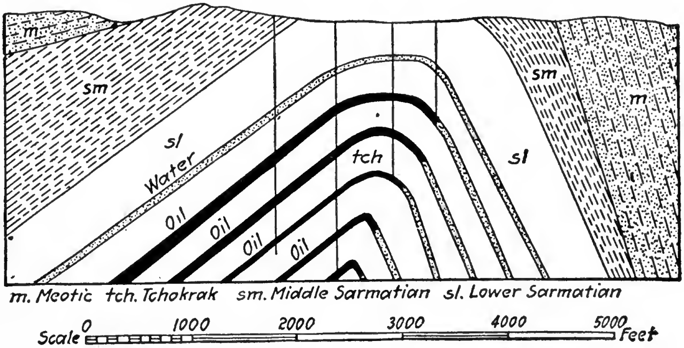

FIG. 40.—Section of Grozny oil field, Russia. (*After Thompson.*)

Certain folds contain central cores of igneous or sedimentary rocks on which the sedimentary beds lie unconformably. These cores were once hills. Their rocks were already compact, and in the compacting and settling of the overlying sediments, which were thicker away from the core, a gentle inclination of the beds away from the core was developed. The beds were thus arched as if by folding, and their initial dip away from shore lines was emphasized. Some investigators believe that the compacting of shales of varying thickness in Kansas fields has given rise to recognizable structural features.[1]

In the Tampico-Tuxpam field of Mexico the sedimentary rocks dip eastward at low angles. At many places igneous intrusives have been thrust into the sediments, and reservoirs have formed near them. The intrusions probably cause a gentle doming of the

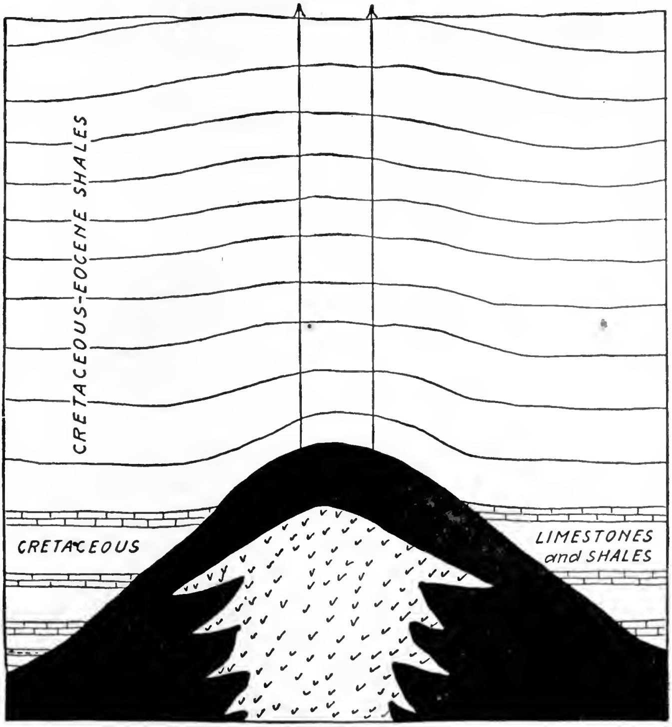

Fig. 41.—Hypothetical section of a type of reservoir in principal Mexican oil field, according to *Garfias*. The reservoir is formed around a basaltic intrusion that penetrated the series of Cretaceous limestones and shales and only slightly disturbed the Cretaceous-Eocene shales. Black represents the fractured and porous material which constitutes the reservoir. It is covered by an impervious cap.

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[1] Blackwelder, E. B : The Origin of Central Kansas Oil Domes. Amer. Asso. Petrol. Geologists, vol. 4, No. 1, pp. 89-94, 1920.

rocks, sufficient to influence accumulation.[1] The folding generally decreases toward the surface, where it is at many places difficultly recognized (Fig. 41). In the Ebano field, according to Garfias,[2] an igneous plug has domed the rocks it penetrates and on solidifying and sinking it has drawn the beds downward near its contact with them. This has given rise to what he terms the anticlinal ring and funnel structure. This structure is rare in other oil fields, although similar processes have operated in volcanic regions of the western United States, in which the sedimentary rocks dip away from intrusive masses except near the contact, where for short distances they dip toward the intrusives.

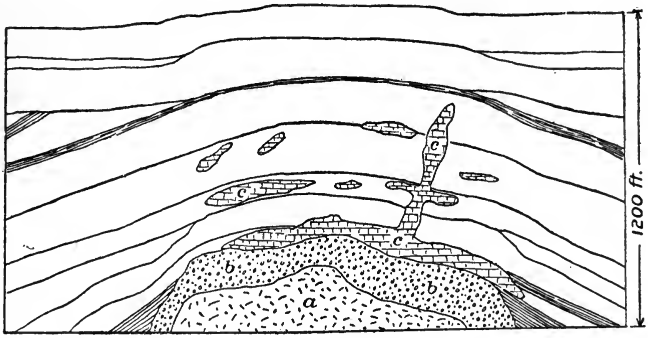

Fig. 42.—Section of Spindletop oil field, Texas. *a*, rock salt; *b*, gypsum; *c*, limestone. (*After Lee Hager.*)

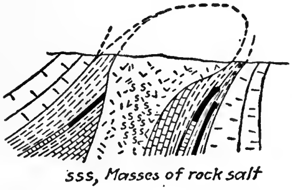

Fig. 43.—Section of Baicoi oil field, Rumania. (*After Bosworth.*)

Salt domes are structural domes that contain bodies of salt (Fig. 42). In some anticlines the lower rocks are thrust through the upper ones, complicating the structure by faulting (Fig. 43). Such is the case in Rumanian salt domes, where plugs of salt are

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[1] Garfias, V. R.: The Effects of Igneous Intrusions on the Accumulation of Oil in Northeastern Mexico. *Jour. Geology*, vol. 20, p. 666-672, 1912; The Oil Region of Northeastern Mexico. *Econ. Geology*, vol. 10, pp. 195-224, 1915.

Garfias, V. R., and Hawley, H. J.: Funnel and Anticlinal Ring Structure Associated with Igneous Intrusions in the Mexican Oil Fields. Am. Inst. Min. Eng. *Trans.*, vol. 57, pp. 1071-1082, 1917.

[2] Garfias, V. R., *op. cit.* (*Jour. Geology*).

thrust through clays and sands. The sands are sealed above by the central mass. The structure shown at the left in Fig. 43 is essentially a fault trap, but differs from monoclinal fault traps in its different arrangement of dips. Structure of this sort is probably developed where rigid rocks alternating with unconsolidated weak rocks are deformed by strong pressure. Crystalline salt is much more rigid than clay and sand. The thickness of the salt in some of the plugs is very great. In some places the salt beds are probably on edge. In the salt-dome fields of Texas and southern Louisiana the domes apparently occur along axes of deformation by folding and faulting.

Arrangements of Anticlinal Folds That Form Reservoirs.—In some regions oil lies in lines of pools that are elevated portions or nodes along anticlinal crests. On the Shoshone anticline, which lies east of the Wind River Mountains, Wyoming, four domes or elevated portions of the anticline yield oil or gas. Oil is found in several fields on high parts of the Coalinga anticline, California. Along the axes in the Yenangyaung and Yenangyat-Singu fields, in Burma, oil and gas have accumulated at several places where the crests of the anticlines are higher than elsewhere.

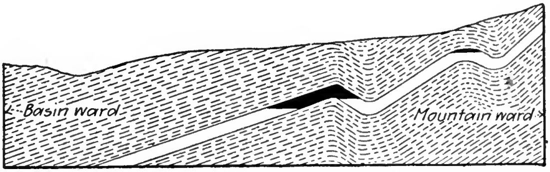

Fig. 44.—Ideal sketch showing oil accumulated principally on the lower anticline or the one on the basinward side of the larger fold; the accumulation is greatest on the basinward limb of the anticline. Black represents oil and gas.

In other regions the oil pools in domes or anticlines lie rudely in curved lines corresponding to axes of deformation. In still other places the pools are very irregularly distributed, owing doubtless either to deformation at two periods or to gentle deformation without much definition. As a rule the elevated crests that lie lower are more productive than the higher ones in the same series (Fig. 44). Thus in Oklahoma the Cushing field is more productive than the Barstow region, and the Glenn pool is more productive than the region about Muskogee. In the region near Red River, southern Oklahoma, the oil fields are grouped near the outer border of the Permian rocks, which dip southwestward along Red River and rise again south of the river, forming a deep salient or embayment. The Healdton dome, which is a basinward fold, is more productive than those which are higher up, including the Fox, Graham, and others. This relation is clearly shown in the Big Horn Basin, Wyoming (p. 400), where, as stated by Hewett and Lupton, the more productive anticlines are those which lie basinward. In this basin there are two circles of anticlines, of which the inner is much more highly productive than the outer. Thus the Elk Basin, Byron, Greybull, Torchlight, and Bonanza domes are more productive than the Lovell, Spence, Midnight, Tensleep, and Bud Kimball, which yield a little oil or are barren. On the west side of the basin the Warm Springs, Grass Creek, Little Buffalo, Oregon Basin, and Cody anticlines are more productive than the Rawhide, Gooseberry, Wagonhound, and Hamilton. The oil evidently migrated upward from the basin into the elevated portions, and the gathering ground on the basinward side is much greater than on the side toward the mountains. Moreover, in the outer circle of anticlines, the ground water doubtless has entered and in some places washed the beds clean of any oil they may have once possessed. Evidence of this lies not only in oil springs, but also in the fact that some of the folds carry, below the oil, water that is not highly saline compared with waters of other fields.

A small dome near the center of a basin obviously has a small gathering ground and should not be expected to contain a large deposit.

Segregation of Oil on Basinward Sides of Folds.—In many fields the portion of the oil sand that carries oil and gas is not symmetrical with respect to the fold. As a rule it descends farther down the flank of the gentle limb than it does down the steep flank. This is noteworthy in the Yenangyat-Singu field of Burma, where on a long, sharp, unsymmetrical anticline (p. 556) practically all the wells are west of the crest of the fold, on its gentler flank. In the Big Horn basin, Wyoming, the basinward flank almost invariably has the greater accumulation. In the Salt Creek field (in the first Wall Creek sand) the oil blanket extends deeper on the northeast side of the dome, which has a greater gathering ground. In the Cushing pool the accumulation is greater on the basinward side, and some of the sands that yield oil on the west side of the dome yield gas only on the east side. These observations show that in many folds the gravitational separation is not perfect. Beal[1] suggests that the gas accumulates first and banks up near the crest of the fold and prevents the oil that collects on the side where the gathering ground is greatest from passing over to the opposite side.

In steep symmetrical domes, containing sands that are everywhere permeable, the contact between oil and water would normally be flat. If higher at one point than another, the water would descend by gravity and push the oil up where it is lowest. At many places however, where gravitational separation is clearly indicated by the position of the accumulation with respect to the structure, the contact between the water and the oil is not level. This condition may be due to tightness of the sands in places, which prohibits free circulation of oil around the dome on nearly level lines. The maximum accumulations of oil on the domes of Osage County, Oklahoma, are, according to Mason,[2] on the north and northwest sides of the domes. The maximum accumulations of oil and gas, however, are not all on the long limbs of the folds. In the Caddo and Crichton fields, Louisiana, according to Crider,[3] in certain areas short limbs are most productive.

In the Cushing field, Oklahoma, in the Layton and Wheeler sands, the contact is gently inclined in the direction of the dip of the strata. This attitude may be due in part to differences in porosity or to differences in the size of the pores in the reservoir rocks.

RESERVOIRS IN MONOCLINES

A considerable number of the world's oil and gas fields lie on monoclines that are sealed in various ways. Monoclines may be sealed where impervious rocks meet above the reservoir rock (Fig. 45), at impervious fault planes or where faults throw impervious rocks against the reservoir rocks (Fig. 46), where the sands become impervious by cementation of their interstices or where the interstices were filled with clay particles when the sands were deposited

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[1] Beal, C. H.: Geologic Structure in the Cushing Oil and Gas Field, Oklahoma, and Its Relation to Oil, Gas, and Water. U. S. Geol. Survey *Bull.* 658, p. 44, 1917.

[2] Mason, S. L.: A Statistical Investigation of the Effects of Structure Upon Oil and Gas Production in the Osage. Amer. Assoc. of Petrol. Geologists, vol. 3, pp. 407-417, 1919.

[3] Crider, A. F.: Oil and Gas Possibilities in Mississippi. *Bull.* of the Southwestern Assoc. of Petrol. Geologists, vol. 1, pp. 152-155, 1917.

(Fig. 47), or where the oil itself at or near the surface, on drying hardens to form asphalt (Fig. 48). A few oil fields are formed where a tilted eroded petroliferous series is covered unconformably by a later series. If permeable strata such as conglomerates and sandstones are laid down upon the petroliferous strata, the beds of the later series may carry oil. If muds or clays cover the petroliferous bed, gas, oil, and water will probably be segregated in the lower bed. Reservoirs are found at unconformities in many fields.

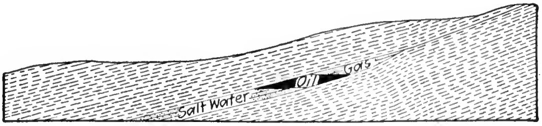

FIG. 45.—Sketch showing reservoir sealed by impervious rocks overlying and underlying the reservoir rock and joining above the reservoir.

In the Maikop field, on the north flank of the Caucasus, Russia, oil has accumulated in a sand that was deposited upon an older hilly surface and in turn covered by a impervious bed so that it is effectively sealed (Fig. 57, p. 150). In the Tampico-Tuxpam field, Vera Cruz, Mexico, petroliferous beds are sealed by igneous intrusives that cut across the beds. It is obvious that monoclines sealed by impervious rocks joining above the reservoir rock and monoclines sealed by local cementation and at unconformities are discovered with greater difficulty than monoclines sealed by other

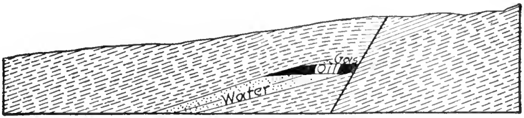

FIG. 46.—Sketch showing reservoir sealed by fault bringing oil sand against impervious rocks.

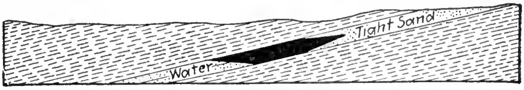

FIG. 47.—Sketch showing reservoir sealed by tight sand. Black is oil and gas.

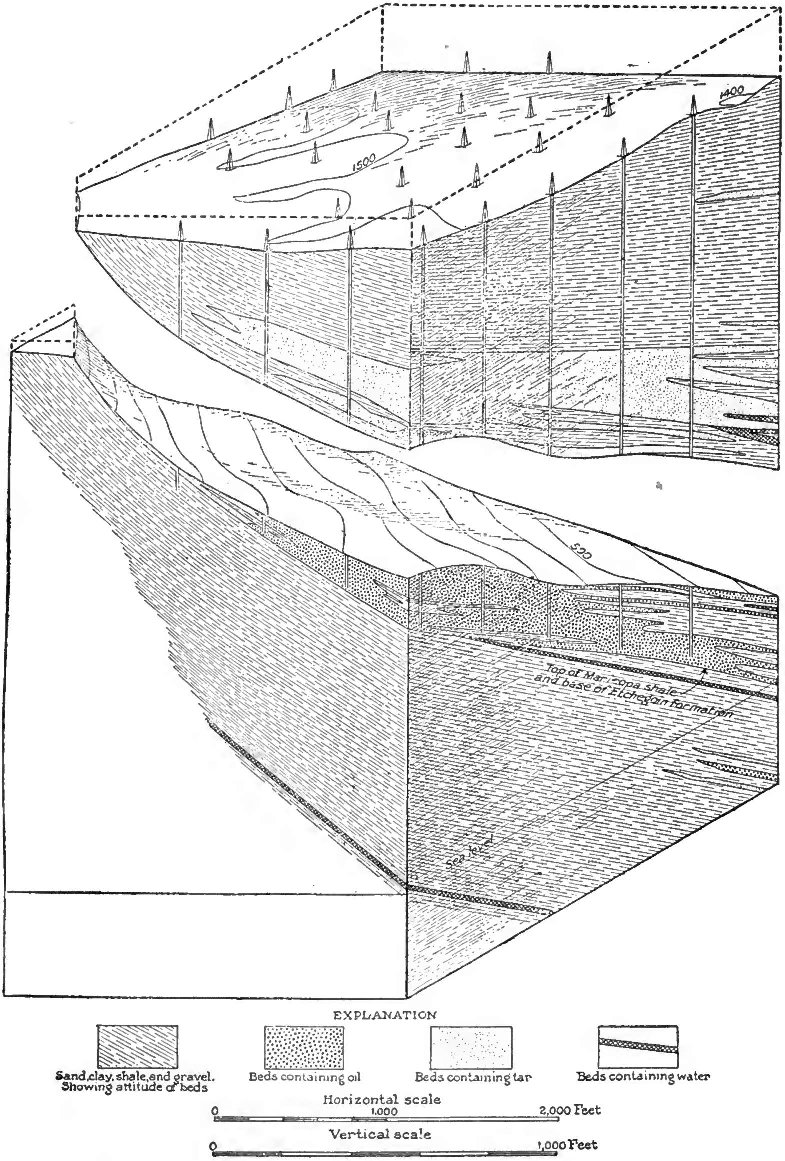

Fig. 48.—Stereogram showing reservoir sealed by asphalt forming in oil sand near the surface, Sunset-Midway field, California. (*After Pack, U. S. Geol, Survey.*)

processes. Oil pools in such positions are discovered, more often than otherwise, by "wildcat" drilling or by wells sunk for water.

Monoclines Sealed By Overlying and Underlying Clays or Shales Joining Above Reservoirs.—Monoclines sealed by clays or shales are found at many places. In the Appalachian geosyncline, which includes many of the great oil pools of the United States, the sands generally thin out toward the west. The land mass that supplied the sediments during Paleozoic time was southeast of the oil field. At the end of the Paleozoic era the strata were folded and the great Appalachian geosyncline was formed. Parallel to the axis of the geosyncline there are many subordinate folds. Where the porous strata rise west of an axis of such a fold or west

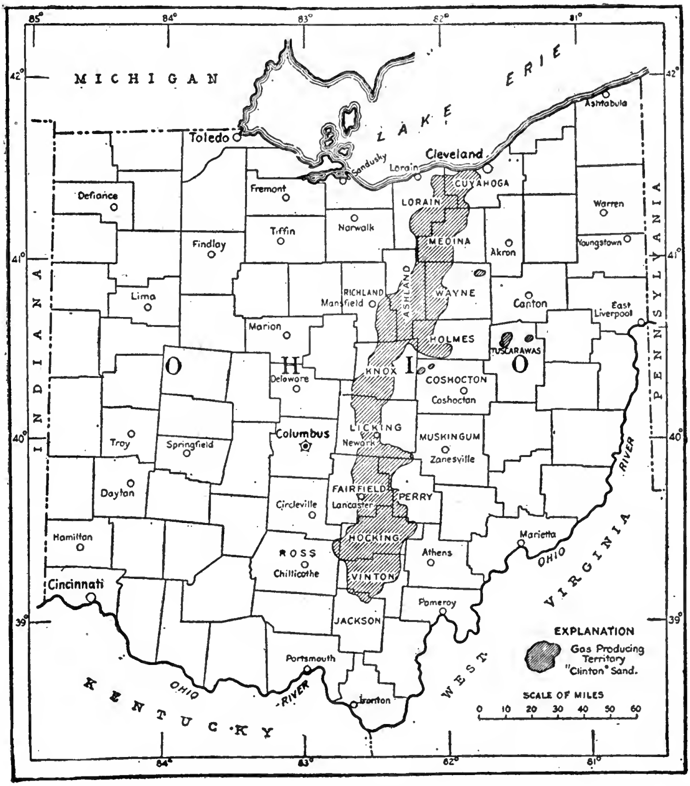

FIG. 49.—Map showing location of "Clinton" gas field, Ohio. (*After Bownocker.*)

of the axis of the great geosyncline, accumulations of oil and gas are likely to be found. In eastern Ohio (Fig. 49), where the "Clinton" sand thins out up the dip, the shales above and below it come together. The upper part of this sand contains gas under great pressure. From Cleveland southward to Jackson County, a distance of 170 miles, wells producing gas are sunk to this reservoir at many places. The general relations in the Appalachian field are illustrated by Fig. 50.

In Eastern Ohio oil and gas are found in the Berea sand, near the lower part of the Mississippian.[1] The Sunbury shales lie above the Berea, and the Bedford shales below it. The Berea yields oil or gas in many counties.

Approximately along the area indicated by the line *X*-*Y* in Fig. 51, there is, according to Panyity, a noteworthy change in the character of the sedimentary rocks. East of the line and parallel to it, where the sand is thin and lenticular, the most productive fields are found. These include the fields of Barnesville, Temperanceville, Summerfield, Macksburg, Dudley, and others. East of the gas fields, down the dip, are the most productive Berea oil pools. In places where anticlinal structure is present the positions of

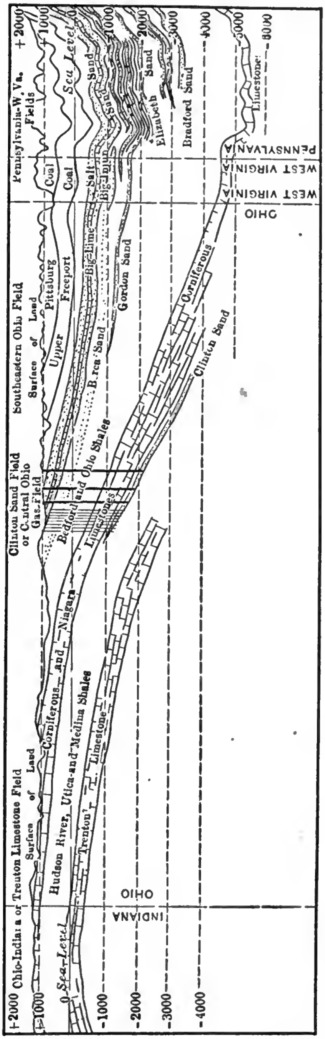

Fig. 50.—Generalized cross-section from Cincinnati anticline to Allegheny front, showing position of wells in "Clinton" field of Central Ohio. (*After Clapp.*)

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[1] Panyity, L. S.: Lithology of the Berea Sand in Southeastern Ohio and Its Effect on Production. Am. Inst. Min. Eng. *Bull.* 140, pp. 1317-1320, 1917.

the gas, the oil, and the water are in accord with the structural theory (Fig. 52). The controlling factor in most of these pools, however, is, according to Panyity, the western limit of the sand. West of the line *X*-*Y* there is a water-bearing sand. Near Byesville small gas pools are developed on minor uplifts above the water. The only field of any considerable size developed west of the line is the Corning pool.

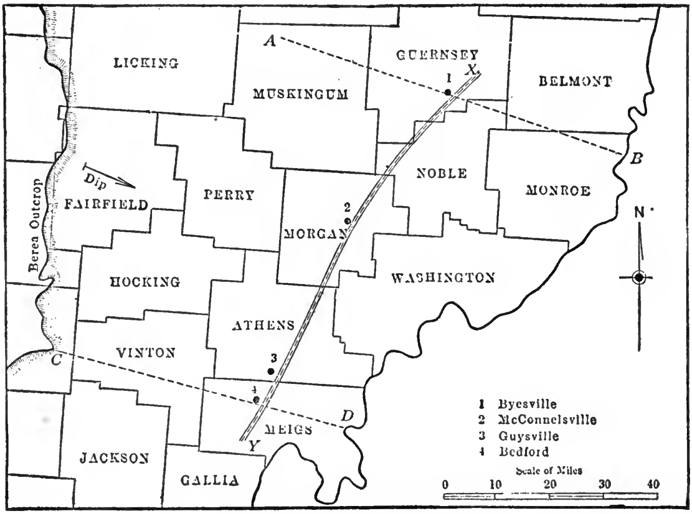

FIG. 51.—Sketch map showing position of certain oil pools in Berea sand in southeastern Ohio. Oil is found in sealed monocline east of line *X*-*Y*. (*After Panyity.*) For section along *AB* and *CD* see Fig. 52.

Monoclines Sealed By Faults.—Some faults afford channels along which fluids escape. Other faults are accompanied by finely ground clay that seals the opening, making the fault impervious. Faults that cross shaly strata or other soft rocks are generally impervious. Some oil pools are on monoclines sealed up the dip by faults. In the Appalachian fields no monoclines of this character have been described, nor have they been recognized in western Ohio, Indiana, or Illinois. In Kentucky the Irvine field is developed along a faulted anticline, but at most places the reservoir has been sealed by folding, or by folding and faulting together. (See Fig. 106, p. 241.) In Oklahoma, southeast of Cushing and southwest of the Glenn pool, oil has accumulated, probably in places where faults sealed the petroliferous sands above, but the details of the structure in this area have not been made public. Where a plunging anticline is faulted across the strike a "fault trap" is formed. In Wyoming part of the oil produced in the Big Muddy field was obtained on an anticline plunging away from a fault. In the Los Angeles field, California, a fault has apparently sealed a petroliferous stratum (Fig. 184, p. 464). At Binagadi, Russia, the reservoir rocks are faulted (Fig. 53). Where faults bring permeable sands into juxtaposition, the seal is less likely to prove effective, as is shown by Fig. 54.

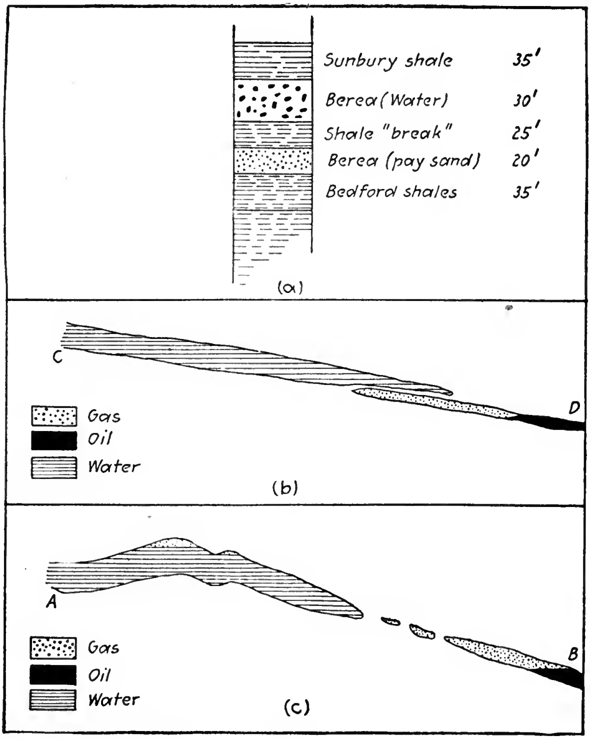

FIG. 52.—Sketch showing (*a*) section of Berea sand and adjacent strata; (*b*) reservoir in Berea sand on monocline (line *CD*, Fig. 51) and (*c*) reservoir in Berea sand on monocline and gas in anticline (on line *AB*, Fig. 51.) All in southeastern Ohio. (*After Panyity.*)

Monoclines Sealed By Local Cementation of the Reservoir Rock.—Oil migrates up the dip. If it reaches a place where the reservoir rock is impervious it will halt. The reservoir stratum may be made impervious by deposits of clay, calcite, iron oxide, or carbonate in the interstices between the grains. Some petroliferous strata are impervious at places where clay was deposited when the strata were laid down. Whatever the cause, the impervious portion of the stratum will delay or stop migration and cause an accumulation. The famous Glenn pool, in Oklahoma, is on a fluted monocline, and the accumulation of oil is believed to be due in part to changes in the character of the sands above the oil pool.

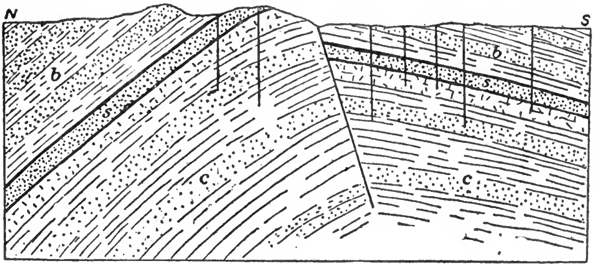

Fig. 53.—Section of Binagadi oil field, Russia. *b*, Freshwater beds, Miocene; *c*, Lower Miocene; *s*, Spiralis beds. (*After Thompson.*)

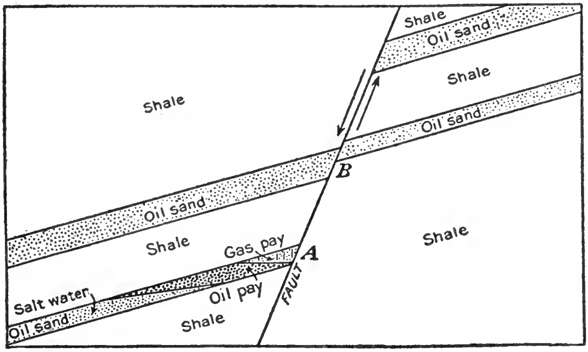

Fig. 54.—Diagrammatic cross-section showing (at *A*) an accumulation of oil and gas caused by a fault and (at *B*) a possible condition under which a fault may not seal a reservoir. (*After Fath.*)

Monoclines Sealed By Asphalt.—Some reservoirs on monoclines are sealed above by tarry products that have resulted from hardening of materials in the oil (Fig. 55). Reservoirs containing the heavier asphaltic oils are more generally sealed in this manner than reservoirs containing the lighter paraffin oils, although vents leading from reservoirs are known to contain both the asphaltic and the paraffin bitumens. This subject is treated in connection with a discussion of bituminous dikes (pp. 29 to 32). It is generally supposed that the tarry products result from partial oxidation of the oil or from reaction of the oil with ground water or from loss of gases and the lighter liquids by partial evaporation. At some places bituminous solids have formed at depths from 1,000 to 2,000 feet below the surface and it appears improbable that atmospheric oxygen, under the conditions, should be effective at such great depths.

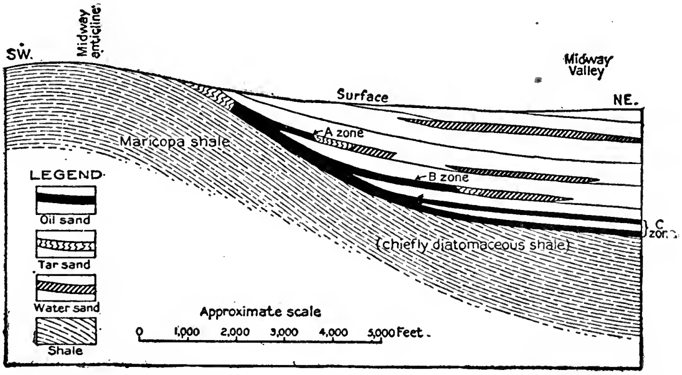

FIG. 55.—Diagram showing relations of productive oil zones in the vicinity of Fellows, Midway-Sunset district, California. (*After Pack.*)

The best known fields of which the reservoir rocks are sealed by bitumens are the Coalinga field and the Sunset-Midway field of California. In both of these fields highly productive reservoirs are sealed by tar plugs. In the Sunset-Midway district[1] the reservoirs containing the oil are sealed up by tarry oil or tar which is formed by the interaction of the mineralized waters and the hydrocarbons that compose the oil. It is a reaction which results in the

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[1] PACK, R. W.: The Sunset-Midway Oil Field, California. U. S. Geol. Survey *Prof. Paper* 116, p. 87, 1920.

reduction of sulphate water to form sulphides and the addition of the sulphur or sulphides to the oil.[1]

According to Pack[2], the reactions that result in the formation of tarry products may be divided into two classes, one that takes place near the surface; another at greater depth, in many places at the very base of the oil zone, below the beds containing the productive oil sands.

The reactions that take place close to the surface, particularly along the outcrop of the oil-bearing beds, result in sealing up the outcrop and preventing the escape of the oil. The extent to which the oil undergoes alteration is evidently far greater near the surface than it is at depth, for the deposits of tar and of sulphur are greater there. The surface water characteristically contains more sulphates than the waters at greater depth, and the oxidation of the oil is aided to a large extent by other oxidized products in the rocks that lie close to the surface, or by exposure to the air itself. Not only are the oils at or near the surface changed more or less completely to tar, but the sulphate waters are changed so completely that great quantities of free sulphur are formed, and deposits of native sulphur such as the one occurring south of Old Sunset result. Sulphur is widely scattered along the foothills in which the oil sands crop out.

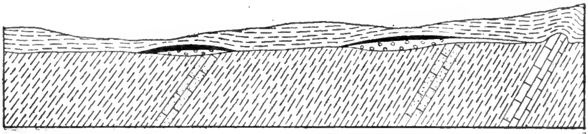

FIG. 56A.—Sketch of section showing oil and gas (black) in porous deposits that rest unconformably on a tilted series of oil sands and carbonaceous shales.

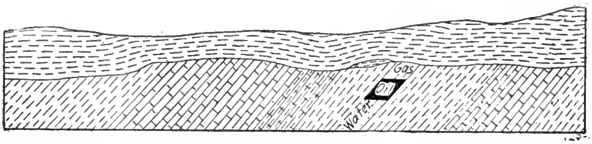

FIG. 56B.—Sketch of section showing accumulation of oil and gas above water in a tilted bed overlain unconformably by an impervious bed.

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[1] ROGERS, G. S.: Chemical Relations of the Oil-Field Waters in San Joaquin Valley, California (preliminary report). U. S. Geol. Survey *Bull.* 653, 119 pp., 1917.

[2] *Op. cit.*, p. 88.

In the Midway region, according to Pack,[1] there is clear evidence that oil has been hardened by surface water to depths 800 or 1,000 feet. The effect of the deeper waters on the oil is not so extensive as that of the surface waters, but it is evident none the less, for at many places where water is found in the oil sand a deposit of tar or heavy oil separates the portion of the sand occupied by oil from that occupied by water. The reason for the lesser effect of the deeper waters and thus for the smaller amounts of tar in the deeper sands is evidently the fact that the waters in the deeper sands contain normally a far smaller amount of sulphate than the surface waters.

Monoclines Sealed at Unconformities.—At many places tilted beds are covered by relatively flat-lying beds. Unconformities are favorable places for accumulation, because the younger deposits commonly include coarse sandstone or conglomerate near the base (Fig. 56A). Some monoclines, it is said, are sealed by impervious beds that cover the tilted beds by overlapping them (Fig. 56B).

If the underlying older strata contain sands or other porous rocks covered by shales and the sands become saturated with petroleum and water the petroleum will rise toward the surface and be halted or diverted when it reaches the impervious cover. The line or zone of junction is rarely level, and accumulation is unequal at different places where the porous bed is covered. If the junction is sealed at the high end by warping or at a place where the reservoir rock is tight, a trap is formed in which the oil or gas or both may find lodgment.

In Brenning Basin, in the Douglas oil and gas field, near Douglas, Wyoming, the nearly flat White River (Tertiary) beds rest on tilted Cretaceous strata that include nearly all the beds of the Colorado and Montana groups (Cretaceous), which are productive elsewhere in Wyoming. Barnett[2] states that the petroleum in migrating upward along bedding planes and through porous sandstone finds a barrier when it reaches the White River formation, so that oil and gas accumulate near the contact. They penetrate the White River beds only where they encounter porous material or fault planes.

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[1] *Op. cit.*, p. 88.

[2] Barnett, V. F.: The Douglas Oil and Gas Field, Converse County, Wyoming. U. S. Geol. Survey *Bull.* 541, p. 69, 1914.

The structural conditions are somewhat similar in the Healdton pool, south of the Arbuckle Mountains, Oklahoma, where Pennsylvanian strata rest on steeply tilted Ordovician beds.[1] A little of the Healdton oil was probably originally in the Ordovician beds, where they are covered by the Pennsylvanian shales. The principal part of the output, however, is derived from Pennsylvanian rocks.

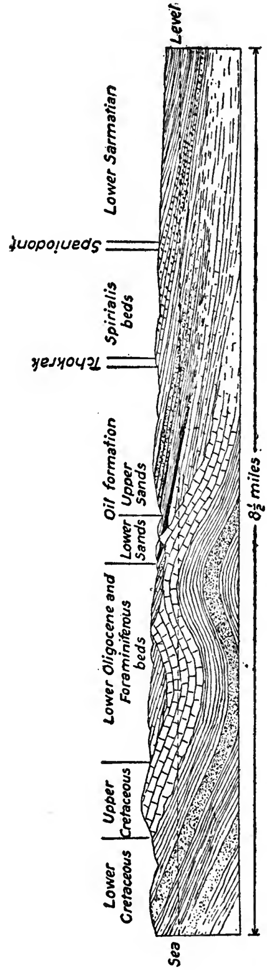

FIG. 57.—Section of Maikop oil field, Russia. (*After Thompson.*)

In the Madill pool, Oklahoma, just south of the Arbuckle uplift, folded Paleozoic sediments dip at at high angles. Above them are Cretaceous rocks that lie nearly flat. The lowest member of the Cretaceous, the Trinity sand and gravel, is saturated with oil that is probably derived from the underlying Carboniferous strata,[2] which are highly productive in this region.

In the McKittrick-Midway-Sunset region, California, the Monterey (lower Miocene) and Santa Margarita formations, which lie in a conformable series, are tilted, and the McKittrick (upper Miocene) overlies them unconformably.[3] The oil is believed to have originated in the diatomaceous shales of the Monterey and to have migrated to the sandy layers in the Monterey or to the sands and gravels of the un-

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[1] POWERS, SIDNEY: The Healdton Oil Field, Oklahoma. *Econ. Geology*, vol. 12, pp. 594-606, 1917.

[2] TAFF, J. A., and REED, W. H.: The Madill Oil Pool, Oklahoma. U. S. Geol. Survey *Bull.* 381, pp. 504-513, 1910.

HUTCHINSON, L. L.: Rock Asphalt, Asphaltite, Petroleum, and Natural Gas in Oklahoma. Oklahoma Geol. Survey *Bull.* 2, p. 252, 1911.

[3] ARNOLD, RALPH, and GARFIAS, V. R.: Geology and Technology of the California Oil Fields. Am. Inst. Min. Eng. *Bull.* 87, pp. 383-470, 1914.

conformably overlying McKittrick formation. With a few exceptions the productive sands of the region are at the base of the McKittrick, above the unconformity.

In the districts mentioned above oil has originated in the older series, below the unconformity, and has accumulated in the older series where it is sealed in or has passed into the porous beds of the younger series. Examples are known, however, where the oil has originated in the younger series and has accumulated in sandy beds of that series where they rest upon an old erosion surface that existed before the reservoir rocks were formed and where the reservoir rocks are sealed above by overlapping impervious rocks. The best known example is the Maikop field (Fig. 57), on the north side of the Caucasus Mountains, about 300 miles west of Grozny, Russia. Here Tertiary beds dip away from an erosion surface of Cretaceous rocks. The oil is accumulated in Tertiary sands, which are covered by later impervious beds, and in places it rises to the contact of the sands with the Cretaceous, as is shown in Fig. 57. The overlying beds extend farther over the ancient surface of the Cretaceous rocks, overlapping the petroliferous sands. As shown in the sketch by Thompson,[1] the significant structural feature is not the fold in the Cretaceous rocks but the steep eroded surface of the Cretaceous, which is progressively overlapped by the Tertiary strata.

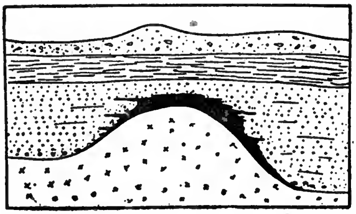

Fig. 58.—Gas pool at unconformity, New York. (*After Clapp.*)

In Ontario, in Quebec, and probably also in northern New York, according to F. G. Clapp,[2] gas is found in basal sandstones overlying crystalline rocks (Fig. 58). The structure of these beds has not been described in detail. The accumulations are probably due to the larger openings in coarser material near the base of the formation.

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[1] Thompson, A. B.: The Relation of Structure and Petrology to the Occurrence of Petroleum. Inst. Min. and Met. *Trans.*, vol. 20, p. 258, 1911.

Trench, R. H.: Discussion of Thompson's Paper. *Idem*, p. 247.

[2] Clapp, F. G.: A Proposed Classification of Petroleum and Natural Gas Fields, Based on Structure. *Econ. Geology*, vol. 5, p. 519, 1910.

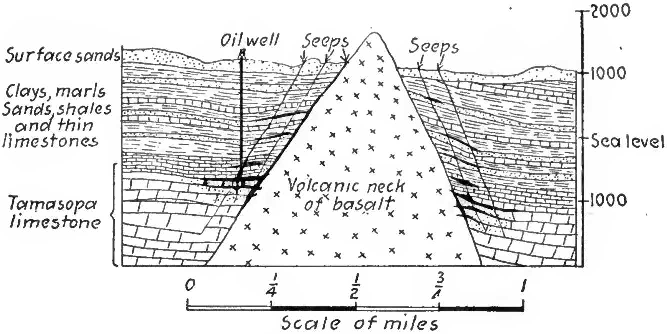

FIG. 59.—Hypothetical cross-section of a volcanic plug in the coastal plain of Mexico. (*After Clapp.*)

Monoclines Sealed By Igneous Intrusions.—In the Tampico-Tuxpam region, Mexico, oil accumulations are found in areas where

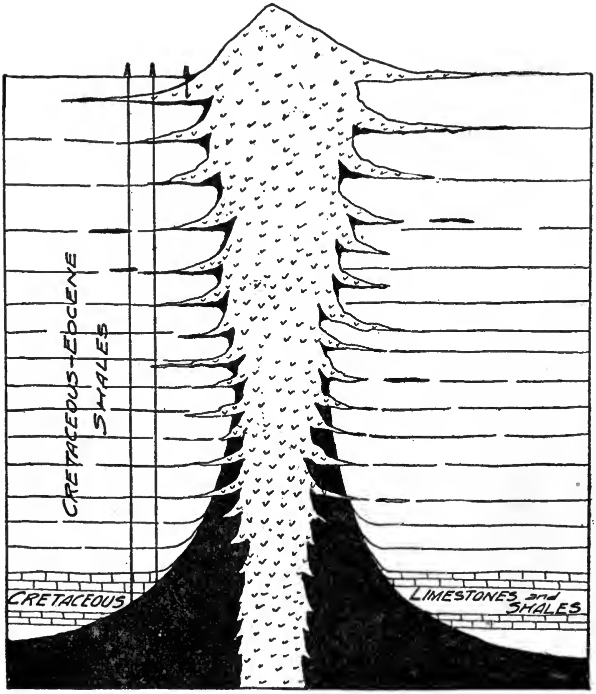

FIG. 60.—Hypothetical section, according to Garfias, illustrating basalt intruding the oil series of Mexico and reaching the surface. Black represents the places that are favorable for oil accumulation. The plug is larger near the surface, where expansion is easier, owing to lighter load.

dikes or other igneous bodies cut across the petroliferous beds. As a rule the intrusion appears to have been attended by uplifting of the strata into domes. Clapp described an occurrence where the strata are uplifted on both sides of a plug (Fig. 59). In an example illustrated by Garfias (Fig. 60) there is practically no doming of the strata.

RESERVOIRS IN FLAT-LYING BEDS

Aclines.—Aclines are bodies of rock that lie essentially flat. In such rocks large accumulations of oil are rare. The Rivadavia field, Argentina, is on a broad monocline that dips east. The rocks are so nearly flat that the field has been regarded as aclinal.

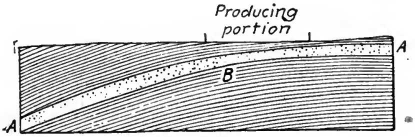

Fig. 61.—Ideal section of Gaines Pool, Pennsylvania, showing its relation to supposed change of depth. *A*, oil sand; *B*, brink of terrace where oil is supposed to have accumulated. (*After Fuller.*)

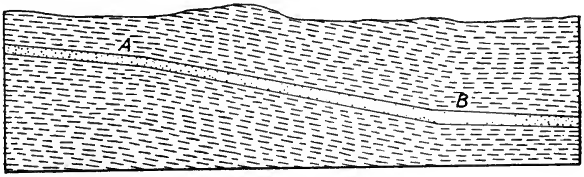

Fig. 62.—Ideal section showing position of oil accumulation on a terrace. If the oil migrates upward as it does in saturated rocks, it will accumulate near A. If it migrates downward it will accumulate near *B*.

Recently, however, it has been shown that the oil has accumulated in very shallow domes. (See p. 592.) In the New Plymouth field, New Zealand, no elevated structural features are recognized.

Terraces.—There is apparently a lower limit of inclination beyond which petroleum will not migrate up the dip.[1] This limit depends on the size of the openings, gas pressure, and the viscosity of the oil. Where there is a change from a dip up which oil will move to one up which oil will not move an accumulation is likely to take place (Fig. 61). If salt water is associated with the oil and

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[1] Clapp, F. G.: Revision of the Structural Classification of Petroleum and Natural Gas. Geol. Soc. America *Bull.*, vol. 28, p. 572, 1917.

the movement is up the dip the accumulation will be near the axis of flexure, where the dip changes, and in general the greatest accumulation will be near the lower edge of the terrace (Fig. 62). Such conditions exist in the Peru field, in southern Kansas. On the other hand, if little water is associated with the oil it tends to move downward, and accumulation may take place on the upper part of the flat limb of the terrace. These relations have been shown by experiments at the University of Minnesota (see p. 112).

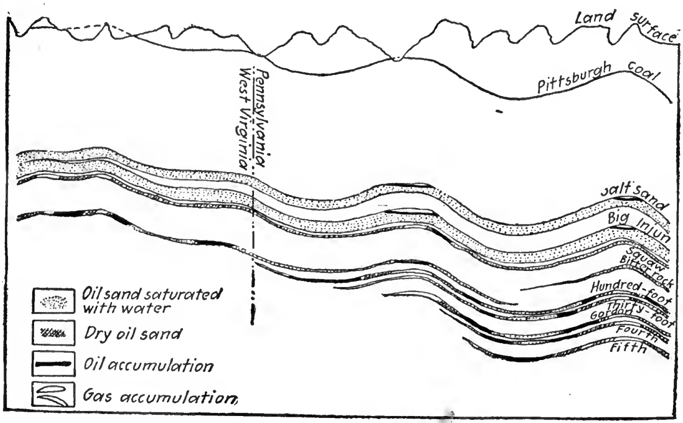

FIG. 63.—Ideal sketch showing accumulation of oil and gas in Appalachian region. The higher sands are saturated and oil and gas rises to crests of anticlines. The lower sands are not saturated and the oil and gas is found low on the flanks of the anticlines or in synclines. (*After Griswold and Munn.*)

RESERVOIRS IN SYNCLINES

Oil is found in synclines in parts of the Appalachian region. In the Catskill strata in Pennsylvania and West Virginia petroleum and gas are found in sands between shales. These beds are not saturated with water. Reeves[1] states that these unsaturated beds, which are land sediments, had dried out before they were submerged in the sea and that the spaces of their reservoirs were filled with air. Later when marine sediments were laid down above them, the oil evidently migrated into them, but not enough water to float the oil to the tops of folds. Some of the Mississippian sands above the Devonian in Pennsylvania are saturated, and in

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[1] REEVES, FRANK: The Absence of Water in Certain Sandstones of the Appalachian Oil Fields. *Econ. Geology,* vol. 12, pp. 254-278, 1917.

them the oil and gas occur in anticlines. These features are illustrated by Fig. 63.

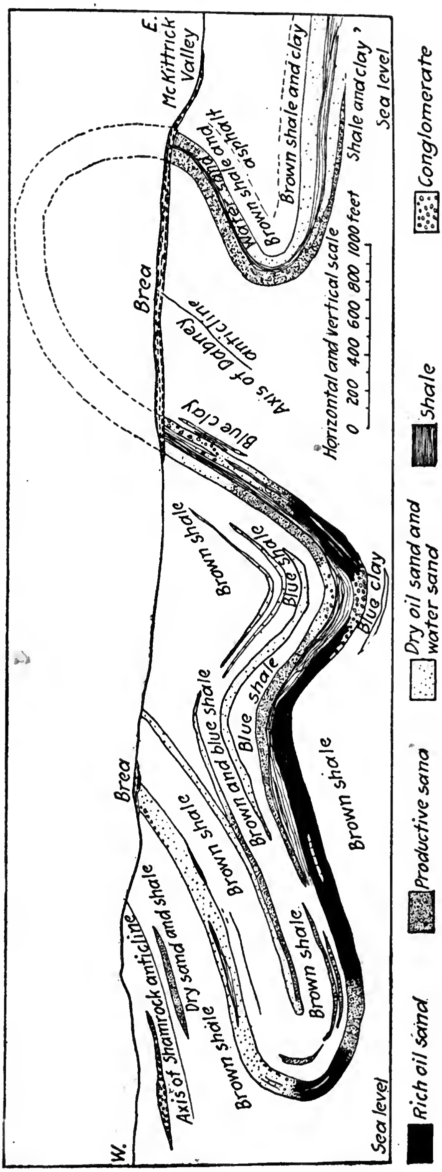

FIG. 64.—Hypothetical section across the south end of the McKittrick oil field in California. (*After Arnold and Johnson.*)

At Urado, Colorado, in the Uinta Basin, near the Colorado line, oil has been produced from a tunnel driven in a flat-lying sand, the base of which is warped to form gentle sags in which the oil collects. Small amounts of oil have been obtained also near De Beque, in western Colorado, from wells sunk near the axis of a low minor anticline which is developed in a broad syncline. In southeastern Utah a little oil has been found in a syncline in the San Juan field. In the McKittrick district, California, a considerable concentration of oil is found in an overturned syncline (Fig. 64). In Galicia also oil is found in synclines in the Boryslaw field.

The large deposits of oil in well-defined synclines in consolidated rocks are in the Appalachian field. Most other fields in which large concentrations are found in synclines are in unconsolidated rocks that have been intensely deformed. Under such conditions as have already been noted, petroleum is apparently found in many different structural positions.

Some synclines are merely gentle sags near the crests of anticlines. Such sags may be saturated with oil or gas or both (Fig. 65). Others contain a little water near the axis of the sag. In still others the sand may be filled with water.

RESERVOIRS FORMED BY FISSURES

Practically all consolidated rocks are jointed, and many of them are appreciably fractured. The earlier investigators of oil reservoirs in the Appalachian region laid much emphasis on fissures as containers of oil and gas. Later, when great fields in unconsolidated rocks were developed in Russia, in California, and elsewhere it appeared less probable that fissures play so important a part, for in soft rocks fissures will close. The effect of openings formed by solution, dolomitization, fracturing, and brecciation has been mentioned in connection with the discussion of reservoir rocks. Such openings[1] doubtless add materially to the capacity of reservoirs in certain fields where oil occurs in Paleozoic rocks. In the unconsolidated rocks of some Tertiary fields they are generally less effective. The capacity of fissures is attested by those that are filled with bitumens—some containing many millions of tons. In some fields oil is recovered from fissures in shale.

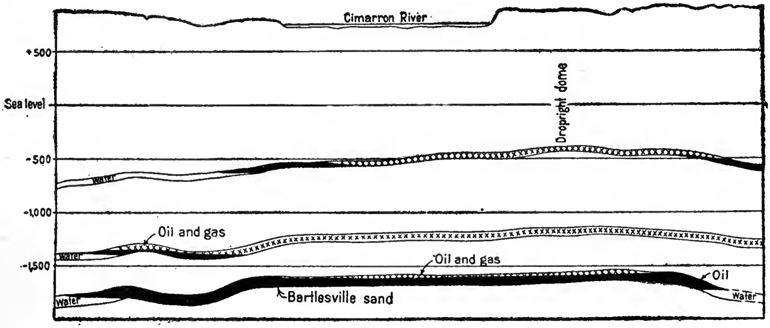

Fig. 65.—Section of Cushing field, Oklahoma, showing oil in a synclinal sag near the crest of an anticline. (*After Beal.*)

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[1] Lauer, A. W.: Petrology of Reservoir Rocks and Its Influence on the Accumulation of Petroleum. *Econ. Geology*, vol. 12, pp. 435-465, 1917.

Lewis, J. O.: (Discussion of Lauer's Paper). *Idem*, vol. 13, pp. 65-69, 1918.

At Florence, Colorado, according to Washburne,[1] the principal reservoirs are fissures in the shale of the Pierre formation. This is a uniform shale, and in the lower part, which carries the petroleum deposits, no sands are present. The fissured area is in a great synclinal basin, the Canyon City embayment, and the fissures are associated with small flexures and faults. The oil is not all floated on water, although some salt water appears in some of the deeper wells. The oil is associated with gas under pressure, and some of the wells are exploited for gas alone. The oil does not follow any bed or series of beds in the shale. As shown by the outcrop, the oil zone does not contain any sandstones or other porous beds capable of forming reservoirs. Evidence that the oil lies in joints and fissures consists (*a*) of a correspondence in direction of the major joints in the rocks at the surface with the alinement of wells which have interfered with one another; (*b*) of the fact that many wells have been drilled within a few feet of one another without encountering oil at the same depth; (*c*) of the fact that gas struck in a shallow well often immediately ruins an adjacent well several hundred feet deeper by tapping the source of pressure; (*d*) of the fact that many wells drain adjacent wells that are shallower; (*e*) of the indication of vertical connection between the oil bodies shown by the marked increase in maximum pressure with depth; and (*f*) of the dissimilar pressures in adjacent wells of the same depth.

In the Salt Creek field, Wyoming,[2] considerable oil has been found in fissures in the Cretaceous shale. This region is a domatic uplift and yields oil of good grade from the Wall Creek sands of the Frontier formation. The oil in the sands is found in elevated portions of the dome. West of the dome there is a great syncline with thick shale beds in which the oil sands carry only water. In nearly every well drilled in this field, according to Wegemann, some oil is found in the shale, a few wells having an initial production of as much as 1,500 barrels a day. The oil is not obtained from porous beds in the shale, and it is found in adjoining wells at different depths. The shale is so fine grained that it would not in itself constitute a reservoir for oil, as the openings between the

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[1] Washburne, C. W.: The Florence Oil Field, Colorado. U. S. Geol. Survey *Bull.* 381, pp. 517-544, 1910.

[2] Wegemann, C. H.: The Salt Creek Oil Field, Wyoming. U. S. Geol. Survey *Bull.* 670, p. 36, 1917.

particles are too small to permit oil to flow rapidly through them. The oil from the Wall Creek sand and the oil from shale are practically identical, the only difference being that the oil from the sand contains a little more gas.

The shale wells start flowing under considerable pressure, and fragments of calcite are often ejected from the wells. The calcite is like that which fills or partly fills the fissures in the shale. Presumably the oil is derived from the Wall Creek sand below. Certain of the faults in the shale extend down to the sand and afford passages through which the oil in the sand, under great pressure, has been forced upward into the shale. As the fissures in the shale are not confined to the dome itself but extend into the adjoining syncline on the west, oil has been forced laterally through the fissures into the shale of the syncline. The Wall Creek sand, wherever it has been reached in this synclinal area, has produced water.

Shales that yield oil also yield gas. In some regions gas only is obtained from the shale reservoirs. In Cleveland, Ohio,[1] and in the surrounding country wells have been sunk in the shale for domestic supply. As a rule the pressure is low and the yield small, but the wells have long life, so that farmers find the fuel suitable for domestic use. Some wells supply one or two farm houses.

Orton,[2] describing the differences between shale gas and "reservoir gas," notes that:

> Shale-gas wells are generally of small volume, compared to wells deriving their gas from sand reservoirs. Moreover they lack uniformity of rock pressure. Wells drilled in close proximity and to the same depth may have very different pressures. In sand reservoirs, pressures are generally greater and more nearly uniform. In the wells yielding shale gas there is no definite horizon from which their gas supply is derived. The stratum that yields it may be several hundred feet thick, and gas is likely to be found at any point in the descent. Shale-gas wells, though in the same field, may be expected to show a considerable range in depth. Some shale-gas wells occur independently of oil production. Gas may be abundant, while petroleum is altogether wanting. Shale-gas

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[1] VAN HORN, F. R.: Reservoir Gas and Oil in the Vicinity of Cleveland, Ohio. Amer. Inst. Min. Eng. *Bull.* 121, pp. 75-86, 1917.

[2] ORTON, EDWARD: Geological survey of the Iola Gas Field. Geol. Soc. America *Bull.*, vol. 10, p. 100, 1899.

wells are long lived. Weak flows are maintained for long periods. Shale gas is not dependent on the structural arrangement of the rocks which contain it. If it is not associated with oil or water, it can not be displaced nor crowded out by them.

ACCUMULATION IN SANDS OF IRREGULAR PORE SPACE

In many oil fields the oil-producing sands are irregular or "spotted." Borings that yield neither oil, gas nor water may be sunk in a sand that contains oil or gas on all sides of it. Examination of fragments of the oil stratum in the boring may discover a tight sand in which the pore space is filled by calcite, pyrite or other secondary minerals, or one that is filled with clay.

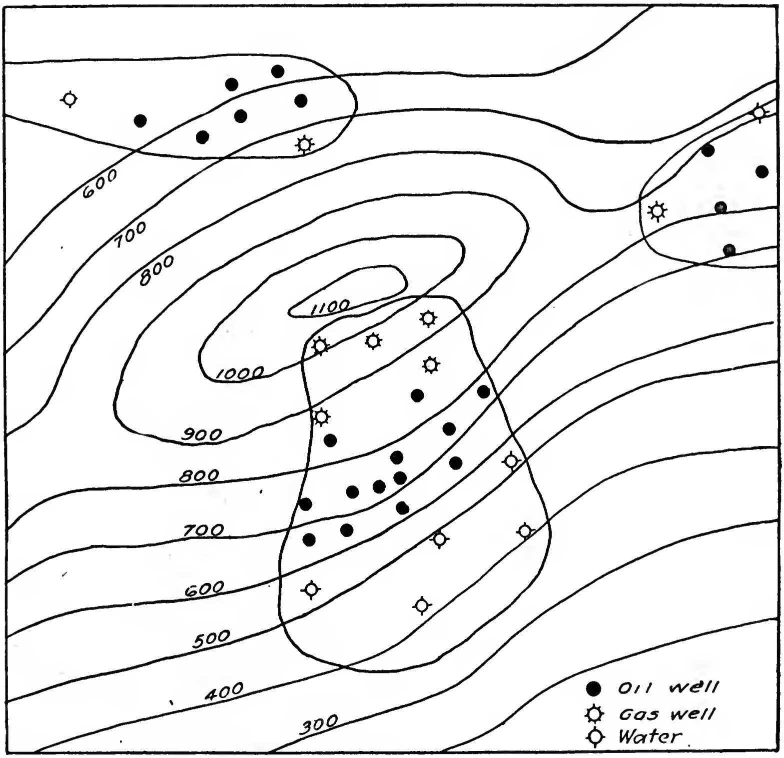

Fig. 66.—Sketch contour map showing accumulations of oil and gas in sands that are only locally pervious.

On many domes and anticlines, as already noted, a belt that yields oil is found below a disk of gas-filled sand. Some wells, however, that are sunk in the oil-producing belt may yield gas only. Examination may reveal a sand that is coarser grained and contains larger pores than the sands elsewhere in the oil-bearing area, for in some fields, gas tends to accumulate in the larger openings. Irregular and fantastic patterns of areas of production are displayed in pools containing "spotted" sands. Nevertheless, in the areas of porous rock that are surrounded by impervious rocks at the same horizon, the oil, gas, and water that are concontained in the porous rock are generally segregated in belts, the gas above the oil and the water below it, as is illustrated by Fig. 66. In such a field where pools are not connected by open spaces

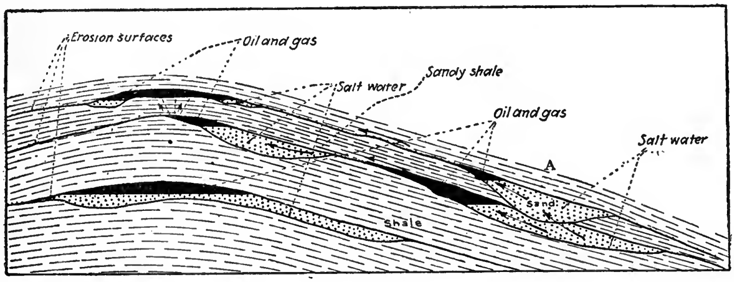

FIG. 67.—Ideal sketch through a dome, showing accumulations of oil and gas in sand-filled channels, and directions of migration. (*After Wallace Lee.*)

in the petroliferous stratum the lines of contact between gas and oil and between oil and water may be found at widely different elevations.

ACCUMULATIONS AT UNCONFORMITIES

Unconformities are favorable places for the accumulation of oil and gas because the material laid down first along an advancing shore line is generally coarse. The strata formed at the bottom of a sedimentary series generally contain conglomerate and coarse sand. As a rule, such material has been washed over by waves and the fine clay has been removed from it. Thus the basal beds are likely to contain many large openings suitable for the accumulation of oil and gas. At some unconformities the surface on which the upper series was laid down is irregular, and the porous beds are likely to be distributed as small lenses. Thus the reservoirs formed by such rocks will be spotted. When such a reservoir is thrown into folds the oil and gas will accumulate at the crests of the folds where the lenses of porous rock lie at the crests and in the upper parts of the lenses that lie on the flanks of the folds (Fig. 67). In the Colmar district, Illinois, oil and gas are found in the Hoing sand, at the base of the Niagara, which lies unconformably on the Maquoketa shale at places where it is locally developed.

Among the examples of reservoirs at unconformities are those of the McKittrick-Sunset district, California, where large accumulations are found at the base of the McKittrick beds, which overlie older rocks unconformably. In the Coalinga district, California, oil-bearing beds are found at three unconformities. Some other examples of accumulation at unconformities are mentioned on pages 149-151.

SUCCESSIONS OF PETROLIFEROUS STRATA

Oil reservoirs are almost invariably related to geologic structure. There is no better proof of this relation than the accumulation of oil in different beds, one below the other, in the same field, and the absence of oil in commercial accumulations in the surrounding regions.

In many pools oil is found in more than one stratum. In some it is found in five strata or more. Where the structure is anticlinal and there is an accumulation of petroleum in the upper sand at the crest, it is reasonable to suppose that lower strata, if conformable, lie in anticlines also, and that if they are porous they may contain additional reserves. In some districts the amplitude of folds increases with depth, and deeper accumulations, situated on the greater folds, are more productive than the shallow pools. Many fields have been revived again and again by deeper drilling.

Where petroliferous beds are steeply folded, as they are in the Grozny field, north of the Caucasus Range, Russia; in the Yenangyat-Singu field, Burma; and in other fields that contain accumulations of oil in Mesozoic and Tertiary rocks, where successive oil strata have been discovered, the planes that pass through the crests of folds or the "crest loci," are not vertical but dip at high angles. In general, if not invariably, the crest locus will dip toward the gentle limb of an asymmetric fold, and accumulation on the gentle side of the fold as shown at or near the surface will be even more pronounced in depth.

In oil fields on monoclines regular successions of petroliferous strata are less likely to be discovered than on domes. Nevertheless, such series have been found at many places. Even some monoclinal traps that are formed by the porous sands tightening up the dip, either by changing to clayey strata or by cementation of porous sands, have been found to contain several accumulations, one below another. Sands wedge out away from shore lines, and many sands, one below another, may be related to the same shore line. Faults that bring impervious strata against sands and thus seal reservoirs may cross a series of sands providing conditions for accumulation at several horizons. Dikes or other intrusive bodies that seal one member of a petroliferous series are likely to seal others.

In oil fields on terraces more than one petroliferous bed may be found. Obviously, if the rate of dip changes in the higher beds, it will generally change also in the lower beds.

DISTANCES COVERED IN THE MIGRATION OF PETROLEUM

In some regions there is evidence that petroleum has migrated considerable distances. In Wyoming, where the dips are high, essentially all the petroleum recovered is found in small sharp domes or other uplifts. The gathering grounds are very large compared with the areas of accumulation. Some of the oil has probably moved several miles, perhaps a score of miles or more, to accumulate in the high structural positions. In this and other regions the contact with the salt water that lies below the oil—that is, the "edge water"—is not a level line but descends to lower levels on the side toward which the gathering ground is greatest. In the Salt Creek dome the base of the conical oil blanket descends about 100 feet on the northeast side, toward the great syncline that lies between the Big Horn Mountains and the Black Hills. In the Cushing field, Oklahoma, the oil descends to greater depths down the west side of the dome, which lies toward the basin, than it does on the east. In Lambton County, Ontario, there are noteworthy descents of the oil-saturated rocks of each of the great pools, and accumulations are greatest toward the areas where the gathering ground is greatest. On the Volcano anticline, West Virginia, the accumulation is concentrated on the west side of the axis. In these and many other regions the positions of the most productive sides of the domes with respect to the greatest gathering areas indicate clearly that migration of petroleum has been greatest where the area from which supplies could have come is greatest.

In many regions minor anticlines or domes are found one below another down the dip on great monoclines that slope away from mountain uplifts. The greatest accumulations are commonly on the lower folds—that is, on those that lie on the basinward side—which in general have greater gathering grounds than folds higher on the monocline. These relations are clearly shown in the Big Horn Basin, Wyoming,[1] and at many other places.

Some accumulations are so great that the inference is warranted that they are drawn from large areas. In the famous Baku oil field of Russia accumulations that cover small areas are very large. More than one-tenth of the world's production of petroleum has been derived from an area of less than 3,000 acres in the Balakhany-Sabunchy-Romany field. It is improbable that such large accumulations could form only from strata near them. The oil doubtless has moved great distances to collect in the structurally favorable areas.

These observations tend to confirm the conclusion that oil has migrated considerable distances in some districts. In northeastern Oklahoma, where the domes and anticlines are flat and closely spaced and saturation is high, the oil pools are near together, especially in the area east of Bartlesville, in Osage, Washington, and Nowata Counties. In this area the oil has probably migrated shorter distances. More definite statements are not warranted. An extreme view is expressed by McCoy,[2] who believes that the oil of this area has been derived from materials near at hand and has entered the oil reservoirs themselves along faults connecting the sands and the shales. It is believed by Van Verveke that the petroleum of the Alsace field originated near the reservoirs that contain it.

MINIMUM INCLINATION NECESSARY FOR MIGRATION

The inclination necessary for migration varies with the porosity and size of pores, gas pressure, and viscosity of the oil. Examples are not rare where segregation has taken place in sands dipping less

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[1] Hewett, D. F., and Lupton, C. T.: Anticlines in the Southern Part of the Big Horn Basin, Wyoming. U. S. Geol. Survey *Bull.* 656, p. 44, 1917.

[2] McCoy, A. W.: Notes on Principles of Oil Accumulation. *Jour. Geology,* vol. 27, p. 254, 1919.

than half a degree. In the Lambton County field, Ontario, where the oil is found in a porous limestone, the segregation in pools at crests of folds is very clear. The beds in general dip less than 50 feet to the mile, and at many places the dips are much lower. In the Mid-Continent field, migration has probably taken place in beds dipping less than 20 feet to the mile. Laboratory experiments at the University of Minnesota (p. 110) show that oil will move very readily through sands in tubes tilted less than one degree, when gas is present under low pressure in a closed system.

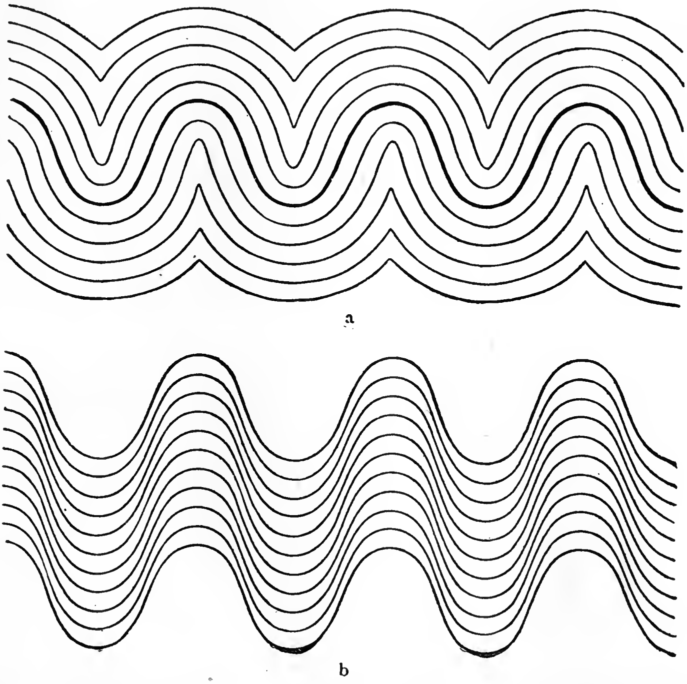

Fig. 68.—Sketches illustrating (*a*) ideal parallel, and (*b*) ideal similar folds. (*After Van Hise.*)

BEHAVIOR OF FOLDS IN DEPTH

The zone of deformation affected by mountain-forming folds is comparatively shallow. Thus, in the region between Tyrone and Harrisburg, Pennsylvania, the depth involved as calculated by

R. T. Chamberlin[1] is estimated to be 5.7 miles at one end of an earth element and 32.7 miles in the region affected at greatest depth.

In areas of deformation two types of folding are distinguished. In one type the beds are approximately parallel throughout. Such folds are known as parallel folds (Fig. 68, a). In the other type the curvatures of the beds tend to remain the same. In readjustment of beds to fit the fold, all parts of the bed are affected. Such folds are known as similar folds (Fig. 68, b). Similar folds are characteristic of deformation at great depths, where beds are folded in the zone of flowage. Folding of this type is exhibited in the Vermilion iron range, in the Marquette iron-bearing district, and at many other places in the Lake Superior region, where it has been investigated by Van Hise,[2] Leith,[3] and others.

In areas of similar folding the folds persist vertically and may remain similar through great depths. In areas of parallel folding the deformation is less intense and the amplitude of the folds is likely to change with depth. The highest bed represented in Fig. 68a, shows folds of very low amplitude; the amplitudes of the folds in the lower beds become greater but finally decrease again. This is the type of folding which is characteristic of many petroliferous areas in rocks older than the Mesozoic. In such areas, therefore, the amplitude of folds may be expected to increase in depth where erosion has not removed the higher parts of the folded zone, exposing conditions illustrated in the lower part of Fig. 68a.

Where only one fold is developed such a fold also may become sharper with depth. The conditions are illustrated by Fig. 69, which represents an experiment by Willis.[4] The fold was produced by force applied at the right end. The anticline shown in the lower sketch is sharper in the lower beds.

Pressure applied horizontally to bodies of strata is frequently

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[1] Chamberlin, R. T.: Appalachian Folds of Central Pennsylvania. *Jour. Geology*, vol. 18, pp. 228-251, 1910.

[2] Van Hise, C. R., and Leith, C. K.: Geology of the Lake Superior Region. U. S. Geol. Survey *Mon.* 52, p. 123, 1911.

Van Hise, C. R.: Principles of North American Pre-Cambrian Geology. U. S. Geol. Survey *Sixteenth Ann. Rept.*, part 1, pp. 597-601, 1895.

[3] Leith, C. K.: Structural Geology. P. 107, New York, Henry Holt & Co., 1913.

[4] Willis, Bailey: Mechanics of Appalachian Structure. U. S. Geol. Survey *Thirteenth Ann. Rept.*, part 2, p. 247, 1893.

relieved by faulting. The stresses are applied at considerable depths but are relieved upward because the rock bodies can most readily move upward. Frequently the stresses are relieved along an inclined plane, as is illustrated by Fig. 70. If the upper strata include shales or clays, as is common in oil fields, the upthrust is

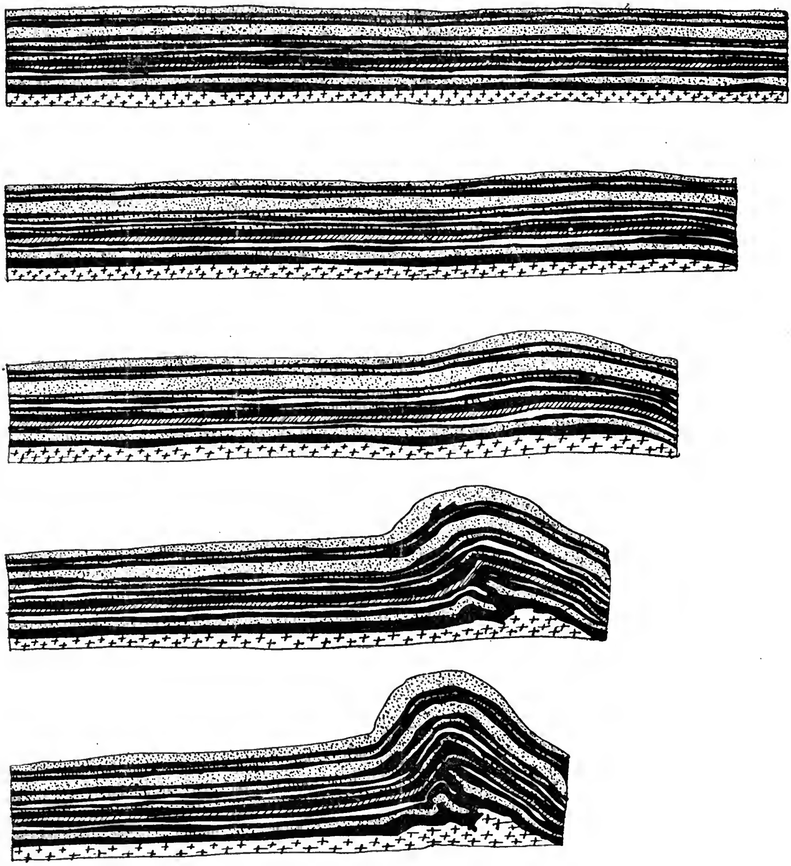

FIG. 69.—Sketches showing deformation of beds by lateral pressure. (*After Willis.*)

partly taken up by compacting the shales. Thus in areas of relatively gentle deformation the fold originating in depth may tend to die out toward the surface.

In many oil fields of the earth the amplitudes of folds increase with depth. That is true in certain European fields where folding occurred between the periods of deposition of the several petroliferous series. It is illustrated in Rumania, where folding and deposition of strata that yield petroleum took place alternately through a long period in Miocene time. In the Oklahoma-Kansas field the increase in amplitude of folds with depth has been noted by many investigators. In northern Texas some very gentle half domes become closed with depth. In some folded areas the amplitudes of folds increase with depth because the lower beds were folded before the upper ones were laid down unconformably over them.

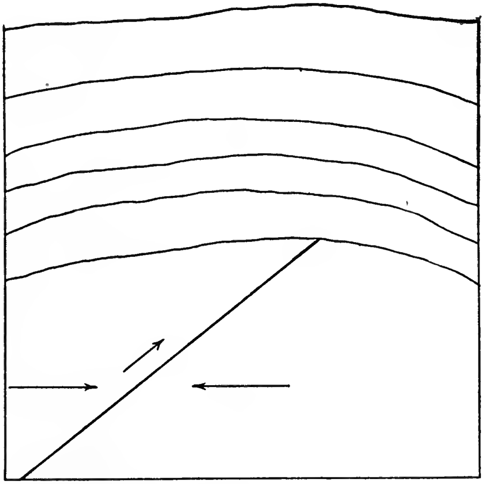

Fig. 70.—Sketch showing folds developed above a fault.

The increase of folding with depth is illustrated in the Cushing pool, Oklahoma. Fig. 71 shows contours on the out-cropping Pawhuska limestone as mapped by Buttram. These contours indicate folds of small amplitude. The contours on the Bartlesville sand as mapped by Conkling[1] indicate folds of much greater amplitude (Fig. 72). As shown by the cross section along the north line of Secs. 8 and 9 (Fig. 73), the Tucker sand dips much more steeply than the Bartlesville sand. The shale between the Bartles-

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[1] Conkling, R. A.: The Influence of the Movement in Shales on the Area of Oil Production. Am. Inst. Min. Eng. *Bull.* 119, pp. 1969-1972, 1916.

ville and the Tucker becomes thinner at the crest of the anticline. Ohern[1] states that there is probably an unconformity below the Bartlesville sand in the Cushing region.

In Oklahoma, northern Texas, and Louisiana, gentle deformation has been going on until a very late geologic period, continuing, locally at least, well into the Tertiary, if not to recent times. It is obvious that, for the parts of this region where parallel folds have formed and where erosion has not cut too deep into the deformed zone, the present surface is in the upper part of the deformed element, as illustrated in Fig. 68a, and that an increase of amplitude of folds with depth may be expected.

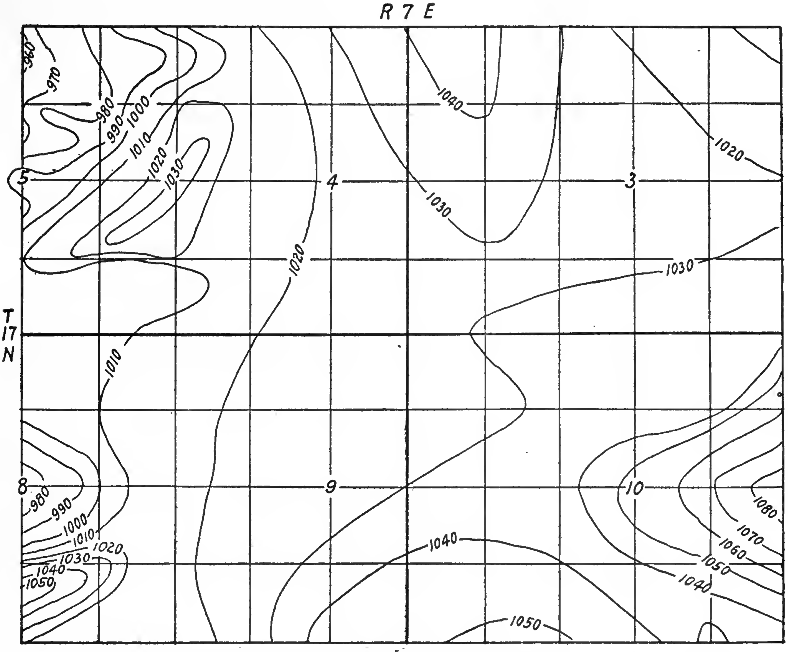

Fig. 71.—Sketch showing part of Cushing field, Oklahoma, with contours on Pawhuska limestone. (*After Buttram.*)

It is noteworthy that in the lower part of Fig. 68a the amplitudes of the upward folds decrease with depth. Toward the axes

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[1] Ohern, D. W.: The Influence of the Movement in Shales on the Area of Oil Production (Discussion of Paper by Richard A. Conkling, New York Meeting, Feb., 1917). Am. Inst. Min. Eng. *Bull.* 123, pp. 389-390, 1917.

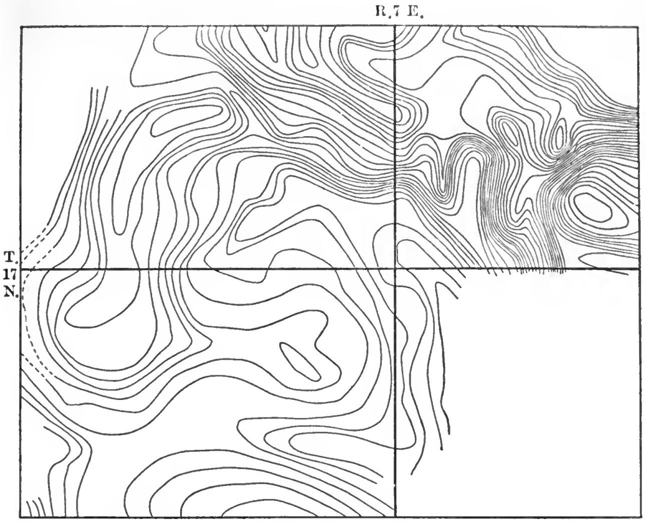

FIG. 72.—Sketch showing part of Cushing field, Oklahoma, with contours on Bartlesville sand. Contour interval is ten feet. (*After Conkling.*)

of these folds the dip increases. Stigand[1] states that when the dips increase toward an anticlinal axis on both sides, such anticlines "can rarely give good results." Such anticlines, he states, are found in Crimea.

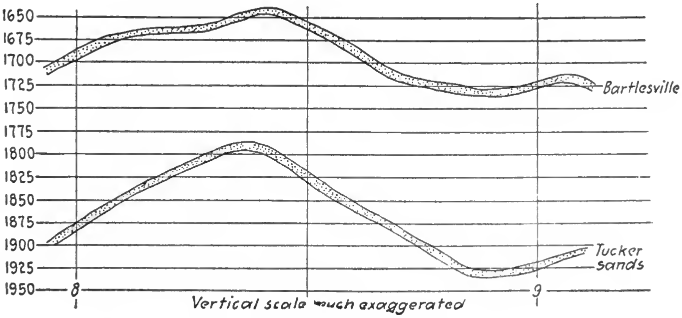

FIG. 73.—Section showing top of Bartlesville and Tucker sands in part of Cushing field, Oklahoma. The interval between the sands increases away from the crest of the anticline. (*After Conkling.*)

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[1] STIGAND, I. A.: Discussion of a Paper by THOMPSON in Inst Min. and Met. *Trans.*, vol. 20, p. 264, London, 1911.

CHAPTER XI

DEFORMATION OF PETROLIFEROUS STRATA

Deformation in Unconsolidated Materials.—In many districts the petroliferous beds are covered by strata that include considerable thicknesses of unconsolidated clay, marl, or clayey sand. In such districts, even after extensive deformation by folding and faulting, the reservoir rocks may retain large accumulations of oil and gas. Some of the most productive oil fields are in areas of rocks that are largely unconsolidated where the beds lie in overturned folds or are greatly disturbed by complicated faults. In unconsolidated materials openings due to faulting and folding tend to close promptly, so that the oil remains in the reservoir. In such materials there is generally some leakage, however, and oil seeps, asphalt, gas seeps, mud volcanoes, brine springs, and other surface associates of oil or gas are generally found above the reservoirs. Many of the Tertiary oil fields are in highly deformed rocks. These include many districts in Galicia, Rumania, Russia, Burma, Java and other fields of Oceanica, and the principal fields of California. These fields in general are marked by prominent surface indications of oil, and most of them are in areas of complicated faulting or folding. In consolidated rocks that had undergone so much deformation the gas pressure would have driven the bulk of the available oil from its reservoirs. In consolidated rocks the most productive fields are found in regions that have suffered only gentle deformation. Oil reservoirs in consolidated rocks have doubtless lost their stores by leakage attending thrust faulting and overturned folding. In consolidated rocks oil generally is in the simpler structural features only; in unconsolidated rocks it is often found in the most complicated ones, as is shown in many fields in California, Galicia and Rumania. In some of these fields folding probably took place after accumulation. In such strata the oil may be found in synclines or in any other position with regard to the structure.

Influence of Faulting on Reservoirs.—The shales that supply the so-called impervious covers to keep the petroleum confined within the sandstones are not absolutely impervious to fluids, otherwise the oil and gas could not pass from them to the porous beds in which they are found. Fracturing doubtless facilitates the passage, however, by supplying more readily available openings. In the Santa Clara, Summerland, Puente Hills, Los Angeles, and other California districts the fracturing appears to have aided accumulation by permitting the oil to move from lower to higher levels, where it is, of course, more readily accessible. The oil accumulation in the dome near Jennings, Louisiana, is said to be related to a fault. In the Labarge and Spring Valley regions, Wyoming, the oil seeps are obviously related to planes of movement subsidiary to the great Absaroka fault. In the Brunswick district, Oklahoma, several quarries of bituminous rock are opened on or near normal faults.[1] Other asphalt and ozokerite deposits in fissures have been mentioned. It is clear that some faults have served as channels through which petroleum has moved.

As is well known by students of ore deposits the fissures that serve as channels of metalliferous waters and the openings that are filled by metalliferous ores are in general the fissures and faults of small throw rather than the great faults. Except in limestone a comparatively small number of veins are formed in faults of considerable tangential movement. Without doubt the gouge developed along the greater faults provides an impermeable barrier and prevents circulation. It is obvious that this principle will apply also in many districts that yield petroleum. The smaller faults may serve as channels for migration and escape of oil, whereas the greater faults may seal the reservoirs.

In many oil fields the beds are cut by faults along which neither asphalt nor oil seeps have been observed. In the Lander field, Wyoming, oil seeps and tar springs are found at the surface, but along a thrust fault over 2 miles long, with a throw of 1,180 feet, that penetrates the Little Popo Agie dome, neither oil seeps nor asphalt deposits were noted, although the oil flows from some of the wells and is under pressure.[2]

The Irvine oil field, Kentucky, lies along a fault, as do also the Homer and Gusher Bend fields, Louisiana. According to McCoy

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[1] Eldridge, G. H.: The Asphalt and Bituminous Rock Deposits of the United States. U. S. Geol. Survey *Twenty-second Ann. Rept.*, part 1, p. 306, 1901.

[2] Woodruff, E. G.: The Lander Oil Field, Fremont County, Wyoming. U. S. Geol. Survey *Bull.* 452, 1911.

small faults are present in many of the Oklahoma fields and apparently influence accumulation favorably.

In the southern California districts many strong faults cut the oil-bearing strata, but relatively few of these are marked by great oil seeps and asphalts. In the Santa Cruz district[1] the Thurber, New, and Hole bituminous sandstone quarries are on faults, as is also a prominent brea deposit in the Los Angeles district. Considering, however, the large amount of oil and of asphalt and bituminous rock in California, and the large number of faults that occur in the oil fields, the number of faults that carry large deposits of the natural hydrocarbons is small.

The Buckhorn district, Oklahoma, contains numerous faults and numerous areas of bituminous rock, yet there is no very obvious relation of some of the deposits of the bituminous rock to the greater fault planes.[2] In the Uinta Basin, Utah and Colorado, the gilsonite veins, though remarkably uniform as to strike, apparently occupy fissures of little or no displacement,[3] and so also do the wurtzilite veins in the Uinta district. The grahamite vein in Ritchie County, West Virginia, occupies a fissure along which very little if any displacement by faulting has been shown.[4]

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[1] Eldridge, G. H.: *Op. cit.*, p. 393.

[2] Eldridge, G. H.: *Op. cit.*, p. 274.

[3] *Idem*, p. 339.

[4] White, I. C.: Origin of Grahamite. Geol. Soc. America *Bull.*, vol. 10, p. 278, 1898.

Eldridge, G. H.: *Op. cit.*, p. 232.

CHAPTER XII

METAMORPHISM OF PETROLEUM BY DYNAMIC AGENCIES

Petroleums and the materials of which they are formed are changed by the heat and pressure that attend dynamic metamorphism of strata. In the Appalachian region and in the Mid-Continent field of the United States petroleum and gas are closely associated geographically with beds containing coals, and the degree of metamorphism of the coals affords a kind of index to the intensity of the metamorphic processes. In these regions the coals are altered progressively more toward the areas of intense deformation. The hydro-carbons are driven off and the coal becomes richer in fixed carbon. In the Appalachian region the amount of fixed carbon is greater in the most highly folded area and decreases toward the west, where the intensity of metamorphism is decreased. Petroleum and gas in reservoirs associated with the coals show differences corresponding to the alteration of the coals. This relation between the distribution of oil and the character of coal was first shown by David White[1] and has been treated also by Fuller[2] and by Gardner.[3]

In the Appalachian region, as stated by Fuller, neither oil nor gas, except in a few minor accumulations, has been found east of the west face of the outermost strong fold of the Appalachian Mountains (Fig. 74). Between this face and the line of 60 per cent carbon coals there is much gas in the northern part of the field and some in the southern part, with an oil pool here and there, but the main oil field is west of the 60 per cent carbon line. (See Fig. 75.)

In the Ouachita-Arbuckle region, Oklahoma and Arkansas, according to Gardner, gas only has been found in the region near and northwest of the Choctaw fault. The main oil fields are 50

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[1] White, David: Some Relations in Origin Between Coal and Petroleum. Washington Acad. Sci. *Jour.*, vol. 5, pp. 189-212, 1915.

[2] Fuller, M. L.: Appalachian Oil Fields. Geol. Soc. America *Bull.*, vol. 28, p. 643, 1917.

[3] Gardner, J. H.: The Mid-Continent Oil Field. Geol. Soc. America *Bull.*, vol. 28, pp. 685-720, 1917.

miles or more northwest of the Choctaw fault, although there are 10 or more gas fields in this region.

Fig. 76 is a map showing isovols[1] in Oklahoma, according to Fuller.[2] The maximum production has come from the zone between the 50 and 55 isovols. Fuller states that the promise of the various zones is roughly as stated below:

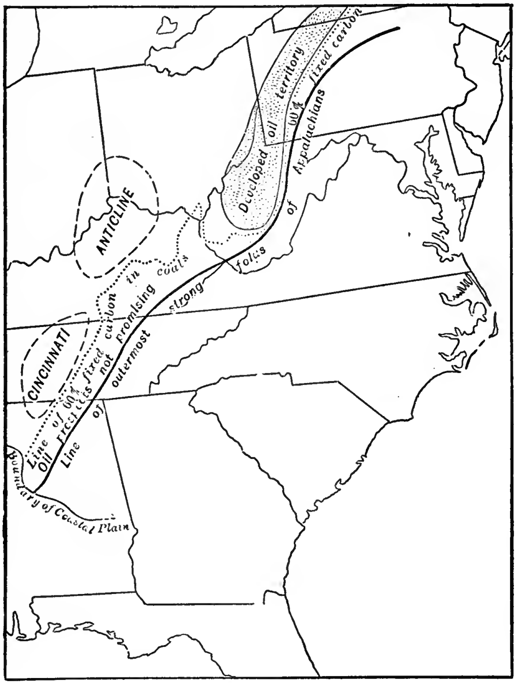

Fig 74 —Map of Appalachian region, showing relation of developed oil fields to the line of 60% fixed carbon in coals. (*After Fuller.*)

	Relative Chances of Finding Oil
Zone of 50% to 55% carbon ratios	100
Zone of 55% to 60% carbon ratios	10
Zone of 60% to 65% carbon ratios	1

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[1] An isovol is a line connecting points where the coals have equal percentages of fixed carbon (and therefore of volatile matter). See White, David, Washington Acad. Sci. *Jour.*, vol. 5, p. 198, 1915.

[2] Fuller, M. L.: Carbon Ratios in Carboniferous Coals of Oklahoma and Their Relation to Petroleum. *Econ. Geology*, vol. 15, p. 232, 1920.

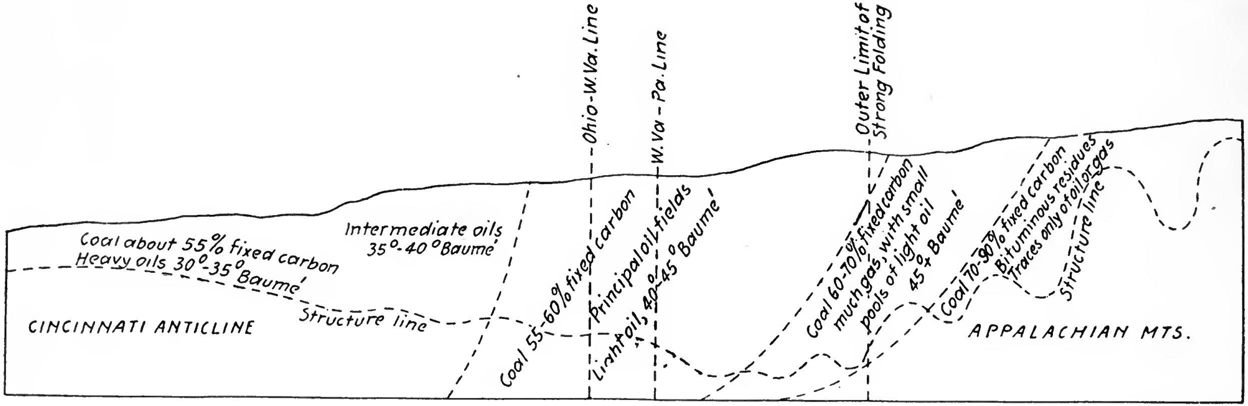

FIG. 75.—Generalized section, showing relation of distribution of Appalachian oils of different gravities to the zone of dynamic disturbance and to the fixed-carbon percentages in coals. (*After Fuller.*)

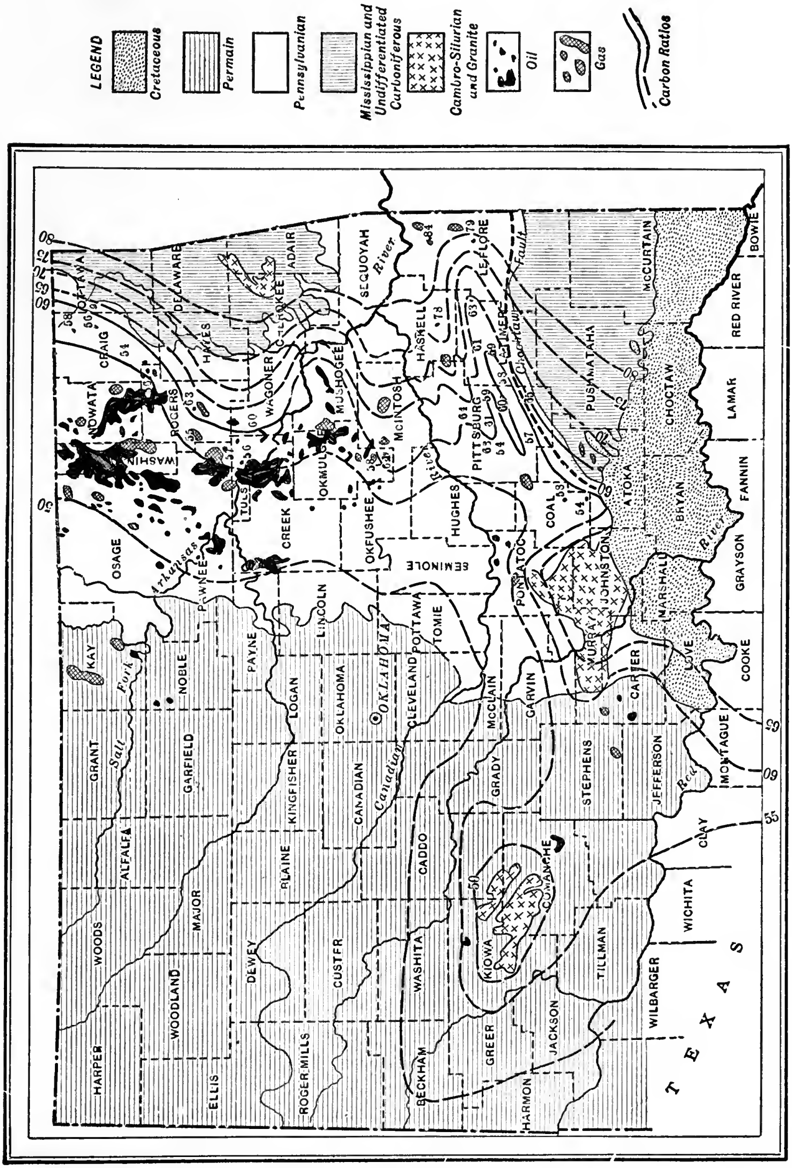

FIG. 76.—Isovol map of Oklahoma. (*After Fuller.*)

In north-central Texas many of the oil pools are associated with strata that contain coals. The coals become richer in fixed carbon toward the east. Nearly all the oil pools lie between the 50 and the 55 per cent isovol (See Fig. 77). In the belts yielding coals

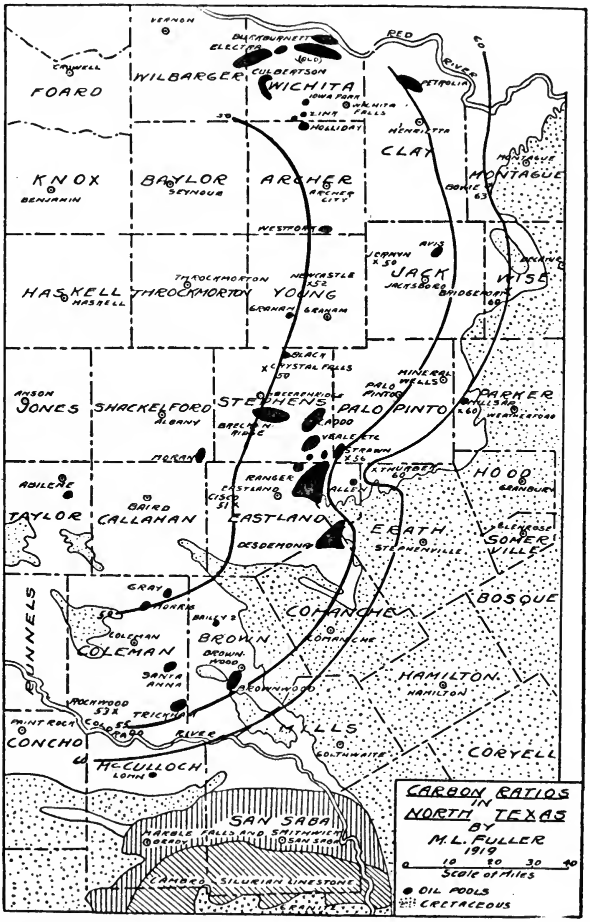

FIG. 77.—Sketch map showing isovols and relation of oil pools to carbon ratios of coals in Northern Texas. (*After Fuller.*)

that carry between 55 and 60 per cent of fixed carbon some oil is present, with considerable gas. East of the line showing 60 per cent fixed carbon no commercial accumulations have been developed.

It is noteworthy that in southern California, Rumania, and Galicia oil pools are found in rocks that have been closely folded and intensely faulted. In such surroundings large quantities of petroleum, much of it of heavy grade, remain. In these regions the strata include unconsolidated clays or marls that have probably sealed the faults as they were being formed. Deformation of the petroliferous strata probably took place under much thinner cover than in the Appalachian and Mid-Continent fields. As has been pointed out by Fuller, the fixed carbon in coals doubtless increases with depth, and in certain regions, as would be expected,

RELATION OF OIL AND GAS TO CARBON IN COAL[a]

Carbon Ratios (Surface)	Prevailing Characteristics of Sands	Prevailing Water Conditions (in Mixed Formations)[b]	Production[c]
Over 70	Hard and tight.	Water usually absent except near surface.	No oil or gas, with rare exceptions.
65-70	Tight, with a few porous spots.	Water usually absent below 1,500 feet.	Usually only "shows" or small pockets. No commercial production.
60-65	Variable, with porous beds of limited extent.	Water usually absent below 2,500 feet (often below 2,000 feet).	Commercial pools rare, but oil of exceptionally high grade when found. Gas wells common, but usually isolated rather than in pools.
55-60	Fairly continuous and open.	Water usually absent below 3,000 feet (often below 2,500 feet).	Principal fields of light oils and gas of the world.
50-55	Softer, less firmly consolidated, and more continuous and porous.	Water usually absent below 3,000-3,500 feet.	Principal fields of medium oils of Ohio-Indiana and Mid-Continent fields.
Under 50	Usually unconsolidated.	Sands usually saturated to all depths reached by wells.	Fields of heavy Coastal Plain oils and of unconsolidated Tertiary or other formations.

[a] FULLER, M. L.: Relation of Oil to Carbon Ratios of Pennsylvanian Coals in North Texas. *Econ. Geology*, vol. 14, p. 538, 1919.

[b] Unusually porous sands like the Dakota of the West and the St. Peter of the East carry water in quantities far above the average and to far greater depths and distances from the outcrops. Water is also carried in fissures.

[c] Statements of quality apply to oils from sandstones; oils from limestones are usually heavier.

the oils are lighter and higher grade in the deeper sands. Intense deformation probably does not result in metamorphism of oil to form the higher grades and gas, unless there is a considerable cover above the petroliferous strata.[1]

[1] Attempts have been made to ascertain whether the fixed-carbon content of carbonaceous shales shows a similar correspondence to the character of petroleum associated with the shales. According to Fuller, the results are inconclusive (1919).

CHAPTER XIII

GAS PRESSURE AND OIL RECOVERY

Gas Pressure.—Whenever petroleum is formed gas is probably generated. Oil absorbs gas, the amount absorbed depending upon the pressure. Whether the oil and gas are formed before or after deformation of the strata, the gas tends to accumulate in the highest parts of a closed fold. If, however, there is enough oil to absorb the gas present at the prevailing pressure, it will be completely absorbed, and oil and gas will issue together from a boring sunk to the top of a high fold. At the temperature and pressure that prevail in most fields, methane and ethane are probably always in the gaseous state, though some of the heavier gases that issue in the gaseous state may be liquids in the reservoirs. Pentane and hexane are liquid. They are the chief constituents of gasoline.

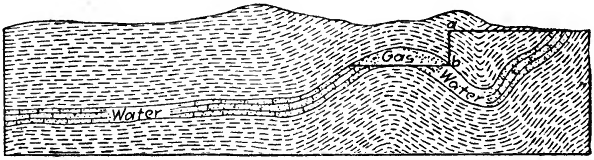

FIG. 78.—Sketch illustrating a gas pool with underlying water body in sand connected freely with surface. The level of ground water is assumed to be at the surface. Theoretically the pressure should equal the weight of a column of water as high as *ab*.

If the gas accumulates at the top of the fold it exerts a pressure on the oil and tends to drive it to a lower structural position. The oil in turn drives down the water. If the reservoir rock communicates with the surface of the earth at any place and is permeable the water will flow out of the reservoir. Thus the gas pressure will equal the weight of a column of water as high as the difference between the elevation of the gas body and the surface opening where the reservoir rock crops out. (See Fig. 78.)

In New York, according to Orton,[1] the gas pressure at many

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[1] ORTON, EDWARD: Petroleum and Natural Gas in New York. New York State Mus. *Bull.*, vol. 6, No. 30, p. 488, 1899.

places is independent of depth. In Pennsylvania, according to I. C. White,[1] the gas pressure generally increases with depth.

In Oklahoma, according to Gardner,[2] the gas pressure in many wells is about that of a column of water equal in length to the depth of the well—or, in other words, 43.4 pounds to the square inch for each 100 feet of depth. The well pressure is usually somewhat more or less than this figure, owing partly to differences in weight of water due to differences of salinity. The gas pressure moreover, is evidently not everywhere a reactive pressure against a water head. A well at Cushing 2,600 feet deep gave a gas pressure of 1,120 pounds; figuring the theoretical hydrostatic pressure of 43.4 pounds per hundred feet gives 1,128.4 pounds. A well near Claremore, at a depth of 860 feet, gave a pressure of 375 pounds; the theoretical pressure as above calculated is 373.2. A well near Collinsville, at a depth of 1,100 feet, gave a pressure of 495 pounds; the theoretical head at this depth is 477.4 pounds. These were closed pressures on new wells. On the other hand, some pressures are below what would be expected. Haworth reported a well in Kansas 1,000 feet deep with a pressure 250 pounds to the square inch, whereas one-half a mile away 900 feet deep showed 375 pounds.

Lenses of sand that are completely sealed may contain gas deposits under pressures that are independent of their depth. As deposits on monoclines are generally sealed above, and as many of them are also sealed below, gas deposits on monoclines are likely to exhibit pressures independent of depths. As pointed out elsewhere, petroleum is probably converted to gas by heat and pressure attending dynamic metamorphism. As stated by White and by Fuller, the amount of metamorphism sufficient to change coals so that their carbon ratio equals 65 per cent or more is probably sufficient to convert oil to gas. In general, heat and pressure increase with depth, so that the amounts of gas, and therefore the gas pressure, will increase. Thus an increase of gas pressure with depth may be expected, whether the gas pressure is balanced by hydrostatic pressure or not.

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[1] White, I. C.: The Mannington Oil Field. Geol. Soc. America *Bull.*, vol. 3, p. 196, 1892.

[2] Gardner, J. H.: The Mid-Continent Oil Fields. Geol. Soc. America *Bull.*, vol. 28, p. 702, 1916.

INITIAL GAS PRESSURES AT DIFFERENT DEPTHS IN SEVERAL GAS FIELDS
(Prepared by Mills and Wells)

Name of Bed	Locality	Depth (Feet)	Initial Gas Pressure (Pounds per Square Inch)	Average Pressure per 100 Feet Depth (Pounds per Square Inch)	Authority
Salt sand	Woodsfield, Ohio	1,295	280	22	Mills and Wells
Big lime sand	Southwest corner of Wayne Township, Belmont County, Ohio	1,310	365	28	Do.
	Southeast corner of Malaga Township, Monroe County, Ohio	1,412	400	28	Do.
	Wayne Township, Belmont County, Ohio	1,465	440	30	Do.
Keener sand	Woodsfield, Ohio	1,515	475	31	Do.
Big Injun sand	Woodsfield, Ohio	1,468	500	34	Do.
Berea sand	Woodsfield, Ohio	2,090	710	34	Do.
	Summerfield, Ohio	1,698	565	33	Do.
	Sunsbury Township, Monroe County, Ohio	2,060	735	36	Do.
Butler gas sand	Summit Township, Butler County, Pennsylvania	1,200	380	32	Do.
Hundred-foot sand	Butler, Pennsylvania	1,400	780	56	Do.
Third sand	Butler, Pennsylvania	1,700	785	46	Do.
	Butler, Pennsylvania	1,452	600	41	Do.
Fourth sand	Butler, Pennsylvania	1,800	870	48	Do.
	Butler, Pennsylvania	1,568	225	14	Do.
Fifth sand	Butler, Pennsylvania	1,950	870	45	Do.
"Clinton" sand	Harrison Township, Knox County, Ohio	2,700	810	30	Do.
	Cleveland, Ohio	2,500 2,900	800 1,100	32–38	Rogers[a]
	Newberg, Ohio	3,000	425	14	Van Horn[b]
Trenton limestone	Findlay, Ohio	950	400–450	42–47	Orton[c]
	Kokomo, Indiana	650	328	50	Do.
	Cleveland, Ohio	4,500	37	0.82	Van Horn[b]
Benson sand	Barbour County, West Virginia	4,090	1,800	44	I. C. White[d]
(?)	West Virginia	2,989	1,420	47	Do.
(?)	Havre, Montana	947	490	52	Stebinger[e]
(?)	Havre, Montana	1,370	540	39	Do.
(?)	Louisiana	1,650	650	39	Knapp[f]
Unconsolidated sand	Louisiana	1,800	600	33	Do.[g]
(?)	Loco, Oklahoma	750	310	41	McMurray and Lewis[h]

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[a] ROGERS, G. S.: The Cleveland Gas Field, Cuyahoga County, Ohio. U. S. Geol. Survey *Bull.* 661, p. 37, 1917

[b] VAN HORN, F. R.: Reservoir Gas and Oil in the Vicinity of Cleveland, Ohio. Am. Inst. Min. Eng. *Trans.*, vol. 56, p. 839, 1917.

[c] ORTON, EDWARD: The Trenton Limestone As a Source of Petroleum and Natural Gas in Ohio and Indiana. U. S. Geol. Survey *Eighth Ann. Rept.*, p. 645, 1889.

[d] Personal communication.

[e] STEBINGER, EUGENE: Possibilities of Oil and Gas in North-Central Montana. U. S. Geol. Survey *Bull.* 641, p. 73, 1916.

[f] KNAPP, I. N.: Discussion of Paper by R. W. JOHNSON, The Rôle and Fate of Connate Water in Oil and Gas Sands. Am. Inst. Min. Eng. *Trans.*, vol. 51, p. 593, 1915.

[g] KNAPP, I. N.: Discussion of Paper by W. H. KOBBE, The Recovery of Petroleum from Unconsolidated Sands. *Idem*, vol. 56, p. 825, 1917.

[h] MCMURRAY, W. F., and LEWIS, J. O.: Underground Wastes in Oil and Gas Fields and Methods of Prevention. Bur. Mines Tech. *Paper* 130, p. 13, 1916.

The table, prepared by Mills and Wells,[1] (p. 182) shows the gas pressures in many reservoirs and the depth of the wells. The fifth column shows the pressures per 100 feet of depth. The differences are noteworthy. In most of these districts, at least, it is highly improbable that the gas bodies are in equilibrium with a water column connecting with the surface. Evidently the reservoirs did not communicate freely with the surface.

Behavior of Certain Wells That Yield Oil and Gas.—Some borings that penetrate reservoirs yield initially large amounts of oil that flows from the well and may be thrown under pressure high above the derrick floor. Such wells are termed "gushers" in the United States and "spouters" or "fountains" in foreign fields that are developed by the British. They are characteristic of fields that have reservoirs containing gas under high pressure. Production may increase for a few days while drainage lines are being established in the reservoir, but almost invariably the initial production declines rapidly after a short period. The gas, under pressure, forces out the oil into the boring and causes it to rise vertically. Sand and gravel frequently rise with the oil and gas. A well that penetrates only the top of a sand reservoir may "drill itself in," or sink to the bottom of the reservoir while sand is being expelled with the oil. This process is commonly attended by increased production during the early stages of the well's life.

Since the pressure of gas forces oil out of the rocks into the wells, its pressure is of great economic interest. In porous rocks the decline of gas pressure over a field is approximately uniform. Every thousand feet of gas that is lost in general tends to lower the pressure. The practice of allowing the gas to issue freely in open wells is now forbidden by law in many states. Good pressure in a field after a long period of production is looked upon as a favorable indication for its future.

Some wells that at first yield gas subsequently yield oil. Indeed, it is a common, though wasteful practice to allow gas to escape from a well in the hope that ultimately the well will produce oil. Not only is the gas wasted, but oil also is likely to be wasted, because the gas is the means by which the oil is expelled from the rocks. If a small pocket of gas has accumulated at some high

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[1] Mills, R. V. A., and Wells, R. C.: The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas. U. S. Geol. Survey *Bull.* 693, p. 28, 1919.

point in the roof of a reservoir and is punctured by a drill gas will rise first and later oil, which is under pressure. This is illustrated in Well 1, Fig. 79. If a gas well is on the flank of a fold near the contact of gas and oil, it is obvious that release of the gas pressure which holds the oil down will permit the oil to rise higher in the reservoir, or to be pushed up by water pressure. Thus in Well 2, Fig. 79, gas would issue first, and oil later. Some wells yield petroleum first and salt water later. Well 3, Fig 79, would be first a petroleum well, and as the pressure declined and petroleum was removed from the reservoir, salt water would rise to take its place. Many petroleum wells become salt-water wells. A famous example is the Dos Bocas well, in Mexico, which after yielding oil at the rate of 100,000 barrels a day for 58 days, began to spout water in large quantities.

Many oil wells flow by heads, or spout periodically like geysers. The bore is gradually filled with oil, and gas accumulates below, until the pressure is sufficient to cause the oil to overflow. As the oil flows out the casing head, pressure is relieved and that allows the gas to expand suddenly and to raise the column of oil with force.

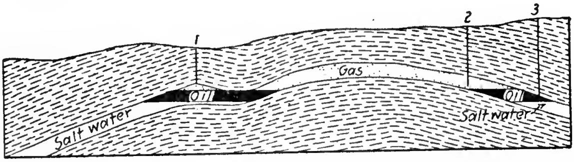

Fig. 79.—Sketch showing gas wells (1 and 2,) that would become oil wells if, because of decrease of pressure of gas, the plane of contact of oil and gas were to rise. If the plane of contact between oil and water were elevated because of removal of gas or oil, well 3 would cease to flow oil and would flow water.

Some flowing wells, after being capped and reopened will cease to flow. In other cases if the flow of the oil is stopped it may not be re-established in its original force. As a result many operators prefer not to shut off a well entirely, but to allow it to flow at a low rate during the period that preparations are made to dispose of the oil. In some cases the gas pressure has been reduced by other wells tapping the reservoir between the time of closing and reopening the well.

When a reservoir containing gas is pierced by a boring and the pressure is decreased by the issue of gas, a series of changes in

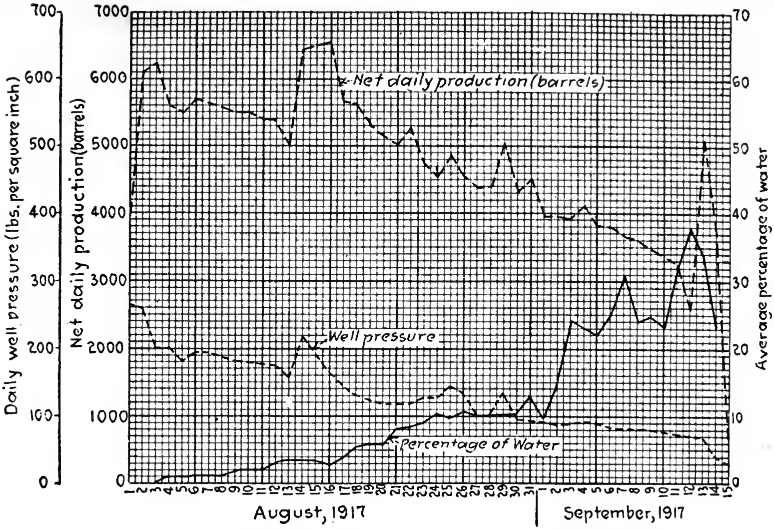

Fig. 80.—Chart showing relation of rock pressure to production of oil in a well in Midway field, California. (*After Beal.*)

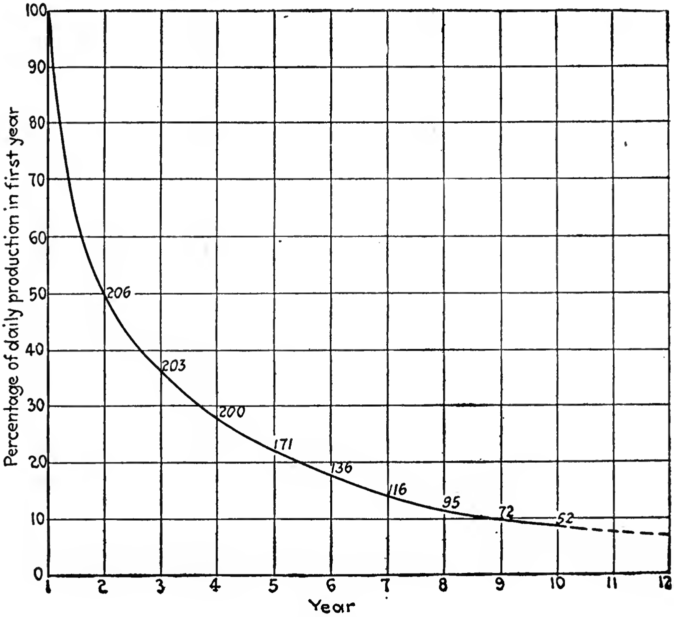

Fig. 81.—Composite decline curve for the Bartlesville field, Oklahoma. (*After Beal.*)

equilibrium results. Expansion lowers the temperature of the gas, and the salt-water spray which is commonly present in the issuing gas will be cooled. Gas under low pressure will absorb more water than gas under high pressure, and evaporation results. As a result of the cooling and evaporation, much salt is deposited. The casings of wells and the interstices of sands may be filled with sodium chloride so that the well will cease to flow.[1] Calcium carbonate, magnesium carbonate, iron carbonate, and calcium, barium, and strontium sulphates are deposited in casings and presumably also in interstices of sands in reservoirs.

Paraffin wax is commonly dissolved in oil. Cooling follows relief of pressure. In some wells the wax is deposited in quantities so great as to retard production.

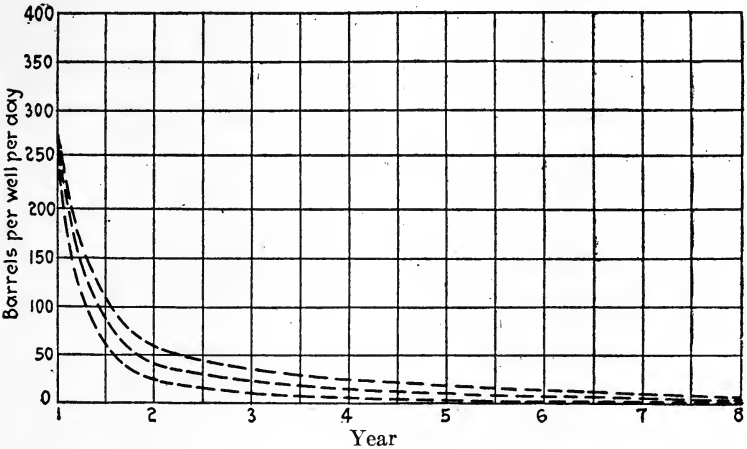

Fig. 82.—Generalized decline curve of the wells in the eastern part of the Osage Indian Reservation, Oklahoma. (*After Beal.*)

The life of most oil wells is comparatively short. Some start flowing at high rates, many spouting 5,000 or 10,000 barrels a day or more. As a rule they decline rapidly and steadily after they have reached their maximum, which is generally during the first few days. The first year's flow is usually much greater than the yield of any other year. Curves showing the rates of decline for several fields are given in Figs. 80 to 84. The numbers at yearly

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[1] Mills, R. V. A., and Wells, R. C.: The Evaporation and Concentration of Water Associated with Petroleum and Natural Gas. U. S. Geol. Survey *Bull.* 693, pp. 44-50, 1919.

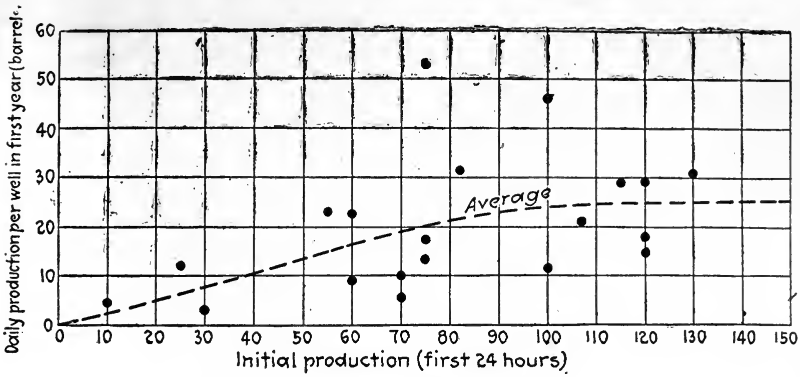

FIG. 83.—Curve showing relation of initial production to average daily production per well during the first year in the Lawrence County field, Illinois. (*After Beal.*)

intervals on the curves of Figs. 81 and 84 represent the number of properties employed in determining averages of each year.

In estimating the future production of a field, two methods are employed. In one, curves such as those prepared by Beal are used.

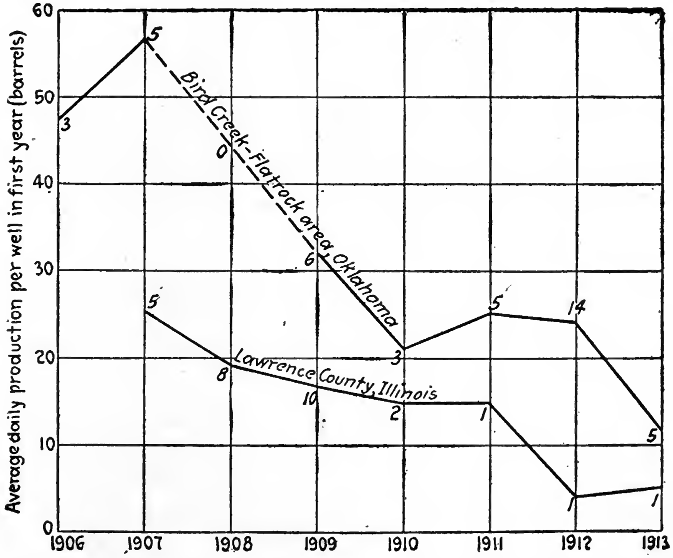

FIG. 84.—Curves showing the decrease in daily production during the first year on several properties in the Bird Creek-Flatrock field, Oklahoma, and in the Lawrence County, Illinois, pool. The numbers on the curves show the number of wells used to obtain the data. (*After Beal.*)

In the other the volume, porosity, and saturation of the sands and the amount of oil which may eventually be recovered are estimated from the data available. The latter method, which has been developed by Washburne and others, is a useful check on the curves showing decline of wells, but the results are not expected to be precisely accurate because the determinations are affected by many variable factors, and generally not all of these are known.

VOLUME OF A HORIZONTAL SAND, PER HECTARE AND PER ACRE[a]

Area	Thickness of Sand	Volume of Sand[b]	
		Cubic Meters	Barrels of 42 United States Gallons
1 hectare	1 meter	10,000	62,898
1 hectare	1 foot	3,048	19,171
1 acre	1 foot	1,233	7,758

[a] WASHBURNE, C. W.: The Estimation of Oil Reserves. Am. Inst. Min. Eng. *Trans.*, vol. 51, p. 646, 1916.

[b] The figures of the last column multiplied by the thickness of the sand, by the porosity, and by the relative saturation give the capacity of the sand in barrels per unit area. Thus, a sand 12 feet thick, with a porosity of 15 per cent and a relative saturation of 75 per cent, contains $12 \times 0.15 \times 0.75 \times 7{,}758 = 10{,}473$ barrels per acre. With an assumed extraction factor of 60 per cent, each acre would produce 6,284 barrels.

The data showing decrease of yield of groups of wells in a district may be presented in many ways, as shown in a recently issued bulletin by Beal.[1] Each method exhibits certain advantages under certain sets of conditions.

It is noteworthy that not only does the yield of individual wells diminish rapidly, but the initial yields and total production of wells generally diminish steadily as more wells are put down in the field.

Probably half the oil in some reservoirs remains in the rocks after the fields have ceased to yield. It adheres to sand grains, and in

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[1] BEAL, C. H.: The Decline and Ultimate Production of Oil Wells, with Notes on the Valuation of Oil Properties. U. S. Bur. Mines *Bull.* 177, pp. 1-215, 1919.

the absence of gas under pressure it can not be moved (Fig. 85). By proper management and conservation of gas pressure, the maximum yields may be obtained. If the gas is tapped above the oil and the gas pressure is wasted without allowing the gas to do its work, it may be impossible to obtain the principal part of the oil stored in the rocks. It is common practice to increase the flow by pumping the sands to a vacuum. Another method consists in driving water into the sands and floating the oil to points of issue. Thus water that is allowed to enter the sands in one well will make its way down the dip to another well, pushing the oil ahead of it. A third method consists in pumping compressed air into the sands. Natural gas is used in some fields instead of air and has the advantage that it absorbs the gasoline, which may be recovered by condensing the gas after it has issued from the wells. These methods[1] prolong the life and increase the production of a field, but they are generally not employed until the field is near exhaustion.

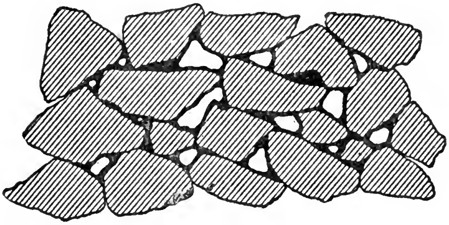

FIG. 85.—Sketch illustrating a pile of sand grains, and showing how oil is retained by adhesion. (*After Lewis.*)

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[1] LEWIS, J. O.: Methods for Increasing the Recovery from Oil Sands. U. S. Bur. Mines *Bull.* 148, pp. 1-128, 1917.

CHAPTER XIV

PETROLIFEROUS PROVINCES AND PETROLEOGENIC EPOCHS

Petrologists have long used the term "petrographic province" for a district or region that contains bodies of igneous rocks which, though differing somewhat in composition and character, nevertheless exhibit similar features that indicate similar generic relations. Similarly, the ore deposits of certain regions that have common characteristics are grouped within a metallogenic province.[1]

The term "petroliferous province," first used by Woodruff,[2] suggests a region containing accumulations of petroleum that are nearly related genetically and that have closely similar geologic surroundings.

Schuchert[3] classifies areas as regards petroliferous possibilities as follows:

1. The impossible areas for petroliferous rocks.
    - (*a*) The more extensive areas of igneous rocks and especially those of the ancient shields: exception, the smaller dikes.
    - (*b*) All pre-Cambrian strata.
    - (*c*) All decidedly folded mountainous tracts older than the Cretaceous; exceptions, domed and block-faulted mountains.
    - (*d*) All regionally metamorphosed strata.
    - (*e*) Practically all continental or fresh-water deposits; relic seas, so long as they are partly salty, and saline lakes are excluded from this classification.

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[1] LINDGREN, WALDEMAR: The Geological Features of the Gold Production of North America. Am. Inst. Min. Eng. *Trans.*, vol. 33, pp. 790-845, 1903; Metallogenetic Epochs. *Econ. Geology*, vol. 4, pp. 409-420, 1909.

EMMONS, W. H.: The Principles of Economic Geology, pp. 269-270, 1918.

[2] WOODRUFF, E. G.: Petroliferous Provinces. Am. Inst. Min. Eng. *Bull.* 150, pp. 907-912, 1919.

[3] SCHUCHERT, CHARLES: Petroliferous Provinces; Discussion of Paper of E. G. WOODRUFF. Am. Inst. Min. Eng. *Bull.* 155, p. 3059-3060, 1919.

- (*f*) Practically all marine formations that are thick and uniform in rock character and that are devoid of interbedded dark shales, thin-bedded dark impure limestones, dark marls, or thin-bedded limy and fossiliferous sandstones.
- (*g*) Practically all oceanic abyssal deposits; these, however, are but rarely present on the continents.

2. Possible petroliferous areas.
   - (*a*) Highly folded marine and brackish water strata younger than the Jurassic, but more especially those of Cenozoic time.
   - (*b*) Cambrian and Ordovician gently folded strata.
   - (*c*) Lake deposits formed under arid climates that cause the waters to become saline; it appears that only in salty waters (not over 4 per cent?) are the bituminous materials made and preserved in the form of kerogen, the source of petroleum; some of the Green River (Eocene) continental deposits (the oil shales of Utah and Colorado) may be of saline lakes.

3. Petroliferous areas.
   - (*a*) All marine and brackish water strata younger than the Ordovician and but slightly warped, faulted, or folded; here are included also the marine and brackish deposits of relic seas like the Caspian, formed during the later Cenozoic. The more certain oil-bearing strata are the porous thin-bedded sandstones, limestones, and dolomites that are interbedded with black, brown, blue, or green shales. Coal-bearing strata of fresh-water origin are excluded. Series of strata with disconformities may also be petroliferous, because beneath former erosional surfaces the top strata have induced porosity and therefore are possible reservoir rocks.
   - (*b*) All marine strata that are, roughly, within 100 miles of former lands; here are more apt to occur the alternating series of thin- and thick-bedded sandstones and limestones interbedded with shale zones.

Perhaps the greatest petroliferous province is the Tertiary province of Eurasia, which includes all the important producing oil fields of the Old World, except England and Germany. In the producing fields of Alsace, Galicia, Rumania, the Caucasus, Turkey, Persia, Burma, Oceanica, and Japan, nearly all the petroleum is derived from Tertiary rocks, except some of that produced in Galician fields, which comes from the Upper Cretaceous. The greater part of the oil from the Tertiary beds is obtained from the Miocene and Oligocene. The oil is accumulated in raised structures except where there has been extensive folding and faulting of unconsolidated rocks near the surface. In general the rocks of this province are not thoroughly consolidated. Although some of the oil is a high-grade light oil, with paraffin base, a larger part of it is low-grade asphaltic oil. The characteristic structural features are domes and anticlines, although oil is found in faulted monoclines in Alsace, in synclines at Boryslaw, at an unconformity in Maikop, and in fault traps and near salt plugs in Rumania. Deformation affecting the petroliferous strata took place in all these areas in the later part of Tertiary time. There is not a continuous belt of Tertiary strata between the oil-bearing regions named. At some places the Tertiary has been eroded; at other places there were probably islands or larger land masses between the Tertiary seas. In general, however, this region between Alsace, Borneo, and Japan, with an arm extending from Borneo to New Guinea and thence possibly to New Zealand, was a site of deposition in early and middle Tertiary time and of extensive deformation later in the Tertiary.

In the Egypt field,[1] near the Gulf of Suez, oil is found in Tertiary beds that were deformed in late Tertiary time. This field is closely affiliated with the Eurasian province. On the other hand, in the English field, oil comes from Paleozoic strata that are thoroughly consolidated. The English field should not be included in the Eurasian province. Certain small fields in Germany produce oil from rocks older than the Tertiary.

In North America (Fig. 86) the Pacific coast fields and also the Gulf coast field of Texas and Louisiana are more closely affiliated with the fields of the Eurasian province than with the Appalachian and Mid-Continent fields. They derive their oil chiefly from Tertiary strata that were extensively deformed in late Tertiary time. The rocks are not consolidated, as they are in the Appalachian and most of the Mid-Continent fields. Most of the oil, like

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[1] It is reported that oil has recently been developed in the Cretaceous in Egypt.

the greater part of that from the Eurasian field, is of low grade, with asphalt base.

The Appalachian fields, the Lima-Indiana field, and the Mid-Continent field, except northern Louisiana and eastern Texas, supply oil from Paleozoic strata that are well consolidated but not extensively deformed. In general the oil is of high grade, with a

FIG. 86.—Map of North America, showing petroliferous provinces according to the interpretations of E. G. Woodruff. The lined areas are in the main unfavorable.

paraffin, or paraffin and asphalt base. The Ontario fields of Lambton and Middlesex Counties supply oil of similar character from Paleozoic strata similarly deformed and constitute a part of the Appalachian province.

The northern Louisiana and eastern Texas fields, including those of the Balcones fault region, Texas, supply oil from Upper Cretaceous strata, from which also nearly all the oil produced in Wyoming, Montana, and Colorado is derived. These fields, though far apart, have certain common features. Each group constitutes a province nearly related to the other group.

In the Caribbean province, including the West Indies, Trinidad, the Gulf coast of Mexico, and the northern part of South America, oil is found in both Cretaceous and Tertiary rocks in various stages of consolidation. The grades of the oil show wide differences.

Petroleogenic epocns are those in which beds that contain oil were laid down. The most productive strata are those of Paleozoic, Cretaceous, and Tertiary age. Petroleogenic epochs are discussed in connection with the geologic age of petroliferous strata on pages 10 to 15.

CHAPER XV

APPALACHIAN, LIMA-INDIANA, AND MICHIGAN FIELDS

INTRODUCTION

The United States is divided into physiographic provinces which embrace the principal mountain ranges, plateaus, and plains (Fig. 87). The principal oil fields are in the Appalachian Plateau and interior plains; the Gulf Coastal Plain; the Rocky Mountains; and the California valley and Coast Range. The Appalachian Plateau lies west of and is parallel to the Appalachian Mountains and with the interior plains it constitutes the interior lowlands orographic element.[1] This element, which lies between the Appalachian Mountains and the Rocky Mountains, contains many of the

FIG. 87.—Sketch showing physiographic provinces of the United States. (*After Blackwelder.*)

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[1] "An orographic element is a region which is characterized by certain distinctive geologic features, particularly by a certain type of structure and a more or less unified geologic history. . . . The orographic elements tend to coincide with the physiographic provinces."—BLACKWELDER, ELLIOTT, United States of North America. *Handbuch der Regionalen Geologie,* Band 8, Abt. 2, (Heft 11), p. 69, 1912.

largest oil fields in the United States. Among them are the Appalachian field, the Lima-Indiana field of Ohio and Indiana, the Illinois-Indiana field, and the Mid-Continent field except the Sabine uplift, which is included with the Gulf coast field in the Coastal Plain. The Rocky Mountain element includes the fields of Wyoming and Colorado. Some of these fields perhaps should

SYMBOLS AND COLORS ASSIGNED TO ROCK SYSTEMS IN THE UNITED STATES[a]

Era	System	Series	Symbol	Color for Sedimentary Rocks
Cenozoic	Quaternary	Recent	Q	Brownish yellow
		Pleistocene		
	Tertiary	Pliocene	T	Yellow ocher
		Miocene		
		Oligocene		
		Eocene		
Mesozoic	Cretaceous	Upper	K	Olive-green
		Lower		
	Jurassic	Upper	J	Blue-green
		Middle		
		Lower		
	Triassic	Upper	Tr	Peacock-blue
		Middle		
		Lower		
Paleozoic	Carboniferous	Permian	C	Blue
		Pennsylvanian		
		Mississippian		
	Devonian	Upper	D	Blue-gray
		Middle		
		Lower		
	Silurian		S	Blue-purple
	Ordovician	Cincinnatian	O	Red-purple
		Mohawkian		
		Lower		
	Cambrian	Saratogan	E	Brick-red
		Acadian		
		Georgian		
Proterozoic	Algonkian		A	Brownish red
	Archean		AR	Gray-brown

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[a] U. S. Geological Survey.

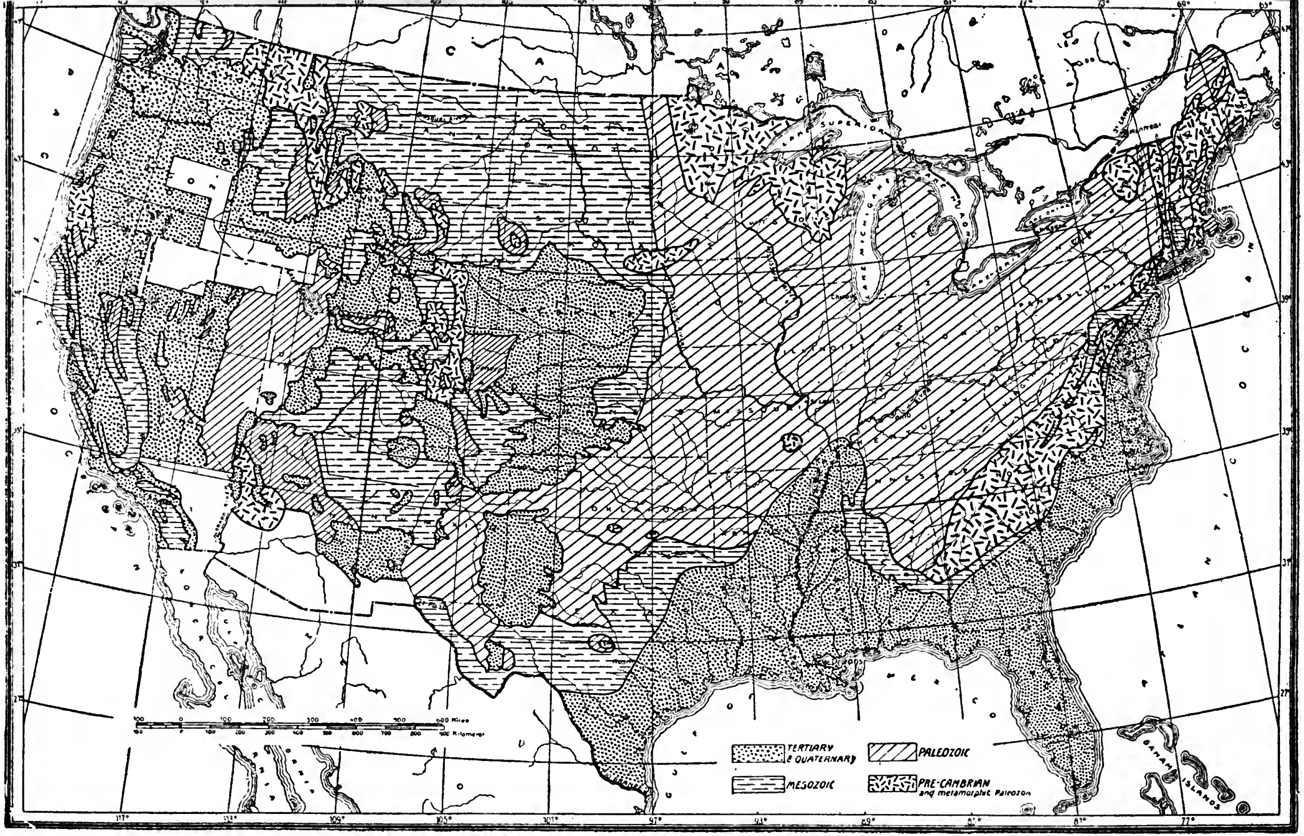

FIG. 88.—Generalized geologic map of the United States. (*Adapted from Willis by Blackwelder.*)

be included in the interior lowlands for they lie on foothill folds of the Rockies much as the fields of the Appalachian geosyncline lie with respect to the Appalachian Mountains. In accordance with the practice of the statistical branch of the United States Geological Survey, these are described with other fields in the Rocky Mountain division. The California valley and Coast Range embrace the fields of southern California.

Petroleum is found in the United States in rocks that range in age from Ordovician to Recent. Considerable oil is obtained from Paleozoic, Mesozoic, and Tertiary rocks. The general distribution of the strata is shown by Fig. 88.

In the interior lowlands the prevailing rocks are of Paleozoic age. The geologic structure is generally simple, the rocks dipping at low angles. The attitude of the rocks is influenced by the mountain ranges to the east and west of the lowlands and by the structural uplifts which lie between (Fig. 89). These areas of uplift are not much higher than the surrounding lowlands. They are anticlines, domes, or regions of close folding and some of them have a far-reaching influence on the structure of the rocks in the lowland area around them.

The Appalachian Plateau is a geosyncline that strikes northeastward and parallels the Appalachian Mountains. On it are superimposed a number of parallel folds, the axes of which lie approximately parallel to the long dimension of the plateau and the Appalachian Mountains. The strata rise gently toward the Cincinnati geanticline, on which are developed the Cincinnati arch in Kentucky, Ohio, and Indiana and the Nashville arch in Tennessee. West of the Cincinnati arch the rocks dip west of north toward Indiana and Illinois, where they form the great coal basin in Illinois, Indiana, and western Kentucky. They rise again toward Missouri and Arkansas in the region of the Ozark Plateau. The strata dip away from the Ozark Plateau in all directions, rising toward the west in and near the foothill region of the Rocky Mountains and toward the south in the Ouachita Mountains.

The Ouachita Mountains, which lie in central Arkansas and southern Oklahoma, were formed at about the same time as the Appalachian Mountains and are regarded by some as an extension of that range. The Mississippi embayment, which contains rocks of much later age, separates the two ranges by about 300 miles.

Close folding is characteristic of regions near the central axes of the Appalachian and Ouachita Mountains. In the Rocky Mountains the folding is generally less intense, yet the beds are steeply tilted, so that at many places they lie on edge or are overturned. The Cincinnati arch and the Ozark uplift cover wide areas but are marked by low dips.

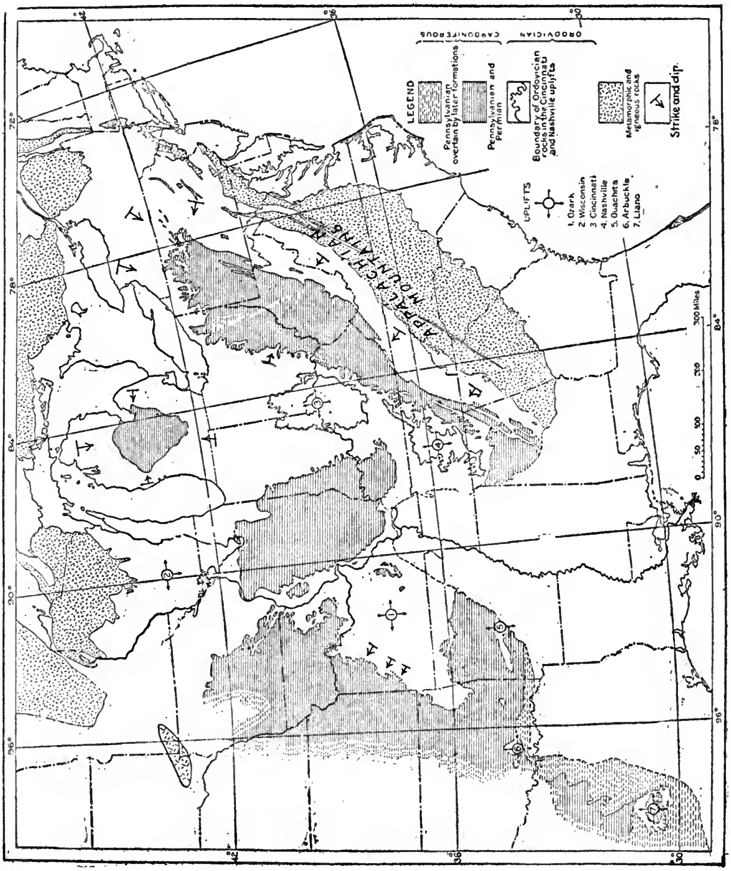

FIG. 89.—Map of eastern United States, showing position of principal uplifts. (*Based on map by Siebenthal.*)

The Ouachita orographic element is not a continuous range but consists of a series of uplifts separated by rocks which are more nearly flat-lying. The Ouachita element extends westward from Hot Springs, Arkansas, into southern Oklahoma. It embraces the Ouachita Mountains in Arkansas, the Arbuckle Mountains, in south-central Oklahoma; and the Wichita Mountains, in southwestern Oklahoma. Between the Arbuckle and Wichita Mountains the rocks dip at comparatively low angles.

South of the Ouachita Mountains, near the center of Texas, is the Llano uplift of ancient rocks. This uplift, although its surface is rather rugged, does not rise conspicuously above the surrounding country, but its influence on the attitude of the strata is apparent in the plains country far to the north, where in the north Texas field large deposits of petroleum have been discovered.

In the interior lowlands the outcropping rocks are mainly Paleozoic sedimentary beds (Fig. 88). Pre-Cambrian rocks crop out in small areas in the Ozark Plateau, southeastern Missouri; in the Arbuckle and Wichita Mountains, Oklahoma; in central Texas; and in larger disconnected areas in southwestern Minnesota, extending into Iowa and South Dakota. At some places ancient igneous rocks, principally granite, have been encountered below the surface. A deep well at Rolla and also one in the Joplin district, Missouri, were sunk to granite, and farther west, in Kansas, a great belt of granite has been revealed below the surface by borings sunk for oil. Granite is found also in wells west of Minnesota and Iowa, and east of the Rocky Mountains. Generally the granite is regarded as pre-Pennsylvanian and possibly pre-Cambrian. Gardner[1] states that there is little or no metamorphism of the overlying sediments. Possibly some of the granite is Carboniferous or later, however, for Twenhofel[2] found at the Silver City dome, Woodson County, Kansas, in the matrix of a limestone breccia, crystals of hornblende, epidote, and chlorite, suggesting the presence of an igneous rock near by.

The structure of the Appalachian Mountains resembles that of the Ouachita element in many respects,[3] and it has been suggested that the two areas are connected below the beds of Mississippi embayment by strata having similar structure. This correlation is not certain for the regions of intense deformation, because the mountain areas differ in strike. Both regions, however, are parallel

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[1] Gardner, J. H.: Mid-Continent Oil Fields. In Geol. Soc. America *Bull.* vol. 28, p. 691, 1917.

[2] Twenhofel, W. H.: The Silver City Quartzites. Geol. Soc. America *Bull.*, vol. 28, pp. 419-430, 1917.

[3] Branner, J. C.: The Former Extension of the Appalachians Across Mississippi, Louisiana, and Texas. *Amer. Jour. Sci. Series* 4, vol. 4, pp. 357-371, 1897

to the ocean deeps to the east and south and are evidently related in a broad way to them. There is, moreover, toward the lowland interior a continuous belt of less intense deformation, that is probably related to the mountain areas.

The correlation of Appalachian folds with those that strike through Kentucky was first brought out by Gardner,[1] who reviewed the work of other investigators, among them Campbell, Orton, Munn, Muller, and Glenn. Later Reger,[2] of the West Virginia Geological Survey, investigated the same structural features. He agrees that the Rough Creek uplift, the Irvine-Campton anticline, and the Chestnut Ridge anticline are in the same belt of deformation (Fig. 90). The Ozark uplift of Missouri appears to be connected by a belt of deformed rocks with the Appalachian Plateau, suggesting that the greater segments to the south—the Ouachita Mountains of Oklahoma and Arkansas—may be connected with the Appalachian Mountains, which lie east of the Appalachian Plateau. As Siebenthal[3] shows, the Ozark axis extends into northeastern Oklahoma. (See Fig. 91.)

FIG. 90.—Sketch map showing axes of deformation west of the Appalachian Mountains, and north of the Ouchita Mountains. (*Data from Gardner, Siebenthal, and others.*)

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[1] GARDNER, J. H.: A Stratigraphic Disturbance Through the Ohio Valley, Running from the Appalachian Plateau in Pennsylvania to the Ozark Mountains in Missouri. Geol. Soc. America *Bull.*, vol. 26, pp. 477-483, 1915.

[2] REGER, D. B.: The Possibilities of Deep-Sand Oil and Gas in the Appalachian Geosyncline of West Virginia. Am. Inst. Min. Eng. *Trans.*, vol. 56, p. 856, 1916.

[3] SIEBENTHAL, C. E.: Origin of the Lead and Zinc Deposits of the Joplin Regions. U. S. Geol. Survey *Bull.* 606, p. 34, 1915.

PETROLEUM MARKETED IN THE UNITED STATES, 1859-1917, IN BARRELS OF 42 GALLONS
(After Northrop)

Year	Pennsylvania and New York	Ohio	West Virginia	California	Kentucky and Tennessee	Colorado	Indiana	Illinois	Kansas
	Barrels	Barrels	Barrels	Barrels	Barrels	Barrels	Barrels	Barrels	Barrels
Prior to 1908	687,425,409	366,250,105	185,039,718	201,965,825	5,276,578	8,874,285	90,127,511	28,866,683	[a]42,357,150
1908	10,584,453	10,858,797	9,523,176	44,854,737	[e]727,767	379,653	3,283,629	33,686,238	1,801,781
1909	10,434,300	10,632,793	10,745,092	55,471,601	[e]639,016	310,861	2,296,086	30,898,339	1,263,764
1910	9,848,500	9,916,370	11,753,071	73,010,560	[e]468,774	239,794	2,159,725	33,143,362	1,128,668
1911	9,200,673	8,817,112	9,795,464	81,134,391	[e]472,458	226,926	1,695,289	31,317,038	1,278,819
1912	8,712,076	[g]8,969,007	12,128,962	[h]87,272,593	[e]484,368	206,052	970,009	28,601,308	1,592,796
1913	8,865,493	8,781,468	11,567,299	97,788,525	[e]524,568	188,799	956,095	23,893,899	2,375,029
1914	9,109,309	8,536,352	9,680,033	99,775,327	[e]502,441	222,773	1,335,456	21,919,749	3,103,585
1915	8,726,483	7,825,326	9,264,798	86,591,535	[e]437,274	208,475	875,758	19,041,695	3,823,487
1916	8,466,481	7,744,511	8,731,184	90,951,936	1,203,246	197,235	769,036	17,714,235	8,738,077
1917	8,612,885	7,750,540	8,379,285	93,877,549	3,100,356	121,231	759,432	15,776,860	36,536,125
	779,986,062	456,082,381	286,608,082	1,012,694,579	13,836,846	11,176,084	105,228,026	284,859,406	102,999,281

Year	Texas	Oklahoma	Wyoming	Louisiana	Montana	Other	United States	Total Value
	Barrels	Barrels	Barrels	Barrels	Barrels	Barrels	Barrels	
Prior to 1908	117,819,991	[b]45,084,441	[c]85,785	27,413,511	....	[d]21,471	1,806,608,463	$1,657,113,275
1908	11,206,464	45,798,765	[f]17,775	5,788,874	....	[d]15,246	178,527,355	129,079,184
1909	9,534,467	47,859,218	[f]20,056	3,059,531	....	[d]5,750	183,170,874	128,328,487
1910	8,899,266	52,082,718	[f]115,430	6,841,395	....	[d]3,615	209,557,248	127,899,688
1911	9,526,474	56,069,637	[f]186,695	10,720,420	....	[d]7,995	220,449,391	134,044,752
1912	11,735,057	51,427,071	1,572,306	9,263,439	....	....	222,935,044	164,213,247
1913	15,009,478	63,579,384	2,406,522	12,498,828	....	[i]10,843	248,446,230	237,121,388
1914	20,068,184	73,631,724	3,560,375	14,309,435	....	[j]7,792	265,762,535	214,125,215
1915	24,942,701	97,915,243	4,245,525	18,191,539	....	[j]14,265	281,104,104	179,462,890
1916	27,644,605	107,071,715	6,234,137	15,248,138	44,917	[j]7,705	300,767,158	330,899,868
1917	32,413,287	107,507,471	8,978,680	11,392,201	99,399	[k]10,300	335,315,601	522,635,213
	288,799,974	747,973,387	27,423,286	134,727,311	144,316	104,982	4,252,644,003	3,824,923,207

[a] Includes Oklahoma in 1905 and 1906.
[b] Production for 1905 and 1906 included in Kansas.
[c] Includes Utah in 1907.
[d] Michigan and Missouri.
[e] No production recorded for Tennessee.
[f] Includes Utah.
[g] Includes Michigan.
[h] Includes Alaska.
[i] Alaska, Michigan, Missouri, and New Mexico.
[j] Alaska, Michigan, and Missouri.
[k] Alaska and Michigan.

PETROLEUM MARKETED IN THE UNITED STATES, 1859-1917, BY FIELDS, IN BARRELS OF 42 GALLONS
(After Northrop)

Year	Appalachian	California	Lima-Indiana	Rocky Mountain	Illinois	Mid-Continent	Gulf	Other	United States
	Barrels	Barrels	Barrels	Barrels	Barrels	Barrels	Barrels	Barrels	Barrels
Prior to 1908....	947,150,206	201,965,825	386,969,115	8,960,070	28,866,683	94,651,699	138,023,394	[a]21,471	1,806,608,463
1908...........	24,945,517	44,854,737	10,032,305	397,428	33,686,238	48,823,747	15,772,137	[a]15,246	178,527,355
1909...........	26,535,844	55,471,601	8,211,443	330,917	30,898,339	50,833,740	10,883,240	[a]5,750	183,170,874
1910...........	26,892,579	73,010,560	7,253,861	355,224	33,143,362	59,217,582	9,680,465	[a]3,615	209,557,248
1911...........	23,749,832	81,134,391	6,231,164	413,621	31,317,038	66,595,477	10,999,873	[a]7,995	220,449,391
1912...........	26,338,516	87,272,593	4,925,906	1,778,358	28,601,308	65,473,323	8,545,040	....	222,935,044
1913...........	25,921,785	97,788,525	4,773,138	2,595,321	23,893,899	84,920,225	8,542,494	[b]10,843	248,446,230
1914...........	24,101,048	99,775,327	5,062,543	3,783,148	21,919,749	97,994,900	13,118,028	[c]7,792	265,762,535
1915...........	22,860,048	86,591,535	4,269,591	4,454,000	19,041,695	123,294,317	20,578,653	[c]14,265	281,104,104
1916.........	23,009,455	90,951,936	3,905,003	6,476,289	17,714,235	136,934,439	21,768,096	[c]7,705	300,767,158
1917...........	24,932,205	93,877,549	3,670,293	9,199,310	15,776,860	163,506,205	24,342,879	[d]10,300	335,315,601
	1,196,437,035	1,012,694,579	445,304,362	38,743,686	284,859,406	992,245,654	282,254,299	104,982	4,252,644,003

[a] Michigan and Missouri.
[b] Alaska, Michigan, Missouri, and New Mexico.
[c] Alaska, Michigan, and Missouri.
[d] Alaska and Michigan.

Igneous intrusive rocks are found at a few places along the line of deformation. Basic igneous rocks, generally as dikes, are found in Ste. Genevieve County, Missouri, intruding the Cambrian[1] between the area of pre-Cambrian rocks of the Ozarks and the Bald Hill uplift of southern Illinois. An area containing basic dikes and fluorspar veins is found in southern Illinois and western Kentucky.[2] Basic dikes are found also in eastern Kentucky,[3] in southwestern Pennsylvania,[4] and in central New York.[5]

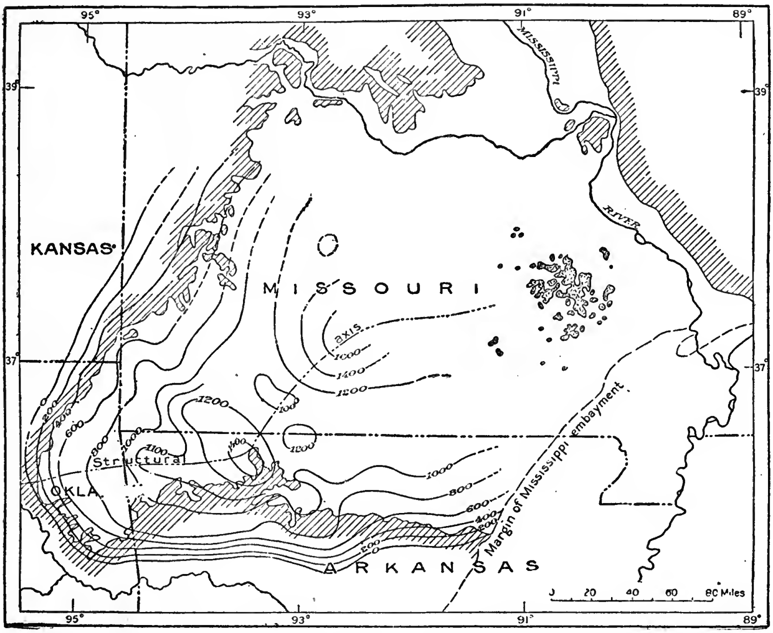

FIG. 91.—Map showing deformation of part of Ozark uplift. Figures on contours represent approximate elevation of base of Mississippian limestone above sea level; parts shaded with diagonal lines represent areas in which Pennsylvania shale is at the surface; areas with strokes and dots represent exposures of crystalline rocks.

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[1] BUCKLEY, E. R.: Lead and Zinc Deposits of the Ozark Region, in Types of Ore Deposits, p. 105, San Francisco, 1911.

[2] ULRICH, E. O., and SMITH, W. S. T.: The Lead, Zinc, and Fluorspar Deposits of Western Kentucky. U. S. Geol. Survey *Prof. Paper* 36, p. 26, 1905.

[3] DILLER, J. S.: Peridatite of Elliot County, Kentucky. U. S. Geol. Survey *Bull.* 38, pp. 1-29, 1887.

[4] HICE, R. R.: Pennsylvania Geol. Survey *Biennial Rept.*, 1910-12.

[5] BLACKWELDER, ELIOT: *Op. cit.*, p. 117.

West of the Appalachian Mountains, in the great Appalachian geosyncline, there are many parallel folds. Most of these strike northeast, parallel to the Appalachian Mountains. The Burning Springs-Volcano anticline, in West Virginia, however, strikes north, making a large angle with other Appalachian folds. This anticline is shorter but much steeper than the neighboring folds.

The Warfield-Campton-Rough Creek-Bald Hill-Ozark axis of deformation has been mentioned. It is probably the most persistent structural feature of the lowlands element. The LaSalle anticline of Illinois, the anticline that extends from the Black Hills into Kansas, and the Glendive anticline of eastern Montana and western North Dakota are noteworthy features.

The great synclines of the interior lowlands are the Appalachian geosyncline, the basin of the southern peninsula of Michigan, the Illinois-Indiana-Kentucky coal basin, and the great geosyncline lying east of the Rocky Mountains, extending to Minnesota, Iowa, Kansas, and Oklahoma.

Besides the folds already mentioned there are a number of smaller undulations in the interior of the lowland region, where the beds rise in domes, anticlines, and anticlinal noses. Such folds have supplied the gathering grounds for petroleum and gas in many of the oil fields.

Faults are not numerous in the interior lowlands, except in certain local areas. In western Kentucky and southern Illinois they are closely spaced in the fluorspar region along Ohio River. Faults are found also in the oil fields of eastern Kentucky. In the oil region of Oklahoma faults of small throw are not uncommon, and in the eastern part of Oklahoma, in Cherokee, Adair, and Sequoyah Counties, faults with considerable throw are rather closely spaced. A few faults have been discovered also in the Joplin region, Missouri; in northeastern Oklahoma; and in the Sabine uplift, Louisiana and Texas. On the whole, however, the rocks of the interior lowlands are very gently deformed. This lowland region contains, indeed, one of the largest bodies of Paleozoic strata of the earth that has undergone so little deformation.

The Paleozoic strata of the lowlands are consolidated, but they are not much metamorphosed by pressure. They consist principally of shales, sandstones, and limestones. Muds, sands, and marls are generally lacking. Nowhere, except near the mountain uplifts are pronounced secondary structural features developed in the shales. They are rarely slates or schists. The sandstones may be locally altered to quartzite, through infiltration and cementation. The limestones are generally recrystallized somewhat, but away from the mountains they show very little evidence of deformation by pressure.

APPALACHIAN OIL FIELD

General Features.—The Appalachian field includes all the oil and gas producing districts in the United States east of central Ohio and northeast of central Alabama. These districts are in New York, Pennsylvania, West Virginia, southeastern Ohio, Kentucky, Tennessee, and northern Alabama. This field, which was the first great oil field in the world to be extensively developed, still produces about 25,000,000 barrels annually.

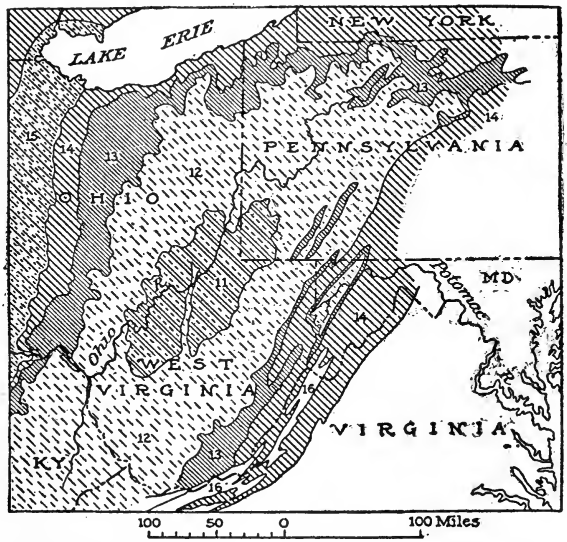

Fig. 92.—Sketch showing the areal geology of part of the Appalachian geosyncline; 11, Permian; 12, Pennsylvanian; 13, Mississippian; 14, Devonian; 15, Silurian; 16, Ordovician. (*After Willis.*)

Surface indications of oil are not numerous, although they are present at several places. Noteworthy among them are Oil

Spring, Allegany County, New York; Oil Creek, Venango County, Pennsylvania; the gas seep at Burning Springs, Wirt County, West Virginia; and the grahamite dike in Ritchie County, West Virginia. The oil from seeps was gathered by Indians and by early settlers and used for medicinal purposes. In the early days oil was encountered in small amounts in many wells sunk for brine, but it was not generally regarded with favor because there was little use for it.

The Appalachian field is a great geosyncline that lies west of the Appalachian mountain front and extends from southwestern New York to northern Alabama. On the west the strata rise to the Cincinnati geanticline in Ohio, Kentucky, and Tennessee. The field is somewhat larger than the Appalachian coal basin, although some of the most productive parts of it are below the area occupied by that basin. A comparatively small portion of it yields oil. Fuller[1] estimates the oil-bearing areas to be as follows:

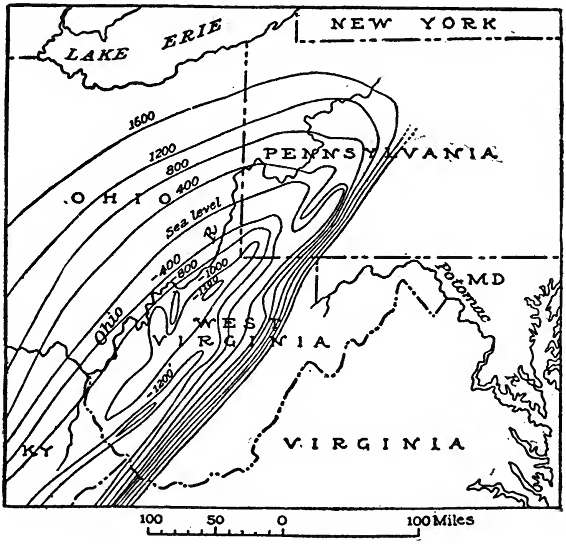

FIG. 93.—Structure contour map of part of the Appalachian geosyncline, showing contours on the Big Injun sand. (*After Reeves.*)

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[1] FULLER, M. L.: Appalachian Oil Fields. Geol. Soc. America *Bull.*, vol. 28, p. 646, 1917.

AREA OF APPALACHIAN OIL AND GAS POOLS, IN SQUARE MILES

	Oil	Gas
New York	300	540
Pennsylvania	2,000	2,730
West Virginia	570	1,000
Southeastern Ohio	115	110
Kentucky	400	290
Tennessee	69	....
Alabama	50	40
	2,504	4,710

The strata that yield oil or gas in the Appalachian field (Fig. 92) include those of the Cambrian, Silurian, Ordovician, Devonian, and Carboniferous systems. The pools occur generally on axes and flanks of anticlines, parallel with the strike of the Appalachian Mountains, on minor terraces or other structural features associated with them, and in water-free synclines. The reservoir rocks are mainly sandstones or conglomerate layers. An exception is the Big lime (Greenbrier limestone), which contains oil in West Virginia.

The Paleozoic rocks of the region are mainly shales, sandstones, and limestones. The general structure is shown by Fig. 93. The contour interval on this map is not small enough to show the details of folding. The map does show, however, the great Burning Springs-Volcano anticline, in western West Virginia. Unlike the other minor folds of the geosyncline, which strike northeast, the Volcano fold strikes nearly north, across the regional strike of the country. (See also Figs. 97 and 98.) A section from eastern Ontario southward to West Virginia is given in Fig. 94. The strata vary in character so that a section taken at one place differs considerably from other sections. There are, however, certain persistent and fairly constant strata that can be correlated. The Pittsburgh coal lies near the surface over much of this area. It is a persistent member and because of its value its position has been determined with great accuracy. It therefore serves as a horizon marker and a key rock to the structure. Below the Pittsburgh coal are other coals, which also serve as keys to the structure. The section containing the coals is made up principally of sandstones, shales, and limestones. Another horizon marker is the Salt sand, which is the top of the Pottsville formation. Below the Salt sand is the Big lime. The Big Injun sand lies below the Big lime, and below it are the Gordon, Elizabeth, Bradford, and other sands. A section of the rocks is shown in Fig. 95. Other sections are given on pages 213 and 215.

X

CORRELATIONS IN THE APPALACHIAN FIELD
(After Fuller; Figures Indicate Thickness in Feet)

			Pennsylvania and Northern West Virginia (Rogersville Folio, Clapp)	Southern West Virginia (Buckhannon Folio, Taff and Brooks)	Kentucky (London Folio, Campbell)	Tennessee (Briceville Folio, Keith)	Alabama, Warrior Coal Field (Birmingham Folio, Butts)
Carboniferous	Permian	Upper barren	Dunkard, 1100 sh ss coal				
	Pennsylvanian	Upper productive	Monongahela, 400 ss ls coal	Braxton, 700		Coal measures (not correlated), 2500	
		Lower barren	Conemaugh, 700 gray ss + sh	Upshur, 400			
		Lower productive	Allegheny, 300 gray ss + sh	Pugh, 400	Lower coal measures, 500		
		Conglomerate	Pottsville, 150 ss + sh	Pickens, 400	Lee, 1000	Lee, 1000	Pottsville, 2500
	Mississippian		Mauch Chunk, 100 Red sh + ss	Canaan shale, 600	Pennington, 100	Pennington, 300	Pennington, 200
			Greenbrier, 100 Ls	Greenbrier First, 350	Newman, 200	Newman, 700	Greenbrier, 200
			Pocono, 600 ss + sh	Pocono, 50	Waverly, 350		
Devonian			Catskill, 500 ss + sh	Hampshire, 800	Chattanooga shale, 150	Chattanooga shale, 50	Chattanooga shale, 0-25 (Frog Mountain sandstone?) ?
			Chemung and Hamilton, 3500 sh sh + ss	Jennings, 800 +			
Total			7450	4500	2300	2050	2925

Pittsburgh

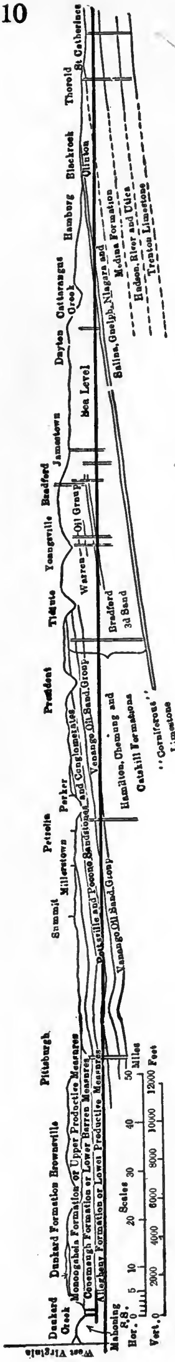

FIG. 94.—Section from Eastern Ontario, southward through Pennsylvania. (*After Clapp.*)

New York, Pennsylvania and West Virginia.—The great Appalachian synclinorium is about 800 miles long. It is over 200 miles wide at the northeast end and 50 miles or less at the southwest end. The synclinorium embraces many minor anticlines and synclines, which are of considerable amplitude in the eastern part of the field, near the mountains, but gradually die out or become flatter toward the northwest. Noteworthy folds are the Burning Springs-Volcano-Eureka anticline (Fig. 36, p. 131), the Wick anticline, the Arches Fork anticline, and the Chestnut Ridge and Laurel Ridge anticlines. In southern West Virginia the subordinate folds become less pronounced toward the northwest, the beds rising gradually toward the west, where they are exposed at the Cincinnati anticline in Ohio, eastern Kentucky, and eastern Tennessee. As a rule the dips are gentle, commonly less than 3°. Locally the strata dip at higher angles, and exceptionally, as on the flanks of the Burning Springs-Volcano anticline, the dips rise to 10° or 20° or more. In New York, Pennsylvania, West Virginia, and Ohio there is very little faulting in the oil fields. In eastern Kentucky and Tennessee faults of considerable magnitude are present.

Where the rocks are saturated with salt water, as a general rule the oil and gas occupy the anticlines, terraces, or domes, and the gas rises above the oil. According to Griswold and Munn,[1] this is true of deposits in the Salt sand and in the Big Injun sand below it, which belongs to the Pocono of the

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[1] GRISWOLD, W. T., and MUNN, W. J.: Geology of Oil and Gas Fields in Steubensville, Burgettstown, and Claysville Quadrangles, Ohio, West Virginia, and Pennsylvania. U. S. Geol. Survey *Bull.* 318, 1907.

Mississippian. The still lower Catskill sands are not fully saturated, and some of them are dry. The oil apparently has been let down from the higher structural positions and in some places is held up on the flanks of synclines by water that remains in the beds. (See Fig. 63, p. 154). If no water remains the oil will be at the bottoms of the folds. The water content of the reservoir strata in the region south of Pittsburgh a few years after Griswold and Munn's examination was investigated by Reeves.[1] The Catskill,

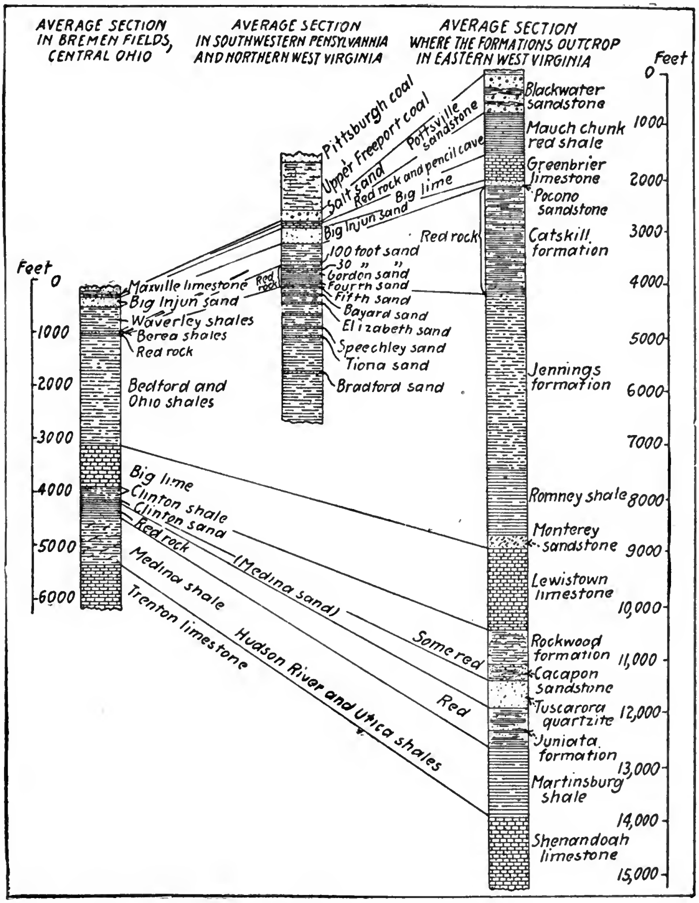

Fig. 95.—Comparative stratigraphic columns for Ohio, Pennsylvania and West Virginia. (*After Clapp.*)

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[1] Reeves, Frank: Absence of Water in Sandstones of the Appalachian Oil Fields. *Econ. Geology*, vol. 12, pp. 254-278, 1917.

which is a terrestrial phase of the Devonian,[1] is developed over a considerable area. It is a series of red shales and thin reddish or white sandstones. Eastward along the outcrop, the formation consists of 600 to 900 feet of alternating layers of shale and sandstone, red and green, which are unfossiliferous and in places sun-cracked and ripple-marked. The shale contains about 6 per cent of ferric oxide. These sands are not saturated.

Many wells in this field produce both oil and gas, and some produce both from the same stratum. In many wells the gas carries considerable gasoline. In 1917, according to Northrop,[2] West Virginia marketed 32,668,647 gallons and Pennsylvania marketed 13,826,250 gallons of gasoline derived from natural gas.

Many of the folds yield gas only, and in general such folds lie east of the petroleum-bearing folds and nearer to the Appalachian Mountains. Where dynamo-chemical alteration has been sufficient to alter the coals so that they have a high carbon content, gas only is produced. This relation was first pointed out by David White[3] and was further developed by Fuller.[4] According to Fuller the occurrence of 65 to 70 per cent of fixed carbon in pure coals establishes a sort of dead line as regards commercial deposits of oil or gas. Where coals range from 60 to 65 per cent of fixed carbon, gas may be found in quantity, but little commercial oil. Where coals range from 55 to 60 per cent of fixed carbon, oils are found in abundance, with abundant gas. In the west part of the Appalachian field carbon ratios are lower. Some of the oil lies east of the gas.

The first serious attempt to develop the petroleum industry in the northern Appalachian region resulted from the drilling of a well at Titusville, Pennsylvania, by E. L. Drake in 1859. Although it was not a large well, there was a sale for the oil and other wells were drilled, opening many oil pools. The first flowing well or gusher was one sunk near Rouseville in 1860, and several others yielding from 3,000 to 4,000 barrels a day were brought in

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[1] Barrell, Joseph: The Upper Devonian Delta of the Appalachian Geosyncline. Am. Jour. Sci., 4th ser., vol. 36, pp. 429-472, 1918; vol. 37, pp. 87-109, 225-253, 1914.

[2] Northrop, J. D.: U. S. Geol. Survey Mineral Resources, 1917, part 2, p. 1119, 1919.

[3] White, David: Some Relations in Origin Between Coal and Petroleum. Washington Acad. Sci. *Jour.*, vol. 5, pp. 189-212, 1915.

[4] Fuller, M. L.: Geol. Soc. America *Bull.*, vol. 27, p. 649, 1917.

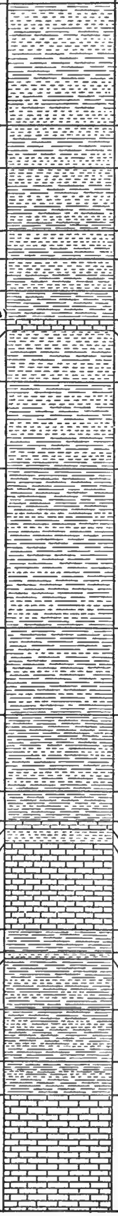
		Series	Columnar section	Thickness (feet)	Total (feet)	Description
Permo-Carboniferous		Dunkard		1150	1150	Variegated shales and gray sandstones with a few thin coal beds
Carboniferous	Pennsylvanian	Monongahela (Pittsburgh coal at base)		400	1550	Gray sandstones, gray shales, limestones, and coal beds
		Conemaugh		600	2150	Gray or brown sandstones, gray and red shales, and coal beds
		Allegheny		250	2400	Gray sandstones, gray shales, and coal beds
		Pottsville (Salt sands of West Virginia)		300	2700	Gray sandstones, and shales, with a few coal beds
	Mississippian	Mauch Chunk (Contains Maxton sand of West Virginia)		250	2950	Red shales with a few thin sandstones
		Greenbrier (Big lime of West Virginia)		100	3050	Limestone
		Pocono (Big Injun at top; Berea sand at base)		500	3550	Gray sandstones and gray shales
Devonian		Catskill (Gordon group of oil sands)		800	4350	Brown sandstones and red shales
		Chemung (No productive sands in West Virginia)		1500(?)	5850	Olive-brown, shales with sandstones lentils
		Portage (No productive sands in West Virginia)		800(?)	6650	Gray shales with sandstones lentils
		Hamilton (No productive sands in West Virginia)		700(?)	7350	Brown, shales with sandstone lentils
		Marcellus or Romney Gas in Ohio and Kentucky)		300(?)	7650	Brown, or black bituminous shales with sandstone lentils
		"Onondaga" limestone (Ragland sand of Kentucky)		50(?)	7700	Dark flinty limestone
		Oriskany		150(?)	7850	Gray sandstone
Silurian		Helderberg Salina, and Niagara (Big lime of Ohio)		800(?)	8650	Limestone
		Clinton		200(?)	8850	Variegated shales
		Medina white sandstone (Clinton oil sand of southern Ohio)		50(?)	8900	White sandstone
		Medina shales		500(?)	9400	Red shales and thin sandstones
Ordovician		Martinsburg or Cincinnati shale (Contains Hudson sand of Kentucky)		500(?)	9900	Gray shales with sandstone lentils
		Utica		300(?)	10200	Black shales with sandstone lentils
		Trenton and other limestones (Oil and gas horizon of northern Ohio)		1200(?)	11400	Limestones

FIG. 96.—Columnar section for central part of West Virginia oil fields, Marion and surrounding Counties. (*After Reger.*)

Pottsdam SS.

during 1861. Development in this region thereafter was rapid, reaching a maximum in 1891, from which it has slowly declined. The oil is of high grade, is rich in lighter derivatives, has a paraffin base, and is essentially free from sulphur.

The most productive portion of the Appalachian field lies in New York, Pennsylvania, and West Virginia. Geologic sections for Pennsylvania and West Virginia are given in Fig. 95 (p. 211), and for the central part of the West Virginia in Fig. 96. The trends of the principal folds in these States are shown in Fig. 97, and cross sections are given in Fig. 98. The distribution of oil and gas pools in New York and Pennsylvania is shown by Fig. 99 and in West Virginia by Fig. 100.

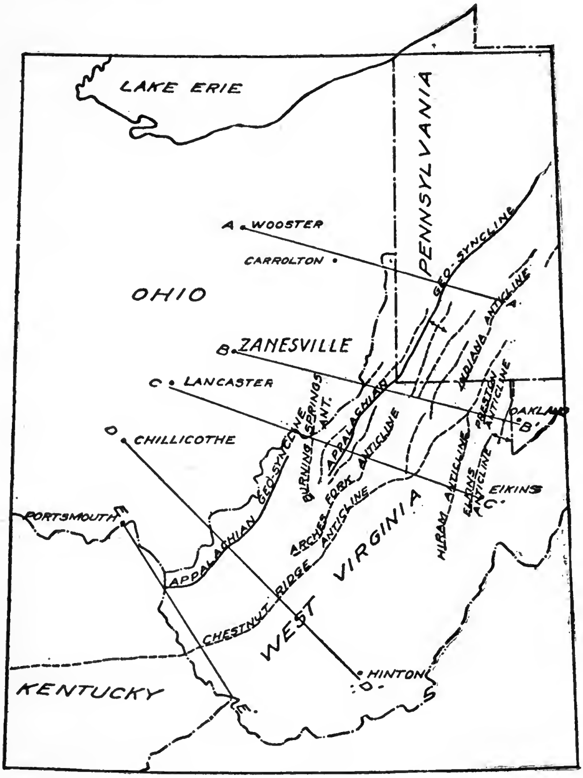
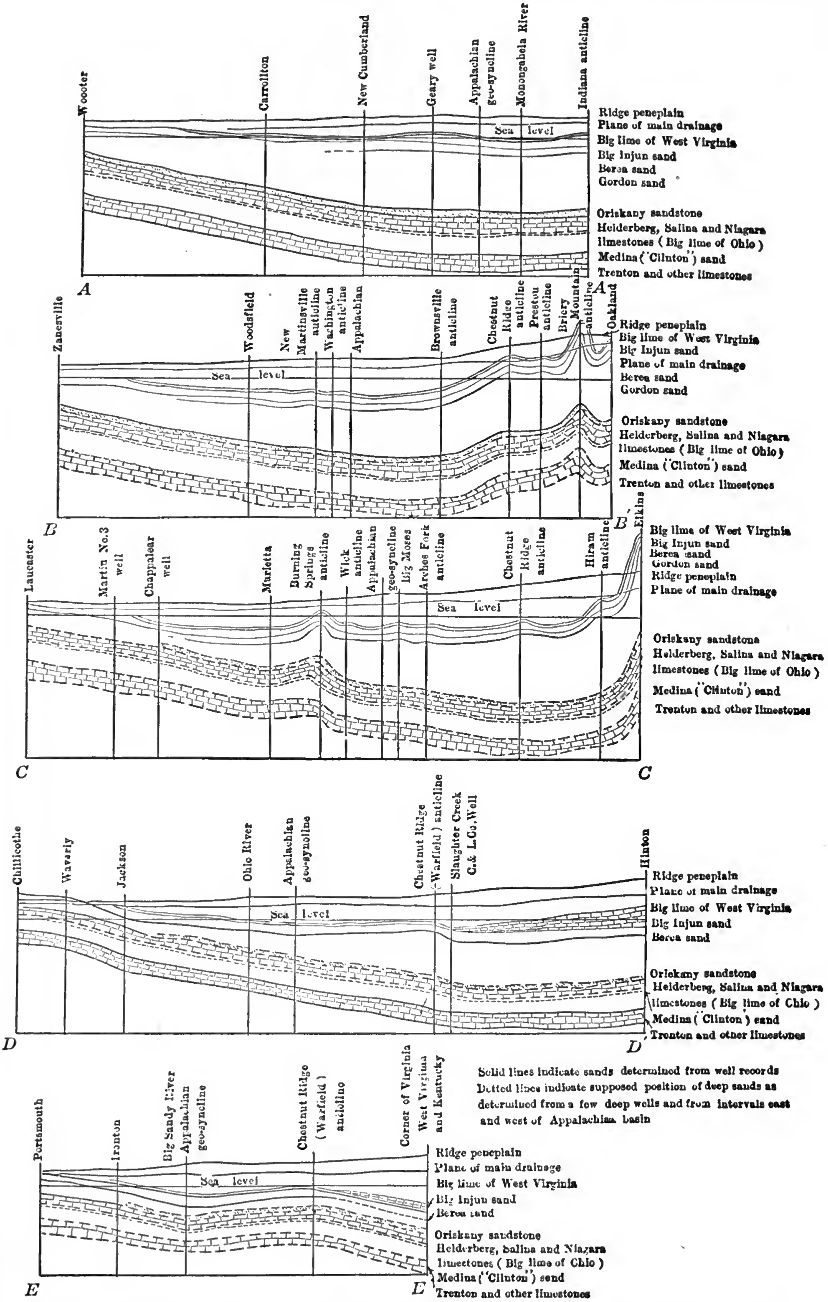


FIG. 97.—Map showing axes of folds in part of Appalachian geosyncline. For sections along lines *A-A'*, etc., see Fig. 98. (*Based on map by Reger.*)



Solid lines indicate sands determined from well records
Dotted lines indicate supposed position of deep sands as determined from a few deep wells and from intervals east and west of Appalachian basin

FIG. 98.—Cross-sections showing position of folds in part of Appalachian geosyncline. For lines of sections, see Fig. 97. (*After Reger.*)

In New York the greater part of the oil is derived from the Bradford sand, in the Chemung formation, or from other sands not far above or below it. Gas is produced from the Corniferous limestone of the lower Devonian; from the Guelph limestone, Niagara limestone, and Medina sandstone of the Silurian; from the Trenton limestone and Lorraine shale of the Ordovician; and from the Potsdam sandstone of the Cambrian.

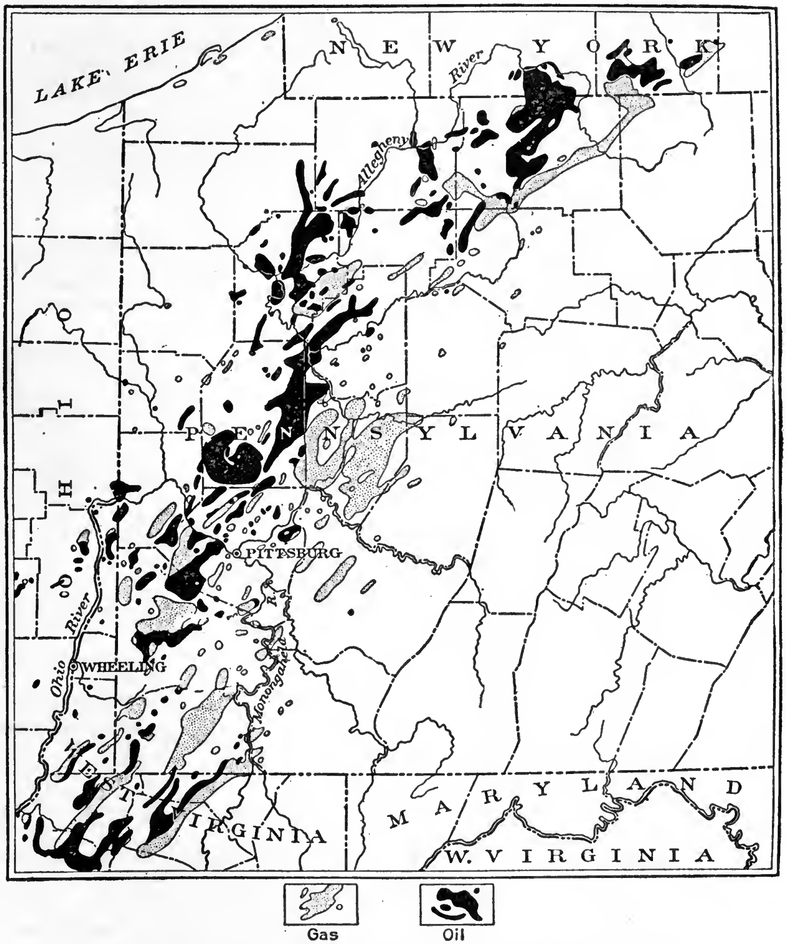


Fig. 99.—Map of oil and gas producing areas of northern Appalachian region. (*After Munn.*)

In the Pennsylvania-West Virginia area oil is found both above and below the Pittsburgh coal in the Pennsylvanian series, and in the Mississippian and Devonian. Oil is produced from the Kane sand, in the Chemung, 3,770 feet below the Pittsburgh coal. (See p. 219.) Some of the formations that produce gas in New York will probably be found productive in Pennsylvania and West Virginia, where these formations lie at great depth.

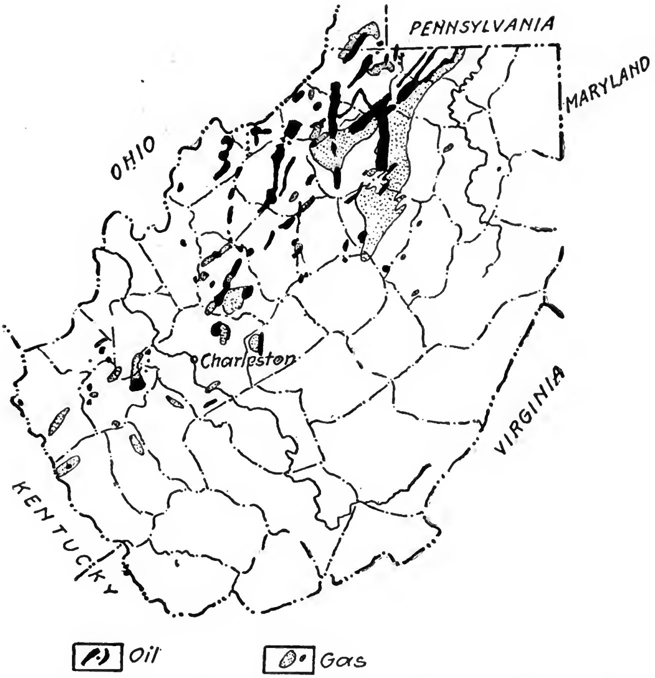


FIG. 100.—Map showing principle oil-producing areas in West Virginia.

The principal oil horizons in the Pennsylvanian and West Virginia districts are stated on pages 218-219.

OIL HORIZONS OF PENNSYLVANIA-WEST VIRGINIA DISTRICT[a]

	Distance Above (+) or Below (−) the Pittsburgh Coal, in Feet
Carboniferous:	
Pennsylvanian:	
Monongahela formation (Upper Productive measures):	
Carroll sand (Uniontown sandstone), productive in West Virginia only	+ 300
Pittsburgh coal horizon.	
Conemaugh formation (Lower Barren measures):	
Murphy, Shallow, Little Dunkard, or First Cow Run sand (Saltsburg sandstone)	− 200
Big Dunkard or Cow Run sand (Mahoning sandstone)	− 500
Allegheny formation (Lower Productive measures):	
Second Cow Run sand (Freeport sandstone)	− 600
Gas sand	− 800
Pottsville formation (Salt sand):	
Johnson Run sand (Homewood sandstone)	− 900
Upper Salt sand (Lower Conoquenessing sandstone)	− 950
Middle Salt sand (Lower Conoquenessing sandstone)	−1,050
Lower salt (Sharon conglomerate)	−1,150
Mississippian:	
Mauch Chunk formation:[b]	
Maxton or Cairo sand (of West Virginia)	−1,200
Greenbrier limestone (Big lime)	−1,250
Pocono formation (Big Injun sand):	
Keener sand	−1,300
First, Second, and Third Pay sands (Top)	−1,400
Squaw sand	−1,450
Wier sand	−1,500
Upper Gas sand	−1,550
Berea or Thirty-foot sand	−1,750
Murrysville or Butler sand	−1,800
Gantz, First, or Hundred-foot sand[c]	−1,850

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[a] FULLER, M. L.: Appalachian Oil Fields. Geol. Soc. America *Bull.*, vol. 28, p. 633, 1917. See also CLAPP, F. G.: Outline of the Geology of Natural Gas in the United States. *Econ. Geology*, vol. 8, pp. 520-521, 1913.

[b] REGER divides the Mississippian into Mauch Chunk, Greenbrier, and Pocono. See Fig. 96.

[c] FULLER places the Upper Gas, Berea, Butler, and Hundred-Foot sands in the Catskill. Following recent United States Geological Survey practice here, I have placed them in the Mississippian.—(W. H. E.)

Devonian:	
Catskill formation:	
Fifty-foot sand	–1,900
Nineveh, Thirty-foot, or Second sand	–2,000
Gray, Gordon Stray, or Boulder sand	–2,100
Gordon, Third, or Campbells Run (?) sand	–2,150
Fourth sand (Gordon of West Virginia?)	–2,200
Fifth sand (McDonald of West Virginia?)	–2,250
Bayard sand	–2,400
Chemung formation:	
Elizabeth or Sixth sand	–2,600
Warren First sand	–2,700
Warren Second sand	–2,800
Tiona sand	–2,900
Speechley sand	–3,000
Balltown or Cherry Grove sand	–3,120
Sheffield or Cooper sand	–3,320
Bradford sand	–3,430
Second Bradford sand	–3,480
Elk sand	–3,650
Kane sand	–3,770

In southwestern Pennsylvania and northwestern West Virginia the sands in the Upper Devonian contain much oil and gas. These sands constitute the Venango oil-sand group, which is an important oil-bearing series in southwestern Pennsylvania. Below the Catskill the Corniferous limestone is found at great depths in this field. A well near McDonald, Pennsylvania,[1] penetrated the Lower Devonian limestone. At a depth of 6,260 feet a sandstone, possibly the Oriskany, was encountered which contained concentrated brine. Reeves states that the Catskill sands are free from salt water because they were laid down under arid conditions. According to Reeves they have never been saturated with water, although the marine sediments both above and below are saturated with brine.

In many of the oil sands the oil and gas occur in pockets, where the sands are coarser (p. 115). In the Carboniferous rocks, which are generally saturated with water, the oil at many places is on high parts of the folds. A well-known example is the Volcano dome of the Burning Springs-Volcano-Eureka anticline in West Virginia.

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[1] WHITE, I. C.: Note on a Very Deep Well Near McDonald, Pennsylvania. Geol. Soc. America *Bull.*, vol. 24, pp. 275-282, 1913.

The occurrence of oil and gas on anticlinal noses and terraces has been noted.

Because of its great gas production (see p. 142), extensions eastward of the "Clinton" sand have aroused much interest. The sand dips eastward from central Ohio at a low angle and rises again toward the west front of the Appalachian Mountains. As stated by Bownocker, the small oil pools found in the sand contain no water, and he suggests that they may occur in small shallow basins rather than on anticlines. It is believed by some that large

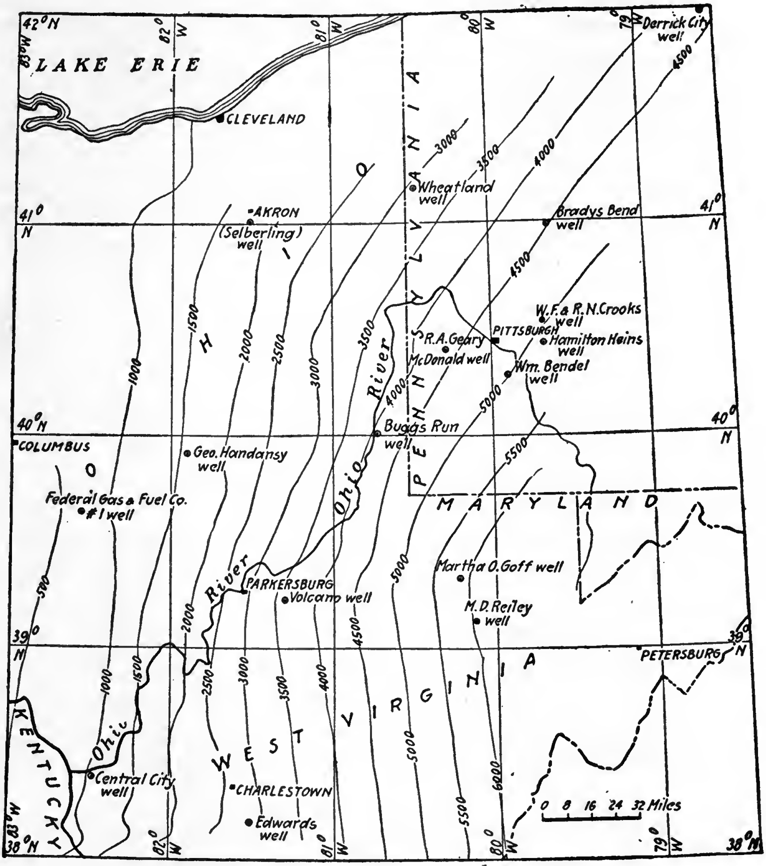

FIG. 101.—Map showing location of certain wells and, by contours, the approximate thickness of the Upper Devonian in part of the Appalachian oil field. (*Redrawn from a map by I. C. White.*)

deposits of oil will be found below the gas in the deeper part of the basin. Many deep wells have been sunk in the Appalachian basin, but in the central part of the basin none of them have penetrated the "Clinton" sand. These wells supply information concerning the strata in a large part of the Appalachian field.

Fig. 101, after White,[1] is a sketch showing the thickness of the Upper Devonian. The strata are measured between the Berea sand and the top of the Corniferous limestone. The Upper Devonian shales are only 500 feet thick in the region near Columbus, Ohio, but their thickness becomes very great toward the central part of the basin. At the Martha O. Goff well, in northern West Virginia, which is one of the deepest wells in the world, the Upper Devonian is nearly 6,000 feet thick. The formations encountered in this well, below the Pittsburgh coal, which before erosion was not far above the casing head, are shown in the following table:

			Thickness	Depth
Pittsburgh coal, base of Monongahela series			Feet	Feet
Conemaugh series	600′	Pennsylvanian	1,150	1,150
Allegheny	290			
Pottsville	260			
Mauch Chunk	260′	Mississippian	590	1,740
Mountain (Greenbrier) limestone	65			
Big Injun, Squaw, and Berea sand group	265			
Catskill, containing Venango oil sand group, to base of Bayard oil sand	770′	Upper Devonian shales	5,823	7,563
Chemung shales, containing Elizabeth, Speechley, Bradford (Benson) and Kane oil sands	2,190			
Portage beds	1,207			
Genesee slate	288			
Hamilton and Marcellus	1,368			
Corniferous limestone to present bottom			23	7,586

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[1] White, I. C.: Discussion of the Records of Some Very Deep Wells in the Appalachian Oil Fields of Pennsylvania, Ohio and West Virginia. West Virginia Geol. Survey *County Repts.*, Barbour and Upshur Counties, pp. xxv-lxv, 1918.

The record of the well[1] is stated below:

	Feet
Native coal (Elk Lick)	83– 86
Little Dunkard sand	170– 186
Big Dunkard sand	305– 336
Gas sand	436– 446
First Salt sand	690– 815
Second Salt sand	860– 880
Maxton sand	1,025–1,040
Little lime	1,183–1,194
Pencil cave	1,194–1,210
Big lime; gas at 1,253 feet	1,210–1,275
Big Injun sand; water at 1,304 feet	1,275–1,394
Squaw sand	1,410–1,428
Berea sand	1,512–1,540
Gantz sand consolidated with Fifty-foot	....
Fifty-foot sand; gas at 1,749 and 1,757 feet	1,748–1,885
Thirty-foot sand	1,900–1,980
Gordon Stray sand	2,090–2,097
Gordon sand	2,130–2,142
Fourth sand	None
Fifth sand	None
Bayard sand	2,300–2,310
Slate shells	2,310–2,830
Hard lime	2,830–2,893
Slate and lime shells	2,892–3,125
Hard lime	3,125–3,145
Slate shells	3,145–3,222
Hard lime	3,222–3,240
Slate shells	3,240–3,480
Hard sand	3,480–3,505
Slate	3,505–4,166
Lime shells (Benson sand); with puff of air (gas)	4,166–4,167
Slate	4,167–4,425
Lime	4,425–4,500
Slate and shells	4,500–4,790
Lime	4,790–4,850
Slate shells	4,850–5,200
Slate shells at	5,700
Slate shells at	5,775
Dark slate	5,840–5,995
Lime shells	5,995–5,998
Dark slate	5,998–6,210
Light slate	6,210–6,235
Lime	6,235–6,265
Dark slate	6,265–6,272
Lime	6,272–6,280

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[1] White, I. C.: *Op. cit.*, pp. lvi-lviii.

Dark slate	6,280–6,294
Lime	6,294–6,304
Dark slate	6,304–6,318
Lime	6,318–6,330
Dark slate	6,330–6,360
Lime	6,360–6,380
Dark slate	6,380–6,385
Lime	6,385–6,395
Dark slate	6,395–6,420
Lime	6,420–6,426
Dark slate	6,426–6,438
Lime	6,438–6,447
Dark slate	6,447–6,465
Lime	6,465–6,470
Dark slate	6,470–6,500
Black slate	6,500–6,505
Black lime	6,505–6,510
Black slate	6,510–6,532
Dark slate	6,532–6,580
Dark slate	6,580–6,625
Hard shells	6,625–6,627
Brown shale	6,627–6,640
Hard shells	6,640–6,645
Black slate	6,645–6,660
Black shale	6,660–6,676
Black sand	6,676–6,680
Hard lime	6,680–6,690
Dark slate	6,690–6,714
Dark lime	6,714–6,747
Hard shell	6,747–6,750
Slate	6,750–6,755
Dark slate	6,755–6,775
Hard sand shells	6,775–6,780
Black shale	6,780–6,800
Black slate	6,800–6,823
Hard lime	6,823–6,865
Slate and shells	6,865–6,950
Hard lime	6,950–7,057
Lime shells	7,057–7,069
Hard sand	7,069–7,071
Hard lime	7,069–7,075
Lime	7,081–7,093
Hard lime	7,093–7,097
Hard lime	7,097–7,110
Slate and shells	7,110–7,150
Slate	7,150–7,160
Hard lime	7,160–7,162

Lime shells	7,162–7,176
Gritty shells	7,176–7,190
Slate	7,190–7,225
Slate	7,225–7,232
Hard shell	7,232–7,245
Black slate	7,245–7,251
Slate and shells	7,251–7,256
Hard lime	7,256–7,261
Dark hard lime	7,261–7,266
Black slate	7,266–7,280
Hard shells	7,280–7,282
Slate	7,282–7,290
Soft slate	7,290–7,295
Soft black slate	7,295–7,300
Black slate	7,300–7,345
Gritty lime	7,345–7,363
Hard flinty limestone, Corniferous, to bottom	7,363–7,386

The R. A. Geary well at McDonald, Pennsylvania, west of Pittsburgh, was described by White[1] in 1913. The record is summarized as follows, beginning at the base of the Pittsburgh coal, the horizon of which is estimated to be 130 feet above the derrick floor:

			Thickness	Depth
			Feet	Feet
Conemaugh series	580′	Pennsylvanian	1,080	1,080
Allegheny series	284			
Pottsville series	216			
Mauch Chunk	3′	Mississippian	672	1,752
Big lime (Mountain, Greenbrier)	29			
Big Injun, Squaw, and Berea sands	640			
Catskill, (including Venango oil-sand group), Chemung, Portage, Hamilton, and Marcellus beds			4,386	6,138
Corniferous limestone			37	6,175
Oriskany sandstone			270	6,445
Helderberg			385	6,830
Salina salt series			340	7,170
Salina shales and Niagara (Clinton?)			208	7,378

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[1] White, I. C.: Note on a Very Deep Well Near McDonald, Pennsylvania. Geol. Soc. America *Bull.*, vol. 24, pp. 275-282, 1913.

The Upper Devonian is 4,386 feet thick, which is somewhat thinner than in the Goff well.

Eastern Ohio.—In Ohio there are three fields that produce oil or gas or both.[1] In an extension of the Appalachian field in eastern Ohio the petroliferous strata developed in western Pennsylvania and West Virginia are present. West of this belt is the "Clinton" sand field, which yields much gas. Still farther west and extending into Indiana is the great Lima-Indiana field, in which oil and gas are derived from the Trenton limestone. This is not classed with the Appalachian oil fields but is related to the Cincinnati arch, which lies west of the Appalachian basin.

PRINCIPAL OIL-PRODUCING ROCKS IN OHIO AND INDIANA
(After Bownocker)

Pennsylvanian...	Mitchell sand (Ohio). Macksburg 140-ft., or first Cow Run sand (Ohio). Macksburg 500-ft. sand (Ohio).
Mississippian....	Huron sandstone (Indiana). Keener sand (Ohio). Big Injun sand (Ohio). Berea sand (Ohio).
Devonian.......	Corniferous limestone (Indiana).
Silurian.........	"Clinton" sand (Ohio).
Ordovician......	Trenton limestone (Ohio and Indiana).

In eastern and southeastern Ohio oil and gas are found in low folds in Pennsylvanian and Mississippian rocks. The producing counties extend almost across the eastern part of the State. Monroe and Washington Counties have been the largest producers. The pools are numerous, but most of them are small, not more than two or three of them including more than ten square miles. Thousands of wells have been drilled. So many tests have been made that the chances of discovering large reservoirs are slight, and, according to Bownocker, the production of 5,586,433 barrels in 1903 will probably stand as the maximum.

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[1] BOWNOCKER, J. A.: Petroleum in Ohio and Indiana. Geol. Soc. America *Bull.*, vol. 28, pp. 667-676, 1917.

GENERALIZED SECTION OF CARBONIFEROUS FORMATIONS IN EASTERN OHIO
(After Mills and Wells)

System	Series	Group or Formation	Thickness (Feet)	Character	Driller's Description
Carboniferous	Permian	Washington formation.[a]	400	Nonpersistent sandstone members with shale and clay of reddish-brown color. A few thin beds of coal and limestone in lower portion.	
	Pennsylvanian	Monongahela formation.	255–275	Limestone, shale, and a little sandstone. Contains the Pittsburgh, Pomeroy, Meigs Creek, Uniontown, and Waynesburg coal beds, all of more or less value in the Woodsfield quadrangle.	
		Conemaugh formation.	460–475	Irregular members grading into shales, commonly of reddish-brown or variegated colors. Upper and lower Pittsburgh limestone members near top; Ames and Cambridge limestone members a little below middle. Mahoning sandstone member at the base, locally productive of oil.	Includes First Cow Run, Buell Run, and Mahoning sands.
		Allegheny formation.	250–265	Sandstone, shale, and important clay and coal beds, including the Lower Kittanning, Middle Kittanning, and Lower and Upper Freeport.	Includes Peeker, Macksburg 500-foot, and Second Cow Run oil sands named in descending order.
		Pottsville formation.	155-170	Consists largely of sandstone and conglomerate, which rest with uneven contact on the eroded surface of the Mississippian beds. The sandstone is generally divided into several parts by beds of clay shale, and coals also are locally present.	Includes Maxton sand.
	Mississippian	–Unconformity Maxville limestone.	0–100	Dark-gray and bluish to light-gray limestone with interbedded shale and fine-grained sandstone.	Big lime; includes Big lime sand.
		–Unconformity Logan formation.	25–100	Consists of sandstone, the Keener sand, interbedded with shale; a valuable source of oil and gas.	Includes Keener oi sand.
		Black Hand formation.	75–175	Coarse sandstone interbedded with and grading laterally into sandy shale.	Probably includes Big Injun and Squaw oil sands.
		Cuyahoga formation.	350–450?	Mostly sandy shale in lower part, with a few beds of shaly sandstone.	Includes Welsh oil sand.
		Sunbury shale.	25–40	Dark carbonaceous shale.	Black shale.
		Berea sandstone.	0–40	Berea sand, consisting of coarse to fine-grained gray to white sandstone. Lenticular in the Woodsfield and Summerfield quadrangles. Unconformity at base.	Berea oil and gas sand.

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[a] At places in eastern Ohio the Greene formation of the Permian overlies the Washington.

GENERALIZED SECTION OF OLDER PALEOZOIC FORMATIONS IN EASTERN OHIO (After Rogers)

System	Group or Formation	Thickness (Feet)	Character	Driller's Description
Devonian or Carboniferous.	Bedford shale.	20–40?	Mottled gray, reddish, and brownish shale.	Ohio shale, 1,100–3,000 feet, usually treated as a unit in southern Ohio.
	Ohio shale group Cleveland shale.	50–120	Massive hard black bituminous, with a few bluish layers in lower portion.	
	Chagrin shale.	850–1,200	Soft bluish-gray clay shale, with some concretionary layers.	
Devonian.....	Huron shale.		Black and bluish shale in upper and lower portions, with a band of gray shale near middle.	
	Olentangy? shale.	80	Gray calcareous shale.	
	Delaware limestone.	500–700	Blue and gray limestone, becoming dolomitic in lower part. Contains a 30 to 50-foot bed of white quartz sandstone, 350 to 450 feet below top.	Big lime; includes Newburg sand and some "stray" sands in lower 300 feet, 490–1,825 feet.
	Columbus limestone.			
Unconformity.	Monroe formation.			
	Salina formation.	400–600	Shale, dolomite, anhydrite or gypsum, and rock salt.	
	Niagara limestone.	400–600	Dolomite and limestone.	
Silurian.	"Clinton" formation.	150–250	Crystalline limestone of various light colors; calcareous shale and thin-bedded limestone, with sandstone layer in lower part.	Includes Little lime, 75–150 feet.
				"Clinton" sand, 0–60 feet.
				25–75 feet.
	Medina shale.	400–300	Red clay shale, with thin layers of sandstone.	Medina red rock.
Ordovician...	Shale and limestone of Cincinnatian age.	750–1,250	Dark shale, with thin layers of limestone, especially in upper part.	Slate and shells.
	Trenton (?) limestone.	(?)	Limestone.	Trenton lime.

One of the most persistent sands is the Berea,[1] which lies near the lower part of the Mississippian, below the Sunbury shale and above the Bedford shale. The Berea yields gas or oil in several counties; its outcrop is practically continuous, and it is generally penetrated wherever the drilling is carried deep enough. Accumulations of oil and gas, as stated by Panyity, are found principally where the sand thins out up the dip. (See p. 145.)

In the Woodsfield quadrangle, which includes parts of Belmont, Monroe, Noble, and Guernsey Counties,[2] the rocks at the surface are of Pennsylvanian and Permian age and include in ascending order the Conemaugh, Monongahela, and Washington formations. The dip or slope of the beds is in general southeastward. The most noteworthy productive sands, named in descending order, are the so-called Cow Run, Big lime, Keener, Big Injun, and Berea. In the Barnesville oil and gas field, in the northwestern part of the Woodsfield quadrangle, the gas occupies the high portion of the anticlinal fold and is flanked by an oil-producing belt a little lower on the slope. The water table in the Berea sand is of local extent and probably has no relation to water tables in the same sand in other areas to the west and north. The partial saturation in this area does not signify that the quantity of salt water becomes less as the oil sand is followed up the dip. On the contrary, great quantities of salt water and also some oil are derived from the Berea all the way from the Woodsfield quadrangle northwestward to Wooster and beyond, where the sand is only a little below the surface.[3] The relations of accumulation to sands and water conditions, according to Condit, are varied and uncertain, although the productive belts in general follow structural contours.

The Wooster region, in Wayne County, has recently been described by Bonine.[4] The Wooster field is a little west of the outcrops of the Pottsville and Allegheny formations (Carboniferous), which mark the northwestern limit of the Appalachian coal basin. The rocks have a general dip to the east and southeast of

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[1] PANYITY, L. S.: Lithology of the Berea Sand in Southeastern Ohio, and Its Effect on Production. Am. Inst. Min. Eng. *Bull.* 140, pp. 1317-1320, 1917.

[2] CONDIT, D. D.: Structure of the Berea Oil Sand in the Woodsfield Quadrangle, Ohio. U. S. Geol. Survey *Bull.* 621, p. 233, 1915.

[3] CONDIT, D. D.: *Op. cit.*, pp. 245-246.

[4] BONINE, C. A.: Anticlines in the "Clinton" Sand Near Wooster, Wayne County, Ohio. U. S. Geol. Survey *Bull.* 621, p. 95, 1915.

about 50 feet to the mile. This dip has been flattened in many places, producing structural terraces. Cross folding of a more or less intense character has likewise taken place, producing folds at right angles to the strike of the formations. These folds are especially pronounced in the "Clinton" sand and exist in a modified form in the Berea sandstone. The surface rocks near Wooster are not well exposed, and consequently it is difficult to determine whether or not they are similar in structure.

The principal structural feature of the gas field is the steeply pitching anticline west and southwest of Wooster, along the crest and sides of which the gas has accumulated.

The "Clinton" gas field[1] is one of the largest sources of natural gas in the world. In 1912 the output of natural gas in Ohio exceeded 56,000,000,000 cubic feet, and in 1913 it was 50,300,000,000 cubic feet. The value of the output in 1912 was nearly $12,000,000 and probably 90 per cent of this came from the "Clinton" sand. The name "Clinton" was early applied to the gas sand at Lancaster, Ohio, and it became well established. However, it was shown by Bownocker that the gas-bearing rock lies below the true Clinton formation and is of Medina age. Natural gas was discovered in this rock at Lancaster in 1887, and the field has been developed so that it now extends from the shore of Lake Erie southward almost to the Ohio River.

The position of the "Clinton" sand in deep wells is easily determined by the great Devonian and Silurian limestones (Big lime), the base of which usually lies from 90 to 150 feet above the sand. The sand itself lies between shales. The "Clinton" sand is not everywhere present in this region. It is not found in the western half of Ohio. The sand thins out in the longitude of Columbus, and farther west its horizon is occupied by shales. The sand along its western border—that is, from Cleveland to Lorain and thence south to the Ohio River—is patchy and uncertain. The sand is thus a lens, or series of lenses, embedded in fine shales (see p. 143).

The thickness of the "Clinton" varies. Its maximum is placed by Bownocker at about 100 feet, but measurements of half that amount are known, and the usual thickness ranges from 10 to 40

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[1] Bownocker, J. A.: Natural Gas in Ohio. Cleveland Engineering Soc. *Bull.*, vol. 8, No. 5, pp. 322-332, 1916.

feet. Its texture is rather coarse. The rock commonly has a light gray color, but in places it is brick-red. At many places it is impervious and barren.

The initial pressure in the field was everywhere high and increases with the depth. In the southern part of the field it was about 700 pounds to the square inch; between Newark and Mount Vernon, 750 pounds; in Ashland County, 1,200 pounds; and in Cuyahoga County 1,050 pounds. The greatest pressure near Butler, Richland County, was 1,260 pounds.

The first large well in the "Clinton" was the Mithoff, at Lancaster, which yielded initially at the rate of 12,000,000 cubic feet a day. From Newark to Mount Vernon the largest wells yielded about 12,000,000 cubic feet, and in Ashland County 13,000,000 cubic feet. A well drilled in Congress Township, Wayne County, early in September, 1915, started flowing at the rate of 22,000,000 cubic feet a day. Many wells flow from 3,000,000 to 5,000,000 cubic feet.

Wells in the "Clinton" are long lived, for gas wells, as a result of the porous nature of the rocks and the high pressure of the gas. Difficulties in drilling are encountered because of brine in the Big lime, which lies a short distance above the gas rock. This brine has done great damage to many wells.

RECORD OF A "CLINTON" OIL WELL NEAR BREMEN, FAIRFIELD COUNTY, OHIO
(After Bownocker)

		Thickness	Depth
		Feet	Feet
Mantle rock		49	49
Cuyahoga and Sunbury sandstone and shales		626	675
Berea sandstone		35	710
Bedford and Ohio shales		975	1,685
Devonian limestone		50	1,735
Silurian	Monroe limestone	275	2,010
	Niagara limestone	360	2,370
	Clinton limestone	95	2,465
Shales		120	2,585
"Clinton" sand		34	2,619
Bottom of well		...	2,620

Many wells have been drilled for oil in the "Clinton." Oil in paying quantities was first obtained in this stratum in 1899, but no large pools were found until 1907, when the reservoir in eastern Fairfield County was discovered.[1]

The oil, which has a density ranging from 35° to 46° Baumé, differs in no important way from the light oils of Pennsylvania and West Virginia. Its occurrence is uncommon in Ohio, in that it appears to be free from water. From this fact the conclusion is reached that the oil lies in shallow basins rather than on the slopes of anticlines. The production of the "Clinton" sand at its maximum was about 1,300,000 barrels a year.[2]

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[1] BOWNOCKER, J. A.: Petroleum in Ohio and Indiana. Geol. Soc. America *Bull.*, vol. 28, p. 672, 1917.

[2] BOWNOCKER, J. A.: *Op. cit.*, p. 673.

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——— The Mannington Oil Field. Geol. Soc. America *Bull.*, vol. 3, pp. 187-216, 1892.

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Kentucky.—The rocks exposed in Kentucky[1] are Paleozoic, Cretaceous, and Quaternary. (See Figs. 102, 103.) The most prominent structural feature of this State is the Cincinnati anticline, which in Ohio and Indiana is termed the Cincinnati arch. (See p. 201.) This anticline extends southward from Cincinnati through east-central Kentucky and passes out of the State in the eastern part of Monroe County. In Tennessee it expands into a great dome in the region of Nashville. From Tennessee it passes southward into Alabama.

[1] HOEING, J. B.: Oil and Gas Sands of Kentucky. Kentucky Geol. Survey *Bull.* 1, 1904.

FOHS, F. J.: Oil and Gas Possibilities of Kentucky. Am. Inst. Min. Eng. *Bull.* 99, pp. 621-628, 1915.

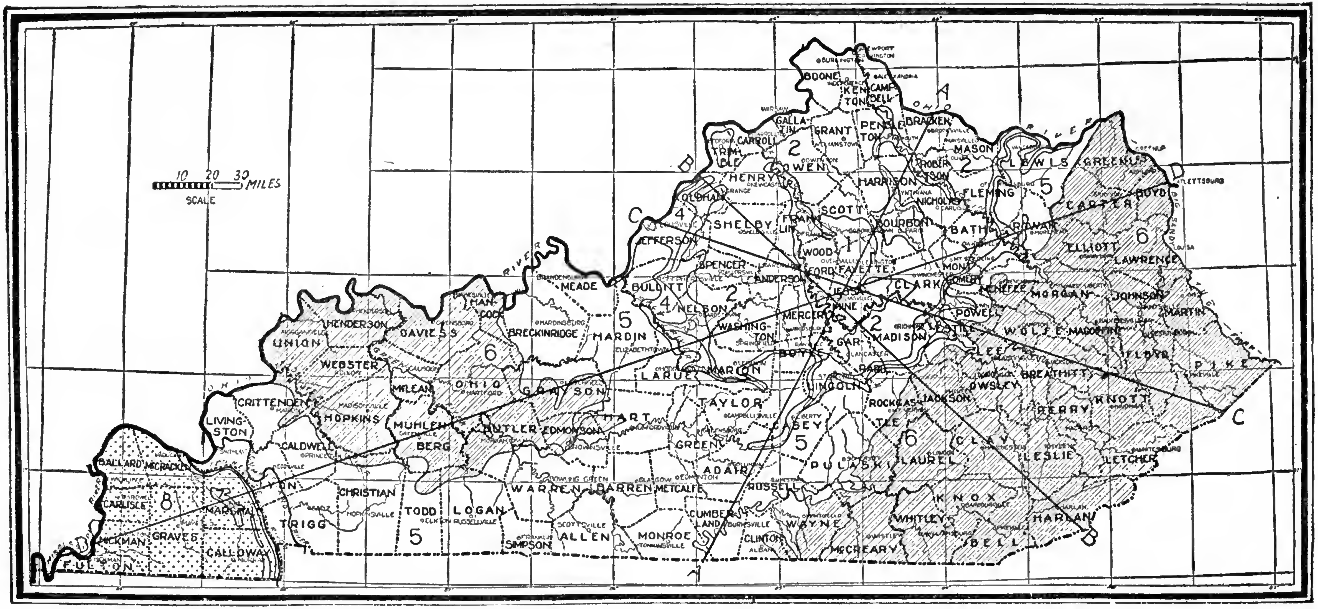

FIG. 102.—Sketch map showing areal geology of Kentucky. 1 and 2, Ordovician; 3, Silurian; 4, Devonian; 5, Mississippian; 6, Pennsylvanian; 7, Cretaceous; 8, Quaternary. For sections along lines *AA*, *BB*, etc., see Fig. 103. (*After Jillson.*)

A zone of deformation known in West Virginia as the Warfield anticline extends into Kentucky, where it is known as the Campton anticline. (See Fig. 90.) This anticline crosses Kentucky from east to west and intersects the Cincinnati arch near the north border of Lincoln County.

The oldest formation in the State, the Mohawkian (Ordovician), is exposed at the crest of this arch in Jessamine County. This portion has been termed the Jessamine dome. Around the Mohawkian is a great area of. Cincinnatian rocks (Ordovician). Silurian, Devonian, Mississippian, and Pennsylvanian rocks occur in succession stratigraphically above the Ordovician central mass. The dip of the beds is essentially eastward to the West Virginia border; the Pennsylvanian coal measures in eastern Kentucky lie on the west limb of the great Appalachian coal basin. In the coal region the rocks are thrown into gentle folds like those in West Virginia. West of the Cincinnati anticline the beds dip westward below the western coal basin and rise again near the Cumberland River.

Most of the oil and gas produced in Kentucky[1] is derived from Devonian limestone, but some is obtained also from Ordo-

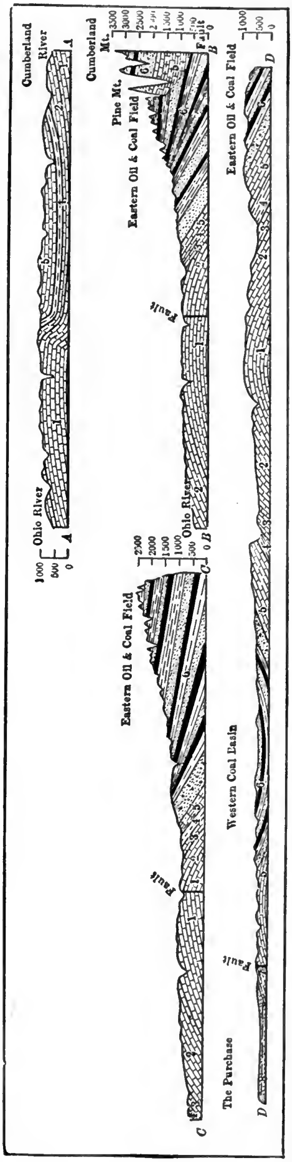

FIG. 103.—Diagrammatic sections showing the structural geology of Kentucky along lines *A A*, etc., in Fig. 102. The numbers of formations in the sections correspond to the numbers in Fig. 102. Vertical scale is greatly exaggerated. (*After Jillson.*)

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[1] JILLSON, W. R.: The Oil and Gas Resources of Kentucky. Kentucky Dept. Geology and Forestry, ser. 5, vol. 1, pp. 1-630, 1919.

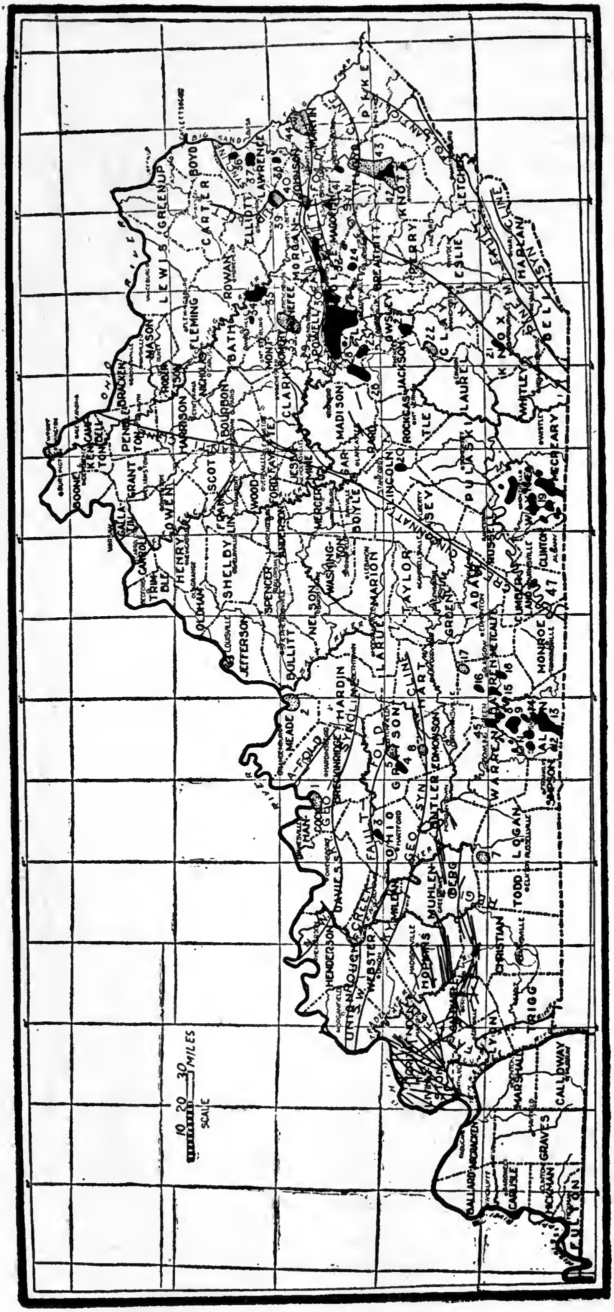

FIG. 104.—Sketch map showing oil pools of Kentucky (solid black, oil; dotted black, gas.) Pools are numbered to correspond to numbers given in accompanying table. (*After Jillson.*)

Field	County	System	Formation	Structure
1. Clover Port (*g*)	Breckinridge.	M	Warsaw.	Dome.
2. Rock Haven (*g*)	Meade.	D	Sand.	(?)
3. Hartford (*o*)	Ohio.	D?	Do.	Anticline.
4. Caneyville (*o*)	Grayson.	M	Waverly.	(?)
5. Leitchfield (*o*)	Do.	M	Do.	(?)
6. Bear Creek (*g*)	Edmonson.	....	....	Dome.
7. Diamond Springs (*g*)	Logan.	....	Waverly, Cypress.	Monocline.
8. Jewell (*o*)	Allen.	D	Onondaga.	Anticline.
9. Gainsville (*o*)	Do.	S, D	Niagara, Onondaga.	Do.
10. Butlersville (*o*)	Do.	D	Onondaga.	Do.
11. Halfway (*o*)	Do.	S, D	Niagara, Onondaga.	
12. Rodemer and Petroleum (*o*)	Allen	S	Niagara.	
13. Adolphus (*o*)	Allen.	S	Do.	
14. Scottsville (*o*)	Allen.	S, D	Niagara, Onondaga.	
15. Steffy (*o*)	Barren.	D	Onondaga.	Anticline.
16. Oil City (*o*)	Barren.	M	Warsaw.	
17. Hiseville (*g*)	Barren.	S	Niagara.	(?)
18. Oskamp (*o*)	Barren.	S, D	Niagara, Onondaga.	(?)
19. Wayne County (*o*)	Wayne.	O, S, M	Many sands.	Anticlines and synclines.
20. Buck Creek (*o*)	Lincoln.	D	Onondaga.	Anticline.
21. Little Richland (Barbourville) (*o*)	Knox.	P	Several.	
22. Burning Springs (*g*)	Clay	M	Big Injun.	Anticline.
23. Island Creek (*o*)	Owsley.	D, M	(?)	Anticline.
24. Frozen Creek (*o*)	Breathitt.	D	Onondaga.	Anticline.
25. Ross Creek (*o*)	Estill.	D	Onondaga.	Anticline.
26. Station Camp (*o*)	Estill.	D	Onondaga.	Anticline.
27. Irvine (*o*)	Estill.	S, D	Niagara, Onondaga.	Anticline.
28. Big Sinking (*o*)	Lee.	S, D	Niagara, Onondaga.	Anticline.
29. Ashley (*o*)	Powell.	D	Onondaga.	Anticline.
30. Campton (*o*)	Wolfe.	D	Do.	Do.
31. Stillwater (*o*)	Do.	D	Do.	Do.
32. Cannel City (*o*)	Morgan.	D	Do.	Do.
33. Menefee (*g*)	Menefee and Powell.	D	Do.	Monocline.
34. Olympia (*o*)	Bath.	D	Do.	(?)
35. Ragland (*o*)	Bath and others.	D	Do.	Monocline.
36. Fallsburg (*o*)	Lawrence.	M	Berea.	Syncline.
37. Busseyville (*o*)	Do.	M	Do.	Monocline.
38. Georges Creek (*o*)	Do.	M	Berea, Wier.	Do.
39. Laurel Creek (*o*)	Johnson and Lawrence.	M	Do.	Dome.
40. Point Creek (*o*)	Johnson and Morgan.	M	Wier.	Dome.
41. Ivyton (*o*)	Magoffin.	M	Pottsville, Wier.	Dome.
42. Beaver Creek (*o*)	Knott.	M, P	Mauch Chunk, Pottsville.	Syncline.
43. Beaver Creek (*g*)	Knott.	D, M, P	Several.	
44. Inez (*g*)	Martin.	M	Big lime, Big Injun.	Anticline.
45. Moulder (*o*)	Warren.	D	Onondaga.	(?)
46. Green Hill (*o*)	Do.	S, D	Niagara, Onondaga.	(?)
47. Burksville (*o*)	Cumberland.	O	Trenton?	(?)

vician, Silurian, Mississippian, and Pennsylvanian rocks. Any porous limestone, where covered with shales, may serve as a reservoir. The reservoir limestones are not uniformly porous, and the production is therefore spotted.

Both east and west of the Cincinnati arch, at places not far from the coal measures, are areas of bituminous sandstones. These are shown on a map by Eldridge.[1] They appear not to be closely connected with the oil pools.

GENERAL SECTION FOR KENTUCKY FIELDS

(Based on Sections by Hoeing, Matson and Jillson)

	Feet
Pennsylvanian:	
Pottsville conglomerate; alternating sands, shales, and coals, conglomerate at base; contains Beaver, Horton, and Pike sands in Floyd, Knott, and Pike Counties, and Wages, Jones, and Epperson sands in Knox County	60–1,000
Mississippian:	
Chester and Mauch Chunk shales and sandstone, some limestone; contains Maxon sand. In eastern Kentucky 30 to 275 feet thick; in western Kentucky	300– 800
St. Genevieve; fine sands, oolitic white limestone (Big lime). Thickness in eastern Kentucky	20– 400
St. Louis; fine gray-white limestone. Thickness in western Kentucky	475–1,000
Waverly sandstones and shales. In eastern Kentucky 400 to 600 feet thick; contains Keener, Big Injun, Squaw, Wier, and Berea sands. In western Kentucky calcareous shales and limestone; contains amber oil of Barren, Warren and Simpson Counties. Thickness in western Kentucky	400
Devonian system:[2]	
Ohio shale; in shallow wells yields an abundance of highly mineralized water	150
"Corniferous limestone," usually a cherty magnesian limestone with some shale beds. Oil sand in Irving region	30
Silurian system:	
Niagaran; blue shales and yellow limestones, in places containing chert; locally includes some sandstone. Oil in Allen County	60

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[1] ELDRIDGE G. H.: Asphalt and Bituminous Rock Deposits of the United States. U S. Geol. Survey *Twenty-second Ann. Rept.* part 1, pl. 26, opp. p. 240, 1901.

[2] The section of the Devonian and older rocks represents the central Blue Grass region, after MATSON, G. C. U. S. Geol. Survey *Water-Supply Paper* 233, 1909.

Ordovician system:	
Richmond formation:	
Upper division, heavy-bedded gray or blue arenaceous limestones, with about 10 feet of dense calcareous shale in lower part; locally an impure sandstone	60
Middle division, blue shale, with some blue or dove-colored limestone	125
Lower division, interbedded blue limestone and shale	80
Maysville formation; interbedded blue limestones and shales, the alternate layers usually thin and nodular; most of the beds thin	230
Eden shale; mainly bluish shale, but upper part is commonly sandy (Garrard sandstone)	200+
Winchester limestone; generally yields moderate amounts of strong brines	60+
Lexington limestone:	
Upper division, gray, crystalline and cherty (Flanagan chert); commonly yields much salt or saline-sulphur water	75
Middle division, light-drab argillaceous limestone, with shale beds; uppermost part, 20 to 60 feet thick, is commonly sandstone, with some phosphatic limestone; yields some strongly mineralized water	194
Lower division, heavy bedded, coarse grained, crystalline, and cherty	30
Highbridge limestone; mainly limestone, with shale lenses; little sandstone; yields moderate amounts of salt and salt-sulphur water, especially from beds near the top	400
Unidentified limestone, similar to Highbridge limestone	100
St. Peter "sandstone;" a siliceous limestone, yielding large quantities of salt-sulphur water. Thickness unknown.	

Most of the gas fields are in the northeastern part of the State, although there are a few along the Ohio River in northwestern Kentucky.[1] The location of oil and gas pools is shown on Fig. 104 after Jillson.

The Campton oil pool is in Wolfe County, about 50 miles southeast of Lexington. The field as it was developed in 1909 is roughly crescent-shaped, with a length of about 3½ miles and a maximum width of 1½ miles.[2] The rocks that crop out in the Campton field are of Pennsylvanian age, belonging to the lower part of the Pottsville group. The oil probably occurs in a sand layer of the

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[1] Clapp, F. G.: Natural Gas in the United States. *Econ. Geology*, vol. 8, p. 522, 1913.

[2] Munn, M. J.: The Campton Oil Pool, Kentucky. U. S. Geol. Survey *Bull.* 471, p. 9, 1912.

Devonian, which Munn considers as the Corniferous. The Campton sand has two pay streaks in which oil occurs in the northeastern part of the field. These are as a rule from 24 to 28 feet apart, and each probably ranges from 3 to 10 feet in thickness. In the central and southern parts of the field rarely more than one pay streak is found. This is from 1 foot to about 14 feet below the top of the sand. The field lies on a monocline, on which is developed a plunging anticline. The south half of the field lies along the axis and sides of a broad, low secondary fold. Over part of the territory the contour on the oil sand 220 feet below sea level marks the dividing line below oil and salt water. As stated by Munn, salt wells form almost a semicircle around the south half of the district.

The Menifee gas field[1] is in Menifee County, about 20 miles northeast of the Campton pool. The rocks are of Pennsylvanian, Mississippian, and Devonian age. The Devonian rocks, however, do not crop out. The gas is found in the Onondaga or Corniferous (Devonian) limestone just below the Ohio shale. On June 1, 1912, the production was reported to be approximately 25,000,000 cubic feet, and the gas had a closed pressure of about 60 pounds to the square inch. The Corniferous limestone is gas-bearing on a monocline between the 290-foot contour on the south side of the field and the 500-foot contour on the north side, the maximum difference in the height of the top of this bed in the field being more than 200 feet.

The Ragland oil field is about 15 miles northeast of the Menifee gas field. The surface rock is of Mississippian age, the beds being essentially the same as in the Menifee field. The Corniferous[2] limestone carries the oil. This formation varies greatly in thickness. At some places it is absent; at Campton it is probably 200 feet thick; at Irvine, a pool some 20 miles southwest of Menifee, it is only 20 feet thick. The oil and gas bearing portion, or "pay streak," as it is called, varies greatly in position and thickness from well to well. Its porosity is due to numerous minute cavities, many of which are of microscopic size.

The Irvine oil field[3] is on the western edge of the Appalachian

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[1] Munn, M. J.: The Menifee Gas Field and the Ragland Oil Field, Kentucky. U. S. Geol. Survey *Bull.* 531, p. 9, 1913.

[2] In this region the "Corniferous" is the Onondaga.

[3] Shaw, E. W.: The Irvine Oil Field, Estill County, Kentucky. U. S. Geol. Survey *Bull.* 661, pp. 149-150, 1918.

coal basin, a few miles east of the eastern border of the broad area of Ordovician limestones. A southeastward dip carries the Ordovician beneath successively younger rocks of Silurian and Devonian age, which crop out immediately west of Irvine. To the east these rocks are overlain by rocks of Carboniferous age (Mississippian and Pennsylvanian).

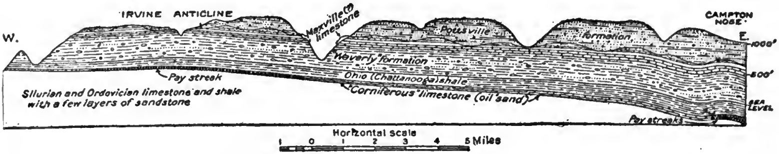

Fig. 105.—Cross-section from Irving to Campton, Kentucky, showing the dip and thickening of formations to the east, the structural features on which oil and gas are found and the general attitude of the surface. (*After Shaw.*)

As a general rule the formations thicken toward the east. The top of the Mississippian series in the western part of the Irvine field averages about 640 feet above the oil sand or "Corniferous" limestone, whereas in the eastern part of the field it is about 700 feet above; in the Campton field, 20 miles to the east, it is about 850 feet; and in the east end of Wolfe County nearly 1,000 feet. This gradual eastward divergence of the Maxville (?) and Corniferous limestones is illustrated in Fig 105.

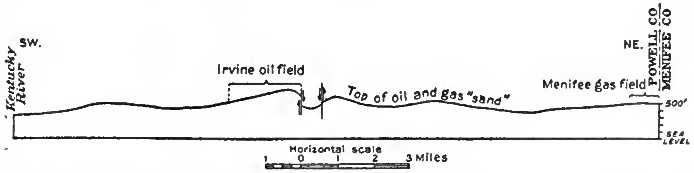

Fig. 106.—Profile of the oil sand across the Irvine field, Kentucky. (*After Shaw, U. S. Geol. Survey.*)

A fault zone borders the crest of the Irvine anticline on the northwest. The effect of the faulting is to drop a block of strata from half a mile to 2 miles wide and probably more than 20 miles long, 25 to 200 feet (Fig. 106).

The Irvine fault zone is nearly parallel to the axis of the Irvine anticline. It runs northeastward from Irvine, curves gradually to an east or slightly north of east course from Estill Furnace to High Rock, bends slightly south of east, and at Glen Cairn resumes an eastward course.

COMBINED SECTION IN ESTILL COUNTY, KENTUCKY
(*After Shaw.* The column showing depth has been recalculated to conform with other sections)

	Thickness	Depth	Geologic Formation
	Feet	Feet	
Heavy sandstone	196	196	Conglomerate measures.
Shales and shaly sandstone	50	246	
Black slate	4	250	
Coal	1	251	
Gray shales	4	255	
Coal	1	256	
Shales	15	271	
Buff earthy limestones	8	279	Chester, 33 feet.
Archimedes limestone	2	281	
Gray limestone	13	294	
Calcareous shales	10	304	St. Louis, 150 feet.
Oolitic limestone	10	314	
Buff limestone	11	325	
Semioolitic limestone	22	347	
Gray limestones	12	359	
Earthy buff limestone	5	364	
Thin gray cherty limestones	24	388	
Massive limestone	22	410	
Blue limestone and shale	38	448	
Earthy yellow limestone	6	454	
Sandstones and shales	490	944	Waverly, 490 feet.
Black shale	125	1,069	Devonian shales, 125 ft.
Estill County oil sand	25	1,094	Corniferous, 25 feet.
Blue and gray shales	145	1,239	Niagara, 150 feet.
Gray lime	5	1,244	
Gray lime	25	1,269	Cilnton, 53 feet.
Gray shale	10	1,279	
Gray lime	8	1,287	
Red lime	10	1,297	Lower Silurian (Ordovician), Hudson and Trenton groups, 1,476 feet.
Gray lime	17	1,314	
Brown lime	40	1,354	
Gray lime	839	2,193	
Greenish-white friable shaly sandstone	10	2,203	
Hard fine-grained limestone, dark dove-color, with occasional bands of dark-blue hard limestone	425	2,628	
Hard gray limestone	145	2,773	
White fine-grained sand and lime	15	2,788	Calciferous (St. Peter?).
Bottom of Whiteoak well.			

The "pay" or oil-bearing portion of the oil "sand," differs from the remainder of the limestone or dolomite in having larger pores and in being softer or less indurated. In places it is cavernous. As this character is due to recrystallization, it is extremely irregular in development. After penetrating the soft, more or less sticky clay shale that overlies the oil sand the drill commonly enters a rather hard limestone or cap rock, which here and there yields water and which ranges from a few inches to several feet in thickness. Below this rock is the soft brown sandy-textured magnesian limestone that constitutes the oil reservoir. In the eastern part of the field, where the whole "sand" is thicker, oil-bearing strata are found at more than one horizon.

Most of the wells in the Irvine field yield little gas. Salt water is probably present in the lower part of the oil sand throughout much of the field, particularly the southern half, and many wells bordering the field have yielded considerable quantities of water. Along the northern border, however, wells that fail to produce oil are commonly reported altogether dry.[1]

Oil was first discovered in quantity in Knox County in 1840, when a well drilled for brine on Little Richland Creek, about 6 miles north-northeast of Barbourville, began flowing oil at a rate of probably 100 barrels a day from a shallow depth. All the outcropping rocks of Knox County belong to the Pottsville group. They consist chiefly of sandstone and shale but also include several beds of coal, clay, and probably limestone. The sands that have furnished oil and gas in paying quantities in Knox County, named in ascending order, are the Epperson sand, the Lower and Upper Jones sands, and the Lower and Upper Wages sands of Pottsville age. They are all white or gray sandstones, containing soft porous pay streaks in which oil and gas are found. The structure[2] is said to be monoclinal, with small terraces locally developed. About 50 holes were drilled in Knox County in 1917, and some of them proved to be 50-barrel wells.[3]

In the Wayne County and McCreary County fields, in southern

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[1] SHAW, E. W.: *Op. cit.*, p. 176.

[2] MUNN, M. J.: The Campton Oil Pool, Kentucky. U. S. Geol. Survey *Bull.* 471, p. 19, 1912.

[3] PEMBERTON, J. R.: A Résumé of the Past Year's Development in Kentucky from a Geological Standpoint. Am. Assoc. Pet. Geologists *Bull.* 2, pp. 38-53, 1918.

Kentucky, the oil is in Ordovician, Silurian, and lower Mississippian rocks. At some places no salt water is present and the oil lies in synclines.

At Busseyville, in Lawrence County, northeastern Kentucky, the oil is in a monocline and comes from Pottsville, Mississippian, and Devonian rocks at depths between 700 and 2,000 feet.

At Petroleum, in Allen County, oil is found in anticlines and synclines, in Silurian rocks, at depths of 80 to 300 feet.

In the Hartford field, Ohio County, western Kentucky, the oil is found probably in the Devonian, in a broad anticline, at depths of 1,500 to 1,700 feet.

Tennessee.—Tennessee is divided into three geologic provinces (Fig. 107). In the eastern part of the State there is a broad belt of closely folded rocks ranging from Cambrian or older to Carboniferous. These rocks are extensively faulted and so far as known contain no oil or gas. The western part of the State is occupied by Cretaceous, Tertiary, and Quaternary rocks, which are apparently flat or dip at low angles. The central part of the State is lower in elevation than the eastern and western parts and is known as the central basin. The oldest rocks in this basin are of Ordovician age and consist of limestones and calcareous shales. Surrounding the Ordovician is a great belt of Devonian and Mississippian rocks. East of the Mississippian is a broad belt of Pennsylvanian conglomerate, sandstones, shales, and beds of coal. The Pennsylvanian belt is only about 35 to 50 miles wide, and at some places the coal beds are eroded.

Although oil seeps of considerable size have been known in Tennessee for many years,[1] the production is small. In the Spring Creek district, about 80 miles east of Nashville, oil in small quantities is produced from wells in the Fort Payne formation (Mississippian) at depths less than 30 feet. In the Superior and Riverton districts, northeast of the Spring Creek district, the lowest outcropping formation is the Fort Payne of Mississippian age, consisting of calcareous shale, a thin sandstone, some limestone, and bedded chert. Underlying the Fort Payne formation and entirely below drainage level is the Chattanooga shale (Devonian), ranging from 25 to 30 feet in thickness. The oil and gas are in the Ordovician rocks below the Chattanooga shale, and are found

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[1] Munn, M. J.: Preliminary Report on the Oil and Gas Developments in Tennessee. Tennessee Geol. Survey *Bull.* 2-E, pp. 9-10, 1911.

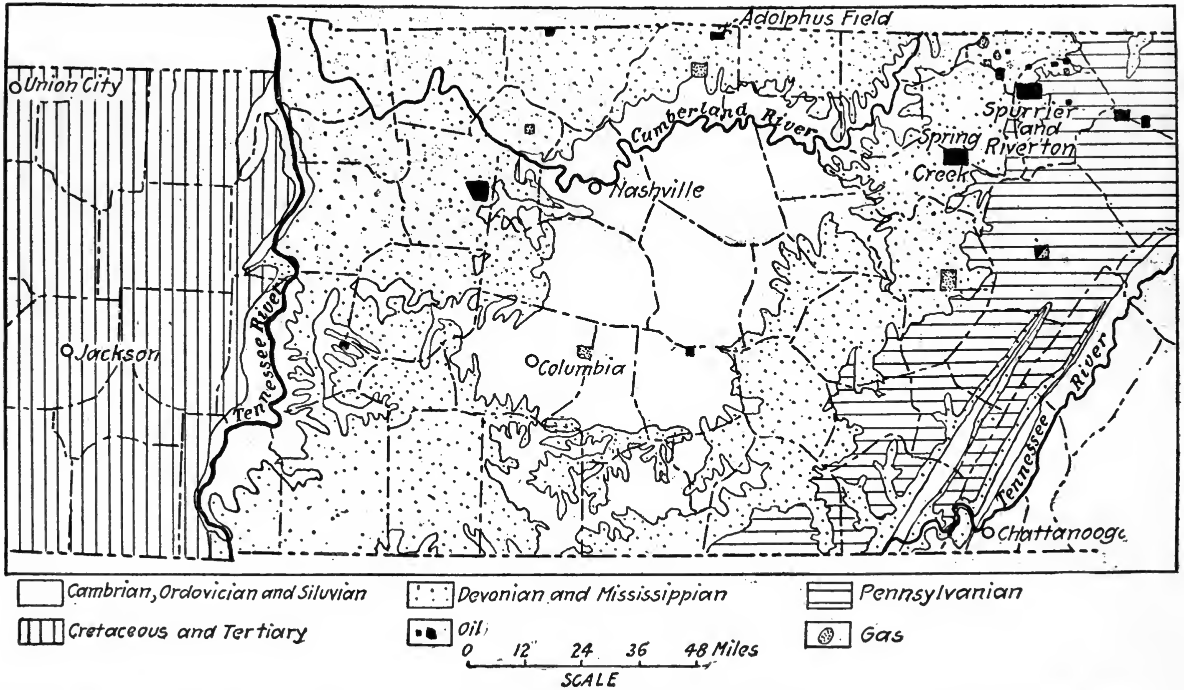

FIG. 107.—Sketch map showing oil and gas occurrences in Tennessee. (*Map after Stafford, oil and gas after Munn.*)

at numerous horizons through more than 1,500 feet of strata, though most of the production comes from the upper 500 feet. Most of the oil is a heavy dark-green to black oil, but in a number of wells a light amber-colored oil of excellent quality has been found. A little salt water is present.

Record of Lacey No. 1 Well, Spurrier, Tennessee

	Thickness	Depth
	Feet	Feet
Shales, etc.	64	64
Chattanooga shale	28	92
Limestone and shale	268	360
Limestone, siliceous (brown)	373	733
Shale, blue, soft	150	883
Limestone and shale alternating	117	1,000

In 1916 a well was drilled on the creek flats about three-quarters of a mile northwest of Glenmary, Scott County.[1] Oil was encountered in a stratum in the St. Louis formation at a depth of 1,232 feet. The production was 10 to 20 barrels a day. The stratum is 8 feet thick and is reported by drillers to be a sand, but according to Glenn it is probably an oolitic limestone. The oil is dark green and of good grade. There was little gas with the oil. The rocks at Glenmary are part of a long monocline that rises gently to the west or west-northwest. The rate of rise at Glenmary is between 30 and 40 feet to the mile. No evidence was found of any fold or flattening or other interruption of this general monocline.

There are numerous anticlines in western Tennessee in the Paleozoic rocks, but folds that inclose permeable rocks overlain by shales seem to be rare. Oil has also been reported to occur in the Eocene rocks at the west end of the State, but the report is unconfirmed. These rocks are similar in general character to some of the beds in the salt-dome region of the Gulf coast.

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[1] Glenn, L. C.: Recent Oil Development at Glenmary, Tennessee. *Resources of Tennessee*, vol. 7, p. 40, 1917.

RECORD OF PEMBERTON WELL NO. 1, GLENMARY, TENNESSEE[a]

	Feet
Soil	0–3
Hard white sand	3–45
Black slate	45–150
Hard white sand	150–305
Slate	305–435
Coarse loam sandstone; salt water at 505 feet	435–540
Black slate	540–547
Hard white sandstone, base of Lee	547–730
Slate and lime shells, top of Pennington	730–775
Red shale	775–795
Black slate	795–822
Dark lime	822–895
Red shale	895–908
Dark lime	908–930
Black slate, base of Pennington	930–950
Limestone, top of St. Louis; a little show of gas at 1045 feet	950–1048
White slate	1048–1051
Dark lime	1051–1144
Black slate	1144–1147
Gray sand	1147–1155
Hard white lime	1155–1232
Gray sand and small pebble, oil-bearing	1232–1240
Hard white lime	1240–1244

[a] GLENN, L. C.: *Op. cit.*, p. 42.

Alabama.—The Fayette gas field[1] is about 50 miles west of Birmingham, Alabama, in the western part of the Warrior coal field. Gas and some oil were found in 1909 in a drill hole put down for oil. Several wells dug later yielded large flows of gas with high pressure at about 1,400 feet. With the exception of a comparatively thick covering of sand, clay, and gravel, of Cretaceous and later age, the rocks penetrated by the drill in the Fayette district appear to belong entirely to the Pottsville formation, which consists of shales with included sandstone beds and coal.

The general structure of the Warrior coal basin, in which the Fayette gas field lies, is that of a broad, flat basin, gently tipped to the southwest. Several of the gas wells appear to tap the sands on the limbs of a gentle anticline. The data are not now sufficient to show the general relation of the gas sands to the structure.

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[1] MUNN, M. J.: The Fayette Gas Field, Alabama. U. S. Geol. Survey *Bull.* 471, pp. 30-55, 1912.

LIMA-INDIANA OR TRENTON FIELD

The Trenton limestone oil and gas field of Ohio and Indiana (Fig. 108) occupies a large area that extends with interruptions from Lake Erie to a point near Marion, Indiana.[1] The width of the field varies greatly; at some places it is sufficient for only a few

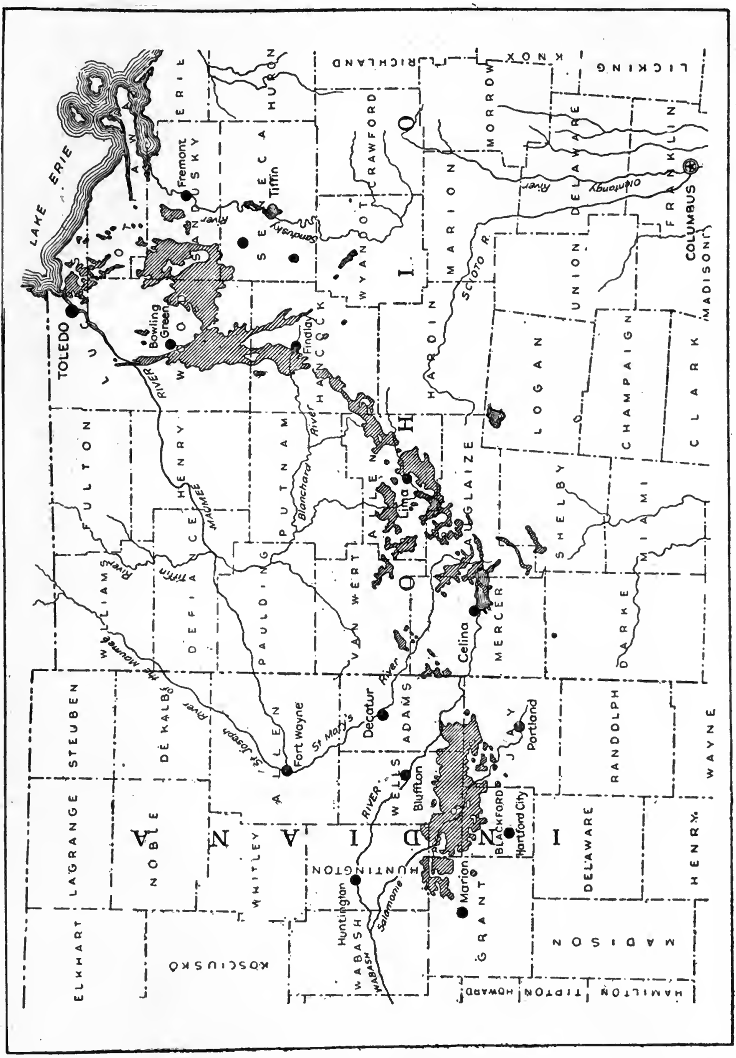

FIG. 108.—Map showing the Trenton limestone (Lima-Indiana) oil and gas field in Ohio and Indiana. (*After Bownocker.*)

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[1] BOWNOCKER, J. A.; Petroleum in Ohio and Indiana. Geol. Soc. America *Bull.*, vol. 28, p. 670, 1917.

rows of wells, but at others it is 20 miles or more. It is said that 30,000 wells have been drilled in the Indiana portion of the Trenton field, and a larger number in Ohio. The output from the field in Ohio attained its maximum in 1896, exceeding 25,250,000 barrels. The maximum production in Indiana was in 1904, when the yield was about 11,300,000 barrels. The pressure and production have greatly declined in recent years. The Trenton oil is sulphurous and has a paraffin base. The gas is about 92 per cent methane.

Surface indications of oil and gas are rare in this field. Nevertheless they led to its development. Prospecting was first carried on in the vicinity of Findlay, Ohio, where gas seeps were common and where as early as 1838 gas was utilized in a small way for domestic heating. Gases, including sulphureted hydrogen, filling cisterns were so common as to be regarded as a nuisance. These seeps led to the development of the Findlay pool in 1865. This pool was shown by drilling to be on a structural dome having about 200 feet of closure.

The rock successions in Ohio and Indiana are shown by the following well records.[1]

OHIO

	Thickness (Feet)
Niagara limestone	167
Niagara shale and Clinton limestone	108
Medina shale	47
Hudson River shale and limestone	462
Utica shale	300
Trenton limestone at	1,092

INDIANA

	Thickness (Feet)
Niagara limestone	153
Hudson River limestone	451
Utica shale	300
Trenton limestone at	954

So regular are the formations that approximately similar well records can be furnished by the thousands, though there is considerable variation in the depths of wells due to their position with reference to folding. In the Ohio fields the depth to the Trenton usually ranges from 1,000 to 1,500 feet, but in Indiana the depth is more uniform and, according to Blatchley,[2] averages 1,000 feet.

[1] ORTON, EDWARD: Ohio Geol. Survey, vol. 6, p. 112, 1888.

BLATCHLEY, W. S.: Indiana Dept. Geology and Nat Res., *Twenty-first Ann. Rept.*, p. 68, 1897.

[2] *Op. cit.*, p. 68.

The principal "pay rock" usually lies within 50 feet of the top of the Trenton, and in early days, in the Ohio part of the field, it was a general belief among drillers that unless oil were found when the drill had penetrated 50 feet of the limestone it was useless to continue sinking. Later, however, a second and a third "pay" were found, but these have proved of small value in comparison with the first.

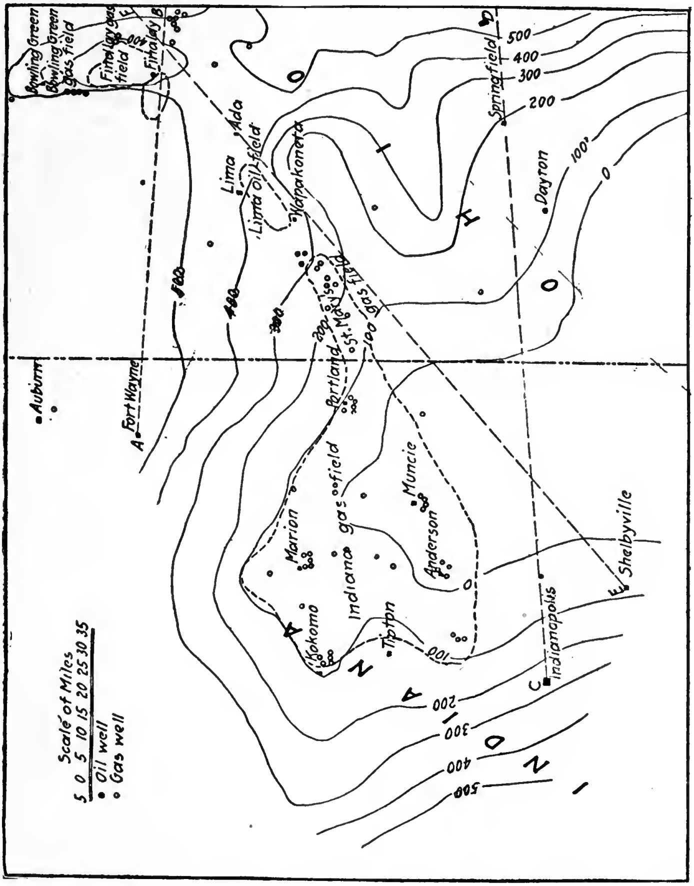

FIG. 109.—Map showing the structure of the Lima-Indiana, or Trenton limestone oil and gas field, Ohio and Indiana, by contours on the top of the Trenton limestone. (*After Orton.*) Sections on lines *AB*, etc., are shown in Fig. 10.

The structure of the Trenton limestone has a marked relation to

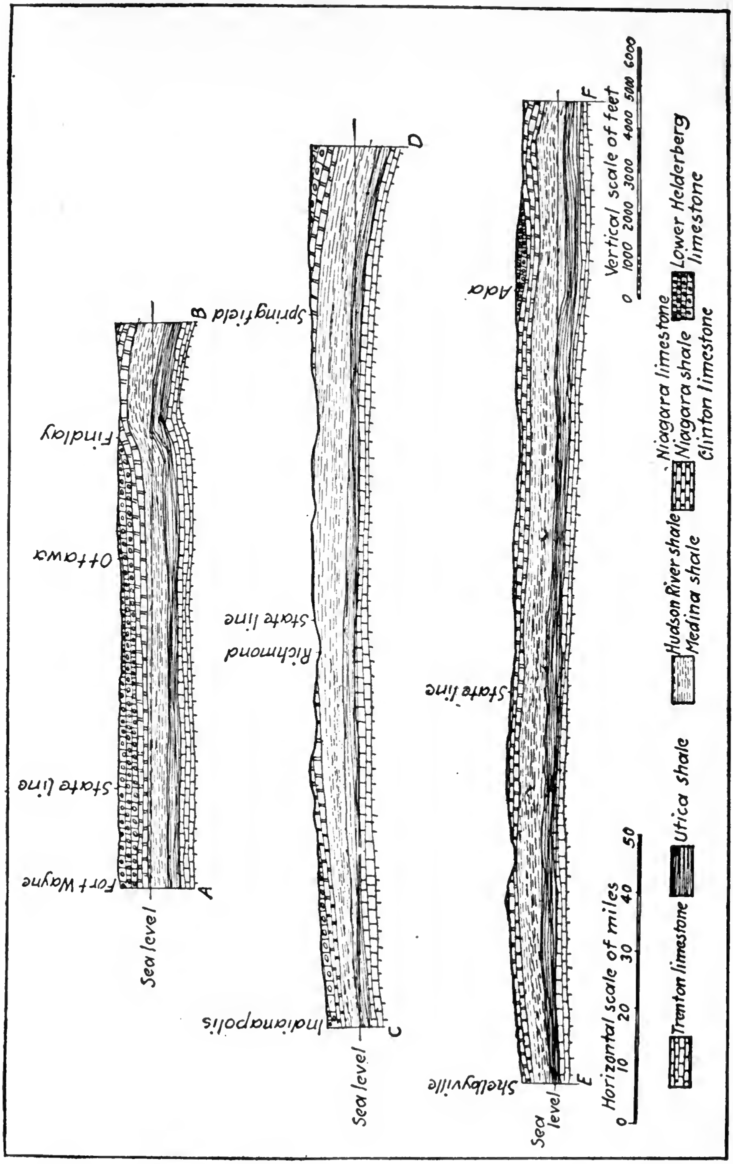

FIG. 110.—Sections through Lima-Indiana oil and gas field along lines *AB*, *CD*, etc., Fig. 109. (*Redrawn from sections by Edward Orton.*)

the production of oil. The region is a broad, flat-topped anticline that has formed as a warping on the Cincinnati arch. The Cincinnati axis crosses the Ohio River a short distance east of Cincinnati. Northward from that place it bifiurcates, one arm extending northwestward toward the south end of Lake Michigan and the other one east of north toward the west end of Lake Erie.[1] In other words, the axis forms a Y, with the stem crossing the Ohio River near Cincinnati. In Ohio part of the richest territory has been found on this arch, but in Indiana it does not appear on the summit of the arch, but on the north side, where the rock dips to the northeast. The Trenton limestone nearly everywhere in these two States contains brine below the oil.[2]

Fig. 109 is a contour map of the region redrawn from a map by Orton, issued in 1889. Sections are shown in figure 110. The extensions of the fields since 1889 are indicated by comparison with Fig. 108, after a map by Bownocker, issued in 1917. As shown by these figures the oil and gas are at crests of the folds in the region near Findlay and on the north slopes of the folds in western Ohio and eastern Indiana.

The fractured and dolomitized Trenton limestone, which contains the oil and gas, underlies the Utica shale. Above the Utica are Hudson River and Medina shales, then in ascending order the Clinton limestone and the Niagara shale and limestone. The surface is practically flat, and on anticlines the Niagara crops out. In general the gas lies about 950 to 1,200 feet deep, and the oil a little deeper, and both are near the top of the Trenton or generally not more than 100 or 200 feet down in it.

The Trenton in the producing region has a high porosity, which, according to Orton, has been developed by dolomitization of limestone. He cites many analyses to show that the Trenton where oil-bearing is much richer in magnesium than where it is barren of oil. Orton's opinion of the origin of the fractures in the Trenton limestone was not shared by Phinney,[3] who maintained that the

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[1] Orton, Edward: Ohio Geol. Survey, vol. 6, p. 46, 1888.

Orton, Edward: The Trenton Limestone as a Source of Petroleum and Inflammable Gas in Ohio and Indiana. U. S. Geol. Survey *Eighth Ann. Rept.*, part 2, pp. 475-662, 1889.

[2] Bownocker, J. A.: *Op. cit.*, p. 672.

[3] Phinney, A. J.: The Natural-Gas Field of Indiana. U. S. Geol. Survey *Eleventh Ann. Rept.*, part 1, p. 617, 1891.

cavities in the Trenton limestone are due to "loss of substance and not to substitution" in the Indiana field. He says the rock is commonly hard, uniform in texture, and compact between the irregular ramifying cavities and pores interspersed through it.

Around the gas field salt water rises to nearly equal altitudes on all sides. Although the Trenton is porous on both sides of the arch over northern and central Indiana, in the southeastern part of the State it is more compact. The main body of the arch may be regarded, then, as a long inverted bifurcating trough having its south end closed and its north ends immersed in the salt water, which is forced up into and around it by the hydrostatic pressure of the water. Orton and also Phinney state that the pressure is due to the pressure of the water around the sides of the arch. The Cincinnati arch is a dome surrounded by a larger basin. The water descends down the slopes of the basin and rises in the arch,

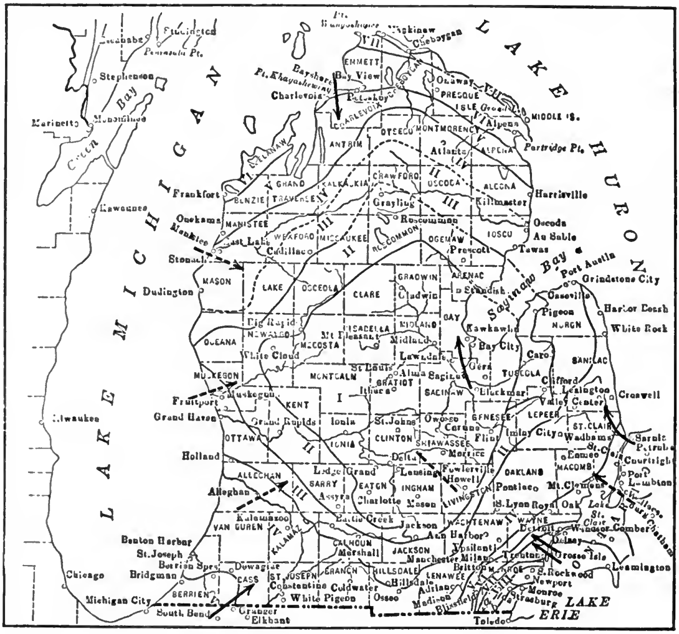

FIG. 111.—Outline geological map of southern peninsula of Michigan. (*After Smith*). Section from Manistee through Petrolia, Ontario, is shown on Fig. 112. Roman numerals refer to formations listed on page 255.

pushing oil and gas ahead of it, and equilibrium is established by the back pressure of gas when it equals the water pressure.

MICHIGAN FIELD

The southern peninsula of Michigan is structurally a great basin (Fig. 111) whose long axis trends north.[1] The country is nearly everywhere deeply covered with glacial drift, and information pertaining to the underlying strata is obtained chiefly from well drillings. The area was a seat of deposition through nearly all of the Paleozoic era, and strata from the Ordovician to Pennsylvanian crop out or are discovered in drill holes. Shales are abundant in the section, limestones are numerous, and a few beds of sand are present. In the eastern part of the peninsula small folds are probably developed on the westward-dipping beds (Fig. 112). At Port Huron oil is obtained from the Dundee formation (Onondaga or "Corniferous"), which is chiefly limestone. This formation is also the source of oil in Lambton County, Ontario, east of Port Huron. (See p. 476.) The Port Huron wells have produced oil since 1900, but the yield has never been large and in 1919 was only a few barrels a day. The oil of Michigan is of good grade and rich in the lighter spirits. Gas and salt water are associated with it.

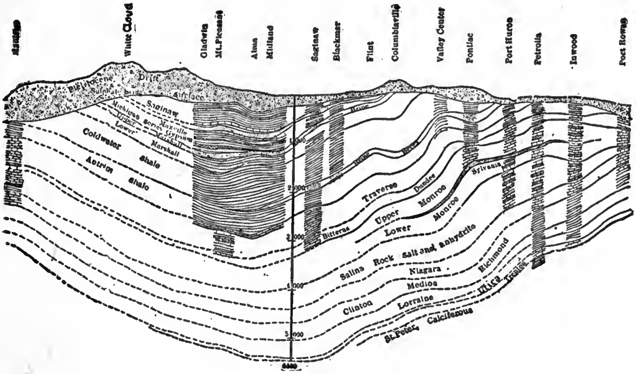

FIG. 112.—Diagrammatic cross-section of the Michigan basin from Port Rowan, Ontario, to Manistee, Michigan. (*After Smith.*)

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[1] SMITH, R. A.: The Occurrence of Oil and Gas in Michigan. Michigan Geol. and Biol. Survey *Pub.* 14, *Geol. ser.* 11, pp. 1-281, 1914.

PENNSYLVANIAN:

I. **Saginaw formation (upper Pottsville) and Parma sandstone (lower Pottsville).**

MISSISSIPPIAN:

II. **Grand Rapids group: Upper Grand Rapids, Bayport or Maxville limestone (upper St. Louis), and lower Grand Rapids of Michigan series.**

III. Marshall formation: (Kinderhook of Iowa, **Black Hand and Logan of Ohio.) Upper** Marshall or Napoleon and lower Marshall.

IV. **Coldwater shale and Berea sandstone.**

DEVONIAN:

V. **Antrim shale.**

VI. **Traverse formation (Hamilton and Marcellus, Erian and Delaware of Ohio).**

VII. Dundee limestone (Corniferous and Schoharie, Ulsterian, and upper Heidelberg).

SILURIAN:

VIII. **Monroe formation: Upper Monroe or Detroit River series, middle Monroe or Sylvanian, and lower Monroe or Bass Island series.**

IX. **Niagara (Guelph and Lockport), Rochester shale, and Clinton.**

CHAPTER XVI

ILLINOIS

Introduction.—The Illinois output of petroleum and gas comes mainly from the southeastern part of the State, nearly all of it from a district including parts of Clark, Cumberland, Lawrence, Jasper, Crawford, and Wabash Counties (Figs. 113, 114, 115). Although petroleum was known in Illinois at an earlier date, commercial quantities were not discovered until 1905. The maximum yield was reached three years later, when Illinois produced 33,686,238 barrels. Production has declined rapidly since then, and in 1917 the state yielded but 15,776,860 barrels. Illinois had in 1917, as estimated by Kay,[1] 230 square miles of oil-producing territory. The oil is of high gravity and relatively free from sulphur.

Most of Illinois[2] is covered with glacial drift and surface indications of oil or gas are meager. Near Chicago bitumen is found in the Niagara limestone, and in Calhoun County there is an oil seep in that formation. Neither of these regions supplies petroleum. In the first producing field the evidences were obtained by deep drilling for coal and by chance prospecting. In the Sandoval dome, in Marion County, oil seeps along a fault into a coal mine. Most of the recent discoveries have resulted from drilling areas mapped and recommended by the Illinois State Geological Survey.

The principal oil-bearing strata are in the Mississippian and Pennsylvanian series. These series consist of sandstones, shales, and limestones, and there are six or more productive "sands" in the principal oil fields.

The sands are variable, some of them attaining a thickness of more than 100 feet in places, but the producing part is generally but a small percentage of the total thickness. The different lenses

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[1] Kay, F. H.: Oil Fields of Illinois. Geol. Society America *Bull.*, vol. 28, pp. 655-666, 1917.

[2] Blatchley, R. S.: Oil Resources of Illinois, with Special Reference to the Area Outside the Southeastern Fields. Illinois State Geol. Survey *Bull.* 16, 1910; Oil in Crawford and Lawrence Counties. Illinois Geol. Survey *Bull.* 22, 1913.

of the Robinson sand in Crawford County average about 25 feet in thickness, whereas the "pay" sand averages only about 7 feet. In two of the pools the sand ranges from 25 to 40 feet and is saturated with oil throughout, but this condition is exceptional.

Total Production of Illinois Sands for Typical Areas to Jan. 1, 1917
(After Kay)

Sand	Depth (Feet)	Period (Years)	Barrels
Casey	350	10	5,309.93 2,919.37
Robinson	900	9	719.14
Bridgeport	800–1,150	9	8,390.49
Buchanan	1,150–1,350	10	36,233.98
Kirkwood	1,350–1,650	9	2,546.22
McClosky	1,750–2,000	8	15,672.80

Structure sections of Illinois are shown in Figs. 114 and 115.

Section for the Area Lying South of a Line Drawn Eastward from the Mouth of the Missouri River to Marshall, Illinois, and the State Line
(After Bain, with Some Additions and Changes after Kay. Made by W. H. E.)

Quaternary:

Glacial till, sand, and gravel; loess and alluvium. Present as surface rocks everywhere except in northwest and extreme south. Thickness, 30 to 225+ feet.

Tertiary:

Lafayette, LaGrange and Porters Creek. Clays, sands, gravel, and ferruginous conglomerate. Occurs only in extreme south. Thickness 250 feet.

Cretaceous:

Ripley. Clay and sand. Occurs only in extreme south Thickness 20 to 40 feet.

Pennsylvanian:

McLeansboro formation. Shales, sandstones, thin limestones and coals. Rocks above top of Herrin (No. 6) coal. Thickness 500 to 1,000 feet.

Carbondale formation. Coals, shales and sandstones. Rocks between the base of Murphysboro (No. 2) coal and the top of the Herrin coal. Thickness about 300 to 350 feet.

Pottsville formation. Sandstone, some thin shales, and coals. Thickness 500 to 600 feet.

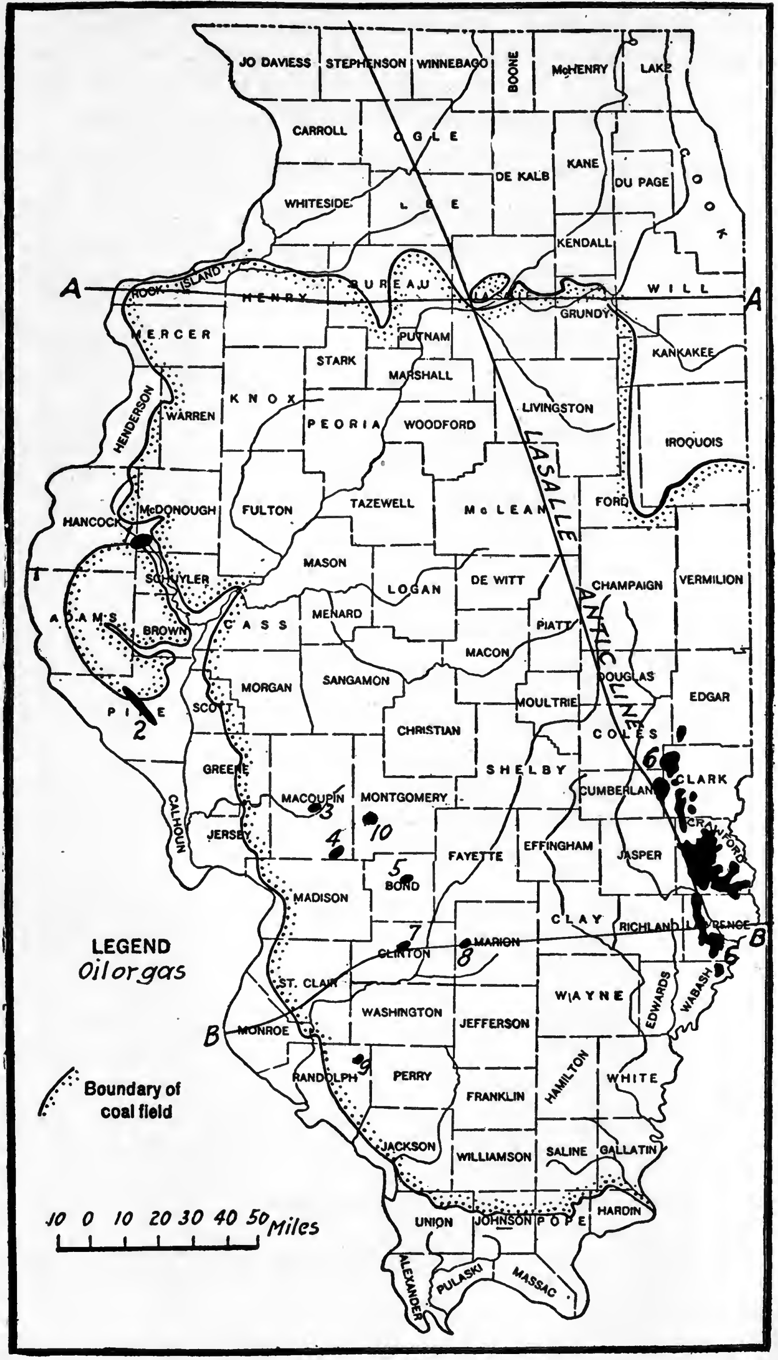

FIG. 113.—Map showing oil and gas fields of Illinois. Sections along lines *AA* and *BB* are shown on Fig. 114. Districts are numbered as follows: 1, Colmar; 2, Pike County; 3, Carlinville; 4, Staunton; 5, Greenville; 6, Main Illinois field; 7, Carlyle; 8, Sandoval; 9, Sparta; 10, Litchfield.

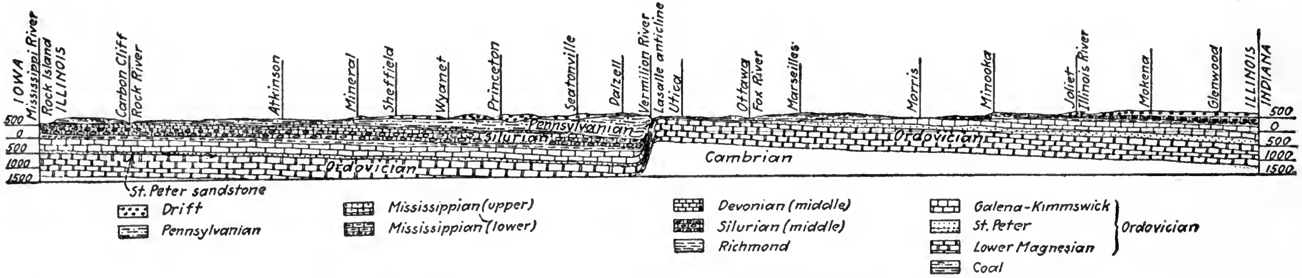

FIG. 114.—Geologic section across northern Illinois along line *AA* in Fig. 113.

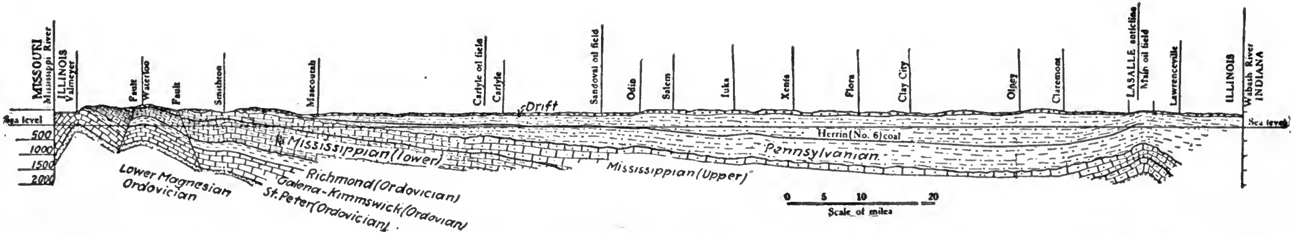

FIG. 115.—Geologic section across southern Illinois along line *BB*, Fig. 113. Vertical scale is about 20 times horizontal scale.

Mississippian:

Chester. Sandstones, shale, and limestones in series, with unconformities at bases of sandstones. At many places six such series are shown. Thickness varies; at several places about 300 feet.[a]

Cypress. Sandstone, very irregular and usually thin in southeastern Illinois. The Cypress sandstone is absent in the oil fields of Lawrence County.

Unconformity.

Ste. Genevieve. Limestone, mostly ooolitic and very cross-bedded. Thickness, 80 to 100 feet.

St. Louis and Salem (Spergen). Limestone, dense becoming oolitic in lower division. Thickness 300 feet.

Osage (Burlington, Keokuk and Warsaw). Shale above and coarse-grained limestone with chert below. Thickness 440 feet.

Kinderhook. Shale and shaly limestone, red. Thickness 60 feet.

Devonian:

Upper Devonian (Sweetland Creek). Shale. Thickness 50 to 60 feet.

Hamilton. Limestone. Thickness about 100 feet.

Onondaga (Grand Tower). Limestone. Thickness 155 feet.

Upper Oriskany (Clear Creek). Chert and limestone. Thickness 200 to 240 feet.

Helderberg (New Scotland). Limestone. Thickness 165 feet.

Silurian:

Alexandrian (Sexton Creek, Edgewood, Girardeau and Orchard Creek). Limestone and shale. Thickness 116 feet.

Ordovician:

Richmond (Cincinnatian). Thebes sandstone, Fernvale limestone. Thickness about 100 feet.

Kimmswick-Plattin (Trenton). Nondolomitic limestone. Thickness 510 feet recorded.

St. Peter. Sandstone. 120 feet recorded.

Prairie du Chien group. Mostly dolomitic limestone with occasional thin layers of sand and shale. 545 feet recorded.

[a] Weller, S.: The Chester Series in Illinois, *Jour. Geol.* Vol. 28, p. 408, 1920.

The producing sands of Illinois, as stated by Kay,[1] range in age from the top of the Carbondale formation of the Pennsylvanian series down to the upper part of the Trenton limestone. The output is derived principally from the sandstones of the Carbondale and Pottsville formations of the Pennsylvanian and the Chester group and Ste. Genevieve formation of the Mississippian. A sandstone at the base of the Niagaran produces some oil at Colmar, McDonough County, in western Illinois.

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[1] Kay, F. H.: Oil Fields of Illinois. Geol, Soc. America *Bull.*, vol. 28, pp. 655-666, 1917.

The producing beds are sands with the exception of the so-called McClosky sand, which is in reality the oolitic Ste. Genevieve limestone, lying immediately beneath the Chester group. Of all the producing beds in the State, those of the Chester are the most regular. The sands of the Pennsylvanian are extremely irregular in thickness and character, and it is often impossible to correlate them from one well to another with certainty. The Hoing sand, at the base of the Niagaran in the Colmar field, is found in smaller areas than any other producing sand. It was deposited in depressions on the Maquoketa surface during the encroachment of the Niagaran sea. Outside of the small area at Colmar numerous drill holes in the western part of Illinois have discovered it, but it is productive only in the Colmar field.

Structurally Illinois is a spoon-shaped basin, the tip lying in the northwest corner and the deepest part of the bowl in Wayne, Edwards, Hamilton, and White Counties, in the southeast corner. (Fig. 113.) The long axis of the spoon extends northwestward, parallel to the main oil fields. In the western and central parts of Illinois the dip toward the axis of the basin is commonly as low as 10 feet to the mile. From the main fields to the basin the dip is more pronounced. On the sides of the basin there are longitudinal folds. The most prominent is the La Salle anticline, which runs from Freeport to a point just east of La Salle, and thence through the main oil field and into Indiana. From western Illinois the rocks dip gently eastward to the Duquoin anticline. At the southern part of the basin the dips of the rocks into the basin are locally 100 feet or more to the mile. East of the main oil fields in Crawford and Lawrence Counties the strata rise gently in Indiana. In southern Illinois strong folds, faults, and igneous intrusions are present.

Crawford, Lawrence, and Adjoining Counties.—The principal oil fields in Illinois are in Crawford, Lawrence, Clark, Cumberland, and Wabash Counties,[1] in the southeastern part of the State. This field, which was discovered in 1905, yielded oil very near the surface and was developed rapidly, reaching its maximum production three years after discovery. In the northern part of the field wells reached producing sands at depths of about 300 feet. The

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[1] Blatchley, R. S.: Oil in Crawford and Lawrence Counties. Illinois State Geol. Survey *Bull.* 22, 1913.

rocks that crop out in this field are of the Pennsylvanian series, and the oil is derived from the Pennsylvanian and Mississippian rocks.

Broadly considered, accumulation has taken place at the southeast end of the plunging La Salle anticline. The dip of the beds to the southeast along the axis of the anticline is comparatively high. The lowest producing stratum, the McClosky "sand" of the Ste. Genevieve limestone, lies within 350 feet of the surface at the northwest end of the Clark County field, whereas in the Lawrence County district it ranges in depth from 1,700 to about 1,860 feet. Minor warpings extend from the La Salle anticline both east and west. As shown by contour maps drawn by Blatchley, the structure is very irregular. There are seven productive sands, and the contour maps for each sand present noteworthy differences. The rocks as a general rule are saturated with salt water, and the oil and gas accumulate on anticlines and terraces. The gas is rich in gasoline, which is recovered, but the gas production is comparatively small.

The crest of the La Salle anticline in Crawford, Lawrence, and adjoining counties is very irregular. The part of the arch containing oil is 2 to 8 miles wide, and nearly 50 miles long. On the flanks of the fold the field is marked off by lines of salt water.[1] Some of the wells, particularly those in the McClosky "sand," were gushers.

The Robinson pool in Crawford County is about 7 miles wide, but narrows southwest of Robinson. The Crawford County pools possess one general oil-producing zone, the Robinson sand, which is of Pennsylvanian age, lying at the top of the Pottsville. This sand is very irregular in distribution and ranges in thickness between 2 and 50 feet, the average being 25 feet. At some places the Robinson sand is a series of lenses with many streaks, tongues, and detached portions. The arch on which the oil is found is very irregular, with an undulating top and a mapped closure of about 100 feet. Although the sands are irregular in distribution and at places impervious, the yield has been large. According to Blatchley,[2] of 2,370 wells mapped in this area all but 206 yielded oil or gas. The initial daily production was between 1 and 1,600 barrels.

The field extends southward into Lawrence County, which contains its most productive portion. Oil or gas occurs in the Bridge-

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[1] Blatchley, R S.: *Op. cit.*, p. 143.

[2] *Idem*, p. 100.

port and Buchanan sands of the Pennsylvanian and in the Gas, Kirkwood, Tracey, and McClosky sands of the Mississippian. Blatchley has contoured each of these sands over the most productive portion of the Lawrence field. The McClosky sand does not produce oil throughout the length of the field, because of local irregularities in structure and the variable nature of the producing stratum. It is variable in thickness and averages not more than 10 feet over the entire field. Instead of being a single bed, it is probably a zone in the upper part of the Ste. Genevieve formation, the position of the oil being controlled by the porosity of the rocks. Within the zone, which has a maximum thickness of 80 feet, one to three oil horizons are reported. Toward the north the sands play out or become thin and unproductive. At the south end of the oil field the structure of the McClosky, Tracey, and Kirkwood sands is different from that of the Buchanan and Bridgeport. (See Fig. 116.) The thickness of the beds between the sands varies from place to place, and there is probably an unconformity near the base of the Buchanan.

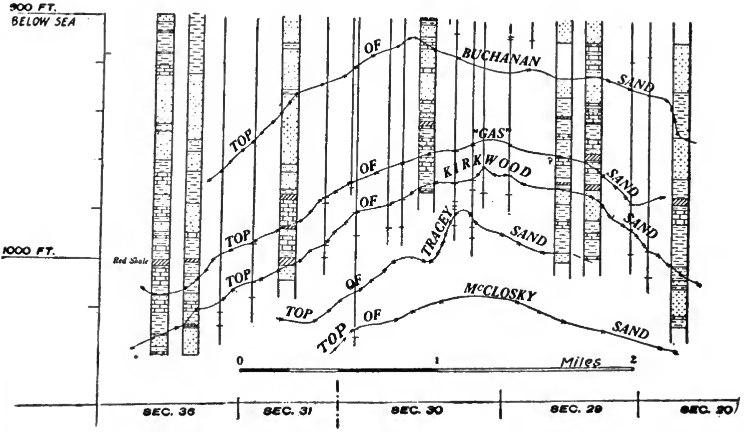

Fig. 116.—Section across dome in oil field in Petty township, Lawrence County, Illinois. The surface of the ground is about 1,000 feet above the top of the section. (*After Blatchley.*)

In the northern part of Clark County the Trenton has yielded oil at a depth of 2,200 feet.

The Allendale field[1] is in Wabash County, 8 miles southwest of the Lawrence County field. Oil was discovered here in 1912. The first solid rocks penetrated are the Pennsylvanian, which consist of a series of shales alternating with sandstones and thin lenses of limestone. The sandstones and shales occur in beds of varying thickness, ranging from only a few feet to 200 feet or more. At the base of the Pennsylvanian is the Pottsville sandstone. The Chester group, of Mississippian age, consists of a series of thin limestones and shales with a few thin beds of sandstone, which increase in thickness toward the base of the section penetrated by the wells. The producing sand in the Allendale field, commonly known as the Biehl sand, has been correlated with the Buchanan sand of the Pottsville. The oil is found in a low dome at about 1,500 feet below the surface.

Central and Western Illinois.—In the Illinois Basin, well up on its sides, the Pottsville rocks are saturated with salt water. In the west-central part of the State, however, a few small domes produce commercial quantities of gas and a little oil. Of these, the Staunton gas field, the Carlinville oil and gas field, and the Litchfield oil and gas field are the most important. In these fields oil and gas are found in lenses. Four productive horizons have been recognized, separated by small vertical intervals. Theoretically, a tilted porous sandstone lens should provide conditions for accumulation of oil and gas at its upper end; but in Illinois, as stated by Kay, the bedding planes of the Pottsville seem generally not impervious enough to prevent the lateral movement of oil and gas unless doming of the strata has capped the edge of the porous bed and prevented escape of the oil.

The oil and gas field near Carlinville, Macoupin County,[2] is one of small production. All the rocks belong to the coal measures, which consist of shales, sandstones, a minor amount of limestone, and several beds of coal. Three persistent beds are recognized—the Carlinville limestone, coal No. 6, and the oil and gas zone at the base of the Pennsylvanian. The intervening shales, although fairly constant in thickness, are changeable in character. Underneath the sands the drill usually strikes limestone, which is sup-

[1] Rich, J. L.: The Allendale Oil Field. Illinois Geol. Survey *Bull.* 31, pp. 59-68, 1915.

[2] Kay, F. H.: The Carlinville Oil and Gas Field. Illinois Geol. Survey *Bull.* 20, pp. 83-95, 1915.

posed to be either the Ste. Genevieve or the St. Louis limestone, of Mississippian age. The Chester shales, sandstones, and limestones, which underlie the area south of Carlinville and which include most of the producing sands of the main oil fields, are absent in this field. Although the productive sands are not invariably found at the same stratigraphic position, they lie near the base of the coal measures and are believed to constitute the Pottsville formation.

Gas has accumulated at the top of the dome, oil occurs below the gas, and salt water lies below the oil.

The first valuable deposit of oil found in Illinois was discovered near Litchfield by the Litchfield Coal Co. in November, 1879. In an effort to find a lower coal seam sufficiently thick to be profitably mined, a hole was drilled in the bottom of the shaft which passed into oil-bearing sand at a depth of 225 feet below the coal and 682 feet below the surface. Salt water at first threatened to flood the mine, but the hole was plugged, though oil leaked into the mine and was skimmed from the mine water for several years. The oil was a heavy lubricating oil and was associated with gas. The structure of the rocks of the area near Litchfield as indicated by that of the Herrin (No. 6) coal shows a distinct dome. The production of oil has not been large.[1]

The oil pool at Carlyle, in Clinton County, southwestern Illinois, about 45 miles east of St. Louis, was discovered early in April, 1911.[2] The oil is found in the Carlyle sand, which belongs to the Chester group (Mississippian). The Carlyle sand is on the whole a soft, porous sandstone of irregular thickness. Around the edges of the pool it is harder than in the center, and in one or two places it pinches out. Above the sand is about 30 feet of bluish shale containing locally red shale. Above the Chester is the Pottsville, which carries salt water and locally gas; this is overlain by Pennsylvanian sandstone, shale, limestone, and coal. The oil sand is practically horizontal. Outside the field the sand dips in all directions except north, and apparently it also pinches out in all directions except to the north.

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[1] Lee, Wallace: Oil and Gas in the Gillespie and Mount Olive Quadrangles, Illinois. Illinois Geol. Survey *Bull.* 31, pp. 71-107, 1915.

[2] Shaw, E. W.: Carlyle Oil Field and Surrounding Territory. Illinois Geol. Survey *Bull.* 20, pp. 43-80, 1915.

The Greenville gas field[1] is in Bond County, about 2 miles south of Greenville. The gas has accumulated in the crest of an anticline that is elongated in an east-west direction. It is found in two sands belonging to the Chester group—the Lindley No. 1 and Lindley No. 2. These sands are separated by a few feet of shaly strata, and Chester shales lie above the Lindley No. 1. The top of the dome is about 50 feet high, which is somewhat above the elevation shown in the Herrin (No. 6) coal. The fold has increased with depth.

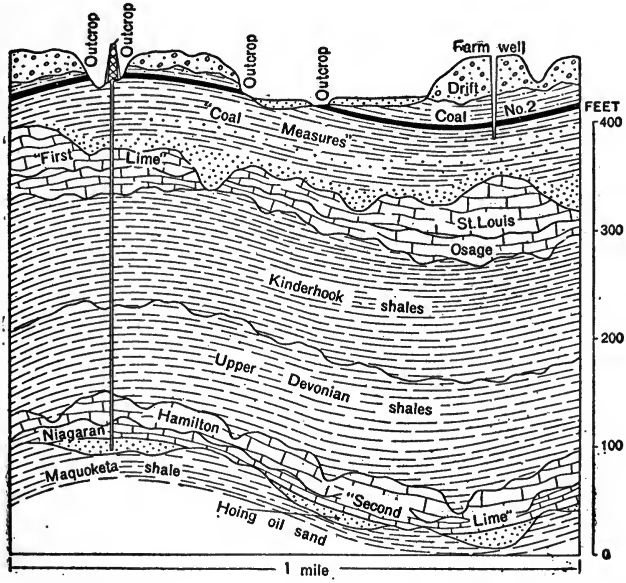

FIG. 117.—Diagram showing unconformities and spotted character of Hoing sand in Colmar field, Illinois. (*After Morse and Kay.*)

The Colmar oil field, in western Illinois, was discovered in 1914. The existence of a dome was first pointed out by Hinds from levels run on coal No. 2, which crops out. Oil was found in a sandstone at the base of the Niagaran, which was probably deposited in depressions on the Maquoketa surface during the encroachment of the Niagaran sea. The sand occurs as lenses separated by areas in which the limestone lies directly on the shale with no interven-

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[1] BLATCHLEY, R. S.: Oil and Gas in Bond, Macoupin, and Montgomery Counties, Illinois. Illinois Geol. Survey *Bull.* 28, p. 45, 1914.

GENERALIZED SECTION OF ROCKS IN COLMAR OIL FIELD AND SURROUNDING TERRITORY (After Morse and Kay)

System	Series	Drillers' Interpretation	Formation	Character	Thickness Feet
Quaternary.		Surface.		Alluvium; confined to valleys.	Variable.
				Loess; most conspicuous along bluffs of Illinois River.	0–75
				Drift; mixed clay, sand, gravel, and boulders.	Average, 25. In filled valleys, 100+.
Carboniferous.	Pennsylvanian.	Coal-rearing formations.	Carbondale.	Principal coal-bearing formation of Illinois. Shales, sandstones, thin beds of limestone, clay and coal.	0–140+
			Pottsville.	Includes beds from base of coal No. 2 to Mississippian. Sandstone and shale, and some limestone, clay, and thin coal.	0–140
			Unconformity.		
	Mississippian.	"First lime."	St. Louis.	Limestone, brecciated, blue, weathers yellow in places; contains scattered corals.	0–30+
			Unconformity.		
			Salem.	Impure limestones of yellow tint, difficult to distinguish from limy sandstone; at places shale increases and the formation consists of limy shales, limy sandstone, and impure limestone.	30 ±
			Unconformity.		
			Warsaw.	Thin-bedded impure limestone and shales, fossiliferous. Considerable blue clay shale is locally present.	30 ±
			Keokuk.	Gray crystalline limestone, fossiliferous, shaly toward top.	30+
			Burlington.	Limestone, generally cherty; not exposed.	?
			Kinderhook.	Shale, bluish gray, limy.	100 ±
			Unconformity.		
Devonian.	Upper Devonian.			Shale, light to dark; many spores of Sporangites, a minute reddish fossil.	100 ±
			Unconformity.		
		"Second lime."	Hamilton.	Limestone, gray, small amount of sand, and some pyrite. Usually not magnesian.	15–30
			Unconformity.		
Silurian.			Niagaran.	Limestone, gray, crystalline, magnesian. Exists in separate lenticular masses; where it is not present. Hamilton rests on Maquoketa shale. Show of oil in places near base.	0–20
		Hoing oil sand.		Sandstone, quartzitic; grains well rounded. In lenses with no connection. Probably accumulated in depressions on Maquoketa surface. Producing bed of Colmar field.	0–25 (Average in Colmar field 14).
			Unconformity.		
Ordovician.			Richmond. (Maquoketa)	Shales, bluish green.	180–200
			Unconformity.		
			Kimmswick-Plattin. (Trenton)	Limestone, gray, white, or brown. Crystalline in places. Odor of oil not unusual. Not magnesian in Colmar field.	300–400
			St. Peter.	Sandstone; generally saturated with mineral water.	145–225 recorded.

ing sand. As stated by Kay, no direct connection is apparent between the Hoing pool, where the sand lies 90 feet above sea level on a terrace at the northeast side of the dome, and the Hamm pool, on top of the dome, where the sand is 70 feet higher. The pool at the town of Colmar[1] lies on the north side of the dome and probably has no direct connection in the sand with either of the other pools.

The Hoing sand, which carries the oil, is as much as 14 feet thick where present but is very erratic in occurrence. The lenses are surrounded by impervious beds. The oil pool lies on the flat part of the oil sand on the side of a low dome and is associated with salt water. Several domes have been discovered by contouring the base of coal No. 2, but the production is small. The anticline in the Canton-Avon region has been described by Savage.[2] (See Fig. 117).

At Sandoval, Marion County, a few miles north of Centralia, a dome has been contoured mainly by using data obtained in coal mining. This dome and an associated terrace yielded oil and gas in two sands below the coal. The area is faulted, and the oil was first noted at a seep into a mine through a fault.

Near Sparta, in Randolph County, western Illinois, gas and a little oil are found in the Chester (Mississippian). The gas occurs along a small synclinal fold, but the relations are uncertain. The field has produced little oil and is not now important.[3]

In Pike County, western Illinois,[4] gas was discovered by drilling wells for water. The gas occurs along an anticline, the eastern limb of which is determined by the line separating the productive from the dry wells. The porous stratum forming the reservoir is a bed of yellowish-brown magnesian limestone which probably belongs to the Niagara. The thick bed of Kinderhook shales that overlies the Niagara limestone in this region provides the imper-

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[1] Hinds, Henry: Oil and Gas in the Colchester and Macomb Quadrangles. Illinois Geol. Survey *Bull.* 23 (extract), pp. 11-13, 1914.

[2] Savage, T. E.: Geologic Structure of Canton and Avon Quadrangles. Illinois Geol. Survey *Bull.* 33, pp. 91-99, 1916.

[3] Blatchley, R. S.: Illinois Geol. Survey *Bull.* 16, p. 146, 1910.

[4] Savage, T. E.: The Pike County Gas Field. Illinois Geol. Survey *Bull.* 2, pp. 78-87, 1906.

Worthen, A. H.: Illinois Geol. Survey, vol. 4, pp. 24-42, 1870.

vious cover of the reservoir. The wells are all shallow, the gas being reached at depths of 75 to 350 feet, depending largely upon the inequalities of the surface. The production is small.

GEOLOGIC FORMATIONS OF PIKE COUNTY GAS FIELD
(After Worthen)

	Feet
Pleistocene: Loess and drift	0–100
Pennsylvanian	20–60
Mississippian:	
St. Louis limestone	0–30
Keokuk group (limestone and shale)	100–125
Burlington limestone	150–200
Kinderhook group (mainly shale)	100–120
Niagara limestone	0–50

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——— Petroleum in Illinois in 1914 and 1915. Illinois Geol. Survey *Bull.* 33, pp. 71-90, 1915.

——— Petroleum in Illinois in 1914 and 1915. Illinois Geol. Survey *Bull.* 33, pp. 71-90, 1916.

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——— Oil and Gas in the Vincennes Quadrangle. Illinois Geol. Survey *Bull.* 33, pp. 147-175, 1916.

SHAW, E. W.: The Carlyle Oil Field and Surrounding Territory. Illinois Geol. Survey *Bull.* 20, pp. 43-80, 1915.

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UDDEN, JON: Coal Deposits and Possible Oil Fields Near Duquoin. Illinois Geol. Survey *Bull.* 14, pp. 254-262, 1909.

WELLER, STUART: Anticlinal Structure in Randolph County. Illinois Geol. Survey *Bull.* 31, pp. 69-70, 1915.

CHAPTER XVII

MID-CONTINENT FIELDS

1500 000 bbls per day

General Features.—The Mid-Continent oil fields include the oil-producing areas of Oklahoma, Kansas, and Missouri, the gas-producing region of Arkansas, and the fields of northern and central Texas and northern Louisiana. The principal producing areas are in Kansas, Oklahoma, and northern Texas and Louisiana. In these fields oil is found mainly in Carboniferous and Cretaceous strata. In the principal fields of Kansas and northern Oklahoma the sand members associated with Cherokee shales produce nearly all the oil. In southern Oklahoma and northern Texas near Red River oil is obtained from sandstones of the Pennsylvanian and from sandstones that are correlated with the Permian (Red Beds) by some investigators and with the upper Pennsylvanian by others. These beds produce gas and oil in the Healdton and neighboring districts. In the Ranger region, northern Texas, oil is found in the Bend series (Mississippian). In east central Texas and northern Louisiana oil is found in Cretaceous sandstones and chalks.

In the Mid-Continent fields oil and gas occur on domes, anticlines, structural noses, structural terraces, and fluted monoclines. On the whole the structural features are somewhat less accentuated than those in the Appalachian oil fields, and the porous rocks are more generally filled with salt water. The oil saturation is greater than in most other fields, and structural elevations with less than twenty feet of closure are searched for diligently and explored. The major uplifts in this region (Fig. 118) are the Ozark dome, the Ouachita orographic element, including the Ouachita, Arbuckle, and Wichita mountains, the Llano-Burnet uplift of Texas, and the Sabine uplift. Although the Ouachita element is more highly deformed than the Ozark dome, the structure of the Ozark is more far-reaching, for the beds dip westward far away from the Ozark center, and southwestward within a comparatively short distance of the Ouachita element.

The Ozark uplift is a low dome with rudely elliptical outline, lying in southern Missouri, northern Arkansas, southeastern

Kansas, and northeastern Oklahoma. As stated by Siebenthal[1] it is roughly bounded on the north and northeast by Missouri and

FIG. 118.—Sketch map showing geology of region containing Mid-continent oil field. The Pennsylvanian outcrops in the areas shown by dots, widely spaced. There are small outcrops of Silurian and Devonian rocks in the Ozark region. These are not shown in the sketch. The igneous rocks which are in the areas represented by small crosses, are older than the sedimentary rocks.

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[1] SIEBENTHAL, C. E.: Origin of the Zinc and Lead Deposits of the Joplin Region, Missouri, Kansas, and Oklahoma. U. S. Geol. Survey *Bull.* 606, p. 23, 1915.

Mississippi Rivers, on the west by Spring and Neosho (Grand) Rivers, on the west and south by Arkansas River, and on the southeast by Black River and some of its tributaries. The uplift as a whole is a table-land bounded by long, low northern and western slopes whose inclination is generally imperceptible to the eye, and for much of its extent by an abrupt southern slope facing the open valley of Arkansas River. Near and parallel to its southern margin the uplift culminates topographically in the Boston Mountains, a long, narrow plateau rising to an elevation of 2,000 feet. The plains that surround the uplift have a general altitude of 500 to 750 feet. The central portion of the Ozarks is an upland lying somewhat below the crest of the Boston Mountains.

The Ozark uplift is a broad anticline in which the strata have no perceptible inclination except at the southern margin, where the Boston Mountains break off into a southward-dipping monocline. Superimposed upon the uplift are quaquaversal domes, of which the principal one is in the region of the St. Francis Mountains.

In the early history of the Ozark region parts of the crystalline rocks of the St. Francis Mountains were islands in an archipelago, and their erosion furnished the material that formed the Cambrian and Ordovician sandstones, and which, with that which formed the associated dolomitic limestones, was spread out over Missouri and the adjacent States. Silurian limestones and shales were deposited on the southern and northeastern margins of the Ozark region, but in the western part of the region there was no Silurian sedimentation. During Devonian time limestone was deposited on the northern and eastern borders of the region and sandstone on the southern border. The Chattanooga shale of the Devonian series underlies a triangular area in northwestern Arkansas, southwestern Missouri, and northeastern Oklahoma. After the Devonian period the Ozark region was submerged and the Mississippian limestones were laid down probably over the whole area. Elevation and erosion followed, during which the limestone land surface developed a sinkhole topography. This land was in turn submerged and upon its irregular, bouldery, cherty surface was laid down a series of shales and sandstones of Pennsylvanian age, the lowest series being the Cherokee shale, which contains the principal oil sands of Kansas and Oklahoma. Until the end of Pennsylvanian time the crystalline area of the St. Francis Mountains was the stratigraphic nucleus of the Ozark region. At the end of the

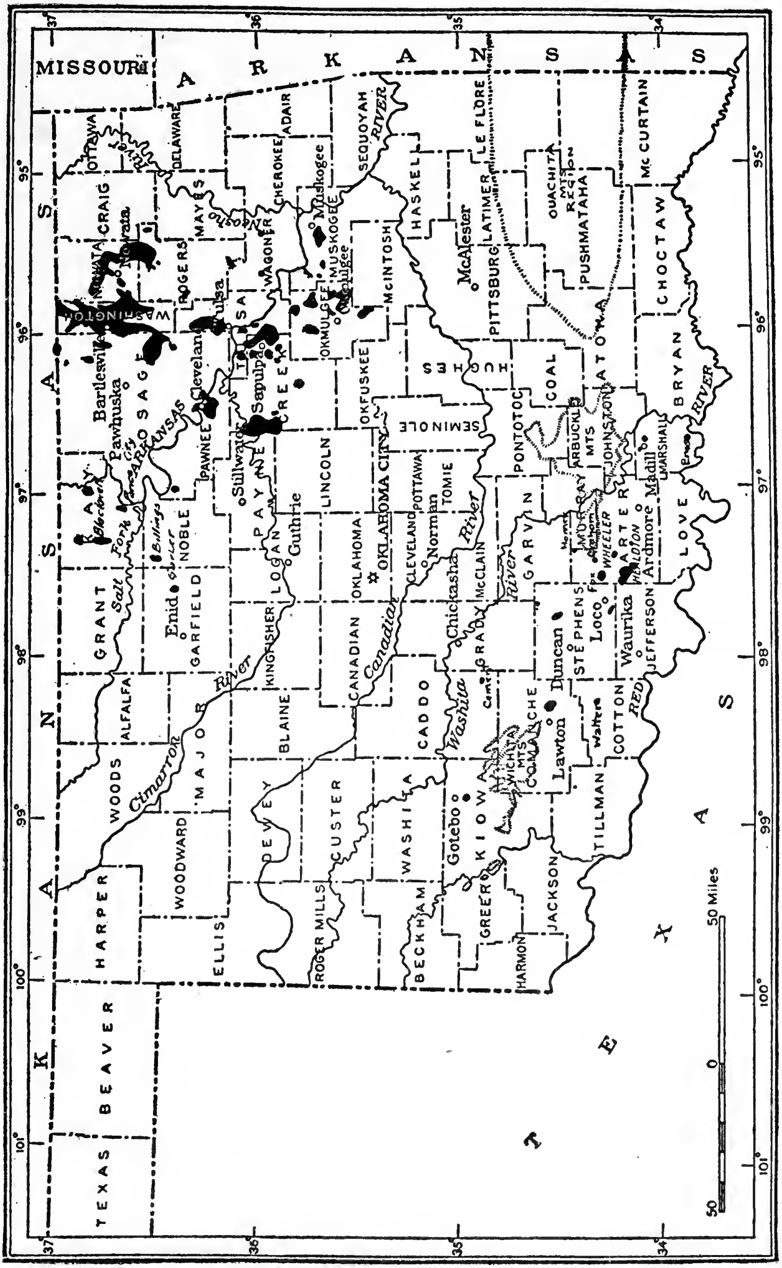

Fig. 119.—Index map of Oklahoma, showing mountain areas and certain oil fields.

Carboniferous period the Ozark region was raised almost to its present position, the highest place coinciding closely with the geographic center. The uplifted area has since been subjected to minor warping.[1]

The Ouachita orographic element (Fig. 119) extends from east to west through western Arkansas and southern Oklahoma for a distance of 350 miles. This element may be subdivided into the Ouachita Mountains, the Arbuckle Mountains, and Wichita Mountains. None of these mountains are very high—indeed, the Boston Mountains, which lie north of and parallel to the Ouachita Mountains on the Ozark-monocline are higher than any part of the Ouachita element or the Missouri Ozarks. The Ouachita element is, however, a center of close folding and is topographically for the most part a plateau rather than a mountain range. It represents the eroded remnant or roots of what was once probably a continuous lofty range.

The Ouachita Mountains of Arkansas and eastern Oklahoma are joined to the Arbuckle Mountains of Oklahoma by a broad area of folded rocks, and the two mountainous regions form structurally a single feature. In the Ouachita Mountains Paleozoic sediments, including those as late as Mississippian, are highly deformed. In Arkansas[2] they are closely folded and in places overturned. In eastern Oklahoma[3] they are folded and also profoundly faulted. The Arbuckle Mountains, in their eastern part, where they coalesce with the plain, are only about 750 feet above the sea, but their elevation increases westward to 1,300 feet. The structural trend is about N. 70° W.

The Arbuckle Mountain region contians a thick series of rocks, chiefly limestones, which range from Middle Cambrian to Devonian. These are succeeded on the borders by an almost equal thickness of Carboniferous conglomerates, shales, and sandstones. In the central part of the district, unconformably beneath the Cambrian strata, there is a mass of granite, granite porphyry, diabase, and associated crystalline rocks. Most of uplifting and folding of the region occurred before the deposition of the Permian

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[1] SIEBENTHAL, C. E.: *Op. cit.*, pp. 11-12.

[2] SIMONDS, F. W., and BRANNER, J. C.: Arkansas Geol. Survey *Rept. for* 1888, vol. 4, p. xiii, 1891.

[3] TAFF, J. A.: U. S. Geol. Survey *Geol. Atlas*, Coalgate folio (No. 74), 1901.

Red Beds, which were laid down across its western part, but in places the Red Beds themselves are distinctly folded.

About 60 miles to the northwest are the Wichita Mountains, which are physiographically in marked contrast to the Arbuckle plateau, being composed of a range of rugged mountains and straggling peaks and hills, standing in a level plain. The Wichita uplift trends N. 70° W. approximately in the same direction as the Arbuckle uplift. It consists of a central mass of igneous rocks, which is partly surrounded, unconformably, by a thick section of Cambrian and Ordovician sandstone and limestone. The stratigraphy is essentially similar to that of the Arbuckle uplift.[1] The Cambrian and Ordovician strata, approximately 6,000 feet thick, bear no evidence that they were either folded or uplifted into land at any time during their deposition. The main Arbuckle uplift began near the middle and culminated near the end of Pennsylvanian time, prior to the deposition of the Red Beds. The Red Beds are only gently folded between the Arbuckle and Wichita Mountains.

The Criner Hills, which lie 15 miles south of the Arbuckle Mountains, consist of a faulted block of Paleozoic strata about 7 miles long, which trends northwest. Structurally they are similar to the Arbuckle Mountains and they include the same Paleozoic strata. As stated by Taff,[2] they are the Arbuckle Mountains in miniature.

Briefly stated the deformation of the Ouachita-Arbuckle-Wichita region has taken place during three periods. These are (1) Pre Pennsylvanian, (2) Post Pennsylvanian, and (3) Post Permian· In the Arbuckle region the major folding was Pre Pennsylvanian,[3] although in the Ardmore district south of the Arbuckles, the Pennsylvanian rocks are highly tilted. North of the Arbuckles also they are rather closely folded. There are also considerable deformation of the Ouachita Mountains in Post Pennsylvanian time.

Since Permian and also since Cretaceous time, minor warpings have taken place in the Mid-Continent fields, for strata of both Pennsylvanian and Cretaceous age are folded. Dips as great as

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[1] Taff, J. A.: Preliminary Report on the Geology of the Arbuckle and Wichita Mountains. U. S. Geol. Survey *Prof. Paper* 31, p. 11, 1904.

[2] Taff, J. A.: *Op. cit.*, pp. 47-50.

[3] Fuller, M. L.: Carbon Ratios in Carboniferous Coals of Oklahoma and Their Relations to Petroleum. *Econ. Geology*, vol. 15, pp. 187-224, 1920.

5° have been noted on the limestones. In Cotton County, southeast of Healdton, Oklahoma, according to Wegemann,[1] the adjustment of minor streams to folds is very exact, and it is possible that movements have continued till comparatively recent times.

The Llano-Burnet region of central Texas lies on the broad coastal slope that extends from the Cordillera to the Gulf of Mexico.[2] In this region erosion has exposed rocks of pre-Cambrian and Paleozoic age within and about the rim of an oval topographic basin which is nearly surrounded by Cretaceous rocks. The Llano-Burnet region is a structural uplift. It exhibits the remnants of an ancient mountain range that has been eroded. The influence of this uplift is reflected by the rock structure far to the north of the Llano-Burnet region.

The rocks of the Llano-Burnet region fall into three subdivisions —(1) pre-Cambrian schists, gneisses, and granites; (2) Paleozoic sandstones, limestones, and shales; and (3) Cretaceous sandstones, clays, and limestones. The Paleozoic strata, which completely surround the pre-Cambrian area, are folded and faulted and are separated from the pre-Cambrian by an unconformity representing a great time interval. The Cretaceous formations are nearly flat. They are separated from the Paleozoic rocks by a great erosional unconformity.

The Llano-Burnet region has been one of elevation and erosion through long geologic periods. The pre-Cambrian rocks were eroded almost to base-level, and on them were deposited Cambrian and Ordovician rocks. The Silurian, Devonian, Jurassic, and Triassic are lacking, showing probably that during much of Paleozoic time the region was above the sea. Near the end of the Paleozoic era and before the Mesozoic rocks were deposited, folding and faulting took place on a considerable scale. The Mesozoic rocks, which lie on the Paleozoic strata, are generally nearly horizontal in the Llano-Burnet region.

The Mid-Continent fields produce oil of high gravity as is shown by the following analyses:

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[1] Wegemann, C. H.: Anticlinal Structure in Parts of Cotton and Jefferson Counties, Oklahoma. U. S. Geol. Survey *Bull.* 602, p. 34, 1915.

[2] Paige, Sidney: Mineral Resources of the Llano-Burnet Region, Texas. U. S. Geol. Survey *Bull.* 450, 1911. See also U. S. Geol. Survey *Geol. Atlas*, folio (No. 183), 1912.

Hill, R. T.: Physical Geography of the Texas Region. U. S. Geol. Survey *Topographic* folio (No. 3), 1900.

ANALYSES OF OILS OF MID-CONTINENT FIELDS[a]

Field	Baumé Gravity	Gasoline, Benzine, Naphtha, Kerosene, 0–300° C. (Per Cent)	Lubricating Oil and Residuum (Per Cent)
KANSAS			
Chanute	23.1	39.5	57.2
Paola	34.5	43	55.8
Augusta	38.3	53.6	46
OKLAHOMA			
Muskogee	38.1	46	52.8
Cushing	40.9	66	30
Bird Creek	34.8	45.5	52.8
Glenn Pool	35.5	50.5	49.9
Healdton	30.3	42	52.9
TEXAS			
Petrolia (deep)	44.9	35	65
Petrolia (shallow)	39.5	19	81
Electra (deep)	42	28.5	71.5
Electra (shallow)	40.8	25	75
Corsicana (light)	36.3	50	50
Corsicana (heavy)	25.9	55 (kerosene)	45
Thrall	38.4	55	45
Strawn	36.3	51	49
LOUISIANA			
Caddo	41	58	40.4
Crichton	39.8	67	33

[a] GARDNER, J. H.: The Mid-Continent Oil Fields. Geol. Soc. America *Bull.*, vol. 28, p. 719, 1917.

In general the crude petroleum of Kansas and Oklahoma is dark green by reflected light, brownish by transmitted light, and has a Baumé gravity of about 34°. Muskogee furnishes oils that are yellowish green in reflected light or bright wine-colored in transmitted light and run as high as 38° Baumé. The Madill yields an oil that has a dark olive color in reflected light or dark wine color in transmitted light and runs as high as 47.5° Baumé. From Garber and Ingalls are obtained green oils of 43° Baumé. Petroleum of slightly inferior grade comes from the Healdton field. It is a very dark oil, with an average Baumé gravity of about 30°, and runs somewhat low in its content of light distillates. Petroleums from the deeper sands, as at Cushing and Blackwell, Oklahoma, or at Augusta, Kansas, average between 35° and 40° Baumé and run relatively high in gasoline and other light products. Petroleums from the Petrolia and Electra fields, Texas, have a dark-brown color in reflected light, and range from 39° to 45° Baumé but are not so high in many of the light distillates as petroleums from Kansas and Oklahoma. Petroleum from the Thrall field of Texas is rather light in gravity and has a brownish color somewhat similar to that of the better grades at Corsicana and Moran, Texas, or at Caddo, Louisiana. Local areas in Texas, as, for instance, the Brownwood district, furnish petroleum running low in gravity and high in lubricating constituents, resembling in this respect oil from the Healdton field, although of lower gravity.

Although the Mid-Continent petroleums are rarely free from asphalt, this constituent is present in very small quantity, ranging from practically nothing to 5 per cent.[1]

NORTHEASTERN OKLAHOMA, SOUTHEASTERN KANSAS, ARKANSAS, AND MISSOURI

General Statement.—The northeastern Oklahoma and southeastern Kansas fields are treated as a structural and stratigraphic unit. East of the area which includes them, extending from northern Missouri almost to Muskogee, Oklahoma, are found Mississippian and older rocks. From Muskogee County, east and southwest to the Arbuckle Mountains is an area containing many gas fields, of which it is said that any oil present may have been vaporized or scattered by metamorphism attending the faulting of the Ouachita element (Fig. 76, p. 176). West of this area in Oklahoma and Kansas the petroliferous rocks are covered by Permian beds, and in that direction limits to the oil fields can not be set. On account of the great depth of the oil sands, the character of the Permian beds, and the smaller amount of folding of the Permian, the structure is difficult to interpret, and development is not rapid.

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[1] GARDNER, J. H.: *Op. cit.*, p. 718.

Nevertheless the field is being slowly and laboriously extended westward. In northeastern Kansas Pennsylvanian rocks are found, but the territory is not known to be petroliferous.

The rocks that crop out in the area are Pennsylvanian and lower Permian. The beds strike about N10°-20° E. and dip west about 30 feet to the mile. Locally the dip increases, and on folds it becomes 100 feet to the mile or more. Reverse dips are rarely more than 1°. Faulting is common east, southeast, and south of the district. Faults are not rare in the Oklahoma portion of the oil-bearing area also, but as a rule the displacement of the faults is very small. On the whole deformation in the region is not intense.

The oil and gas are found in sands and very subordinately in thin-bedded porous limestones. Most of the productive sands are in the Cherokee shale series, above the Mississippian. Recently some oil has been found in the Mississippian limestone and in sands below it. The shales of the Cherokee are generally dark colored or black and carry bands of highly bituminous material.

The Bartlesville sand is by far the most productive, having supplied 90 per cent or more[1] of the oil produced in Oklahoma and Kansas up to 1919. It is a gray to brown sandstone, containing usually a small amount of lime carbonate, enough to effervesce in acid. In the Bartlesville region it is from 30 to 60 feet thick. It has an average porosity of 20 per cent. The thickest sands do not contain oil in large quantities. McCoy[2] states that the pay sands where thickest show many partings of black shale.

Oil and gas seeps are very rare in this area, and at most pools they are lacking. East of the oil-bearing region, however, in southeastern Kansas, southwestern Missouri, and northeastern Oklahoma, the Cherokee is marked at many places by asphalt bodies or oil seeps. Salt water is generally associated with the oil.

The Permian beds contain gas on the Blackwell anticline,[3] on the Garber dome, and on the Billings anticline. In the area where the Permian crops out the Pennsylvanian carries oil near the top.

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[1] Gardner, J. H.: Mid-Continent Geology. *Oil and Gas Journal Suppl.*, May 30, 1919.

[2] McCoy, A. W.: Notes on Principles of Oil Accumulation. *Jour. Geology,* vol. 27, p. 252, 1919.

[3] Gardner, J. H.: Mid-Continent Oil Fields. Geol. Soc. America *Bull.* vol. 28, p. 699, 1917.

Oil residues are found in Oklahoma in Ordovician, Carboniferous and Cretaceous rocks.

The location of the fields in Oklahoma is shown by Fig. 120.

In the northeastern Oklahoma and southeastern Kansas field the larger number of oil and gas bearing districts are on low domes or low anticlines, although a considerable number are on terraces. At least four are developed in lenses. Some of the productive folds are isolated structural features with clearly defined boundaries, like the domes of the Cushing field, Garber, and many others. Other fields are located on zones of gentle crumpling, like the Bartlesville area in Osage County and the areas in Washington County, to the east of it. Although these folds are gentle, many of them are easily recognized on account of numerous exposures. In many of the districts there is an abundance of salt water under strong pressure. In such districts the oil and gas lie above the water. Where the sands lie deep, segregation is more pronounced.

OKLAHOMA

Salient Features.—Oklahoma has produced a much greater proportion of the oil recovered from the Oklahoma-Kansas field than Kansas. The production in Oklahoma has come mainly from Nowata, Washington, Osage, Kay, Rogers, Tulsa, Pawnee, Garfield, Wagoner, Creek, Muskogee, and Okmulgee Counties. In the eastern part of the field the oil is obtained from shallower wells than in the western part, where the Cherokee series lies below great thicknesses of Pennsylvanian or of Pennsylvanian and Permian strata. In the eastern part of the field the pools are not all related to clearly defined folds, although production is generally controlled by slight crumples of the strata, by terraces, and by warpings. In this part of the field the regional dip of the Cherokee is considerably lower than it is in the western part. In Osage, Washington, and Nowata Counties, which lie along the northern boundary of Oklahoma, the dip is much less than it is in counties to the south and west. Apparently the oil traveled up the gradually flattening dip of the beds, and much of it lodged near tops of very gentle folds and local terraces, where the flattening beds checked migration. In the steeper part of the monocline, in Kay, Garfield, Noble, Creek, and Pawnee Counties, the greater concentrations are in clean-cut anticlines or on definitely closed folds that are

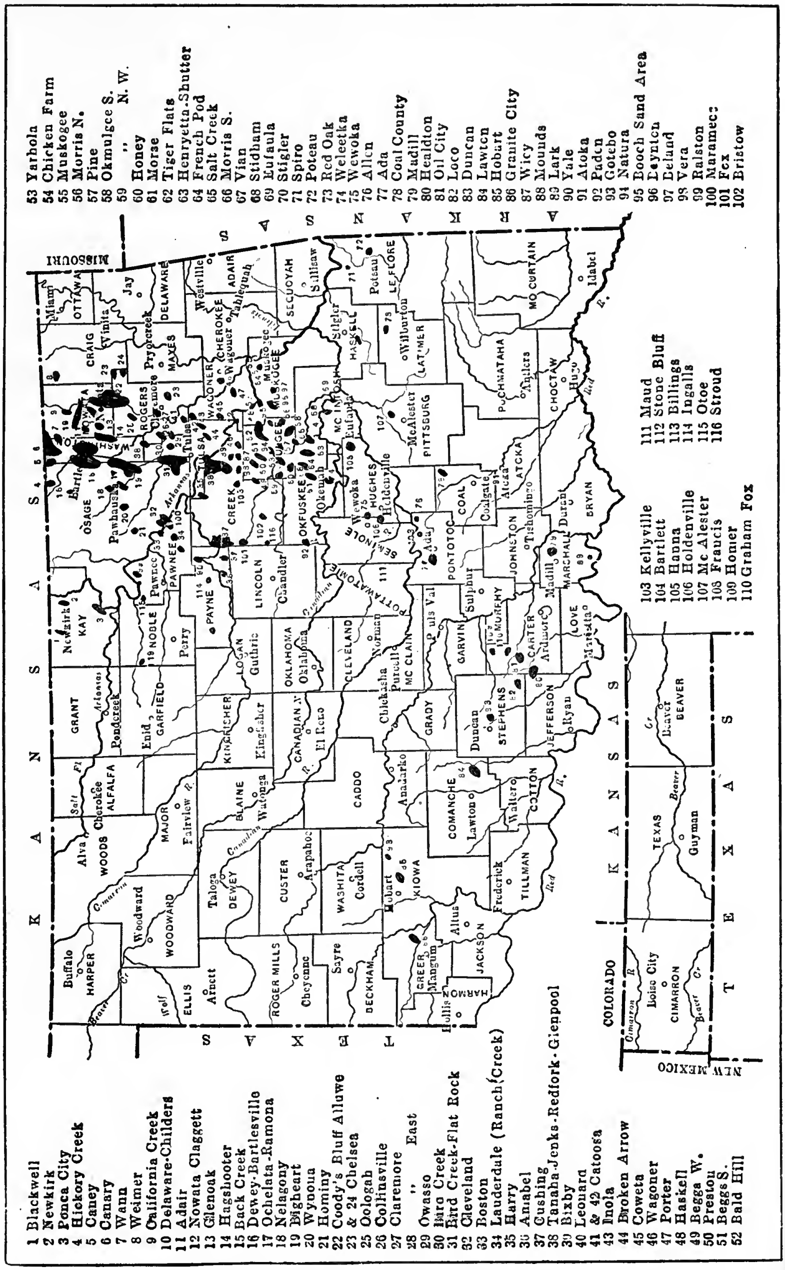

FIG. 120.—Index map showing principal oil and gas fields in Oklahoma. (*Data from Shannon, and others.*)

superimposed upon the great monocline. Noteworthy among these features are the Cushing, Garber, and Ponca City folds.

McCoy[1] states that pools which are not on anticlines or domes show a close relation to faults. Many of these faults do not crop out but are revealed by comparison of drill records. Some of the accumulations of oil appear to occur where sands are sealed by being faulted against shales.

The Cherokee formation, the principal oil and gas producing member of the Pennsylvanian series in Kansas and northeastern Oklahoma, contains the Squirrel, Skinner, Red Fork, Nemire, Bartlesville, Tucker, Dutcher, and other sands. In some districts five or six sands are productive.

The Cherokee formation in the Belton district, south of Kansas City, Missouri,[2] is about 430 feet thick. In southeastern Kansas[3] it is 450 feet thick. From the Kansas line southward the Cherokee formation gradually increases in thickness, so that it is 1,000 feet thick at Pryor Creek. In Kansas the Cherokee is above the Mississippian limestone and below the Fort Scott limestone, two easily recognized formations. Toward the south these limestones disappear, and correlations are less certain. In the Muskogee quadrangle the Winslow and Boggy formations, 1,500 feet thick, are correlated by Taff with the Cherokee, and in his report on the Coalgate quadrangle he correlated the Atoka, Hartshorn, McAlester, Savanna, and Boggy, which have a thickness of 9,000 feet, with the Cherokee. The formations toward the south are overlapped. The greater thickness of the Cherokee toward the south is due in part to the overlap, some of the beds being older than the Cherokee in Kansas.

The sea in which the Cherokee was deposited was probably supplied by sediments mainly from the Ouachita region, the sediments becoming thicker to the south. That the land mass existed toward the south in Pennsylvanian time is obvious also from the character of the sediments. The great shale and sandstone formations of Oklahoma thin out or decrease in thickness toward the north,

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[1] McCoy, A. W.: Notes on Principles of Oil Accumulation. *Jour. Geology,* 27, p. 262, 1919.

[2] Wilson, M. E.: Oil and Gas Possibilities in the Belton Area. Missouri Bur. Geology and Mines, 1918.

[3] Adams, G. I., Girty, G. H., and White, David: Stratigraphy and Paleontology of the Upper Carboniferous Rocks of the Kansas Section. U. S. Geol. Survey *Bull.* 211, p. 65, 1903

where the section contains thicker and more numerous limestone members and less sand and shale.

The Permian beds, which cover large portions of both Kansas and Oklahoma, thicken rapidly toward the west; in Roger Mills County,[1] on the western border of Oklahoma, they are 3,000 feet thick. Between the Arbuckle and Wichita mountains several fields derive oil and gas from beds which some class with the Permian but which others have classified as Pennsylvanian. (See p. 320.)

There are no oil pools in the area of outcropping Mississippian and lower rocks in northeastern Oklahoma, nor in the region of older rocks south of the Choctaw fault. In the area between Fort Smith and Coalgate there is a belt of folded Pennsylvanian strata in which several gas fields are developed but which yield no oil. This condition is due to metamorphism, according to Gardner,[2] who cites as evidence the coals of this belt, which run as high as 70 per cent carbon figured on an ash and moisture free basis.

General Stratigraphic Section in Main Oil and Gas District on Northern Oklahoma

(Compiled from Sections by Taff, Aurin and Gardner, with Economic Notes Mainly from Gardner)

Permian series:

	Feet
1. Unclassified shales, with thin limestone and sandstone members	
2. Herington limestone	18–20
3. Uncas shale	50
4. Winfield limestone	10–15
5. Doyle shale	22–35
6. Fort Riley limestone and other beds of thin limestone, sandstone, and shale down to the Neva limestone, inclusive.[a] Contains near base the shallow gas sands at Blackwell, Billings, and Garber	500–600
7. Elmdale formation; included in Permian of Kansas by Beede	

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[1] Aurin, Fritz: Geology of the Red Beds of Oklahoma. Oklahoma Geol. Survey *Bull.* 30, 1917.

[2] Gardner, J. H.: The Mid-Continent Oil Fields. Geol. Soc. America *Bull.*, vol. 28, p. 699, 1916.

[a] Beal places the base of the Permian in the Cushing field 50 feet above the top of the Neva limestone.

Pennsylvanian series:	
Ralston group: Limestones and shale beds of Kansas section from Americus limestone to Lecompton limestone, inclusive. In Oklahoma consists of red and gray sandstone, red shale, and thin limestones. Contains the Garber oil sand.	
1. Upper division down to Pawhuska limestone, inclusive	650
2. Lower division down to top of Elgin sandstone	140
Sapulpa group:	
1. Elgin sandstone. Probable horizon of shallow oil sand in the Newkirk field and at Ponca City	20–150
2. Oread limestone	0–20
3. Buxton sandstone and shale. Horizon of main oil sand at Ponca City and gas sand at Myers	700–1,000
4. Avant limestone	0–10
5. Ramona formation. Sandstone, shale, and thin limestone beds. Includes Lost City limestone and Musselman oil sands of the Cushing and Cleveland areas	300–400
6. Dewey limestone	15–25
7 Skiatook formation; sandstone, shale, and thin limestone beds. Includes Hogshooter limestone and Layton oil sand	350–400
8. Lenapah limestone	10–20
Tulsa group:	
1. Nowata shale; includes Wayside oil sand	75–150
2. Oolagah limestone or Big lime of the drillers	20–50
3. Labette shale (local coal bed, Dawson coal)	75–100
4. Claremore formation. Sandstone, shale, and beds of thin limestone. Contains at the base the Fort Scott or Oswego limestone. Includes Cleveland and Peru oil sands	275–350
Muskogee group: Beds of shale, sandstone, and thin limestone correlated with the Cherokee shale (Boggy and Winslow formations at Muskogee). Includes the main oil sands of Oklahoma; the Red Fork, Bartlesville (Glenn), Tucker, Taneha, Booch, Morris, and Muskogee sands, the Muskogee lying at the unconformable base of the Pennsylvanian series.	450–1,500
Unconformity	
Mississippian series:	
1. Morrow limestone[a]	100–200
Unconformity.	
2. Pitkin limestone	40–60

[a] Smith places the Morrow in the Glenn pool above the Mississippian. (See p. 293.)

3. Fayetteville formation; sandstone, shale, and limestone. Contains the Mounds oil sand and a deep sand near Sapulpa	20–200
Unconformity.	
4. Boone formation; massive white limestone and massive beds of chert	200–400
Devonian system:	
1. Chattanooga formation; black fissile shale	30–50
2. Sylamore sandstone; clear quartz sandstone	0–25
Unconformity.	
Ordovician system:	
1. Tyner formation; thin sandstone and limestone in shale	60–100
2. Burgen (St. Peter) sandstone; massive quartz sandstone	5–100
Cambrian system:	
Massive limestone beds shown in Harrington well at Joplin, Missouri	1,165

From Muskogee southward the lower portion of the Pennsylvanian series and the older rocks thicken at the rate of about 100 feet to the mile. The following is the general section for the McAlester-Coalgate-Atoka region:

General Stratigraphic Section in Eastern Oklahoma, North of Arbuckle Mountains

(After Sections by Taff[a] and Gardner[b])

Lower portion of Pennsylvanian:	Feet
1. Seminole conglomerate	1–50+
2. Holdenville shale	260
3. Wewoka formation. Sandstone and shale with beds of thin limestone	500–800
4. Wetumka shale	120
5. Calvin sandstone. Approximate horizon of Oswego limestone in northern area	140–240
6. Senora sandstone	140–485
7. Stuart shale	90–280
8. Thurman sandstone	90–280
9. Boggy shale, with beds of thin sandstone; limestone and thin irregular coal at base	2,000–2,600

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[a] Taff, J. H.: U. S. Geol. Survey *Geol. Atlas*, Coalgate folio (No. 74), 1901.

[b] Gardner, J. H.: Mid-Continent Oil Fields. Geol. Soc. America *Bull.*, vol. 28, p. 696, 1917.

10. Savanna sandstone; massive sandstone strata with beds of shale (horizon of Bartlesville sand)	1,000
11. McAlester shale. Includes strata of sandstone. Coal beds of the McAlester-Coalgate region (Oklahoma coal field)	1,800–2,000
12. Hartshorn sandstone	150
13. Atoka formation. Massive beds of sandstone with alternating beds of shale	3,100
14. Wapanucka limestone	100
Mississippian series: Caney shale	1,500
Devonian system: Woodford chert	600
Ordovician and Silurian systems: Sandstone, shale, and limestone	5,000–7,000
Cambrian system: Reagan sandstone	100
Unconformity.	
Pre-Cambrian granites.	

Cushing Pool.—The Cushing[1] oil pool is mainly in western Creek County but extends westward into Payne County. The field includes a number of subdivisions, among them Shamrock, Drumright, Dropright, and Mount Pleasant. The first well in this field was drilled in 1912 by C. B. Shaffer on the Jones farm, about 1 mile north of Drumright. The development was rapid, especially after the discovery of oil and gas in the Bartlesville sand. The production of the field reached about 300,000 barrels of oil a day, and at one time about 160,000 barrels of oil was produced daily by 160 wells from the Bartlesville sand alone.

The following table gives the geologic formations of the Pennsylvanian series as reported by Buttram in the vicinity of the Cushing field—the youngest at the top:

Neva limestone.
Sandstones and shales and thin limestones (556.5 feet).
Pawhuska limestone (provisional correlation). Is 2,340 feet above Fort Scott limestone and 1,243 to 1,262 feet above Lost City limestone.
Shales and sandstones (134 feet).
Elgin sandstone.

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[1] Buttram, Frank: The Cushing Oil and Gas Field, Oklahoma. Oklahoma Geol. Survey *Bull.* 18, pp. 1-60, 1914.

Beal, C. H.: Geologic Structure in the Cushing Oil and Gas Field, Oklahoma, and Its Relation to the Oil, Gas, and Water. U. S. Geol. Survey *Bull.* 658, 1917.

Interval.
Lost City limestone.
Interval (1,078 to 1,097 feet). Includes Layton sand at 700 to 810 feet above Wheeler sand.
Fort Scott or Oswego limestones (75 feet) (= Wheeler sand).
Interval.
Bartlesville sand (in Cherokee shale.)

The most prominent outcropping stratum is a bed of limestone that is probably in part at least equivalent to the Pawhuska limestone of northern Oklahoma.

Oil is produced from six sands, the Layton, Jones, Wheeler, Skinner, Bartlesville, and Tucker. A sketch of the field is shown in Fig. 121 and a section in Fig. 122.

The dominant structural feature in the Cushing field, as stated by Beal, is a broad north-south anticlinal fold (Fig. 123) with domes along its axis and many subsidiary folds and irregularities along its sides. This great fold is one of the largest structural features in northern Oklahoma. The contours of the three oil sands differ locally from the contours of the surface rocks, although the general structural axes are practically identical. Each sand in the field exhibits small irregularities that apparently bear no definite vertical relations to one another—for example, the Bartles-

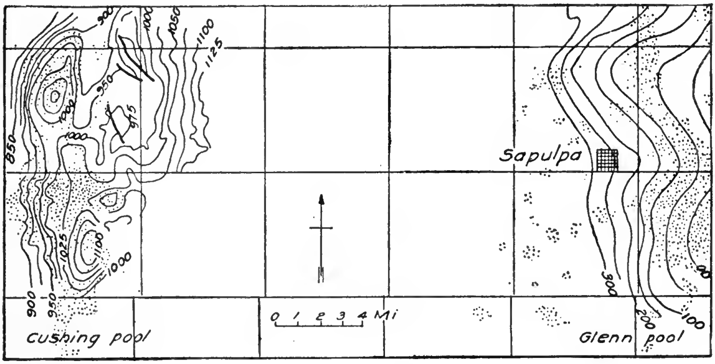

FIG. 121.—Sketch showing structure in Cushing Pool, Oklahoma (*after Beal*) and in Glenn Pool, Oklahoma (*after Smith.*) Contours show elevation of Pawhuska limestone above sea in Cushing Pool and of Fort Scott or Oswego limestone below sea in western part of the Glenn pool. Dots represent oil wells. Some scattered wells are not shown.

ELEVATION IN FEET OF HIGHEST CONTOUR ON CRESTS OF FOUR FOLDS IN THE SURFACE BED, THE LAYTON SAND, THE WHEELER SAND, AND THE BARTLESVILLE SAND, AND THE DIP IN DIFFERENT DIRECTIONS FROM THE CRESTS

(After Beal; +, Above Sea Level; –, Below Sea Level)

	Dropright Dome				Shamrock Dome		
		Amount of Dip				Amount of Dip	
	Elevation of Crest	2½ Miles Northeast of Crest Along Anticline	1½ Miles West of Crest	¾ Mile East of Crest	Elevation of Crest	1½ Miles West of Crest	¾ Mile East of Crest
Surface beds....	+1,050	100	150	125	+1,125	135	60
Layton sand....	– 400	225	175	[a]250	– 325	325	250
Wheeler sand....	–1,075	225	200	[a]350	–1,150	175	200
Bartlesville sand.	–1,525	175	200	200	–1,550	325	250

	Mount Pleasant Dome					Anticline in Northern Part of T. 16 N., R. 7 E.	
		Amount of Dip					
	Elevation of Crest	2½ Miles West of Crest	4 Miles West of Crest	¾ Mile Southwest of Crest	¾ Mile Northeast of Crest	Elevation of Crest	Amount of Dip ½ Mile East of Crest
Surface beds....	+1,100	150	225	75	75	+1,050	50
Layton sand....	– 275	300	425	325	325	– 400	75
Wheeler sand....	–1,100	350	475	325	400	–1,325	50
Bartlesville sand.	–1,450	350	[b]475	325	400	–1,700	100

[a] Part of vertical distance estimated.

[b] Part of horizontal and vertical distances estimated.

ville sand may show a small dome that has no counterpart in the Layton and Wheeler sands.

The distribution of oil and gas in the sands indicates that the source or gathering ground of the oil and gas was west or northwest of the field. The direction they took may be due in part to the fact that the dominant structural feature is an anticline on a great monocline, the fold having a short east limb and a long west limb. The gathering area is therefore practically all on the west limb. Gas first fills up the crest of the fold and acts as a barrier between the water on the east side and the oil migrating up the west limb. The oil, on account of its slower rate of movement through porous rocks, collects after the gas and forms a pool against the gas on the west or long limb. (See Fig. 123.) Below the oil is salt water. The plane between the two is not level, however, but in some sands the water surfaces on which the oil and gas rest are inclined and dip away from centers of anticlinal folds.

In the Cushing field proper there is very little

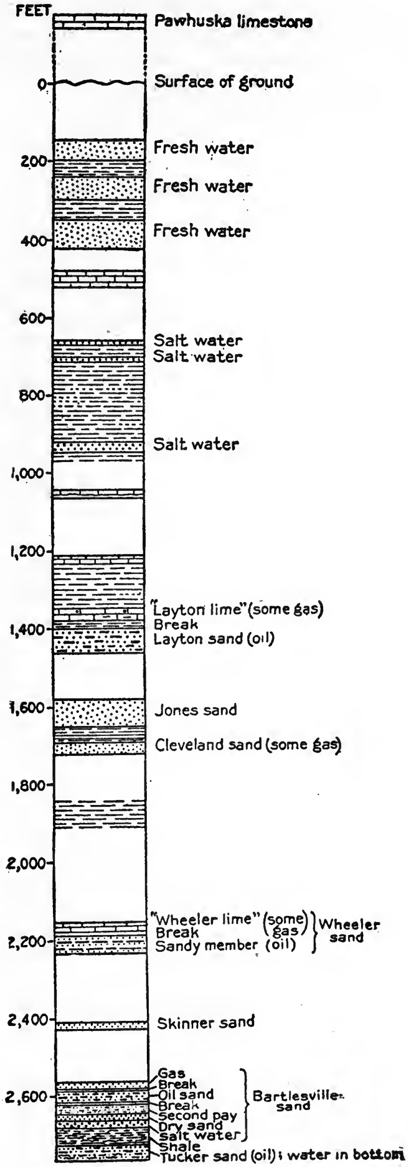

Fig. 122.—Generalized geologic section showing the positions of oil and gas sands in Cushing field, Oklahoma. (*After Beal.*)

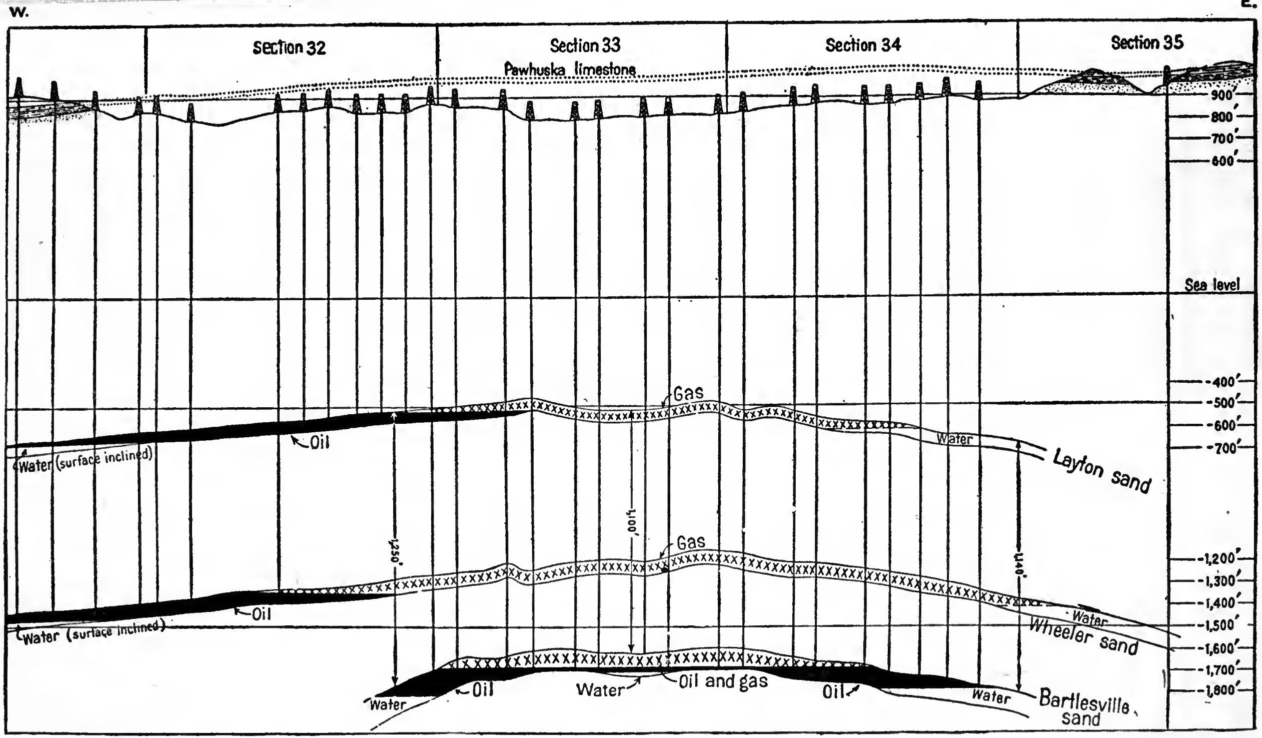

FIG. 123.—Section along south line of T. 18 N., R. 7 E., through the Drumright dome, Cushing field, Oklahoma, showing the stratigraphic relations of the Pawhuska limestone and the Layton, Wheeler and Bartlesville sands, the increase in the Layton-Bartlesville interval and the inclination of the water-oil surfaces. (*After Beal, U. S. Geol. Survey.*)

faulting. In the Bristow quadrangle, however, which lies to the southeast, there are many northwest faults.[1]

Glenn Pool.—The Glenn pool[2], which is southwest of Tulsa and about 30 miles east of the Cushing pool, is one of the most productive of the Mid-Continent field. It includes several minor pools known as the Taneha, Red Fork, and Perryman. The pool was discovered in 1906.

The westward dip of the strata, which is about 50 feet to the mile, is interrupted by areas in which the formations lie flat or nearly so, whereas in other areas the dip is greater than normal. The structure is complicated also by a system of folds whose axes roughly parallel the direction of general dip—slightly north of west. These folds are not well defined but are westward-plunging flutings. which merge

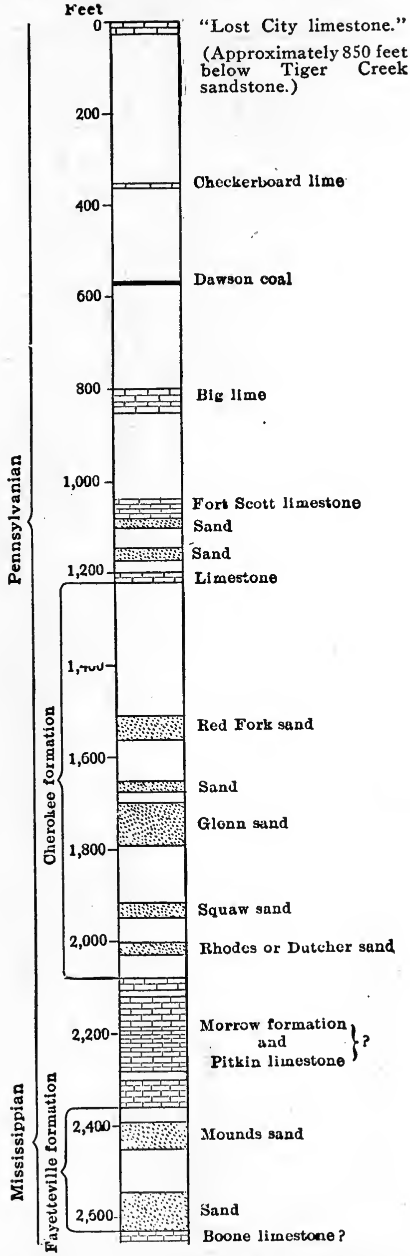

FIG. 124.—Composite skeleton section of the Glenn pool region, Oklahoma. (*After Smith.*)

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[1] FATH, A. E.: Structure of the Northern Part of the Bristow Quadrangle, Creek County, Oklahoma, with Reference to Petroleum and Natural Gas. U. S. Geol. Survey *Bull.* 661, pp. 69-99, 1918.

[2] SMITH, C. D.: The Glenn Oil and Gas Pool and Vicinity, Oklahoma. U. S. Geol. Survey *Bull.* 541, pp. 34-48, 1912.

both to the east and west with the prevailing westward-dipping monocline.

The oil and gas occur in the several sands mentioned below, the field extending westward down the monoclinal dip. Where the strata are fluted on the monocline the wells are closely spaced on the minor warpings of the strata. Both upward and downward flutings carry oil. The monocline is believed to be sealed possibly by tighter sands above the productive portion of the field, or by shales coming together where sands play out.

SECTION SHOWING FORMATIONS EXPOSED IN AND TO THE EAST OF THE GLENN POOL AREA, OKLAHOMA

(After Smith)

Carboniferous system:	
Pennsylvanian series:	Feet
Limestone, bluish gray; locally known as the Lost City limestone	1–40
Shale and sandstone	350
Limestone, bluish, hard; Checkerboard lime of the drillers	2½
Shale, with variable beds of sandstone	215
Coal, Dawson	1⅔–2½
Shale, with irregular beds of sandstone	210–350
Limestone, massive, gray; Big lime of drillers	0–40
Shale, with irregular beds of sandstone	200 ±
Limestone, Fort Scott; Oswego lime of drillers; bluish-gray limestone with 3 to 5 feet of shale near middle	10–30
Shale, sandstone, limestone, and coal; Cherokee formation	1,000 ±
Unconformity.	
Blue to white limestone, with some shale and thin sandstone; Morrow formation	100–120
Unconformity.	
Mississippian series:	
Limestone, blue and brown, locally sandy and shaly; Pitkin	60 ±
Black shale with thin beds of limestone and sandstone; Fayetteville formation	20–60
Unconformity.	
Limestone, Boone; flinty limestone and flint	200 ±

The strata between the top of the Morrow and the top of the Boone merge into one formation in the southeast corner of Kansas, thus eliminating the Fayetteville, the Pitkin, and possibly the Morrow from the section, so that the Cherokee rests on the eroded surface of the Boone. The same conditions exist along the ninety-sixth meridian, where well logs do not show these three formations more than a few miles north of the latitude of Tulsa. Southward from Tulsa the limestone beds in the Morrow and Pitkin probably become thicker and are likely to be mistaken for the Boone limestone. Sandstone beds occur at the top of the Morrow and the top of the Boone. The geologic section is shown as Fig. 124, and a structural map as Fig. 125. A section across the field is shown as Fig. 126.

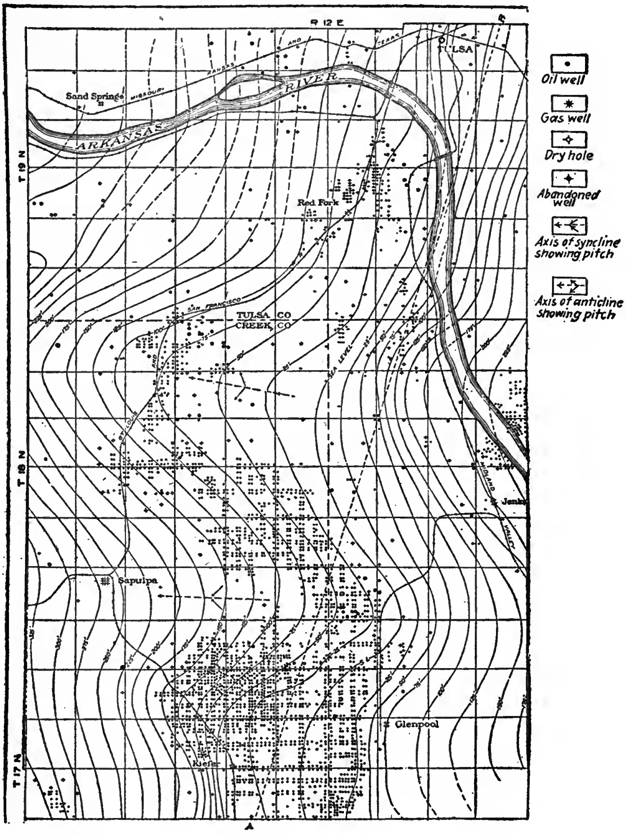

FIG. 125.—Structural map of Glenn oil and gas pool near Tulsa, Oklahoma. (*After Smith.*) The beds dip west. The structural contours show position of the surface of the Fort Scott or Oswego limestone, with reference to sea level. For section along *AB* see Fig. 126.

Bristow Quadrangle.—The Bristow[1] quadrangle, in Creek County, is bordered by some of the most prolific oil fields of Oklahoma. The nearest wells of the east Cushing field are only about 1½ miles west of the Bristow quadrangle. About 9 miles east of the quadrangle is the Glenn pool, and in the area that lies between the Bristow quadrangle and the Glenn pool there are several minor fields. Several anticlines occur in this quadrangle. The strata exposed in the northern part of the quadrangle have an aggregate thickness of about 950 feet. They consist almost entirely of alternating sandstone and shale, the only exceptions being a few limestone beds in the eastern part of the area.

Nowata County Pools.—Nowata County is in the northeastern part of Oklahoma, bordering on Kansas. It contains all or parts of the following pools, many of which have been heavily productive: Adair, California Creek, Coody's Bluff-Alluwe-Chelsea, Nowata (Claggett), Delaware-Childers, and South Coffeeville.

The surface of the county is in general a plain in which the streams have eroded wide valleys. It ranges in elevation from 600 to 926 feet. The surface rocks are Pennsylvanian shales, sandstones, and limestones.[2]

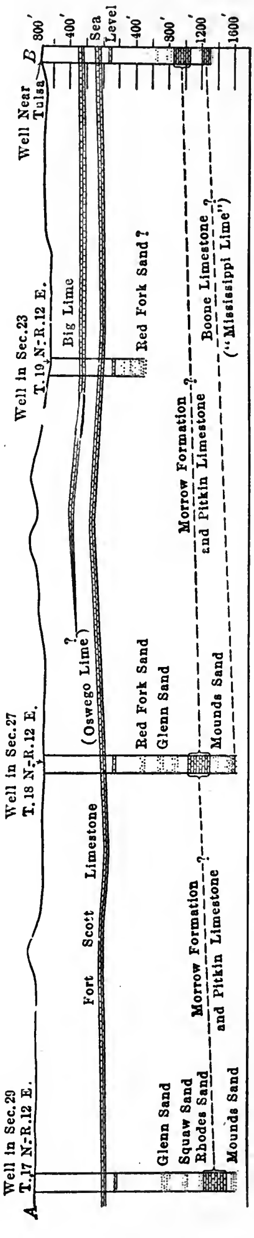

FIG. 126.—Cross section of Glenn Pool, Oklahoma, along line *AB*, Fig. 125. (*After Smith.*)

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[1] FATH, A. E.: Structure of the Northern Part of the Bristow Quadrangle, Creek County, Oklahoma, with Reference to Petroleum and Natural Gas. U. S. Geol. Survey *Bull.* 661, pp. 69-99, 1918.

[2] Oklahoma Geol. Survey *Bull.* 19, part 2, p. 345, 1917.

The structure of Nowata County is in general that of a westward-dipping monocline upon which gentle crumpling is superimposed. In some places the normal dip is interrupted by a flattening or reverse dip to the east. An example of anticlinal folding is the Coody's Bluff-Alluwe-Chelsea field.[1] Some other fields are not clearly related to well-defined structural elevations.

Washington County Pools.—Washington County is west of Nowata County, in northern Oklahoma. It lies entirely in the region of Pennsylvanian rocks and contains the Dewey-Bartlesville, Canary, Copan, Wann, Hogshooter, and Vera pools.

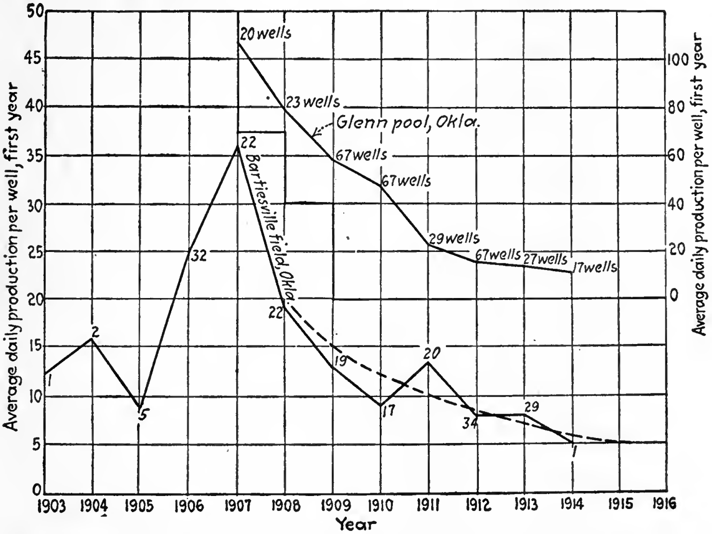

FIG. 127.—Curves showing yearly decrease in the first year's daily production (in barrels) of wells on several properties in the Glenn pool, Oklahoma, and (below) in the Bartlesville field, Oklahoma. The numbers show the number of wells in each group used to supply the data. (*After Beal.*)

Some of the wells drilled during its early period of development (1904-1906) had an initial production of 1,000 barrels a day. In 1906 the average initial production per well was about 73.2 barrels. The average gradually decreased from that time, and in 1914 it was only 10.4 barrels. At the end of 1914 there were 4,816 producing oil wells in this county.

The Dewey-Bartlesville field extends westward for several miles

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[1] *Idem*, p. 347.

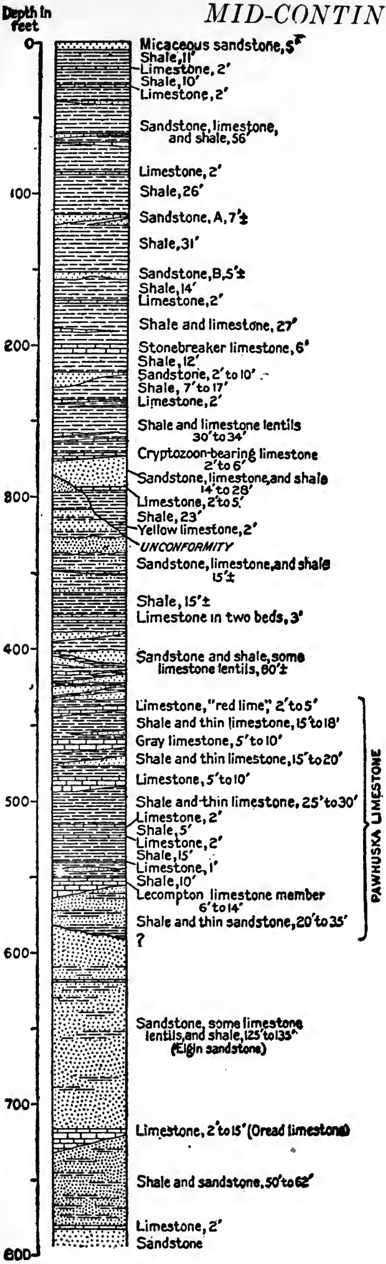

FIG. 128.—Generalized strategraphic section showing rocks exposed in northwestern part of Pawhuska quadrangle, Oklahoma. (*After Heald.*)

into Osage County. The Copan pool, about 7 miles north of Dewey, is practically continuous with this field, as are also the Hogshooter pool, to the southeast, and the Avant-Ochelata pool, to the southwest. The oil is found in Cherokee sands. The producing area seems in general to be closely associated with very gentle anticlinal folding, but the folds are low and generally lack sharp definition. The production of wells in this field is indicated by Fig. 127.

Osage County Pools.—Osage County adjoins Washington County on the west. The eastern and southern parts of the county have been drilled, and a number of pools have been discovered, among them the Back Creek, Nelagoney, Wynona, Big Heart, Delaware, Bird Creek, Flatrock, Hominy, and Cleveland (in part). Federal restrictions have checked development of a large area in this county, which is regarded as probably the most favorable for prospecting in Oklahoma. The area is now being surveyed (1919) by the United States Geological Survey, and structure contour maps of the townships are issued from time to time. Subsequently the land is auctioned by the Federal officers. Structurally the area is part of a monocline, on which many small domes, anticlines, and terraces are developed. There are many small faults, most of which strike northwest. The rocks that crop out are Pennsylvanian, and the oil and gas are found mainly in the Cherokee beds. In the Hominy field oil is said to be derived from the Mississippian limestone.

The Pawhuska quadrangle[1] is in Osage County, just west of the Bartlesville field. The section is shown as Fig. 128. The general structure of the region is monoclinal. The rocks dip almost due west at an average rate of about 35 feet to the mile, but the dip is not uniform. In some localities the rocks dip westward at triple the average rate, and in others the westward dip is very low. A number of small anticlinal folds are known, some of which yield oil and gas.

Kay County Pools.—Ponca City, Newkirk, and Blackwell[2] are in Kay County, near the Kansas line. The southwest corner of Kay County lies in the Permian Red Beds; the rest of the county is occupied by other Permian rocks. The Pennsylvanian series is found in normal development below the Permian, and the oil and gas are obtained in sands of the Cherokee formation. The Ponca City, Newkirk, and Blackwell fields are on domes or high places on an anticlinal axis. The oil and gas occur in several sands, as noted below:

Billings, Noble County.—The Billings field, in Noble County, lies about 20 miles southwest of the Ponca City field.[3] The surface rocks are Permian shale, sandstone, and limestone, which together constitute 500 to 900 feet of beds above the Neva limestone. An anticline that plunges southwest carries a small dome on its southwest end; on this dome gas was encountered in 1916. Subsequently gas wells were brought in to the northeast, high on the anticline. This fold (Fig. 129) has approximately the same strike as the fold just south of Ponca City, and possibly both are on the same axis.

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[1] Heald, K. C.: Geologic Structure of the Northwestern Part of the Pawhuska Quadrangle, Oklahoma. U. S. Geol. Survey *Bull.* 691, pp. 57-100, 1918.

[2] Ohern, D. W., and Garrett, R E.: The Ponca City Oil and Gas Field, Oklahoma. Oklahoma Geol. Survey *Bull.* 16, 1915. See also Petroleum and Natural Gas in Oklahoma. Oklahoma Geol. Survey *Bull.* 19, part 2, pp. 248-280, 1917.

[3] Fath, A. E.: An Anticlinal Fold Near Billings, Noble County, Oklahoma. U. S. Geol. Survey *Bull.* 641, pp. 121-138, 1916.

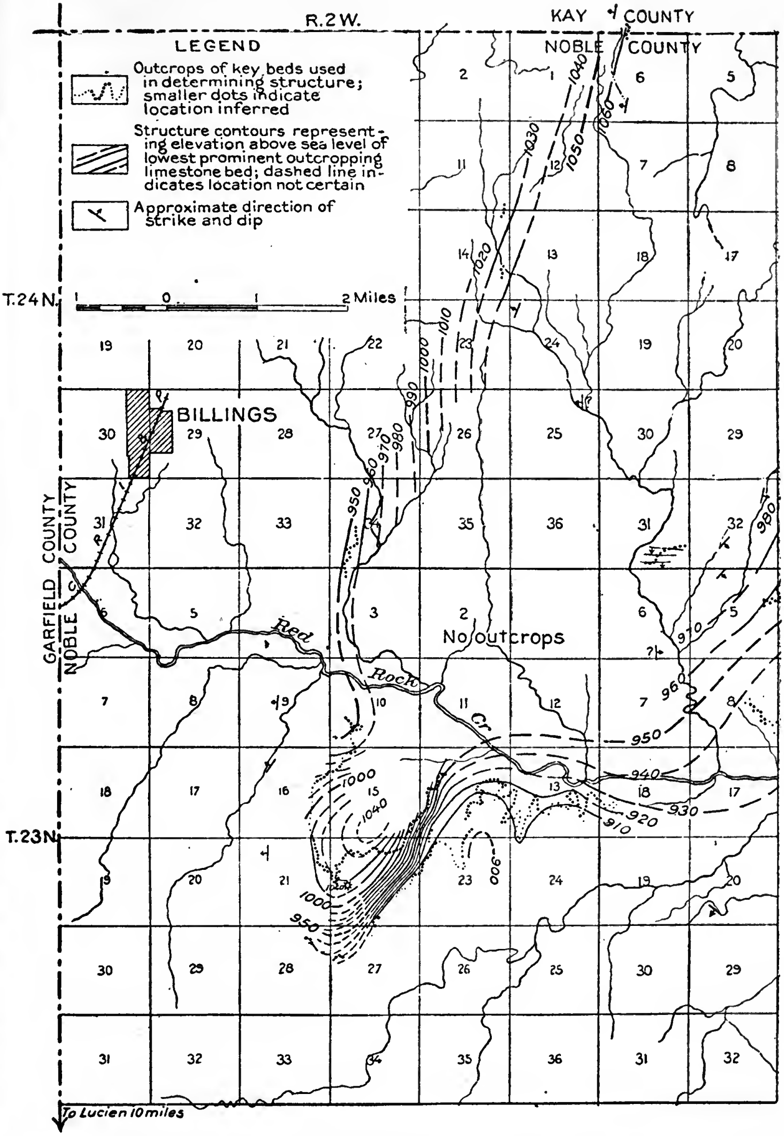

Fig. 129.—Sketch showing the anticlinal fold near Billings, Oklahoma. (*After Fath.*)

OIL AND GAS SANDS IN THE BLACKWELL FIELD, OKLAHOMA

Name	Character	Thickness	Average Depth	Correlation
		Feet	Feet	
Sand	Gas.	20	225	
Sand	Gas.	30	350	
Sand	Gas.	20	450	
Sand	Gas.	25	555	
Blackwell	Gas.	20	750	275-ft. sand at Ponca City.
Sand	Gas.	30	940	470-ft. sand at Ponca City.
Sand	Gas.	15	1,060	550-ft. sand at Ponca City.
Newkirk	Water and gas.	30	1,450	975-ft. sand at Ponca City.
Sand	Gas.	20	1,740	
Sand	Water.	25	1,800	
Ponca	Gas.	20	1,930	1,550-ft. sand at Ponca City.
Sand	Showing of oil.	20	1,970	
Sand	Gas, showing of oil.	15	2,700	
Sand	Water.	50	2,300	
Sand	Gas, showing of oil, water.	90	2,640	Layton of Cushing.
Sand	Water.	25	2,775	
Sand	Gas, showing of oil.	30	3,010	Cleveland.
Sand	Gas, showing of oil, water.	30	3,275	Peru.
Swenson	Oil.	25	3,360	Oswego (Wheeler).

Garber, Garfield County.—The Garber field is in Garfield County a few miles southwest of Billings. The surface rocks are Permian Red Beds, and the structure is domatic. Gas and some oil were encountered in Permian beds and in the upper part of the Pennsylvanian series in 1916. Deeper drilling has revealed many productive sands, containing high-grade oil.

Muskogee County Pools.—The Muskogee oil field[1] (Fig. 130) is

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[1] TAFF, J. A., and SHALER, M. K.: Notes on the Geology of the Muskogee Oil Fields, Indian Territory. U. S. Geol. Survey *Bull.* 260, p. 441, 1905.

situated near and southwest of Muskogee. Oil was discovered here in 1894, when two wells were drilled. In one of these wells oil was encountered in sand at a depth of 665 feet. This sand, after being shattered by an explosive, yielded 12 barrels of oil a day. Another sand, encountered at 1,100 feet, produced 60 barrels after shooting. The oil is of high grade (42° Bé.) It is found

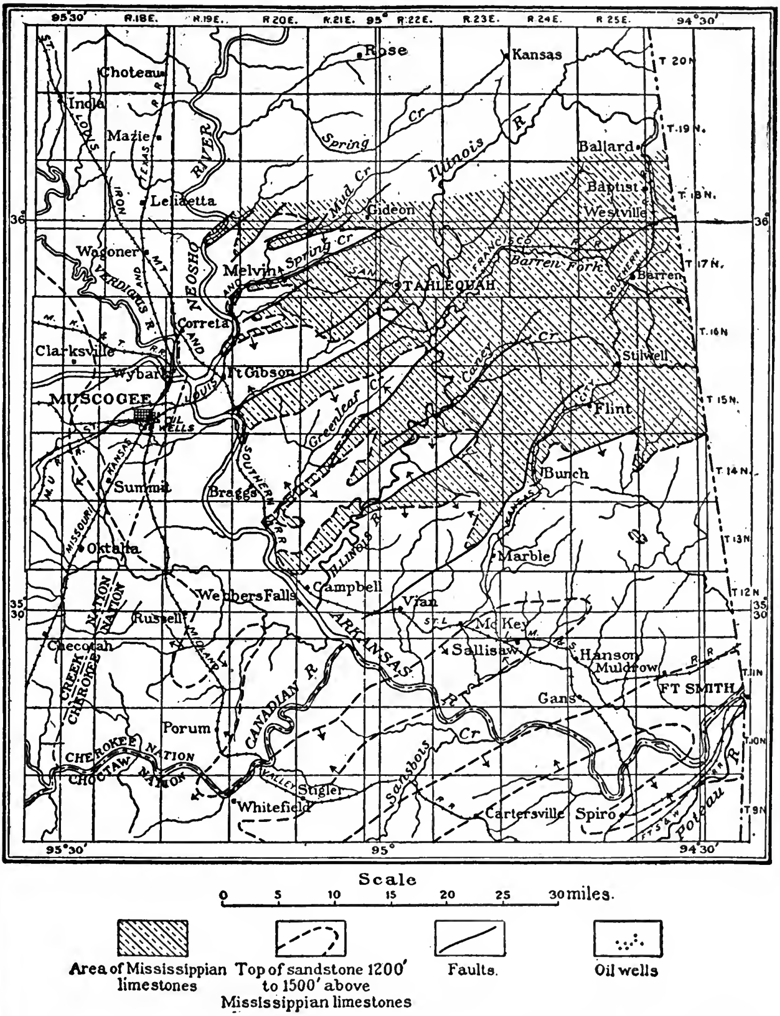

FIG. 130.—Map of Muskogee oil field, Oklahoma. (*After Taff and Shaler.*)

Log of Enid Well, in the Northwest Corner of Sec. 30, T. 23 N., R. 6 W., Garfield County, Oklahoma[a]

	Thickness	Depth		Thickness	Depth
	Feet	Feet		Feet	Feet
Surface	48	48	Red rock	10	2,618
Red sand and shale	782	830	Lime	25	2,640
Lime shell	2	832	Red rock	20	2,660
Red and sandy shale	168	1,000	Slate, white	20	2,680
Shale	430	1,430	Lime	5	2,685
Lime	10	1,440	Slate, white	5	2,690
Shale	160	1,600	Lime	60	2,750
Lime shell	5	1,605	Slate, white	20	2,770
Slate and rotten shale	195	1,800	Slate cave, black	15	2,785
Lime	20	1,820	Slate, white	15	2,800
Slate	70	1,890	Lime	5	2,805
Lime	40	1,930	Slate, white	45	2,850
Slate	70	2,000	Lime	10	2,860
Lime shell	10	2,010	Slate, white	40	2,009
Slate	105	2,115	Lime	10	2,910
Sand	50	2,165	Slate, white	35	2,945
Red rock	53	2,220	Lime	5	2,950
White slate	40	2,260	Slate, white	50	3,000
Limestone	8	2,268	Lime shells	10	3,010
Red rock	72	2,340	Slate	20	3,030
Slate, white	30	2,370	Lime shells	30	3,060
Red rock	40	2,410	Slate	55	3,115
White slate	20	2,430	Lime shells	1	3,116
Red rock	55	2,485	Slate	11	3,127
Slate, white	35	2,520	Lime	15	3,142
Red rock	30	2,550	Slate	23	3,165
Lime	10	2,580	Lime	10	3,175
Lime, black	20	2,580	Sand	7	3,182
Slate, white	10	2,590	Slate	28	3,210
Lime	5	2,595	Lime and slate	155	3,365
Slate, black	10	2,605	Water at	...	3,365

[a] Oklahoma Geol. Survey *Bull.* 19, part 2, p. 200, 1917.

in sandstones that occur near the base of the Pennsylvanian series. The productive sand is 19 feet thick.

Structurally the region is rather complex, although the rocks are not highly tilted. About 6 miles west of Muskogee and 2 miles east of Taft gas is found in the lower part of the Pennsylvanian, where the rocks are arched to form a dome. Near Boynton, 6 miles southwest of Taft, oil is concentrated in a dome.

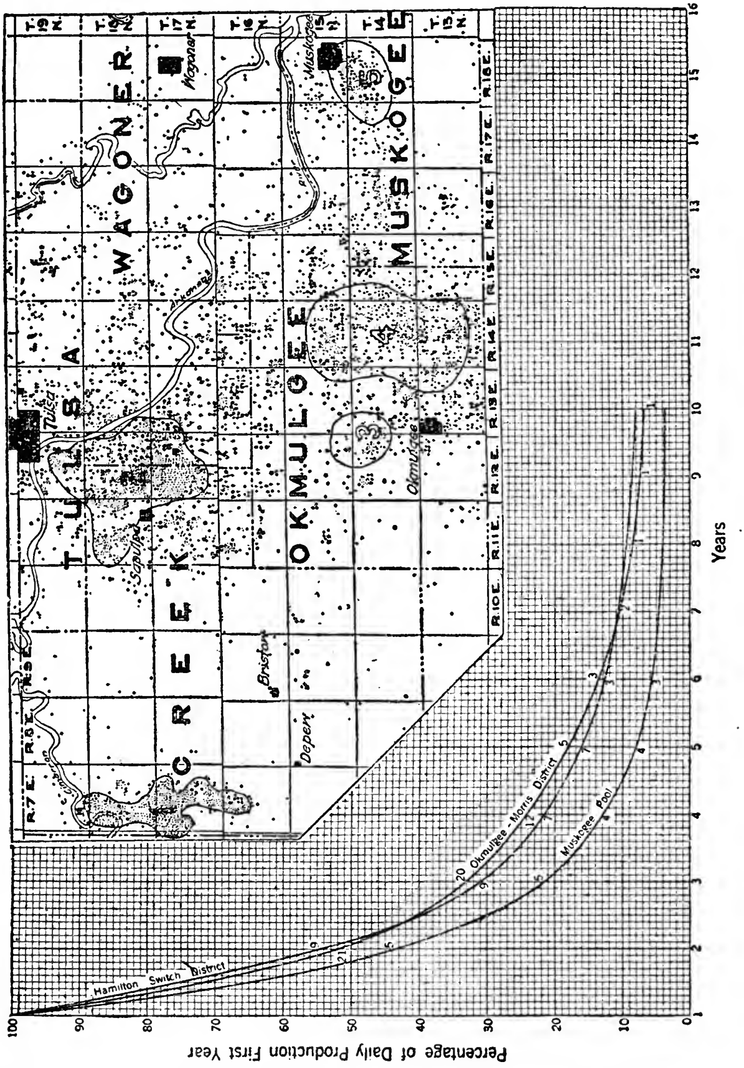

Fig. 131.—Curves showing rates of decline of the Okmulgee-Morris district, Hamilton switch field and of Muskogee pool, Oklahoma. Inset map showing the location of 1, the Cushing field; 2, the Glenn pool; 3, the Hamilton Switch field; 4, the Okmulgee-Morris district; 5, the Muskogee pool. (*After Beal.*)

Okmulgee County Fields.—From Muskogee the rocks dip westward to Okmulgee County, where several highly productive pools are developed. Some of these are on very low anticlines. This region has recently come into considerable production. Decline curves for the Okmulgee-Morris district and the Muskogee pool are shown in Fig. 131.

According to report considerable oil has recently been encountered in or below the Mississippian limestone in the Beggs pool.

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ARKANSAS

The Fort Smith-Poteau gas field[1] is south of Fort Smith, in Arkansas and Oklahoma. Natural gas was discovered some years ago in Massard Prairie, 5 miles southeast of Fort Smith, and also about 2 miles southeast of Mansfield, Arkansas, and more recently it has been found 3 miles east of Poteau, Oklahoma.

The rocks are Pennsylvanian.[2] The oldest formation in the region described by Smith is the Atoka, a series of alternating shales and sandstones 6,000 to 7,000 feet thick. The sandstone constitutes but a small part of the formation and lies in zones about 100 feet thick, separated by beds of shale 1,000 to 1,200 feet thick. In some areas the formation consists almost entirely of shale; in others the beds of sandstone are thick and massive. Above the Atoka is the Hartshorn sandstone, from 100 to 200 feet thick, followed by the McAlester shale, from 2,000 to 2,500 feet thick. The Savanna formation, which overlies the McAlester, consists of three prominent zones of sandstone, each ranging in thickness between 100 and 200 feet, separated by masses of shale. Its total thickness is estimated at 1,200 to 1,500 feet. Above the Savanna is the Boggy shale, about 2,300 feet thick, which contains also about 400 feet of sandstone.

The country lies between the complexly folded and faulted Ouachita Mountains, to the south, and the gently tilted Boston Mountains, to the north. The rocks are thrown into rather steep

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[1] SMITH, C. D.: Structure of the Fort Smith-Poteau Gas Field, Arkansas and Oklahoma. U. S. Geol. Survey *Bull.* 541, p. 23, 1914.

[2] COLLIER, A. J.: The Arkansas Coal Field. U. S. Geol. Survey *Bull.* 326, 1907.

TAFF, J. A., and ADAMS, G. I.: Geology of the Eastern Choctaw Coal Field, Indian Territory. U. S. Geol. Survey *Twenty-first Ann. Rept.*, part 2, pp. 257-311, 1900.

folds, anticlines alternating with synclines. There are also strike faults.

Three areas in this region yield gas. Each is at the crest of an anticline. The principal reservoirs are the Hartshorn sandstone and the sands in the Atoka formation.

KANSAS

In Kansas, which contains the northern part of the Mid-Continent field, the geologic conditions are essentially similar to those in Oklahoma, already described. The rocks that crop out in Kansas[1] are all sedimentary beds. The oldest rocks are Mississippian strata, which are exposed only in the southeast corner of the State. To the west and north is a broad area of Pennsylvanian strata that extends to the north boundary. West of that is a belt of Permian beds, narrow at the Nebraska line and very broad at the Oklahoma line. West of the Permian belt is a broad area of Mesozoic and Cenozoic beds that extends to the west border of the State.

The oil and gas are found mainly in the Cherokee formation, which is the principal producing formation in northern Oklahoma, and the fields exhibit similar structural features. In Kansas the production of gas is relatively important. The Kansas fields are near great industrial centers. The readily accessible market of Kansas City, Missouri, and the development of zinc-smelting, clay-burning, and glass and cement manufacturing plants in Kansas have greatly stimulated gas exploration in these fields.

The strata of Kansas dip northwest, away from the Ozark uplife, in general at the rate of 30 feet to the mile or less. The deposits are on the great westward-dipping monocline, and the minor structural features that localize the accumulations are mainly anticlines, domes, flutings on monoclines, or structural terraces.

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[1] Haworth, Erasmus, and others: Special Report on Oil and Gas. Kansas Geol. Survey, vol. 9, pp. 1-586, 1908.

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In Kansas granite occurs at relatively shallow depths on some of the domes.[1] At Elmdale, Onaga, Wabaunsee, and Zeandale granite is encountered at stratigraphic horizons as high as 1,000

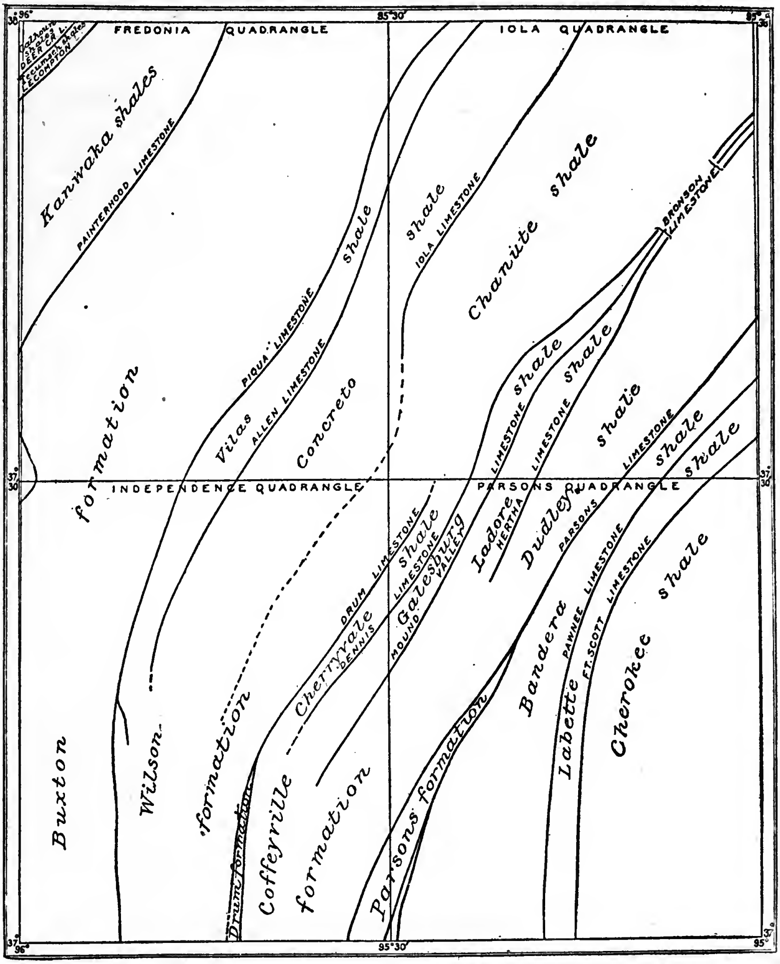

FIG. 132.—Diagram showing limestones thinning out southwestward from Kansas to Oklahoma. (*After Schrader and Haworth.*)

feet above the base of the Pennsylvanian series. At most places there is no evidence of metamorphic action in the beds immediately

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[1] TAYLOR, C. H.: The Granites of Kansas. Southwestern Assoc. Petrol. Geologists *Bull.*, vol. 1, pp. 111-126, 1917.

overlying the granite. It is believed that the granite represents old knobs or probably ridges, that were submerged in the Pennsylvanian sea and ultimately covered by sedimentary material. At a later period these points, which were lines of weakness, became loci of movement so that the strata above them were folded. The dome at Elmdale, according to Gardner,[1] shows a reverse dip of nearly 300 feet at angles as steep as 5°. The depth from the present surface to the top of the granite ranges from 950 feet on the fold at Zeandale to 2,500 feet on the dome near Cottonwood Falls or Elmdale.

In Kansas the Pennsylvanian contains more limestone than in Oklahoma. The limestones, as shown by Fig. 132, thin out toward the Oklahoma boundary.

GENERAL STRATIGRAPHIC SECTION IN THE OIL AND GAS REGION OF KANSAS
(After Haworth, Adams, Schrader, Gardner, and Others)

	Feet
Permian series:	
1. Red and gray sandstones with beds of red and vari-colored shale. Includes salt and gypsum in upper portion	1,000–1,500
2. Wellington shale	75–150
3. Marion limestone	100–200
4. Winfield formation; limestone and shale	20–30
5. Doyle shale	50–70
6. Fort Riley limestone; crops out at Augusta	40–50
7. Florence flint	15–25
8. Matfield shale	60–70
9. Wreford limestone (base of Permian, according to Prosser and to Adams)	35–55
10. Neosho formation and Florence shale or Garrison formation	140–150
11. Cottonwood limestone	5–10
12. Eskridge shale	30–40
13. Neva limestone	5–15
14. Elmdale formation; shale and limestone (base of Permian, according to Beede)	120–140
Pennsylvanian series:	
1. Americus limestone	6–10
2. Admire shale; probably includes oil sand at a depth of about 650 feet at Eldorado	275–325
3. Emporia limestone	5–10
4. Willard shale	60–190

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[1] GARDNER, J. H.: The Mid-Continent Oil Fields. Geol. Soc. America *Bull.*, vol. 28, p. 690, 1917.

Op. cit., p. 691.

	Feet
5. Burlingame limestone	6–12
6. Scranton shale	160–180
7. Howard limestone	2–7
8. Severy shale	40–60
9. Topeka limestone	20–25
10. Calhoun shale	0–50
11. Deer Creek limestone	20–30
12. Tecumseh shale	40–70
13. Lecompton limestone	15–30
14. Kanawa shale	50–100
15. Oread limestone	10–25
16. Lawrence shale; includes Chautauqua sandstone member, which is the most persistent bed of sandstone in this portion of section. Probably to be correlated with the surface bed at Toronto. Occurs at 1,550 feet in wells at Augusta and Eldorado	200–300
17. Kickapoo limestone	5–15
18. Le Roy shale	60–100
19. Stanton limestone	20–40
20. Vilas shale	5–125
21. Allen limestone	6–75
22 Lane shale	30–150
23. Iola limestone	2–44
24. Chanute shale	20–30
25. Drum limestone	3–70
26. Cherryvale shale. About the horizon of the oil sand occurring at 2,450 feet at Augusta and Eldorado (*Gardner*)	40–50
27. Dennis limestone, Galesburg shale, and Mound Valley limestone	80–100
28. Ladore shale	20–25
29. Bethany Falls limestone	15–25
30. Pleasanton shale	20–60
31. Coffeeville limestone	40–60
32. Walnut shale	20–140
33. Altamont limestone	25–60
34. Bandera shale	50–110
35. Pawnee limestone. Horizon of Peru oil sand	10–65
36. Labette shale	25–30
37. Fort Scott (Oswego) limestone	20–70
38. Cherokee shale. Includes main oil sands of Kansas outside of Augusta and Eldorado regions. Contains Bartlesville and Burgess sands	375–400
Mississippian series:	
Limestone, calcareous shale and chert shown in Neosho well. Boone formation	320

Probably older than Mississippian:	Feet
1. Dolomitic limestone, sandstone, and chert in Neosho well..	77
3. Conglomerate and shale in Neosho well.................	23
4. Sandstone, conglomeratic with pebbles up to three-quarters inch in diameter; shown in Neosho well...............	1,823

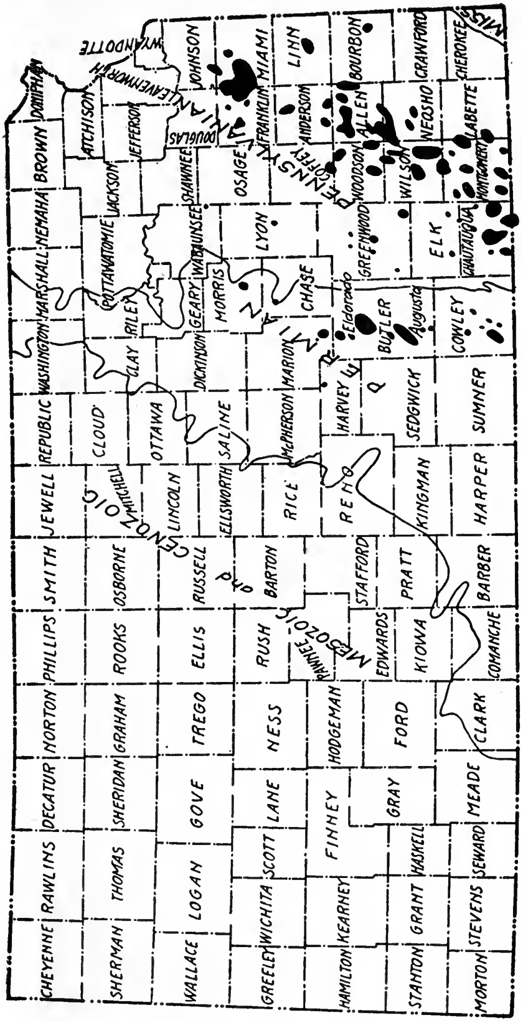

FIG. 133.—Index map of Kansas, showing principle oil and gas fields (black.)

The structural features are in general similar to those of the Oklahoma fields. The principal fields are shown in Fig. 133, and sections are given in Fig 134.

In the Peru region, lying mainly in Chautauqua County, but extending eastward into the western part of Montgomery County,

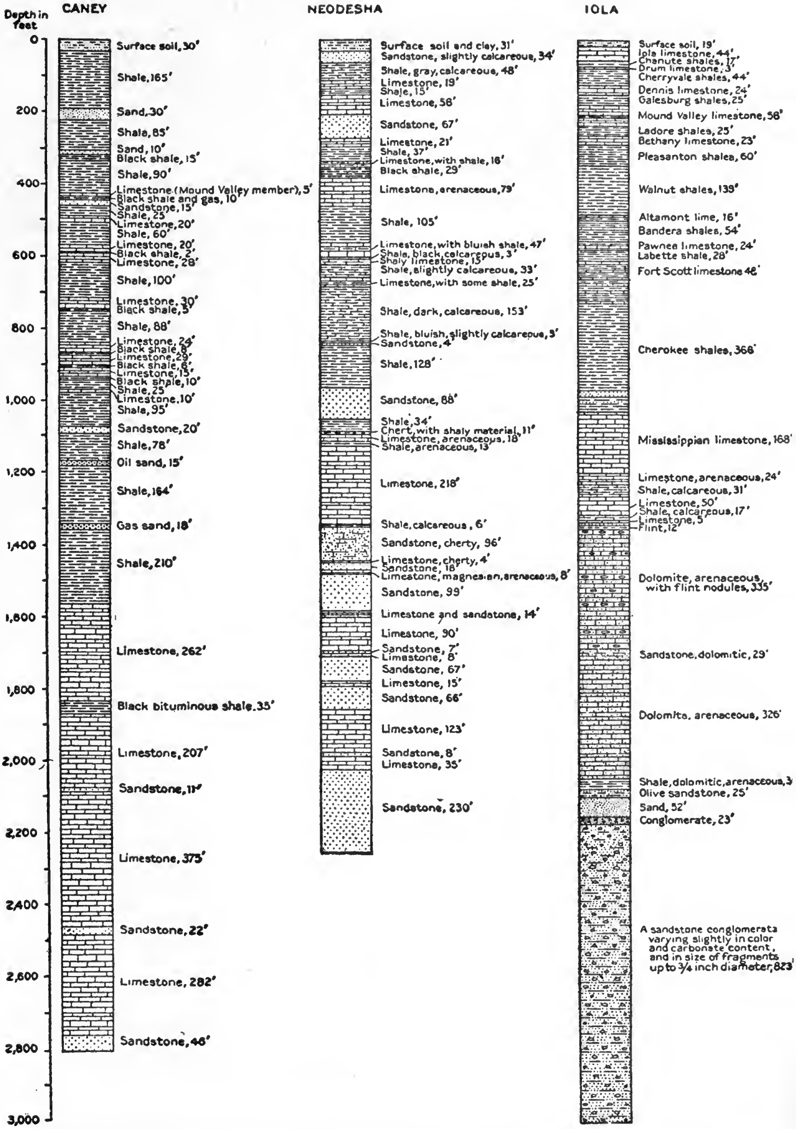

FIG. 134.—Records of deep wells at Caney, Neodesha and Iola, southeastern Kansas. (*After Heald.*)

oil is accumulated on a great structural terrace where the beds lie practically flat. For 25 miles down the dip the rocks dip 4 feet to the mile. West of this terrace for 25 miles the dip is about 50

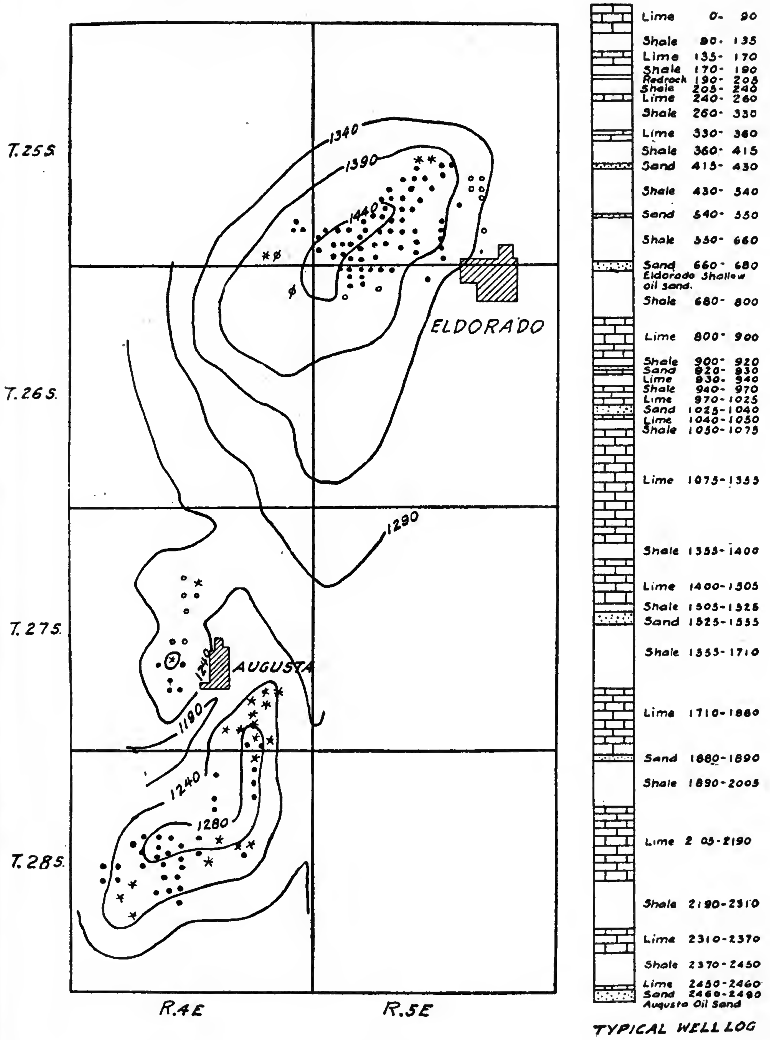

FIG. 135.—Map and section of Augusta and Eldorado fields, Butler County, Kansas. Contours are based on outcrop of Fort Riley limestone. (*After Hager, Bates and Walker.*)

feet to the mile, and east of it for 25 miles it is about 30 feet to the mile.

In the Independence quadrangle, Montgomery County, which lies just east of the Peru pool, between Independence and Coffeyville, there is an extensive area yielding oil and gas which is situated on the crest and well down the flanks of a gentle anticlinal fold. In Wilson County (Fredonia pool) and in Woodson County, to the north, gas and some oil are found on subordinate folds that rise not more than 50 feet above the general plane of the monocline. In the Iola quadrangle, Allen and Neosho Counties, accumulations occur on the monocline in gentle structural ravines and terraces with axes that strike approximately with the beds. In the Iola and La Harpe field, in northern Allen County, there is a low anticline or terrace about 8 miles wide.

The Paola field, in Miami and Franklin Counties, is on a terrace where for 40 miles down the dip of the monocline the beds dip 5 feet to the mile. West of this area in Osage County, the dip is about 20 feet to the mile.

In the Eldorado and Augusta fields, Butler County (Fig. 135), the oil and gas have accumulated in well-defined domes that are superimposed on the monocline.

Pools have recently been developed at Elbing, Peabody and Florence.

MISSOURI

Small quantities of oil and gas have been produced near Kansas City, Missouri, in Cass and Jackson Counties, which lie on the west border of the State. The outcropping rocks are of Pennsylvanian age. These strata extend to depths of 650 to 875 feet or more. The series is divided into two groups of rocks classified as the upper or Missouri group and the lower or Des Moines group. The exposed strata belong chiefly to the upper group, but only its lowest formation, the Kansas City, is present. The limestone members of this formation crop out conspicuously over nearly all of the area.

The regional dip of the rock beds is northwest, off the flank of the Ozark dome. This dip is, however, very low, the average across Jackson and Cass Counties being only from 6 to 10 feet in a mile.[1]

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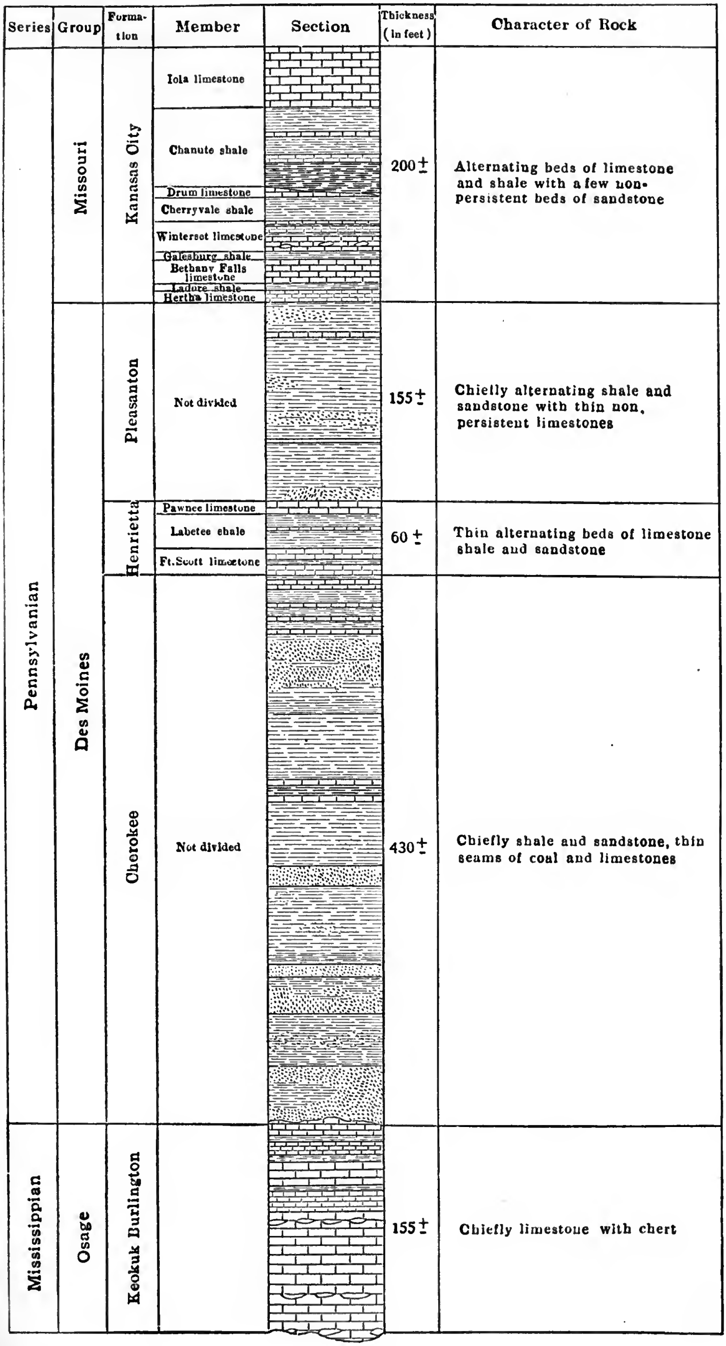
[1] Wilson, M. E.: Oil and Gas Possibilities in the Belton Area. Missouri Bur. Geology and Mines, 1918.



Series	Group	Formation	Member	Section	Thickness (in feet)	Character of Rock
Pennsylvanian	Missouri	Kansas City	Iola limestone		200±	Alternating beds of limestone and shale with a few non-persistent beds of sandstone
			Chanute shale			
			Drum limestone			
			Cherryvale shale			
			Winterset limestone			
			Galesburg shale			
			Bethany Falls limestone			
			Ladore shale			
			Hertha limestone			
	Des Moines	Pleasanton	Not divided		155±	Chiefly alternating shale and sandstone with thin non, persistent limestones
		Henrietta	Pawnee limestone		60±	Thin alternating beds of limestone shale and sandstone
			Labette shale			
			Ft. Scott limestone			
		Cherokee	Not divided		430±	Chiefly shale and sandstone, thin seams of coal and limestones
Mississippian	Osage	Keokuk Burlington			155±	Chiefly limestone with chert

FIG. 136.—Generalized geologic section of region near Belton, Missouri. (*After Wilson.*)

In the region near Belton and Hickman Mills there are a number of low anticlines, domes, monoclines, terraces, and synclines. Southwest of Belton there is a small area of complicated faulting. In several wells sunk to depths of about 400 feet oil or gas or both have been encountered. In 1909 five wells produced about 300 barrels a month of a heavy oil with paraffin base which commanded a good price for use as lubricating oil. The oil was obtained from sands near the bottom of a shallow syncline. A section of the rocks is shown in Fig. 136.

RED RIVER REGION, OKLAHOMA AND TEXAS

General Features.—The Red River region of southern Oklahoma and northern Texas (Fig. 137) includes parts or all of Carter, Love, Stephens, Jefferson, Cotton, and Comanche Counties, Oklahoma, and Clay, Wichita, and Wilbarger Counties, Texas. The Red River oil and gas pools include the Healdton, Fox, Graham, Loco, Duncan, and Lawton pools in Oklahoma, and the Electra, Burkburnett, and Petrolia fields of Texas. In this region, as shown by the contact of Pennsylvanian with Permian rocks (Fig. 118, p. 272) there is an embayment in the Permian outcrop south of the Arbuckle Mountains near the Red River. In the region of this embayment there is a great synclinal trough. The beds dip southward from the Arbuckle Mountains and northwestward from the Llano uplift, in the region south of the Red River. The axis of the syncline plunges west. Superimposed on the larger synclinal basin and probably crossing it, is the great Red River zone

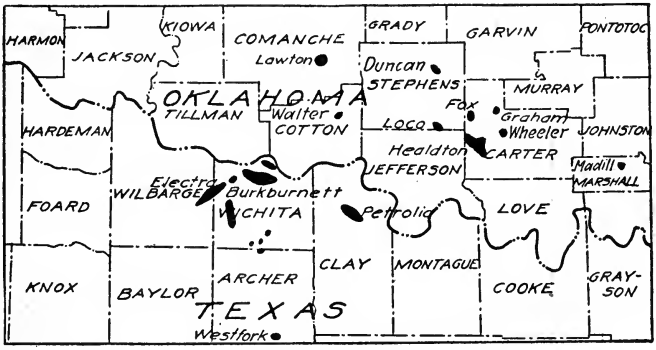


FIG. 137.—Index map of Red River region, Oklahoma and Texas.

of deformation,[1] which here has been identified, mainly by drilling. It extends along Red River and through counties that border the river for over 100 miles. This great uplift is probably of pre-Pennsylvanian age, according to Hager, who states that minor anticlines and domes such as those that exist at Electra and Petrolia, are due to movements of readjustment along old lines of stress in highly folded Ordovician rocks beneath. The less intense deformation took place in Post Pennsylvanian time.

The surface rocks are of Permian age, and the oil and gas are produced mainly from underlying Pennsylvanian strata, although the lower Permian also supplies gas and some oil. Possibly some of the oil has come from strata lower than the Pennsylvanian.

GENERAL STRATIGRAPHIC SECTION SOUTH OF THE ARBUCKLE MOUNTAINS IN OKLAHOMA[a]

Lower Cretaceous (Comanche series):	Feet
1. Silo sandstone	200
2. Pennington limestone	10–15
3. Bokchito formation	140
4. Caddo limestone	60
5. Kiamichi formation	150
6. Goodland limestone	25
7. Trinity sand, which includes the sand yielding light oil in Madill field and the gas sand at Woodville	200–400
Unconformity.	
Permian:	
Red sandstone, varicolored shale, and beds of clay-iron conglomerate with thin lenses of limestone	400–1,500
Unconformity.	
Pennsylvanian:	
1. Franks conglomerate. Limestone (Wapanucka) at top. Beds of chert, gravel, boulders, and sandstone; formation of local extent near mountains	500
Unconformity.	
2. Glenn formation; blue shale with lenticular beds of sandstone. Probable horizon of the main oil sand, Healdton field	1,000–3,000
Unconformity.	

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[1] HAGER, LEE: Red River Uplift Has Another Angle. *Oil and Gas Jour.*, vol. 18, pp. 64-65, 1919.

[a] TAFF, J. A.: U. S. Geol. Survey *Geol. Atlas*, Tishomingo folio (No. 98), 1903; Some Economic Notes by Gardner. Geol. Soc. America *Bull.*, vol. 28, p. 697, 1917.

	Feet
Mississippian:	
1. Caney shale. Top is blue shale with sandy lentils and lower portion is black fissile shale with concretions of dark-blue fossiliferous limestone	1,500
2. Sycamore limestone	0–160
Devonian:	
Woodford chert	600
Silurian:	
1. Hunton limestone	0–200
2. Sylvan shale. Blue clay shale	50–300
Ordovician:	
1. Viola limestone: white and bluish	750
2. Simpson formation; siliceous sandstone, bituminous sandstone, fossiliferous limestone, calcareous sandstone and shale. Possibly contains deep oil sand near center of Healdton field, according to Powers	1,600
Cambro-Ordovician:	
Arbuckle limestone; massive and thin bedded, white and light blue limestone with cherty concretions	4,000–6,000
Cambrian:	
Reagan sandstone; coarse dark brown sandstone with calcareous sandstone and shale at top	50–150
Pre-Cambrian: Granite.	

GENERAL STRATIGRAPHIC SECTION IN NORTHERN TEXAS

(After Paige, Hill, and Others, with Economic Notes by Gardner, Matteson, and Others)

	Feet
Tertiary (Eocene):	
1. Cook Mountain and Mount Selman (St. Maurice of Louisiana, Claiborne). Consists of clays, clay-iron conglomerates, and calcareous glauconitic beds.	
2. Wilcox group (Sabine formation). Sands, clays, and conglomerates with beds of lignite	400–500
3. Midway group. Chiefly clays with some limestone	200–300
Upper Cretaceous (Gulf series):	
1. Navarro group. Clay marls and glauconitic sands	400–700
2. Taylor marls group. Beds of clay and sandy to calcareous soft shale, with local lenses of sandstone. Contains Nacatoch gas sand of Caddo field, oil sands of Corsicana field, and oil-bearing igneous rock (tuff?) of Thrall field	200–500
3. Austin group (Annona chalk and Brownstown marl). Contains some oil and gas in Caddo field	200–600

	Feet
4. Eagle Ford group. Chiefly clays containing the Blossom oil sand of Caddo field	150–400
5. Woodbine sand. Massive soft sandstone with some shale. Main oil sand of Caddo oil field. Occupies approximate time interval of Dakota sandstone in New Mexico and northward into Canada	50–100
Lower Cretaceous (Comanche series):	
1. Washita group. Impure limestone with beds of shale and marl. Contains water sand locally at Paris, Texas; includes, in descending order, the Pennington limestone, Bokchito formation, Caddo limestone, and Kiamichi formation (Denison, Fort Worth, and Preston formations)	175–400
2. Fredericksburg group. Massive white limestone beds, including the Goodland limestone (Edwards limestone and Walnut formation)	25–200
3. Trinity sand. Contains the oil of the South Bosque field in top member	200–400
Permian:	
1. Double Mountain group. Sandstone, limestone, sandy shale, red and blue clays, with beds of gypsum and salt.	1,800–2,000
2. Clear Fork group. Thin-bedded sandstone, magnesian and carbonaceous limestone, red and blue clay shale and irregular beds of cemented clay-iron concretions. Some gypsum	1,500–2,000
3. Wichita group. Sandstone of various colors. Red and bluish clay shale and beds of clay-iron concretions or "Mud-lump conglomerate." Beds of limestone rare east of Baylor County. Correlated with limestone and shale series known as the Albany formation in Baylor County	1,250–2,000
Pennsylvanian:	
1. Cisco group. Sandstone, limestone, gray sandy shale, dark-gray shale, and conglomerate. Contains coal 7. Includes upper oil and gas sands in Petrolia and Electra fields	800–900
2. Canyon group. Sandstone, dark-blue shale, conglomerate, coal, and beds of massive escarpment-forming limestone. Includes lower oil and gas sands in Electra and Petrolia fields	800–950
3. Strawn group. Sandstone, clay, carbonaceous shale, and chert conglomerate. Includes Millsap formations, or beds for 1,000 feet below coal 1. Contains oil and gas sands in Strawn, Ranger, Moran, and Brownwood fields	950–3,700
Unconformity.	

	Feet
Mississippian (Bend series):	
1. Smithwick shale. Black shale. Contains sand lenses that, according to Matteson, yield oil in Allen well, east of Ranger, and in Black well, northern Stephens County	175–500
2. Marble Falls limestone. Bituminous limestone, and some shale. Oil and gas in Ranger and Electra fields and deep sands of Burkburnett pools. Contact with Smithwich yields oil in Ranger and Caddo pools	350–400
3. Lower Bend shale. Black shale	0–125
Unconformity.	
Ordovician:	
1. Ellenberger limestone	400

Healdton, Oklahoma.—Healdton, Carter County, Oklahoma,[1] lies to the south of the Arbuckle-Wichita uplift and is about 12 miles southwest of the Arbuckle Mountains. Petroleum was discovered here in 1913, and the field was developed within three years to one of the most productive fields in Oklahoma, yielding daily over 60,000 barrels. The rocks at the surface are Permian Red Beds and consist of red and gray shale, alternating with brown, white, and red sandstone and thin conglomerate beds. The beds, according to Wegemann and Heald, are at least in part of fresh-water origin. From the surface to a depth of 600 to 950 feet the strata are principally shales, with a few water-bearing sandstones. Below these beds is a zone 250 feet thick which contains four or more petroliferous sands separated by beds of shale. In some wells five sands contain oil. Most of the oil produced in 1915 came from sands 800 to 1,150 feet deep. The higher petroliferous strata are classified as Permian by Wegemann and Heald,[2] and also by Aurin.[3] Powers, however, classes them as Pennsylvanian. The deeper oil-bearing strata are Pennsylvanian.

Structurally the field is an anticline on which several small domes are superimposed. The oil has accumulated at the top of

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[1] Wegemann, C. H., and Heald, K. C.: The Healdton Oil Field, Carter County, Oklahoma. U. S. Geol. Survey *Bull.* 621, pp. 13-30, 1915.

Powers, Sidney: The Healdton Oil Field, Oklahoma. *Econ. Geology*, vol. 12, pp. 594-606, 1917; Age of the Oil in Oklahoma Fields. Am. Inst. Min. Eng. *Bull.* 113, p. 1982, 1917.

Shannon, C. W., and others: Petroleum and Natural Gas in Oklahoma. Oklahoma Geol. Survey *Bull.* 19, part 2, pp. 79-101.

[2] *Op. cit.*, p. 24.

[3] Shannon, C. W., and others: *Op. cit.*, insert table.

the anticline, on the domes, and in the small structural depressions between them. On the flanks of the fold the beds carry salt water. Figs. 29 and 30 (pp. 124-125) are a structure map and a stereogram by Wegemann and Heald. Possibly a small part of the oil is derived from the Ordovician beds, which are covered by the Carboniferous beds. (See Fig. 138.)

Powers[1] states that an angular unconformity separates the Ordovician from the Pennsylvanian rocks, the former being tilted at considerably higher angles. The deeper sands, which have proved highly productive around the outer margins of the field, are lacking in its center, where pre-Pennsylvanian rocks only are found below the higher sands (Fig. 138).

At Fox and at Graham, which lie north of the Healdton field, the surface rocks are Permian. The Permian is thicker than at Healdton, and the oil-bearing strata lie at greater depths. The petroliferous beds are at approximately the same horizons. Anticlines are developed at Fox and at Graham (Fig. 138), but these pools, which lie farther from the basin, are much less productive than the Healdton field.

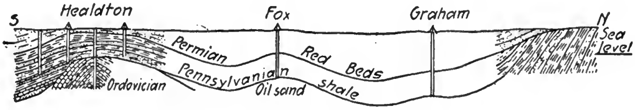

Fig. 138.—Cross section of the Healdton field, Fox and Wheeler anticlines, Oklahoma, showing the relation of the buried Healdton Hills composed of Ordovician strata to the overlying Pennsylvanian and Permian strata. Length of section 21 miles; vertical scale four times horizontal scale. (*After Powers.*)

Loco, Oklahoma.—The Loco field[2] is on the line between Stephens and Jefferson Counties, Oklahoma, about 3 miles southwest of the village of Loco and 10 miles northwest of the Healdton field. For many years asphalt deposits have been known to exist in the vicinity, but deep drilling was not begun until 1912. The first gas well was bored in the spring of 1913, about six months before the Healdton pool was discovered. Six other gas wells of capacities ranging from 6,000,000 to 20,000,000 cubic feet a day

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[1] Powers, Sidney: The Healdton Oil and Gas Field, Oklahoma. *Econ. Geology*, vol. 12, p. 604, 1917.

[2] Wegemann, C. H.: The Loco Gas Field, Stephens and Jefferson Counties, Oklahoma. U. S. Geol. Survey *Bull.* 621, pp. 31-42, 1915.

have been drilled. The rocks exposed in the Loco field are of Permian age and consist of sandstone, shale, and fine conglomerate.

The structure is complicated, an anticline being crossed by a syncline. The gas occurs in sands, some of which are probably of Permian age. Recently some heavy oil has been discovered.

Duncan, Oklahoma.—The Duncan gas field, known also as the Hope field, is in Stephens County, Oklahoma, about 10 miles northeast of the town of Duncan. The principal flow of gas is obtained at depths of about 850 feet, and the wells range in production from 3,000,000 to almost 18,000,000 cubic feet a day.[1] A pipe line has been laid from the field to Duncan and supplies that town with gas.

The surface rocks in the Duncan field are Red Beds of Permian age. They consist of shale, sandstone, calcareous sandstone, and shale conglomerate. The shale is red or bluish gray in color. The sandstone is predominantly white or buff but is in some places red. The cement of the sandstone is calcareous, and in some beds the lime content increases in amount until the rock is a calcareous sandstone.

The principal gas-bearing bed in the Duncan field, a sand from 7 to 19 feet thick, lies 800 to 900 feet below the surface. Showings of gas and heavy oil in small quantity are obtained in some of the wells in shallower sands. The gas accumulation lies in a steeply plunging anticline, which is about 2 miles broad by 5 miles long, and whose axis trends a few degrees west of north.

At Granite, Gotebo, and Wheeler oil or gas or both occur in or near the Red Beds close to the unconformity between the Pennsylvanian and the Permian.

Lawton, Oklahoma.—The Lawton oil and gas field, in Comanche County, Oklahoma, is near the east end of the Wichita Mountains, about 5 miles east of the city of Lawton.[2] Oil was found in Lawton in 1901, in a well dug for water. The surface rocks are Red Beds, consisting of alternating layers of shale and sandstone and, associated with the sandstone, thin layers of shale conglomerate. The wells encounter red sandstone and shales.

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[1] Wegemann, C. H.: The Duncan Gas Field, Stephens County, Oklahoma. U. S. Geol. Survey *Bull.* 621, p. 43, 1916.

[2] Wegemann, C. H., and Howell, R. W.: The Lawton Oil and Gas Field, Oklahoma. U. S. Geol. Survey *Bull.* 621, p. 71, 1915.

The principal anticlinal axis in the Lawton field extends southeastward from the Wichita Mountains and is interrupted by a narrow syncline, which crosses it almost at right angles.

Oil and gas are found in the wells of the Lawton field in three different sands, which are known in the field as the "200-foot," "400-foot," and "800-foot" sands. The "200-foot sand" is from 10 to 30 feet thick and lies at depths of 150 to 250 feet, according to the location of the well with reference to the Lawton anticline. This sand has been found in the greater number of the wells and generally carries at least a show of oil. Some wells are said to have obtained several barrels of heavy oil from this sand, and gas also is reported from it, though only in small quantity.

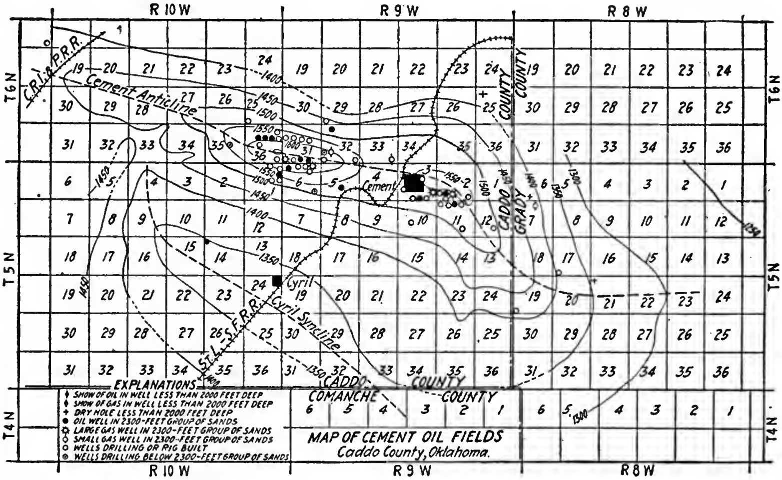

FIG. 139.—Map showing geologic structure and distribution of wells in Cement field, Oklahoma. Contour lines show altitude of Cyril gypsum bed. Contour interval 50 feet. (*After Clapp.*)

In 1916 many wells were producing small amounts of oil. According to Wegemann and Heald, the oil is probably derived from Pennsylvanian strata, above which the Red Beds lie unconformably.

Cement, Oklahoma.—The Cement field[1] is in Caddo County, Oklahoma, northeast of the Wichita Mountains and 60 miles

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[1] CLAPP, F. G.: Geology of Cement Oil Field. *Min. and Met.*, No. 158, sec. 27, pp. 1-9, February, 1920.

northwest of Healdton. It is in the Keeche Hills, which rise some 400 or 500 feet above the surrounding country. The field is on an anticline over 13 miles long and from 1 to 3 miles wide. The major axis trends N. 75° W. from the village of Cement, but east of the village appears to be deflected to about S. 45° E. (See Fig. 139.) The anticline has an undulatory crest, and several of the wells sunk at the high places on the crest have yielded much gas and some oil.

The surface rocks are Permian Red Beds, with gypsum. The base of the Permian series is thought to lie about 2,700 feet from the surface, but some place it at 1,700 feet. The oil and gas are found in the lower part of the Permian, in sandstones covered by shale.

Madill, Oklahoma.—The Madill pool, in Marshall County, Oklahoma,[1] is just south of the Arbuckle uplift. The region includes the Tishomingo granite and Paleozoic and Cretaceous sediments. The Paleozoic sedimentary rocks rest unconformably on the eroded surface of the granite. They are folded and faulted and are overlain by the Cretaceous rocks, which are but slightly tilted. (See Fig. 140.) The lowest and thickest Cretaceous formation is the Trinity sand. It is a compact but unconsolidated, moderately fine sand with a little clay and bands of sandy clay.

Oil seeps and bituminous saturated sands are found in the region. The principal oil-bearing stratum is at or near the base of the Trinity sand, a little more than 400 feet below the surface at Madill. It is a porous bed of sand and gravel in which the particles and pebbles are not cemented.

Of four producing wells brought in to April 1909, one had an initial flow of several hundred barrels. The oil is very light, having a specific gravity of 47.5° B., and is rich in gasoline and kerosene. Taff and Reed believe that the oil and asphalt are derived from the Carboniferous strata which are tilted so that their edges project against the Trinity sand.

Wichita and Clay Counties, Texas.—The productive pools of Wichita County, Texas, include Burkburnett, Electra, Fowlkes, and Iowa Park. These pools are in areas of Permian rock, below which are strata of Pennsylvanian age.

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[1] TAFF, J. A.: U. S. Geol. Survey *Geol. Atlas*, Tishomingo folio (No. 98), 1903.
TAFF, J. A., and REED, W. J.: The Madill Oil Pool, Oklahoma. U. S. Geol. Survey *Bull.* 381, pp. 504-513, 1910.

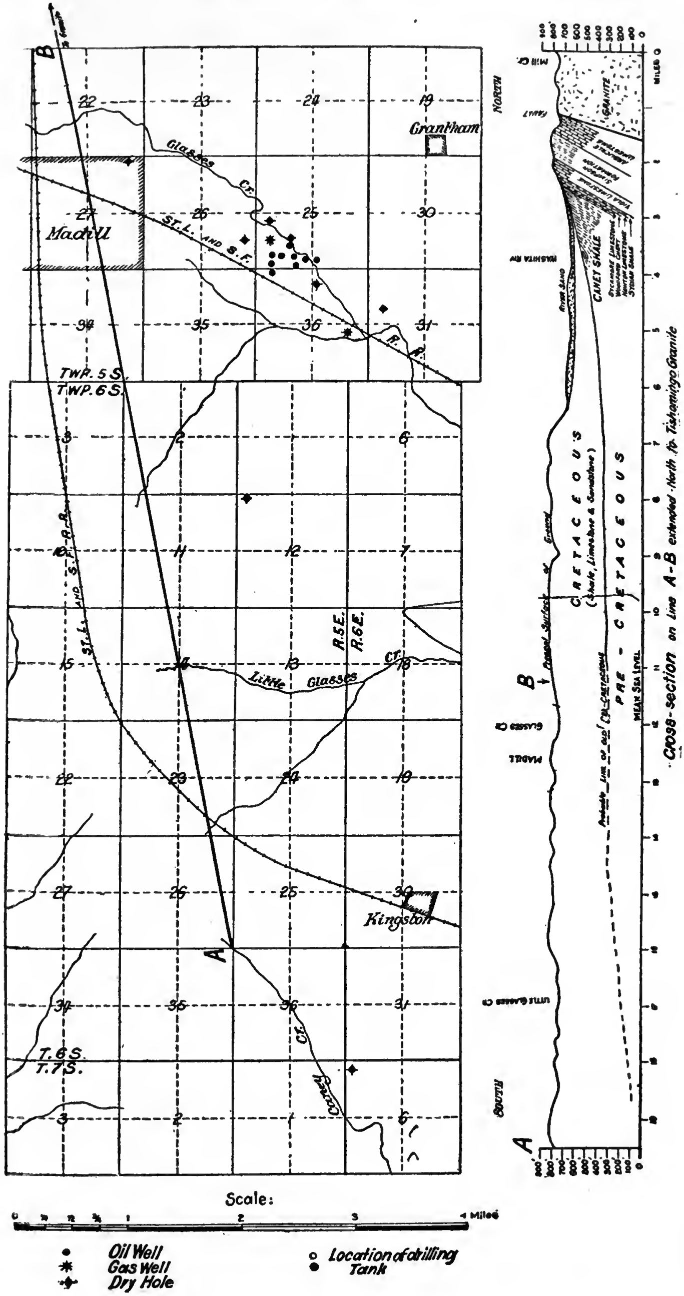

FIG. 140.—Map of Madill oil and gas field, Oklahoma. (*After Hutchinson.*)

The Electra field[1] is in the western part of Wichita County, near the Oklahoma line. The first reported occurrence of oil in this field was in a well dug in 1900 for water, north of what was then Beaver station; this well found oil at 147 feet. South of the station another well found a little oil at 205 feet. Since that date the area has been developed into a steadily productive field, yielding oil of high grade. The outcropping rocks are of Permian age, probably near the base of the Permian. The strata consist of shale and sandstone, with some limestone beds, and are referred to the Albany-Wichita by Udden. (See Fig. 141.) Below the Permian beds are Pennsylvanian shale, clay, and sandstone, with thin beds of limestone.

Oil and gas are found in the Permian (Wichita formation, as stated by Udden), in the Pennsylvanian, and possibly in the Mississippian. The structure of the district is that of a broad anticline with a wide, and at places nearly flat crest.

Burkburnett, which lies northeast of Electra, is one of the most productive fields in the Mid-Continent region. It is said to lie on a broad anticline, which at some places is probably complicated by faulting. It produces oil of good grade, rich in gasoline. A small part of the oil comes from beds that have been correlated with the Permian. The remainder is derived from deeper beds. In 1916 and later many wells yielding from 1,000 to 2,000 barrels a day in flush production were encountered between 1,700 and 2,000 feet. The details of the structural features of this district are not available to me. The broader features of the uplift are treated by Lee Hager.[2]

The Petrolia field[3] (Fig. 142) is in the northern part of Clay County, 12 miles north of Henrietta. The outcropping rocks are Red Beds of the Wichita formation and consist of shales and sandstones. These beds overlie the Cisco shale, of the Pennsylvanian, which consists of sandstones, clays, and shales and contains the oil and gas sands. As shown by Udden and Phillips,[4] the structure

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[1] Udden, J. A.: A Reconnaissance Report on the Geology of the Oil and Gas Fields of Wichita and Clay Counties, Texas. Texas Univ. *Bull.* 246, 1912.

[2] Hager, Lee: Red River Uplift Has Another Angle. *Oil and Gas Jour.*, vol. 18, pp. 64-65, 1919.

[3] Shaw, E. W.: Gas in the Area North and West of Fort Worth. U. S. Geol. Survey *Bull.* 629, pp. 1-75, 1916.

[4] Udden, J. A., and Phillips, D. McN.: A Reconnaissance Report on the Geology of the Oil and Gas Fields of Wichita and Clay Counties, Texas. Texas Univ. *Bull.* 246, 1912.

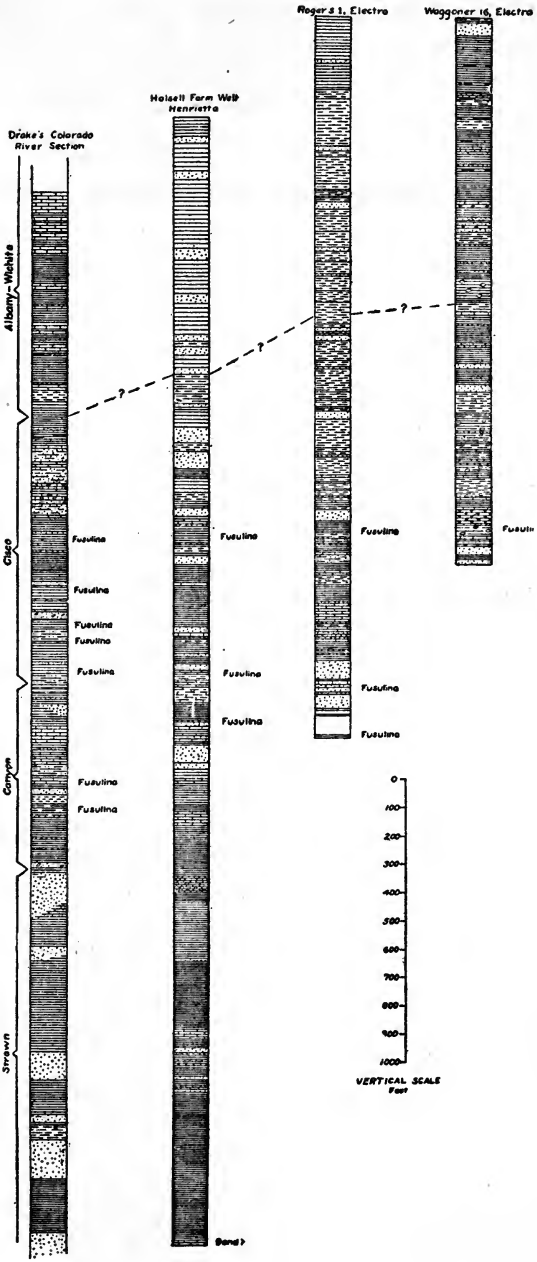

FIG. 141.—Columnar sections of oil fields in northern Texas. (*After Udden and Phillips.*)

is anticlinal. There are three principal sands yielding gas or oil and gas. The average original pressure was 725 pounds to the square inch. Although the field has produced principally gas it has yielded also over 3,000,000 barrels of oil. The oil is light and of good grade.

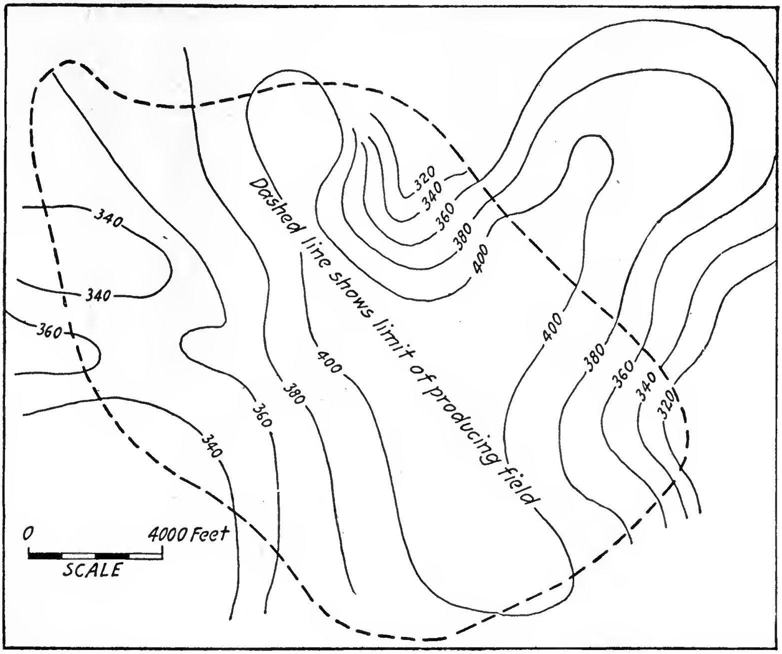

FIG. 142.—Structure contour map of Petrolia oil and gas field, Texas. (*After Shaw.*)

NORTH CENTRAL TEXAS FIELDS

The oil fields that lie entirely or partly in Texas (Fig. 143) are grouped as follows:

1. Red River region of northern Texas and southern Oklahoma.
2. North-central Texas fields, including Strawn, Allen, Duke, Caddo, Veale, Ranger, Breckenridge, Moran, Santa Anna, Brownwood, Trickham, Lohn, and others.
3. Fields in the Upper Cretaceous area east of the Balcones fault.
4. Western part of Sabine uplift in Texas and Louisiana.
5. Gulf coast fields.

The north-central Texas fields[1] as developed in 1919 were practically coextensive with the belt of Pennsylvanian strata that extends northward from the Llano-Burnet uplift nearly to the Oklahoma line. (See Fig. 144.) In nearly all the oil districts the outcropping rocks are Pennsylvanian. These generally dip northwest at low angles. Toward the east the Pennsylvanian is overlapped by the Trinity sand (Lower Cretaceous). Toward the west it is overlain by Permian strata. Below the Pennsylvanian is found the Bend series, which crops out in the Llano uplift but which is buried to the north. This series is unconformable with the overlying Pennsylvanian, as is indicated by the section in Fig. 145.

FIG. 143.—Sketch map of Texas and Louisiana, showing location of certain oil and gas fields. (*After Gardner.*) For more detailed maps see Figs. 137, 150, 152, 155, 156 and 160.

The general character of the Carboniferous formations is shown

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[1] HILL, R. T.: Geography and Geology of Black and Grand Prairies, Texas. U. S. Geol. Survey *Twenty-first Ann. Rept.*, part 7, pp. 1-666, 1900.

WEGEMANN, C. H.: A Reconnaissance in Palo Pinto County, Texas. U. S. Geol. Survey *Bull.* 621, pp. 51-59, 1912.

MATTESON, W. G.: A Review of the Development in the New Central Texas Oil Fields During 1918. *Econ. Geology*, vol. 14, pp. 95-146, 1919.

HAGER, DORSEY: Geology of the Oil Fields of North-Central Texas. Am. Inst. Min. Eng. *Bull.* 133, pp. 1109-1118, 1918.

in the sections on page 335. Sandstones are more abundant in the lower part of the series and toward the east. In the Canyon formation limestones increase toward the south. In the Cisco also limestones increase toward the west and south. In Pennsylvanian time the Arbuckle Mountains and some area toward the east and south, now buried, appear to have been the main sources of sediments of north-central Texas, rather than the Llano area. The region of what is now the Ouachita orographic element was doubtless a land area of large size, as it appears to have supplied material

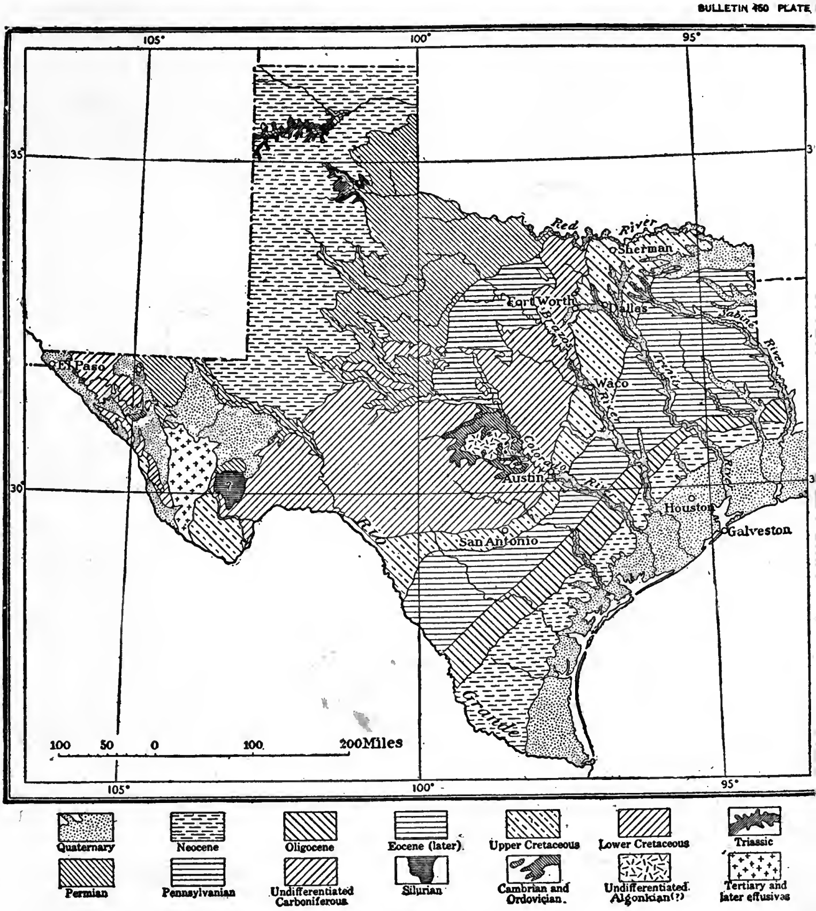

FIG. 144.—Geologic map of Texas. (*After Hill, Willis, Paige and others.*)

for sediments far to the north, toward the Ozarks, and far to the south, toward the Llano Mountains. Its influence on sedimentation was more far-reaching than that of the Ozark uplift or the Llano uplift. Its influence on structure, on the other hand, was more narrowly confined than that of either the Ozark or the Llano center. Mississippian and Pennsylvanian beds dip north from the Llano element to the northern parts of Young and Jack Counties.

The dominant structural feature in the northern Texas field is a monocline dipping northward from the Llano uplift at about 25 feet to the mile. On this monocline is superimposed a low arch that extends from the Llano-Burnet region northward about 150 miles. This arch is more accentuated in the Bend series than in the overlying rocks, and has been designated the Bend arch. Its origin is uncertain. It is on the monocline that was formed by the upthrust of the Llano element, and it extends northward from that element, but it is no more accentuated at the south end than it is 150 miles farther north. One hypothesis, based on data that are not as complete as might be wished, accounts for its origin, by assuming two periods of warping.

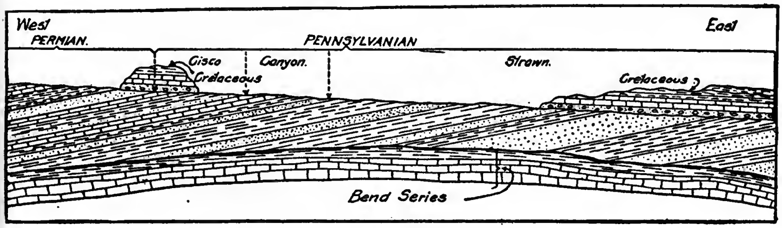

FIG. 145.—Section of Bend arch, north-central Texas. (*After Hager.*)

The vertical scale in Fig. 145 is exaggerated about 25 times. The dip of the Pennsylvanian strata is much lower than is indicated. Before the deposition of the Pennsylvanian the Bend formation was probably almost flat-lying or dipped gently northwest. After Cretaceous time the Bend was tilted eastward, as were also the Cretaceous beds.

The Bend arch (Figs. 146-149) has been the subject of much discussion. Maps of the structure are presented as expressed by

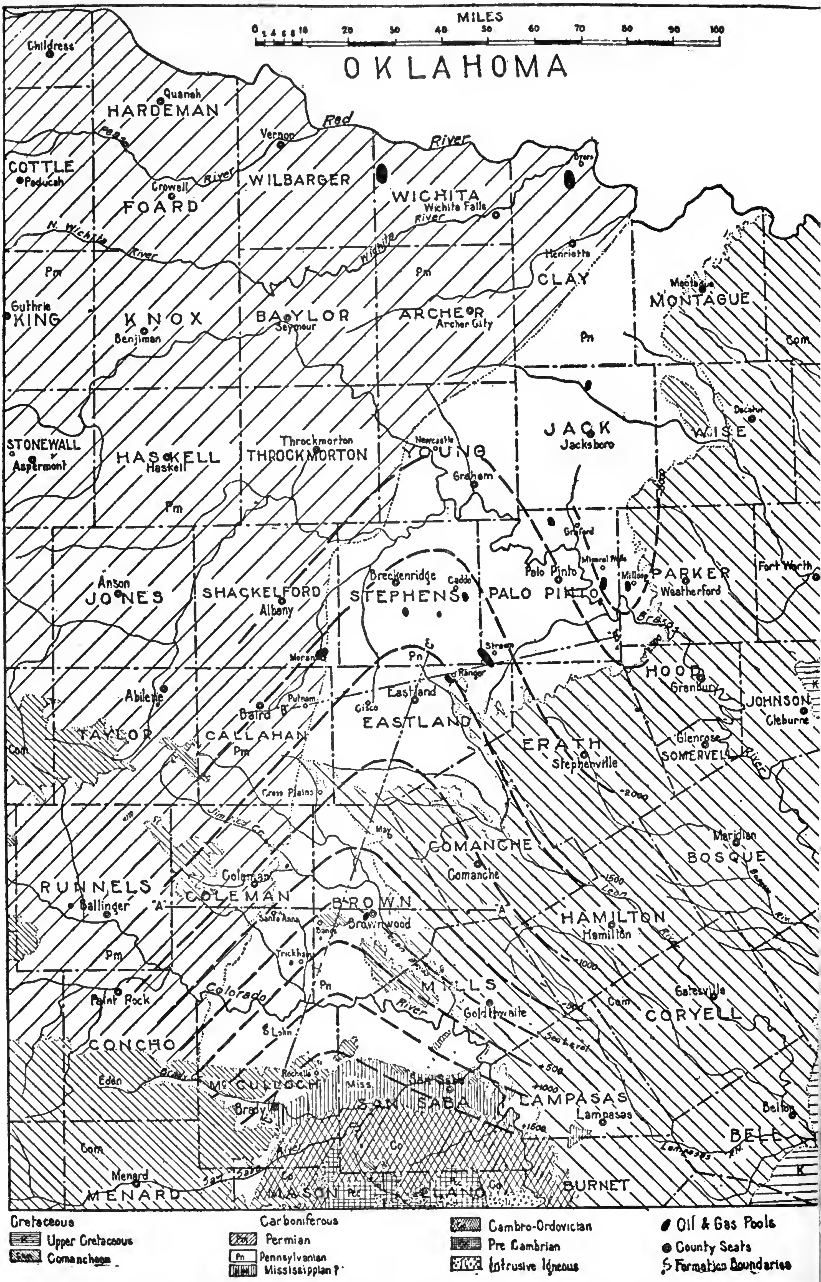

FIG. 146.—Geologic map of north-central Texas. (*After Hager.*) For sections along *A-A*, *B-B* and *C-C* see Figs. 147-149.

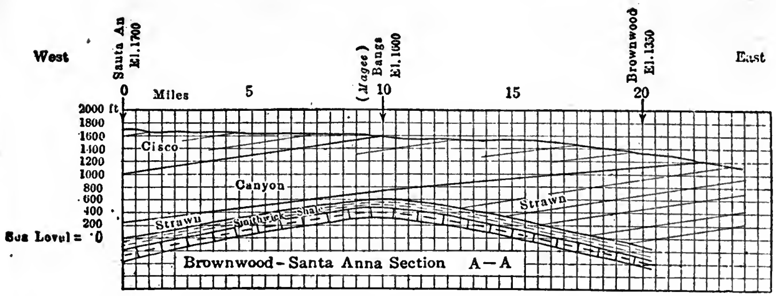

FIG. 147.—Section across southern part of Bend Arch, Texas, along line *A-A*, Fig. 146.

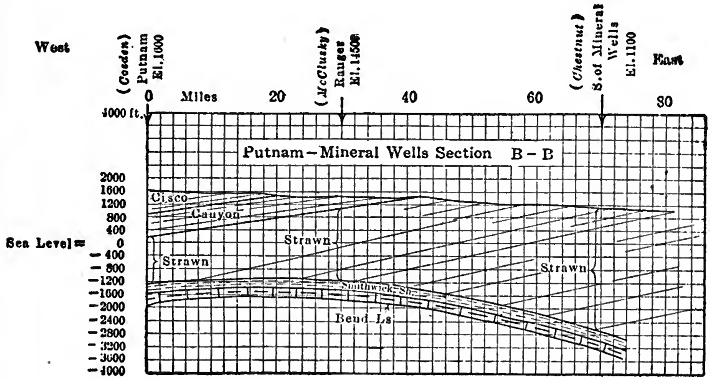

FIG. 148.—Section across northern part of Bend Arch, Texas, along line *B-B*, Fig. 146.

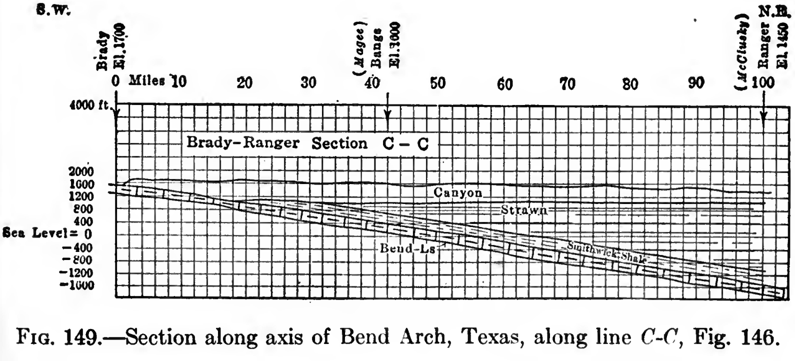

FIG. 149.—Section along axis of Bend Arch, Texas, along line *C-C*, Fig. 146.

Hager and others. Pratt[1] denies the existence of data showing the presence of the Bend arch farther north than Eastland County.

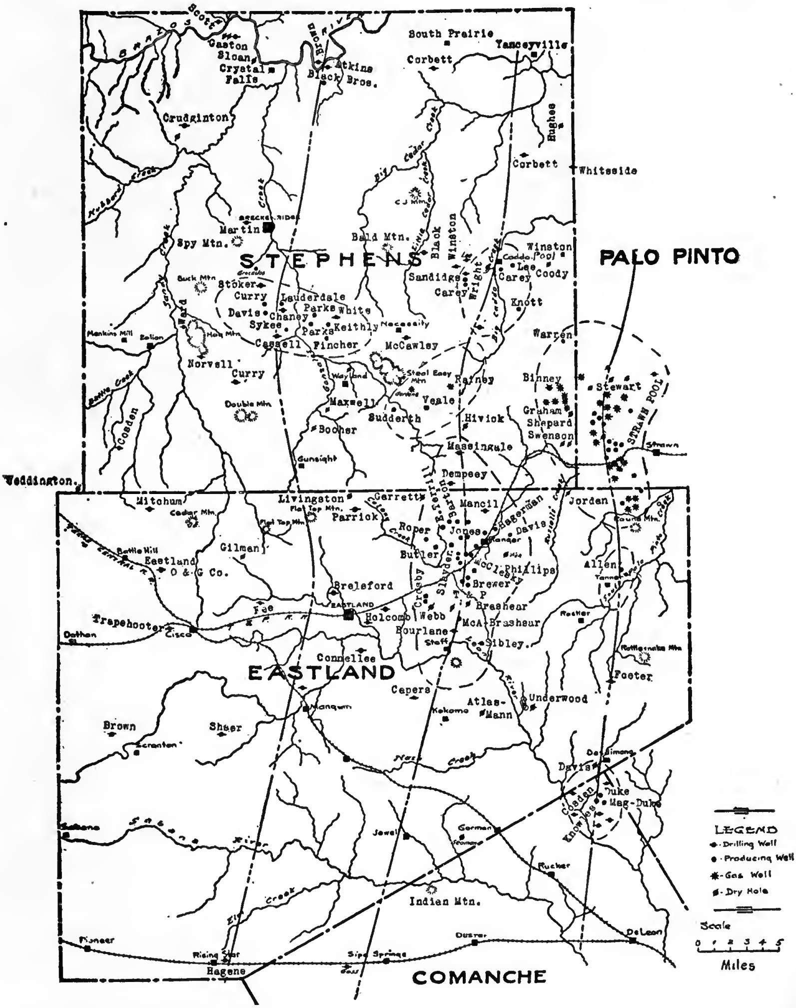

FIG. 150.—Sketch map of Eastland, Stephens and parts of adjoining counties, Texas, showing axes of oil and gas pools as interpreted by *Matteson.* Dashed outlines are not structural lines but indicate main oil-bearing areas as developed in spring of 1819. (*After Matteson.*)

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[1] PRATT, W. E.: Geologic Structures and Producing Areas in North Texas Petroleum Fields, with Discussion by HILL, SCHUCHERT, FULLER, CUMMINGS, BEAL, PEPPERBERG, and others. Am. Assoc. Pet. Geol. *Bull.* 3, pp. 45-70, 1919.

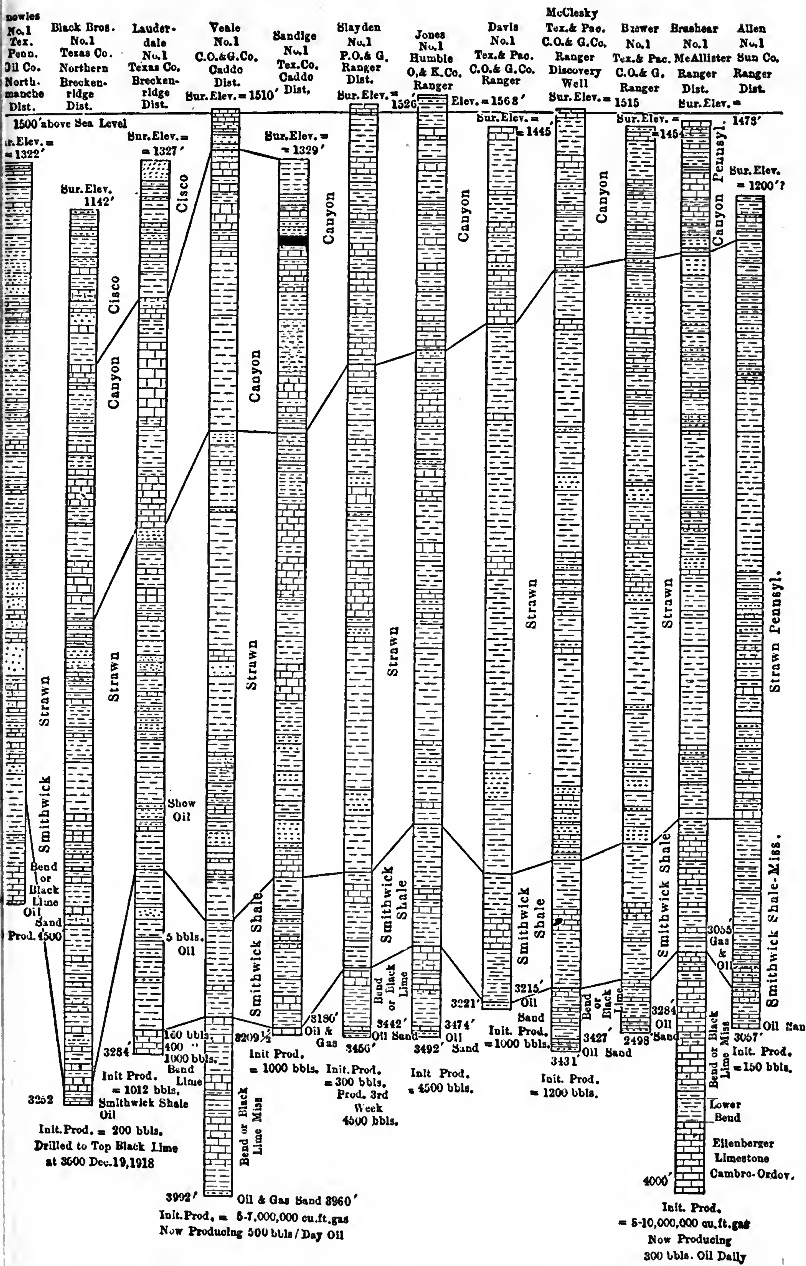

FIG. 151.—Logs of certain wells in north-central Texas fields. The terms "Marble Falls," "Black Lime," and "Bend Lime," are used synonymously (*after Mattison*) "Present Production" means Spring, 1919.

Briefly, the Ranger region is a broad monocline dipping northwestward, on which is superimposed the Bend arch, with its axis gently plunging north. At numerous places small wrinkles are found on the arch. Oil is concentrated below these wrinkles, especially below small open anticlines. Few of the anticlines close at the surface, but the folds become more acute below the surface, so that certain folds which do not close at the surface close in depth. Moreover, owing to the unconformities present, some folds found in depth may not be expressed at the surface, although those found at the surface are generally expressed in depth.

According to Matteson, the Bend arch is not marked by a single axis but consists of several closely spaced parallel folds. He states that in Stephens and Eastland Counties there are three axes (Fig. 150). On the east axis are the Strawn, Allen, and Duke pools. West of this and parallel to it is a second axis on which are the Caddo, Veale, and Ranger pools. Still farther west is a third axis on which are the well of Black Brothers, in the northern part of Stephens County, and the pool south of Breckinridge. Records of the Black well and other wells in this area are shown in Fig. 151.

There is little surficial evidence that petroleum exists in the strata underlying the area containing the Ranger and associated districts. Asphalt and oil seeps are rare or lacking. About 100 miles to the south, in the Llano-Burnet region, according to Paige, the Carboniferous strata have a strong petroliferous odor. A small oil seep in a spring near the town of Burnet has deposited at the surface asphaltic material in the cracks and interstices of the neighboring limestones. In Post Mountain also, just west of Burnet, a little oily residue is found about 20 feet above the base of the Cretaceous, and it is possible that oil has passed from the underlying Carboniferous into the porous Trinity sand and spread laterally.[1]

Oil is obtained at eight horizons in north-central Texas. Of these, according to Matteson,[2] one is at the base of the Canyon or top of the Strawn; another is in the middle of the Strawn; another comprises sand lenses in the Smithwick shale; another is at the contact between the Smithwick and the Marble Falls limestone; and below that are four sands included in the Marble Falls. These

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[1] Paige, Sidney: Mineral Resources of the Llano-Burnet Region, Texas. U. S. Geol. Survey *Bull.* 450, p. 93, 1911.

[2] *Econ. Geology,* vol. 14, pp. 132-134, 1919.

sands are probably lenticular, and different sands are productive in different wells. Slight structural irregularities on the surface, such as noses, terraces, and minor wrinkles, generally indicate more accentuated features at greater depths, and drilling them has frequently revealed oil. At some places drilling has revealed structural features that have no surface indications. Most of the wells yield gas, and in many of them the oil issues under high pressure. Salt water has been encountered in several wells. The initial production of many wells is large, and the oil is of exceptionally high grade.

Owing partly to the escape of gas in wells, the pressure has declined in this region. The absence of sufficient gas to force the oil into the borings has resulted in an exceptionally rapid decline in the yield of oil wells in some of the fields that were originally highly productive.

The oil at Ranger and in other central Texas fields is a high-grade, light gravity (34°-40° B.) crude oil of an olive-green color. An analysis[1] shows the following percentage of ingredients for Ranger crude:

Gravity 38.5° Baumé at 60° F.

Gasoline	22.0 per cent, 59.9° gravity
Naphthas	3.8 per cent, 52.3° gravity
Kerosene	21.8 per cent, 43.9° gravity
Residue (lubricating and fuel oil not separated)	52.0 per cent, 27.9° gravity

FIELDS EAST OF BALCONES FAULT

General Features.—The Balcones fault zone (Fig. 152) extends from Hunt County, northeastern Texas, southwestward to Bexar County, a distance of nearly 300 miles. The rocks involved are strata of the Lower and Upper Cretaceous series, of which a section is given on page 340. Oil or gas or both are found in the Navarro formation, Taylor marl, and Woodbine sand. In the Caddo field, Louisiana, the west edge of which extends into Marion County, Texas, much oil is obtained from the Woodbine sand. In some places in the Balcones region the Woodbine carries water that is only slightly saline but no oil.

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[1] Matteson, W. G.: *Op. cit.*, p. 131.

The fault zone, as stated by Hill,[1] consists of a number of nearly parallel step faults or small jogs, the aggregate displacement of

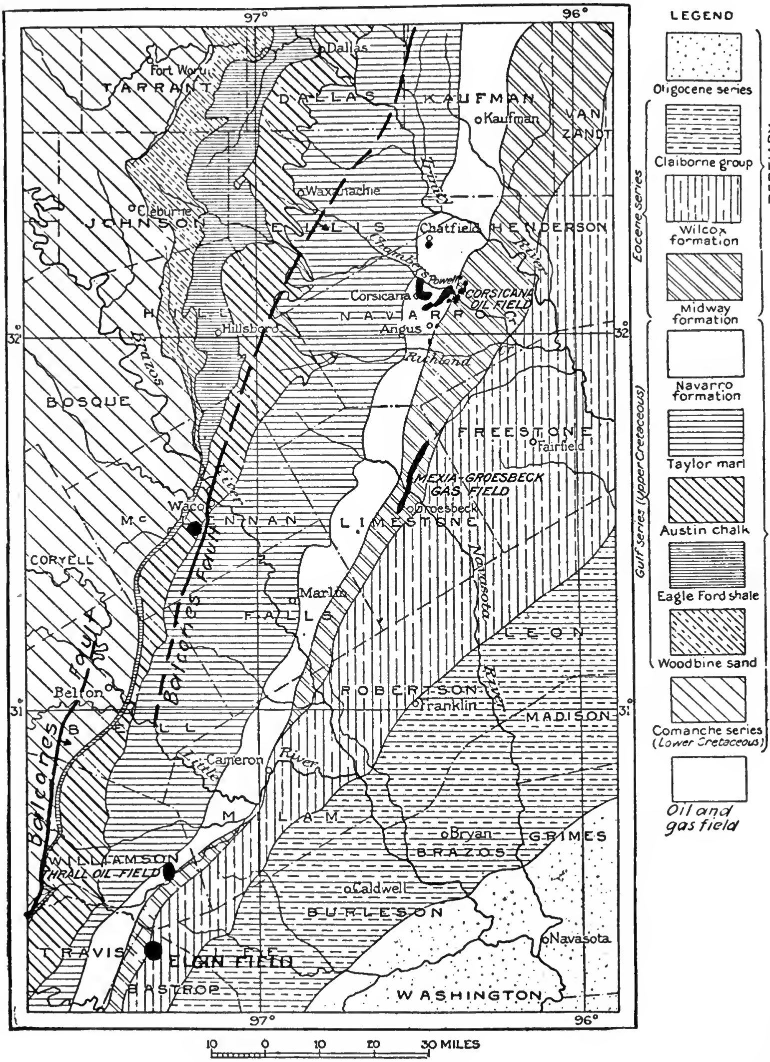

Fig. 152.—Sketch map showing part of Balcones fault region, Texas. (*Data from Hill, Matson, Hopkins and others.*)

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[1] Hill, R. T.: Geography and Geology of the Black and Grand Prairies, Texas. U. S. Geol. Survey *Twenty-first Ann. Rept.*, part 7, p. 382, 1901.

which attains a maximum of 1,000 feet. This zone is limited nearly everywhere on the west by a larger fault, which at Austin has a downthrow of nearly 500 feet. This zone is a number of short faults overlapping en échelon. The fault line from the Nueces River to the Brazos River marks the dividing line between the Black and Grand prairies. North of Waco it passes into the unconsolidated clays of the Black Prairie between Whitney and Aquilla.

The fault generally dips southeast, and the downthrow is on the southeast side. In the zone of deformation east of the fault there are small folds in which oil or gas or both are concentrated. In this zone is the Corsicana field, which embraces the Burke, Eden, Powell, and Chatfield pools and other small pools near by. South of the Corsicana field, in Limestone County, is the Mexia-Groesbeck gas field, west of which, in McLennan County, is the South Bosque field, and south of that the Thrall and Elgin fields. About 100 miles southwest of Elgin is a small field near San Antonio, where gas and heavy oil are found in the Nacatoch sand and the Annona chalk.

Corsicana Field.—The Corsicana oil and gas field,[1] in Navarro County, extends from Corsicana eastward to Powell and from the vicinity of Angus northward to Chatfield. Productive pools having an aggregate area of nearly 50 square miles have been developed in a field that measures 20 miles from north to south and 10 miles from east to west. Oil was first discovered in the city of Corsicana, in a search for water supply. The field was gradually extended eastward and has been productive since 1895.

A section showing the strata in this field is given below.

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[1] Matson, G. C., and Hopkins, O. B.: The Corsicana Oil and Gas Field, Texas. U. S. Geol. Survey *Bull.* 661, pp. 211-272, 1918.

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GENERALIZED SECTION OF FORMATIONS IN THE CORSICANA OIL AND GAS FIELD, TEXAS[a] (After Matson and Hopkins)

System	Series	Group	Formation	Thickness (Feet)	Character
Quaternary.	Recent.				Alluvial deposits along streams.
	Pleistocene.				Terrace deposits.
Tertiary.	Eocene.		Midway formation.	250–500	Micaceous sandy clays, fine argillaceous sands, and limestone concretions.
Cretaceous.	Gulf (Upper Cretaceous).		Navarro formation.	1,800–2,000	Light to dark gray calcareous clay, sandy clay, and fine lenticular beds of sand.
			Taylor marl.		Massive calcareous clay marl, little sand, and glauconite.
			Austin chalk.	400–500	Gray to white chalky limestone containing some hard beds.
			Eagle Ford shale.	300–400	Light to dark colored shale or clay and thinly laminated impure limestone.
			Woodbine sand.	400–450	Sand, sandy lignitic clay, sandstone, ferruginous sand, and clay.
	Comanche (Lower Cretaceous).	Washita.	Denison formation.	150–200	Clay and limestone.
			Fort Worth limestone.	25–75	Alternating beds of limestone and marl.
			Preston formation.	50–100	Calcareous laminated clays and impure limestone.
		Fredericksburg.	Edwards limestone.	300–400	White chalky limestones, variously indurated, and in places fine arenaceous beds.
			Comanche Peak limestone.		
			Walnut clay.	100–200	Calcareous clays and impure marly and chalky limestones.
		Trinity.	Paluxy sand.	125–200	Fine-grained sand and lenticular beds of clay.
			Glen Rose limestone.	300–500	Impure limestone, marl, and calcareous shales.
			Travis Peak sand.	250 ±	Conglomerate, sand, sandstone, shales, and impure limestones.

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[a] The formations below the Navarro formation crop out west of the Corsicana field and dip under it. The Upper Cretaceous formations have been penetrated by the drill in this field and are known from well records; the Lower Cretaceous formations have not been penetrated by the drill in this field but are known from outcrops and well records west of the field. The data relating to the Lower Cretaceous are taken largely from a report by R. T. HILL (Geography and Geology of the Black and Grand Prairies, Texas. U. S. Geol. Survey *Twenty-first Ann. Rept.*, part 7, 1901).

The oil and gas in the Corsicana field are obtained from the upper part of the Upper Cretaceous, the light oil and the gas in the Corsicana oil pool and in the Chatfield and Edens gas pools near by, probably coming from the Taylor marl and the heavy oil and the gas in the other pools from the Navarro formation. The relation of the oil and gas to the geologic structure varies from place to place; as stated by Matson and Hopkins accumulation is concentrated where there are well-developed anticlines, such as occur in some parts of the field that yield heavy oil. The distribution of oil and gas is also influenced by variations in the porosity of the sand, though these variations are not as numerous as in some other regions.

The strata in the Corsicana field dip in general to the southeast at a rate of 50 to 100 feet to the mile. The uniformity in direction and amount of dip is interrupted at a number of places by folds, none of which are continuous over large areas. The greatest dips observed on the folds are at the rate of 560 feet to the mile. The high dips are confined to small areas. The folds trend in two directions—one approximately parallel to the dip of the rocks and the other at right angles to it. There is no evidence of faulting.

The structure of the pool south of Chatfield shows an irregular anticline that trends northeast and is 2 miles long and about three-quarters of a mile wide. The dips on its flanks are as much as 2°. The accumulation of gas is in the crest of the anticline and is backed up on all sides by salt water.

The Witherspoon-McKie pool, southwest of Powell, lies along the crest of a low, flat-topped anticline that extends from the southeastern part of the Witherspoon tract southwestward 1½ miles to the McKie tract. The depth to the highest productive sand is 825 to 875 feet, and to the lowest (1918) about 100 feet more. Oil and gas were present only along the crest of the anticline, and water was troublesome over practically the entire pool. Gas was present originally in both the upper and lower sands, but more abundantly in the lower. All the wells at the north end of the pool have been invaded by salt water and abandoned.

The Burke pool, 1 mile south of Powell, is associated with the most pronounced fold that has been found in the Corsicana field. This fold, which is probably a shortened anticline or dome, has dips of about 185 feet to the mile to the northwest, southwest, and southeast. Oil occurs in the upper part of the fold, where the upper sand is from about 400 to 480 feet below sea level. Where the sand is more than 480 feet below sea level it is generally saturated with brine, although in that area a number of wells have yielded some oil.

Mexia-Groesbeck Field.—The Mexia-Groesbeck gas field is in the east-central part of Limestone County, Texas, where it occupies an area having an approximate length of 12¼ miles and an approximate width of 0.9 mile.[1]

Production began in 1912. Prior to the drilling of the first wells gas had been known in a few shallow water wells west of the field and had been exploited in the vicinity of Corsicana. Wells showing considerable volumes of gas had also been drilled between Corsicana and Mexia, but salt water interfered with development.

The wells in the Mexia-Groesbeck gas field pass through the lower Eocene Midway formation and penetrate a portion of the Upper Cretaceous Navarro formation. The Midway consists of clay, limestone, and sand. Layers of the limestone are exposed on eroded surfaces, and where the surface is level the successive layers form bands that are roughly parallel.

The upper part of the Navarro formation, which underlies the Midway, is composed of clays and shales with thin beds of sand and sandstone.

The gas sand of the Mexia-Groesbeck field is the Nacatoch sand member of the Navarro formation, correlated with the Nacatoch sand of northwestern Louisiana and southwestern Arkansas. The Nacatoch sand in the Mexia-Groesbeck field, as shown by C. E. Van Orstrand, contains from 16.6 to 34.2 per cent of pore space, with an average of 25.5 per cent, which would amount to 2,331,057,000 cubic feet for the entire field. Only a small part of that amount belongs to the undeveloped area, the largest part of it being in the developed areas. The entire pore space of the gas sand was probably occupied by gas, because the pressure when the field was first developed, 276 pounds to the square inch, was sufficient to force the gas into minute pores. The generally uniform decline of pressure throughout the field, as stated by Matson, indicates a uniformly porous rock.[2]

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[1] Matson, G. C.: Gas Prospects South and Southeast of Dallas. U. S. Geol. Survey *Bull.* 629, p. 87, 1916.

[2] Matson, G. C.: *Op. cit.*, p 92.

Thrall Field.—The Thrall oil field is about a mile southeast of Thrall, Williamson County, Texas.[1] Oil was discovered here in 1914 in a well sunk for water, and the district soon developed into a productive field. The outcropping rock is the Taylor marl of the Upper Cretaceous series, which dips east to southeast at 60 to 100 feet to the mile. The strata above the oil-bearing rock consist of shale and clay, with gypsum, calcite, glauconite, and marcasite. The oil-bearing formation is a porous, soft green rock found in the

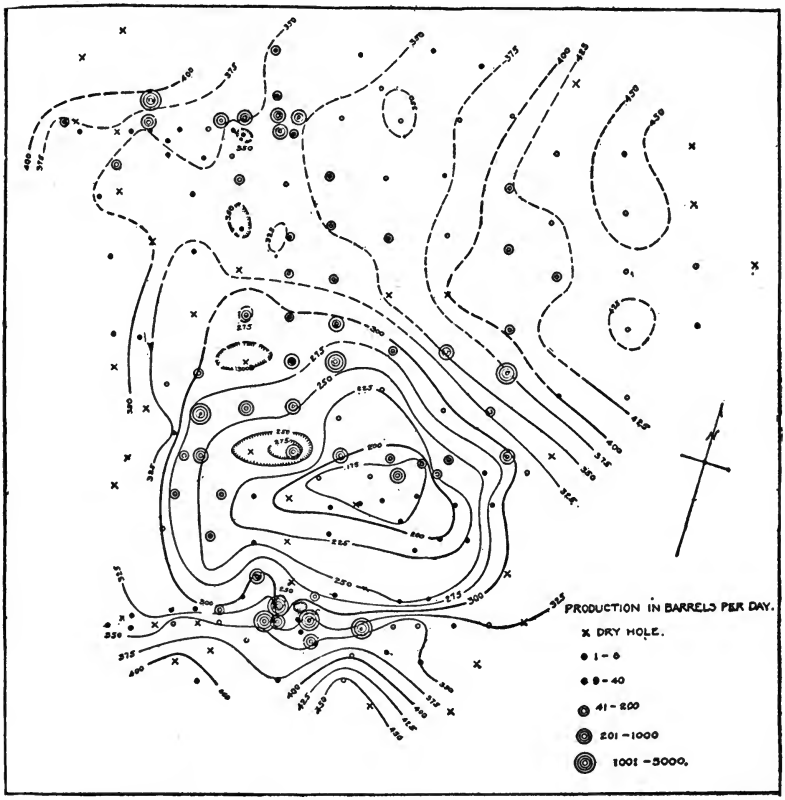

Fig. 153.—Sketch showing the distribution and production of wells, in the Thrall oil field, Texas. Contour lines show position of upper surface of oil-bearing rock in feet below sea level. (*After Udden and Bybee.*)

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[1] Udden, J. A., and Bybee, H. P.: The Thrall Oil Field. Texas Univ. *Bull.* 66, 1916.

Taylor marl at a depth of about 850 feet. It is brecciated and highly altered. Larsen,[1] who examined specimens microscopically, states that some specimens appear to be a fine-grained tuff.

The top of the petroliferous body is arched to form a dome, and the oil accumulation is related to the dome.

The oil is of low specific gravity and has a paraffin base. It is heavier but in many respects resembles the oil of the Corsicana field which comes from a sand in the Taylor marl.

Many of the wells in this field (Fig. 153) produced some gas, and the gushing of the wells is ascribed to gas pressure. The oil deposits paraffin rapidly in pipes and casing, so that wells become plugged with it and cease to yield until treated.

Initial Production of Seventy Wells in the Thrall Oil Field

Production (Barrels per Day)	Number of Wells
5,000 to 1,001	7
1,000 to 201	15
200 to 41	22
40 to 9	19
8 to 1	7

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[1] UDDEN, J. A., and BYBEE, H. P.: *Op. cit.*, p. 39.

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NORTHWESTERN LOUISIANA AND NORTHEASTERN TEXAS

General Features.—Northwestern Louisiana and northeastern Texas are covered with Tertiary and Quaternary deposits, which extend northward on both sides of the Mississippi River to Cairo, Illinois. The country is flat, and rock exposures are rare over considerable parts of the area. The rocks at the surface generally dip at low angles away from the older rocks that occur farther north. There is a gentle dip toward the Mississippi River, which is probably parallel to and not far from the axis of a gentle syncline or broad fluting on the monocline that dips south at a low angle. Superimposed on the monocline of the Mississippi embayment (Fig. 154) are long and relatively narrow zones of deformation marked by faulting or by folding. These zones probably extend for hundreds of miles, although they are not continuously exposed.

One of these zones of deformation is the Red River fault zone (Fig. 155). This zone, as stated by Hill,[1] consists principally of two nearly parallel major fault lines extending S. 60° E., or in a direction perpendicular to that of the Balcones fault zone. Their downthrows are in opposite directions, and between them is a strip or block of uplifted strata, as seen between Red River north of Denison and Cook Spring, to the south. The northern of these faults follows Red River from Marshalls Bluff, near Preston (old), to the northeast corner of Grayson County. Its downthrow is north, and it is occupied by Red River north of Denison. On the north side of Red River the beds from the Woodbine formation downward, are lowered. They face the Antlers sand and Goodland

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[1] HILL, R. T.: Geography and Geology of Black and Grand Prairies, Texas. U. S. Geol. Survey *Twenty-first Ann. Rept.*, part 7, p. 384, 1901.

limestone on the south. The downthrow at Preston is about 626 feet, and north of Denison it is 617 feet.

Nearly parallel to this fault and from 5 to 7 miles south of it is the Cook Spring fault. (See Fig. 155.) This fault line passes from the north edge of Grayson County south of east near Pottsboro and through Cook Spring. Its downthrow consists of several steps to the south and amounts to about 200 feet near Pottsboro. At 1½ miles northeast of Pottsboro the Dexter sands abruptly

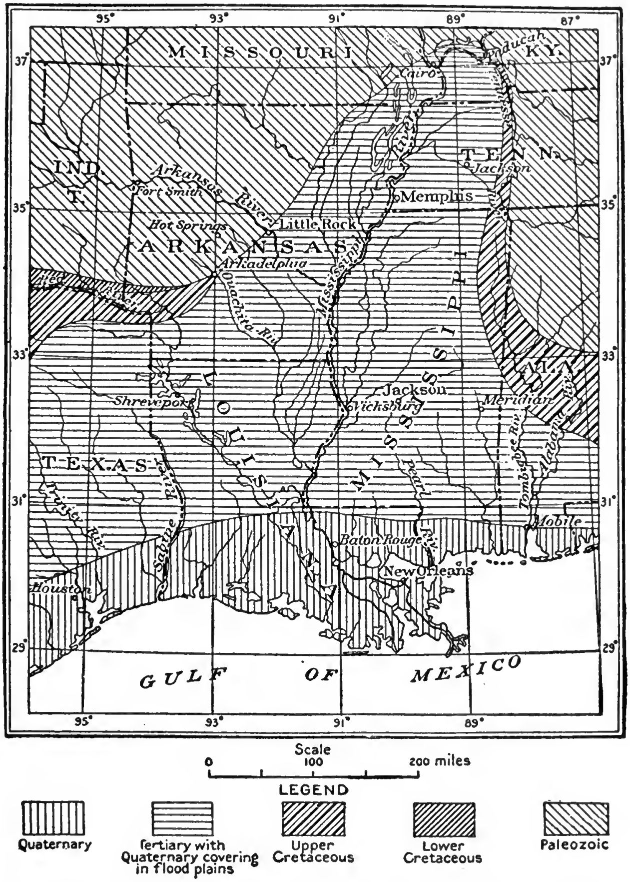

FIG. 154.—Map showing geology of the lower Mississippi valley. (*After Veatch.*)

terminate and the Eagle Ford clays are faulted down opposite the Fort Worth limestone and the basal Denison beds. In the northern part of Grayson County[1] the rocks are folded along an anticline having a generally similar strike. Possibly anticlines in Cotton and Jefferson Counties, Oklahoma, and the Devol anticline in the Grandfield area may belong to the same zone of deformation.[2]

In northwestern Louisiana the Red River zone of deformation is probably represented by a sharp flexure that dips north, away from the Sabine uplift. As mapped by Veatch this zone extends to the Mississippi River.

The Angelina flexure extends from Angelina County, Texas, northeastward into Louisiana and possibly to the Mississippi River. Along the flexure the rocks dip to the southeast at a high angle. Between the Red River zone of deformation and the Angelina flexure lies a great, broad dome—the Sabine uplift. From this dome the rocks dip northeast along the Red River zone of deformation, east to the Mississippi River, southeast along the Angelina flexure, and west in eastern Texas.

In this region deformation has taken place in late geologic time. According to Veatch, shoals on the Sabine River and a ridge across Angelina River are due to this flexure.[3] In the Wilcox formation of the Eocene, the rocks locally dip 10° or more.

Contour maps of the structure of the Sabine uplift, based on well logs, show that the dome has an undulating crest. Three anticlinal axes are noteworthy. These are approximately parallel and strike northeast. On the north one are the oil fields of Caddo Lake. The central axis lies near Shreveport and extends northeastward, passing through the Homer field. South of this is a third axis which is developed in the De Soto-Red River field. It practically coincides with the Gusher Bend fault of that field. High points along the crests of these folds are essentially in line,

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[1] STEPHENSON, L. W.: A Contribution to the Geology of Northeastern Texas and Southern Oklahoma. U. S. Geol. Survey *Prof. Paper* 120, pp. 129-163, 1919.

[2] MUNN, M. J.: Reconnaissance of the Grandfield District, Oklahoma. U. S. Geol. Survey *Bull.* 547, pp. 1-85, 1914.

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[3] VEATCH, A. C.: Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas. U. S. Geol. Survey *Prof. Paper* 46, p. 68, 1906.

suggesting a second series of folds striking northwestward across the axes of the northeast folds.

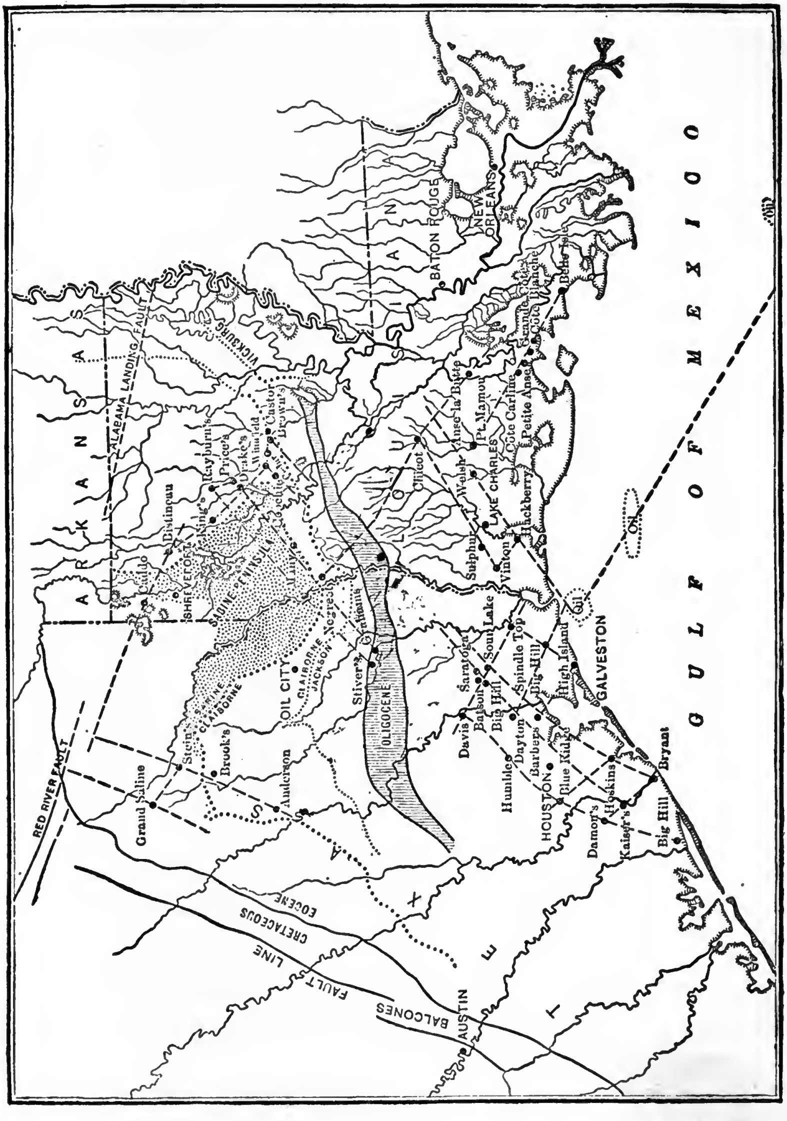

FIG. 155.—Map showing probable structural lines in Mississippi embayment region. (*After Harris.*)

The fields on the Sabine uplift that yield oil or gas or both include the Caddo, Shreveport, De Soto-Red River (Bull Bayou), Elm Grove, Pelican, Homer, Monroe, and others. (See Fig. 156.) The Caddo field yields gas and heavy oil from the Nacatoch sand and also from the Annona chalk of the Austin. It yields light oil (38° B.) from the Blossom sand member of the Eagle Ford clay and from the Woodbine sand. The Shreveport gas field yields gas from the Nacatoch. The Red River-De Soto gas field yields gas from the Nacatoch and much oil from the deeper sands near the bottom of the Upper Cretaceous. The Homer field probably yields oil from the same strata or from the Blossom. The Pelican field yields gas from the Nacatoch and oil from the Blossom. About 100 miles east of Shreveport, at Monroe, Ouachita Parish, Louisiana, a large gas field has recently been developed on a great anticline or dome. Practically all the fields yield gasoline, recovered from gas.

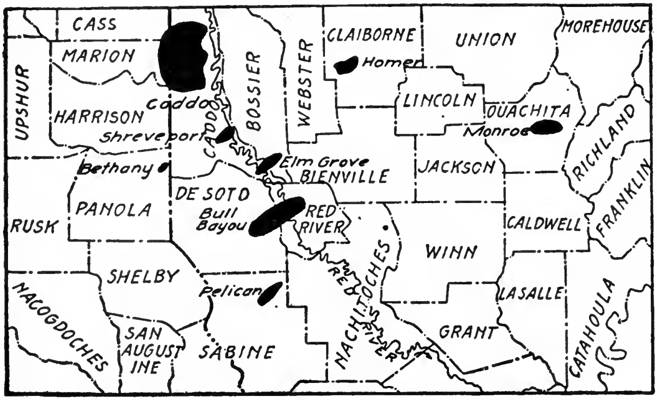

Fig. 156.—Sketch map showing oil and gas fields in northern Louisiana and northeastern Texas. Bethany, Shreveport, Elm Grove and Monroe are gas fields. Caddo, Homer, Bull Bayou and Pelican are oil fields.

The Nacatoch sand is porous over wide areas and is gas-bearing in all the large fields in northwestern Louisiana, as well as in the Balcones fault region, Texas. Its thickness ranges from 50 to 150 feet and averages 125 feet.

The oil in the deeper sands of the northern Louisiana fields is associated with much gas. Some of the wells are large gushers. Recently wells yielding 10,000 barrels a day have been brought in near Homer, on the east extension of the field. Salt water is found below the oil.

A section across this region is shown in Fig. 157.

Caddo Field.—The Caddo oil and gas field is northwest of Shreveport, mainly in Caddo Parish, Louisiana, and extends a short distance westward into Texas. The producing wells occupy an area extending northwestward from Mooringsport, Louisiana, for about 12 miles, and a long, narrow belt extending nearly 10 miles northeastward from the north end of the main field. Natural gas has been known at Shreveport for more than a quarter of a century, though its exploitation was not begun until 1912, after large gas-producing areas had been developed in the northern part of Caddo Parish.[1] The area south, near the city of Shreveport, produces gas and some oil.

The country is flat with small hills rising a few feet above the surface. These hills, according to Matson, are not structural features, but are probably the work of ants.

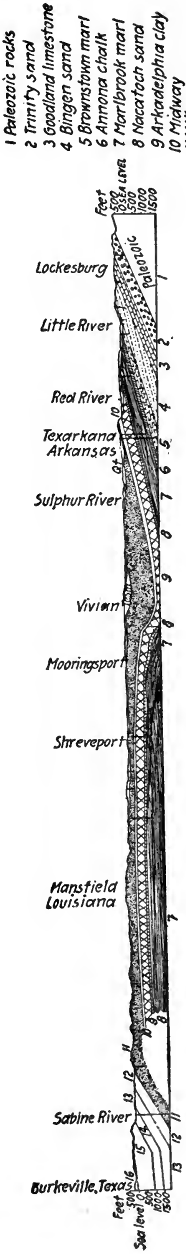

FIG. 157.—Section across portions of Arkansas, Texas and Louisiana (looking west.) (*After Harris.*)

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[1] HARRIS, G. D.: Oil and Gas in Louisiana. U. S. Geol. Survey *Bull.* 429, 1910.

MATSON, G. C.: The Caddo Oil and Gas Field, Louisiana and Texas. U. S. Geol. *Survey Bull.* 619, pp. 1-62, 1916.

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GEOLOGIC HISTORY OF NORTHERN LOUISIANA AND SOUTHERN ARKANSAS
(After Veatch)

Geologic Subdivisions			Characteristic Activities			
			Deposition		Degradation	Deformation
			Thickness, Feet	Character		
Quartenery.	Recent.	Alluvium.	0-20+	Veneer of sand, silt and clay on flood plains.	General degradation of the hill lands. Along Red River in Louisiana the resurrection of buried channels and the drainage of lakes produced by the "great raft." On the Sabine the partial wearing out of shoals produced by the recent movement of the Angelina-Caldwell flexure.	A slight upward movement at the west end of the Rockland-Vicksburg flexure is producing rapids on Sabine and Angelina rivers. A recent movement of 25 ft. along the line of the Red River-Alabama Landing fault has resulted in the swamping of Ouachita River Valley to a point above the mouth of Bayou Moro in Arkansas.
			0-25	Abnormal deposits of silt in Red River valley resulting from the obstruction by the "great raft."		
	Pleistocene.			Formation of natural mounds.	Partial removal of valley fillings and production of present flood plains and principal terraces.	After the main development of the Angelina-Caldwell flexure the beds were faulted along a line extending from a point near Denison, Texas, through Alabama Landing, Union Parish, Louisiana. The downthrow of this fault is to the north and the break approximately 600 feet.
		Port Hudson formation.	0-200	Marine deposits on the coast and fluviatile deposits in the river valleys, partly filling the broad valleys developed in the preceding erosion cycle.		
				Rearrangement of surficial sands and gravels at new levels as erosion progressed.	Long and complex period of erosion, with the land 100 ft. higher than today, in which the formations of the Coastal Plain were profoundly dissected and the major features of the present topography produced.	

GEOLOGIC HISTORY OF NORTHERN LOUISIANA AND SOUTHERN ARKANSAS—*Continued*

Geologic Subdivisions				Characteristic Activities				
				Deposition			Degradation	Deformation
				Thickness, Feet	Character			
Tertiary.	Pliocene.	Lafayette formation.		[a]0-50	A mantle of silt, sand, and gravel spread by combined marine and river action over the relatively even surface of the Coastal Plain and in the tributary valleys			
	Miocene.						A period of erosion, probably composed of several stages, in which the Coastal Plain in this region was essentially base-leveled.	The low fold which extends from the vicinity of Angelina County, Texas, to a point north of Vicksburg, Mississippi, and which is now a line of weakness, began to develop in late Oligocene or early Miocene time. North of this line the older beds are now nearly horizontal; to the south they dip at a rate of from 35 to 150 ft. per mile.
	Oligocene.	Fleming clay.		±260	Green calcareous clays, with a few brackish-water fossils.			
		Catahoula formation.		1,000-1,200	Near-shore deposits; sandstones occasionally quartzitic, and green clays, with fresh-water shells and land plants.			
		Vicksburg formation.		100-200	Limestones and calcareous, somewhat lignitiferous, clays, containing marine shells.			
	Eocene.[b]	Jackson formation.	Undifferentiated Eocene.[b]	200-550	Highly fossiliferous shallow-water marine sandy calcareous clay.			
		Cockfield member of Claiborne.[c]		400-500	Lignitiferous sands and clays, with land plants.	Landward these formations merge into lignitiferous sands and clays without distinctive marine fossils.		The domes developed during late Cretaceous and early Eocene time show a slight movement in post-Claiborne time, but the amount is very small when compared with the initial movements.
		Claiborne formation.		200-500	Fossiliferous sandy clay, containing shallow-water marine shells.			
		Sabine formation.		300-900	Lignitiferous sands and clays, with plants and occasional beds of marine shells.		Beds separated by a pronounced break in the fauna, which is, at present the only indication of a very serious break in sedimentation.	
		Midway formation.		20-260	Limestones and black calcareous clays.			

GEOLOGIC HISTORY OF NORTHERN LOUISIANA AND SOUTHERN ARKANSAS—*Concluded*

Geologic Subdivisions			Characteristic Activities			
			Deposition		Degradation	Deformation
			Thickness, Feet	Character		
Cretaceous.	Gulf series (upper Cretaceous).	Arkadelphia clay.	300-600	Black laminated clays, with marine fossils in lower portions.		The great north-and-south fault of the Coastal Plain of Texas (the Balcones fault) developed late in the Cretaceous. In Louisiana peculiar domes or four-sided folds were produced and reached their major development in the late Cretaceous or early Eocene. About the same time masses of igneous rocks of limited area were intruded into the Paleozoic rocks and Coastal Plain beds in southern Arkansas. In central Texas similar occurrences took place as early as the Austin epoch. The Louisiana and northeastern Texas domes are thought to be due to the upthrust of similar igneous intrusions.
		Nacatoch sand.	100-160	Sand, with occasional calcareous quartzitic layers containing marine shells.		
		Marlbrook formation.	150-750	Very calcareous clay, with marine fossils.		
		Annona chalk.	+100	White chalk.		
		Brownstown formation.	150-500	Blue calcareous clay, with marine fossils.		
		Bingen formation.	40-700 +	Lignitiferous sand and clays, with plant remains (Bingen formation).	The Bingen and Woodbine sands indicate deposits very near shore and the fauna changes sharply at this point, but there is no evidence of a pronounced unconformity or a land period of great length.	
		Sub-Clarksville sand.[d]	50-100	Water-bearing sand.		
		Eagle Ford clay.[d]	0-600	Blue calcareous clay. Some sand.		
		Woodbine formation.	+500	Lignitiferous sands and clays, with plant remains.		
	Comanche series, (lower Cretaceous).	Washita group.	0-400	Dark calcareous clays, with clayey limestone beds.		
		Goodland limestone.	25-30	Massive white limestone.		
		Trinity formation.	500-600	Yellow, somewhat argillaceous pack sands, changing to the east to calcareous clays, with thin beds of limestone and gypsum.		
Pre-Cretaceous.	An immensely long period composed of the following principal states in the order given: (1) deposition, (2) profound folding and faulting, (3) long erosion, which essentially base-leveled these folds. In this planed-off surface the Cretaceous beds were deposited.					

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[a] Normal thickness in northern Louisiana and southern Arkansas not known because of the wide spread and irregular deposition. In southern Louisiana these beds are much thicker than here given.

[b] The Jackson, Claiborne, and Sabine formations, which are fossiliferous and distinct in in central Louisiana, grade into lignitiferous beds containing no distinct fossils as they go northward. In the region under discussion the fossiliferous Jackson limits this lignitiferous complex above. Still farther north, however, the Jackson also grows lignitiferous and merges with the rest. The Midway, likewise, in the upper embayment region shows a decidedly lignitiferous tendency and may in places merge with the lignitiferous time equivalents of the other Eocene beds.

[c] A group without distinctive marine fossils, probably almost wholly of Claiborne age.

[d] These beds do not outcrop in the Arkansas area, except as they may be represented as littoral deposits in the upper part of the Bingen sand, and therefore need not be considered in wells drilled near the northern edge of the Brownstown formation; but they will be found farther south and must there be allowed for in well calculations.

Gas seeps have been noted in water pools and in Caddo Lake, and these led to drilling. Oil or gas or both are found in the Nacatoch sand, the Annona chalk, the Blossom sand member of the Eagle Ford clay, and the Woodbine sand. The oil is of high grade, some of it 38° B. or higher. Some of the oil issues in gushers.

In the Caddo field shallow anticlines and synclines are developed on the Sabine uplift, and smaller folds are superimposed on these. The oil and gas are concentrated in the elevated portions of the folds.

De Soto-Red River Field.—The De Soto-Red River field is about 50 miles south of the Caddo field. The rocks are of Eocene and Upper Cretaceous age. The formations present at Caddo are noted also in this field.[1] The principal oil sand is below the Brownstown marl, at depths between 2,450 and 2,750 feet. Gas and heavy oil are found in the Nacatoch sand, and light oil in the Blossom sand member of the Eagle Ford clay, which lies about 1,600 feet below the Nacatoch. It is not certain whether this is the Blossom or the Woodbine sand. It has been suggested that it may be older than the Woodbine.

A fault with a throw of 200 to 225 feet strikes northeast near the largest anticline. This is known as the Gusher Bend fault, from its occurrence near a bend in Red River where on a small dome numerous wells with large flow were drilled.

Pelican Field.—The Pelican field is about 50 miles south of Shreveport, in the northern part of Sabine Parish, Louisiana. The section is similar to that of the De Soto-Red River field, and the structure is domatic.

The Nacatoch sand is reached at a depth below sea level ranging from 900 feet in the northern part of the field to about 1,350 feet in the southern part. In this area it consists largely of hard sandy shale and sandstone with only a relatively small amount of loose sand. It has yielded gas and heavy oil.

The principal productive oil sand in this field is the Blossom sand, which occurs at a depth ranging from 2,800 feet in the northern part of the field to 3,200 feet in the southern part.

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[1] Matson, G. C., and Hopkins, O. B.: The De Soto-Red River Oil and Gas Field, Louisiana. U. S. Geol. Survey *Bull.* 661, pp. 101-140, 1918.

FORMATIONS OF GULF SERIES (UPPER CRETACEOUS) IN DE SOTO-RED RIVER OIL AND GAS FIELD, LOUISIANA

(After Matson and Hopkins)

Formation	Character	Oil or Gas	Range in Depth
Arkadelphia clay.	Stiff, gummy clay, with some sandy layers in lower part.		
Nacotch sand.	Sand, with some layers of clay and hard sandstone.	Prominent gas sand.	Top at 725-975 feet.
Marlbrook marl.	Shale or marl above; white chalk below.	Some oil, supposedly derived from lower formations through faults.	Top at 850–1,050 feet.
Annona chalk.	Chalk.		
Brownstown marl.	Probably marl and chalk above; shale and sandy shale, with some sand, below.		Showings of oil and gas below base of chalk.
Eagle Ford shale.	Shales, sands, and probably limestone beds.	Principal oil sand of field; also deep gas sand.[a]	Oil sand at 2,450–2,550 feet; deep gas sand at 2,650–2,750 feet.
Woodbine sand.	Not definitely recogstone beds.		

[a] Exact correlation uncertain; may be older than indicated.

Stephensville, Arkansas.—A fifty-barrel well was brought in near Stephensville, Ouachita County, Arkansas, in 1920. The oil is in a sand of the Upper Cretaceous, probably the Woodbine or the Blossom sand.

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VEATCH, A. C.: Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas. U. S. Geol. Survey *Prof. Paper* 46, pp. 1-422, 1906.

CHAPTER XVIII

PROSPECTS IN MISSISSIPPI, ALABAMA AND GEORGIA

Mississippi.—The Vicksburg-Jackson area[1] of Mississippi lies east of the Louisiana fields. The area is no more diversified topographically than other areas in the Coastal Plain where the maximum relief does not exceed 300 feet, the maximum elevation above sea level is not greater than 500 feet, and there are only slight differences in hardness of rocks. The main features are the broad, flat valleys that cross the region in general from north to south and the interstream tracts, which in the western part of the area are much dissected and have angular topographic features and in the eastern part are flat or rolling plains.

The city of Jackson is near the center of a broad, gentle fold, which shows a domelike arch in cross-section from northwest to southeast and a terrace-like form from northeast to southwest. Near the southwestern and southern parts of the anticline the dips are as much as 60 to 70 feet to the mile; in the northwestern and southwestern parts they are 30 feet or less to the mile. The northern extent of this fold has not been determined. No oil seeps are reported.

The presence of a porous stratum is probable, as sands approximately the equivalent of those that are productive in Louisiana, the Ripley and Tuscaloosa, are known to dip under this region, although their depth and nature in the Mississippi field are imperfectly known.

All the rocks of the Vicksburg-Jackson region are sedimentary in origin and relatively young, the exposed rocks ranging in age from Claiborne (Eocene) to Recent, as shown in the upper part of the following table. The formations below the Claiborne are below drainage level.

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[1] Hopkins, O. B.: Structure of the Vicksburg-Jackson Area, Mississippi U. S. Geol. Survey *Bull.* 641, pp. 93-120, 1917.

Crider, A. F.: Geology and Mineral Resources of Mississippi. U. S. Geol. Survey *Bull.* 283, 1906.

Crider, A. F.: Oil and Gas Possibilities in Mississippi. Southwestern Assoc. Pet. Geol. *Bull.* 1, pp. 152-155, 1917.

SECTION OF FORMATIONS IN VICKSBURG-JACKSON AREA

(After Hopkins)

System	Series	Group or Formation	Thickness	Character
			Feet	
Quaternary.	Recent.	Alluvium.	....	Sand, clay, and silt along present streams.
	Pleistocene.	Loess and yellow loam.	0–100	Clay, fine gray to buff, calcareous, and yellow to brown loam.
		Alluvial terrace deposits.	0–50	Sand, gravel, and clay.
Tertiary.	Pliocene.	Sand and gravel.	0–50	Terrace sand and gravel.
	Oligocene.	Catahoula sandstone.	0–75	Unconsolidated sands, sandstones, gray siliceous clay, and some lignitic material.
		Vicksburg limestone.	80–130	Marl and clay above, containing marine shells; limestone and impure limestone and marl below.
	Eocene.	Jackson formation.	250–500 (?)	Sand above, cross-bedded, green to yellow nonfossiliferous; gray clay weathering black below and sand beds at base. Both clay and sand beds contain marine shells.
		Claiborne group.	500–1,000	Marls, sands, lignitic clays, and lignite above; quartzite, clay stone, and marl below.
		Wilcox group.	850–1,500 (?)	Lignitic clays and sands, with sand predominating in middle part.
Cretaceous.	Upper.	Midway group.	100–300	Clay, dark gray to black, and micaceous sandstone, with hard limestone and sandy marl below.
		Ripley formation.	50–300	Sands, clays, marls, and impure limestones of marine origin.
		Selma chalk.	600–1,000	Chalky limestone with argillaceous and sandy beds.
		Eutaw formation.	300–400	Sands, massive and cross-bedded.
		Tuscaloosa formation.	100–300	Irregularly bedded sands, clays, and gravels, containing clay and lignitic layers at top.

Generalized Geologic Section of Western Alabama

Geologic Age	Group	Formation	Thickness	Character
			Feet	
Pliocene-Pleistocene.		Lafayette.	25	Gravel, sands, clays.
Lower Miocene.		Grand Gulf.	50	Soft sandstones and clays.
Lower Oligocene.		St. Stephens limestone.	300	Unusually soft limestone, easily cut with saw.
Eocene.	Claiborne.	Gosport greensand.	30	Glauconitic sands.
		Lisbon.	115	Calcareous clays and sandy clay.
		Tallahatta buhrstone.	400	Aluminous sandstones and siliceous clays.
	Chickasaw (Wilcox).	Hatchetigbee.	175	Sandy clays and cross-bedded sands.
		Bashi.	80	Sands and clays. Fossiliferous greensand.
		Tuscahoma.	140	Gray and yellow cross-bedded sands.
		Nanafalia.	200	Siliceous clays.
	Midway.	Naheola.	150	Gray sandy clays. Glauconitic clays.
		Sucarnochee clay.	100	Dark-brown clay.
		Clayton.	50	Impure limestone.
Upper Cretaceous.		Ripley.	300	Calcareous and siliceous sands.
		Selma chalk.	950	Argillaceous limestones.
		Eutaw sands.	500	Glauconitic sands, cross-bedded.
		Tuscaloosa.	1,000	Irregular bedded sands, clays, and gravels.

Alabama.—Gas and some oil have been discovered in the Pennsylvanian series in northwestern Alabama (see p. 247), but the production has not been large. In southern Alabama, according to Hager,[1] there are several localities where oil may possibly be found in the Cretaceous beds.

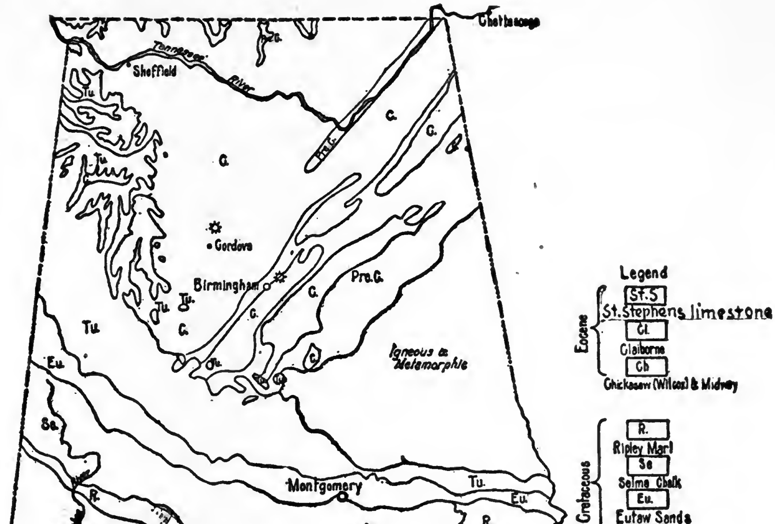

FIG. 158.—Index map of Alabama showing position of anticlines in the southern part of the State. (*After Hager.*)

The Hatchetigbee fold (see Fig. 158), recently described by Hop-

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[1] HAGER, DORSEY: Possible Oil and Gas Fields in the Cretaceous Beds of Alabama. Am. Inst. Min. Eng. *Bull.* 134, pp. 469-476, 1918.

kins,[1] also by Hager, runs in a general southeasterly direction through portions of Choctaw, Clarke and Washington Counties and is about 20 miles long and 4 to 5 miles wide. Along the axis the Hatchetigbee formation crops out. This formation is about 550 feet lower stratigraphically than the St. Stephens limestone, which crops out on all sides of the fold. The reversal is not much less than 500 feet. The pitch of the strata away from the axis of the anticline ranges from 1° to nearly 2°.

The Jackson anticline is in all probability a part of the same fold as the Hatchetigbee anticline. Along the axis of the Jackson anticline, rocks of the Claiborne group are exposed, and the reversal is not much less than that of the Hatchetigbee anticline, from which this fold is separated by a saddle.

Toward the east, according to Hager, no marked folding is noted until Geneva County is reached. In an area near Geneva, covering possibly 20 square miles, the Claiborne rocks are exposed at the surface, with the St. Stephens limestone surrounding them. The reversal on this fold is probably more than 100 feet. In this area exposures are meager, owing to the covering of the Grand Gulf and Lafayette formations.

East of Geneva, near Gordon, there is another anticlinal fold, on the Georgia State line. It has a reversal of 40 feet and covers 10 square miles.

The formations that are regarded by Hager as possible sources of the oil or gas are the Ripley, the Eutaw (Tombigbee sand), and the Tuscaloosa (Woodbine sand).

A well on the Hatchetigbee anticline is reported to have had showings of gas at 750 and 1,500 feet and of oil at 2,250 feet. The 750-foot gas horizon is probably in the Ripley formation, and the 1,500-foot horizon is in the Selma chalk. The oil at 2,250 feet is below the Selma chalk and probably in the Eutaw sands.[2]

Georgia.—A seep of petroleum was reported to be found in 1919 about 1 mile south of Scotland, Telfair County, Georgia.[3] The

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[1] Hopkins, O. B.: Oil and Gas Possibilities of the Hatchetigbee Anticline, Alabama. U. S. Geol. Survey *Bull.* 661, pp. 281-313, 1918.

[2] Hager, Dorsey: *Op. cit.*, p. 475.

[3] Veatch, Otto, and Stephenson, L. W.: Preliminary Report on the Geology of the Coastal Plain of Georgia. Georgia Geol. Survey *Bull.* 26, pp. 60-61, 1911.

Hull, J. P. D., and Teas, L. P.: Oil Prospect Near Scotland, Telfair County, Georgia. Georgia Geol. Survey, pp. 3-5, 1919.

surface deposits throughout the interstream areas in this region consist of 100 feet or less of irregularly bedded sandy clays and sands with subordinate interbedded layers of argillaceous sandstone. They are underlain by 100 feet or more of soft sandy clays and sands, in part water-bearing, with interbedded thin layers of sandstone and quartzite that belong to the Alum Bluff formation. The Alum Bluff formation is underlain by 500 feet or more of limestone with interbedded layers of calcareous sandstone and marl, which probably represent in descending order the Chattahoochee and Vicksburg formations of the Oligocene and perhaps the Jackson formation of the Eocene. These formations contain water-bearing beds. Beneath the limestones are sediments of Eocene and Cretaceous age, which probably have an aggregate thickness of 1,500 feet or more and which rest upon a basement of ancient crystalline rocks. These also contain important water-bearing beds.

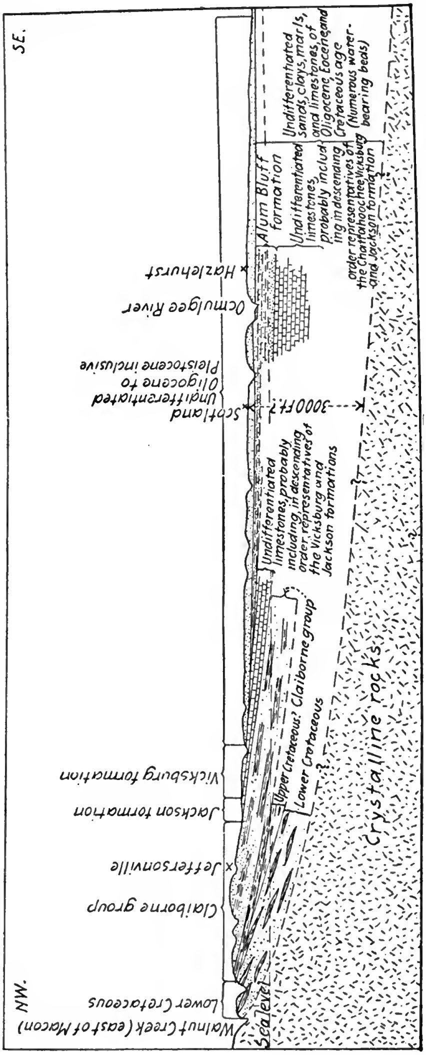

FIG. 159.—Geologic section from point near Macon, Georgia, southeastward through Scotland. (*After Stephenson.*)

The dip of the beds is southeastward and increases with the age of the beds from 4 to 5 feet to about 30 feet to the mile. The general stratigraphic relations of the formations are shown in Fig. 159.

Examination of the underlying rocks where they come to the surface about 75 miles north of Scotland shows them to be largely of marine origin, with remnants of plant and animal life. These rocks belong to the Cretaceous system, which is oil-bearing in Louisiana and Texas.

It is not yet determined whether there is any favorable structure in the area.

CHAPTER XIX

GULF COAST FIELDS OF TEXAS AND LOUISIANA

Eastern Texas and Louisiana are underlain by Mesozoic and Cenozoic rocks, which crop out as broad belts in which the younger rocks lie successively nearer the sea. The younger beds extend farther north in the region of the Mississippi River than east or west of it. Structurally the region has been characterized as a gently pitching trough with its axis lying along the river. The beds in general dip at very low angles, though locally they are sharply flexed.[1]

The country is approximately flat, and details of structure are derived principally from drill holes. At many places low mounds or hills rise above the generally level plain. On some of these there are small lakes from which gas bubbles escape. Sulphur, sulphur dioxide, sulphuric acid, saline water, gas, oil, asphalt, or "paraffin dirt" are sought for as evidences of oil-bearing areas. These indications are found also at some places where there is no mound or rise of the land. Drilling has shown that cores of salt with petroliferous beds underlie many of the mounds or the other places where one or more of the indications noted above are present. The distribution of the salt domes is shown by Fig. 160. A cross-section of a dome is shown by Fig. 42, p. 136. Some of them are described below.

At Spindletop, in southern Texas, about 3 miles south of Beau-

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[1] Harris, G. D.: Oil and Gas in Louisiana, with a Brief Summary of Their Occurrence in Adjacent States. U. S. Geol. Survey *Bull.* 429, 1910.

Fenneman, N. M.: Oil Fields of Texas and Louisiana Gulf Coastal Plain. U. S. Geol. Survey *Bull.* 282, 1906.

Deussen, Alexander: Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain. U. S. Geol. Survey *Water-Supply Paper* 335, 1914.

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Hayes, C. W., and Kennedy, William: Oil Fields of the Texas-Louisiana Gulf Coastal Plain. U. S. Geol. Survey *Bull.* 212, 1903.

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CENOZOIC DEPOSITS OF THE TEXAS COASTAL PLAIN
(After Deussen)

System	Series	Formation	Thickness	Lithology and Characteristic Fossils	
			Feet		
Quaternary	Recent.		0–50	Fluviatile deposits, consisting of brown, red, or black sandy clay or silt of the low, overflow terraces of the streams; flood-plain materials, including sand and gravel bars. Recent buffalo bones, etc. Seaward, these fluvatile deposits grade into interstream deposits consisting of yellow and blue clays and yellow wave-formed sand, sand and shell beaches, bars, and barriers, carrying *Rangia cuneata* and other fossils.	
	Pleistocene.	Beaumont clay.	800 max.	Blue, calcareous clay, with numerous lime concretions about 1 inch through. Lenses of sand and sandy clay. The clays carry *Rangia cuneata*, etc.; embedded logs are common.	Farther inland the Lissie gravel and Beaumont clay are represented along the stream valleys by the lowest and the middle of the three Pleistocene terraces.
		Lissie gravel.	Thin to 900	Gravels and coarse sands, with some small lenses and pockets of red clay in places; limy clays, gravels, and limy conglomerates or "adobe" in others. The fossils include *Equus semiplicatus*, Megalonyx, etc.	
		–Unconformity–			
		Highest Pleistocene terrace (farther inland).	0–50	Fluviatile deposits consisting of granitic gravels in and adjacent to certain drainage areas; flints, limestone débris, and limy conglomerates in others; ferruginous sands and silts, with fragments of iron ore, in still others. In the stream valleys these materials appear as terracés lying 200 to 225 feet above the level of the present stream channels, and grading laterally into an inter-stream or upland phase veneering the uplands with a sheet of gravel where the Yegua and Jackson formations constitute the country rock, but thinning and disappearing south of the Yegua-Catahoula or the Jackson-Catahoula boundary. No fossils.	
		–Unconformity–			
Tertiary	Pliocene.	Uvalde formation (late Pliocene).	0–100	Fluviatile deposits, consisting of flint gravel and limestone débris embedded in a clay matrix. In the plateau region west of the Coastal Plain the the formation appears as the uppermost terrace of the major streams, lying about 350 feet above the levels of the present stream channels. Along the Cretaceous-Tertiary boundary, the terraces grade laterally into an upland gravel deposit, which caps the interstream areas, but thins and disappears a distance to east and south.	

CENOZOIC DEPOSITS OF THE TEXAS COASTAL PLAIN—*Continued*

System	Series	Formation		Thickness	Lithology and Characteristic Fossils
Tertiary	Miocene.	-Unconformity-		Feet	
		Dewitt formation.[a]		1,250–1,500	Lacustrine and littoral deposits, consisting of cross-bedded, coarse, gray, semi-indurated, highly calcareous sandstones. Lenses of clay in places. *Aceratherium* and other fossils. East of the Brazos these beds are almost completely overlapped by the Lissie gravel. Seaward, the time equivalent of the Dewitt formation is represented by about 800 feet of marine sands and clays, carrying *Arca carolinensis* and other upper Miocene marine fossils and believed to involve some of the lower Pliocene. These marine deposits do not outcrop and are not a part of the lacustrine Dewitt formation, which also includes some deposits of early Pliocene age.
		Fleming clay.		200–500	Palustrine deposits, consisting of gray, white, and bluish-white, bedded, calcareous clays, with numerous small concretions of lime and some lenses of sand.
	Oligocene.	-Unconformity-			
	Eocene.	Catahoula sandstone.		500–800	Littoral deposits, consisting of hard, blue, semi-quartzitic, noncalcareous sandstones, with interbedded lenticular masses of green clays.
		Jackson formation.[c]		0–250	Marine deposits, consisting of calcareous blue clays, with large limestone concretions. Carry *Levifusus branneri* and other Eocene forms.
		Claiborne group.	Yegua formation.	375–750	Palustrine deposits, consisting of green clays with concretions of selenite; in places, lenses of sand and lignite.
			Cook Mountain formation.	400	Palustrine and marine deposits, consisting of lenticular masses of yellow sand and clay; in places, lenses of green calcareous, glauconitic, fossiliferous marl. Beds of limonite and lignite. Some of the clays carry fossiliferous calcareous concretions. Formation as a whole is decidedly ferruginous. Fossils: *Ostrea sellaeformis*, *Ostrea divaricata*, *Anomia ephippioides*, and others.
			Mount Selman formation.	350	Palustrine and marine deposits, consisting of red, ferruginous, indurated, and probably altered greensand, with casts of shells, lenses of lignite and clay, beds and concretions of limonite. The formation as a whole is conspicuously ferruginous. Carries casts of *Venericardia planicosta*.

CENOZOIC DEPOSITS OF THE TEXAS COASTAL PLAIN—*Concluded*

System	Series	Formation	Thickness	Lithology and Characteristic Fossils
			Feet	
Tertiary	Eocene.	Wilcox formation	800–1,100	Palustrine, marine, and littoral deposits. The littoral deposits comprise the Queen City sand member, at the top of the formation, consisting of 50 to 200 feet of white, porous, loose, water-bearing sands, with some interstratified clays. The palustrine deposits consist of lenticular masses of sand, clay, and lignite, carrying large, especially characteristic concretions (20 to 30 feet in diameter) of hard flintlike sandstone; the palustrine clays are leaf bearing, and in places carry teeth of *Crocodylus grypus*. The marine deposits consist of calcareous, glauconitic, fossiliferous marls, alternating with beds of sand, clay, and lignite; they are exposed only on Sabine River. Characteristic fossils of the marine phase are *Kellia prima*, *Natica aperta*, and *Pleurotoma silicata*.
		Midway formation.	250–500	Marine deposits, consisting of black and blue clays with interbedded strata of limestone and some lenses of sand, which are somewhat rare north of the Brazos. *Plejona limopsis*, *Enclimatoceras ulrichi*, and other fossils.

[a] What is here called the Dewitt formation is probably represented along the Sabine by the beds described as the Fleming clay.

mont,[1] a low mound covering about 225 acres rises some 15 feet above the surrounding flat country. Gas escapes in shallow pools of water, and these with sulphur incrustations in the soil were noted by A. F. Lucas. Prospecting for sulphur led to the sinking of the Lucas well, which at 1,139 feet proved to be one of the greatest gushers drilled in the United States, yielding 75,000 barrels a day. Other wells, closely spaced, were then sunk, and the field rapidly became very productive and very rapidly declined. The beds are Tertiary or later. The drill holes encounter about 1,000 feet of clay, sand, and gravel. In the lower portion of this series some limestone is found. A 20-foot bed of porous limestone below this series carries the oil. Below the porous limestone is a thick body of gypsum and rock salt; pyrite and sulphur abound. Some oil

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[1] FENNEMAN, N. M.: Oil Fields of the Texas-Louisiana Gulf Coastal Plain. U. S. Geol. Survey *Bull.* 282, pp. 1-146, 1906.

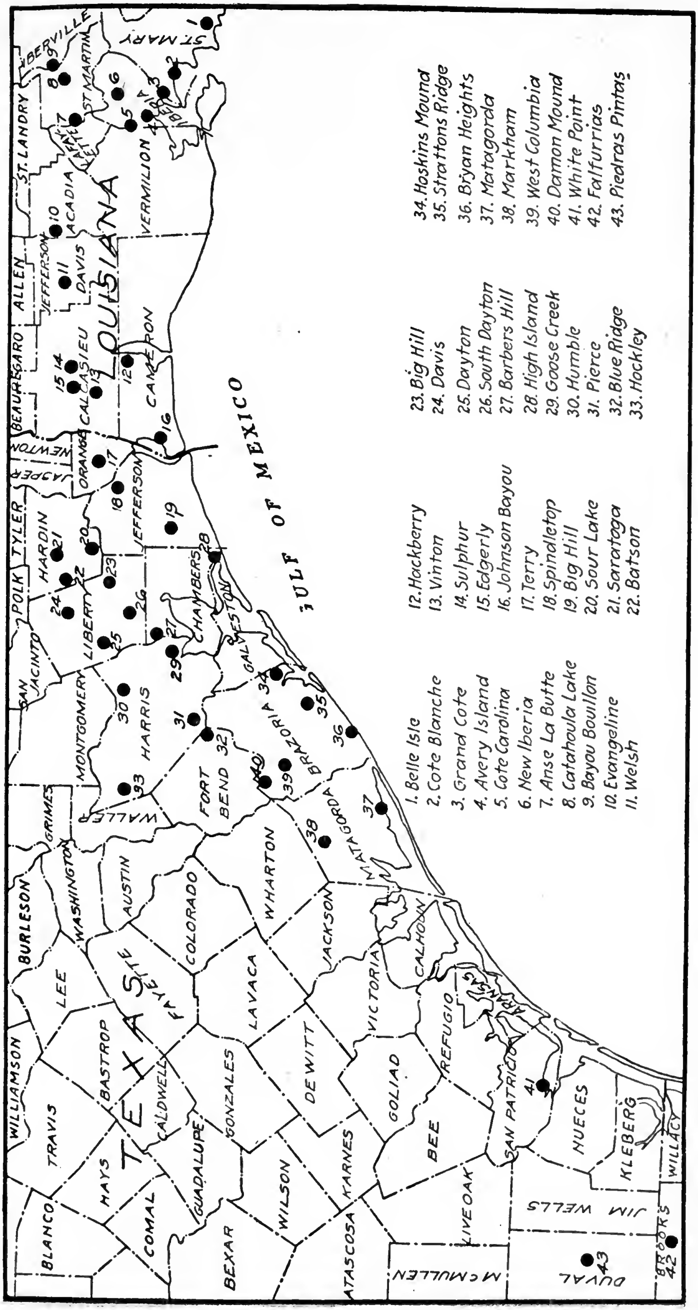

Fig. 160.—Sketch map showing locations of certain salt domes and probable salt domes in Texas, Louisiana coast region.

has been obtained also from sands above the main limestone horizon. The structure of the area is domatic. According to Fenneman, there is an arching of about 200 feet in 4,000.

At Sour Lake, 20 miles northwest of Beaumont, gas, oil, asphalt, and sour water at the surface led to drilling. The production, 8,000,000 barrels in 1903, rapidly declined. The wells encountered 1,600 feet of clays and sands, probably Eocene and Miocene, with some limestone and oil; salt and gypsum appeared below the clay. Deep drilling brought in heavy production again in 1915.

At Saratoga, 12 miles northwest of Sour Lake, gas, oil, and acid waters were noted at the surface. The general features are said to be similar to those at Sour Lake.

At Batson, 7 miles southwest of Saratoga, drilling was done on account of gas bubbles that were observed to rise from pools on a flat country.

At Dayton, about 25 miles southwest of Batson, gas escapes in springs. Below clays and sands about 600 feet deep limestone was encountered, and below the limestone salt and gypsum.

Humble, about 25 miles west of Dayton and 18 miles northeast of Houston, is a highly productive field. An escape of gas led to drilling a hill on a low ridge, and a strong flow of oil was encountered at about 1,200 feet. Recently deep drilling has brought in a large production on flanks of the dome.

At the West Columbia[1] dome, Brazoria County, Texas, wells yielding as high as 30,000 barrels were brought in July, 1920. The surface rises 18 feet above the surrounding country. Barren wells, sunk near the top of the dome, penetrated clay, the limestone cap rock, then salt. The cap rock is not productive. The first well was found on the southeast side of the dome, about 2,700 feet deep, in sands that rested against the steep slope of the salt dome.

At Goose Creek in Harris County, Texas, oil has been found in sands from 1,000 to 3,400 feet deep. No salt nor cap rock has been penetrated. It is not known whether the structure is domatic or not. Some of the wells yield as much as 3,000 barrels a day.

Damon Mound is one of the most conspicuous of the surficial mounds in the Gulf coast region, and the sulphur outcrops and gas showings attracted attention immediately after the discovery of Spindletop in 1901. Several wells were drilled at different points

[1] Segall, Julius: Oral Communication.

on the hill in 1901-1903. These encountered oil and salt and other typical dome materials[1] but were unprofitable. In 1917 a gas well came in with an estimated open flow of 10,000,000 cubic feet. The sand was apparently encountered at a depth of 1,447 feet. This well after being brought under control yielded gas for two months and then oil, about 5,000 barrels daily.

The Evangeline oil field,[2] which has been very productive, is about 6 miles northeast of Jennings, Louisiana. In this field there is a broad erosional depression about 10 feet above sea level, which occupies the side of a low mound some 32 feet above the sea. The productive area is about 1 square mile. Here, as at Spindletop, Texas, gas escaped from a spring in the mound. Because of the surface features, which are similar to those of Spindletop, a well was sunk and struck oil at a depth of 1,822 feet. The beds are Miocene and Quaternary. Little limestone is present. The domatic structure is not so clearly shown as at Spindletop. According to Harris the oil has come up along a strong fault fissure.

At Anse la Butte, Louisiana, gas bubbling on a small depression led to the development of a gusher. Structurally the area is probably a steep dome.

At Welsh gas bubbling in a well led to sinking a hole that developed a small oil area.

The New Iberia district[3] is in Iberia Parish, Louisiana, on Tete Bayou, about 6 miles east of New Iberia. Pronounced escapes of petroleum gas and so-called "paraffin beds" were discovered in this vicinity in the summer of 1916, and these showings led to drilling and discovery. The production to 1918 was small.

The origin of the structure of the Gulf coast fields is one of the most perplexing problems in geology. Perhaps the most widely credited theory is that of Harris,[4] who attributes the doming up to the force of crystallization. He maintains that salt water rose along faults and fissures and solidified, pushing up and doming the weak clays. This force has been recognized by Becker and has

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[1] Hayes, C. W., and Kennedy, William: *Op. cit.*

Deussen, Alexander: A Review of Developments in the Gulf Coast Country. Am. Assoc. Pet. Geol. *Bull.*, vol. 2, pp. 16-37, 1918.

[2] Harris, G. D.: *Op. cit.*, p. 50. Fenneman, N. M.: *Op. cit.*, p. 100.

[3] Deussen, Alexander: Review of Developments in the Gulf Coast Country. Am. Assoc. Pet. Geol. *Bull.*, vol. 2, pp. 16-37, 1918..

[4] Harris, G. D.: Oil and Gas in Louisiana. U. S. Geol. Survey *Bull.* 429, pp. 1-192, 1910.

LOG OF BOLIVAR NO. 1 WELL OF NEW IBERIA OIL CO., NEW IBERIA, LOUISIANA
(After Deussen)

	Thickness	Depth
	Feet	Feet
Blue surface clay	70	70
Gray sand; gas	110	180
Water gravel	225	405
Crust of sand rock	1	406
Soft gumbo and boulders	29	435
Hard gumbo	44	479
Hard gumbo	58	537
Packed sand	153	690
Crystallized sand; pyrite	36	726
Soft gumbo; streaks of crystallized sand and pyrite	44	770
Hard gumbo	29	799
Hard gumbo	22	821
Hard gumbo	29	850
Crystallized sand	20	870
Hard gumbo	66	936
Dry sand; gas	4	940
Very hard gumbo	8	948
Oil sand	12	960
Hard blue gumbo	3	963
Hard gumbo	45	1,008
Sandstone; pyrite, oil and gas	17	1,025
Hard black gumbo	18	1,043
Sandstone; pyrite, oil and gas	27	1,070
Hard sandrock	2	1,072
Cap rock	6	1,078

been recently discussed by Taber[1] in connection with metalliferous deposits. Not all investigators have accepted this theory. Norton[2] has come to the conclusion that the domes represent loci of hot solutions containing lime carbonate, sodium chloride, lime sulphate, etc., ascending through channels opened by faulting and depositing at the surface great masses of travertine and calcareous sinter at the time the sedimentary rocks were being deposited.

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[1] TABER, STEPHEN: Pressure Phenomena Accompanying the Growth of Crystals. Nat. Acad. Sci. *Proc.*, vol. 3, pp. 297-302, 1917.

[2] NORTON, E. G.: Origin of Louisiana and East Texas Salines. Am. Inst. Min. Eng. *Trans.*, vol. 51, pp. 502-513, 1915.

Later they were covered up, and as compacting and subsidence took place the strata sagged away from the hard cores, while at the same time oil was concentrated along bedding planes, rising in the sandy or limy beds to the tops of the domes which were obviously above the old salt deposits.

As many of the domes, at least, show quaquaversal structure, it is assumed that in this field the occurrences of salt and oil are generally in quaquaversals. However, there are many Gulf districts in which the dome structure has not been proved, and some where the principal structural features appear to be faults. There is a fairly uniform occurrence of limestone or dolomite above the salt and gypsum; indeed, in many districts it is this fractured dolomite that carries the oil. Its stratigraphic position suggests that the limestone is a sedimentary rock. One would not expect materials deposited from hot water at the surface of the earth to be as regularly layered as these. Nor does it seem probable that fissures in the soft clay capping of these zones would have let out salt water in sufficient quantities to deposit such enormous amounts of salt. Moreover, if they had, and if the water could have escaped, it would seem probable that the oil would have escaped also. It is improbable that crystals would thrust up hundreds or thousands of feet of sedimentary rock and not fill the great cavities which were left in the limestone that carries the oil. Solutions move to points of less pressure and by deposition fill any available openings already formed. These cavities had not been filled with salt, otherwise they could not have served as containers for the oil.

The domes of the Gulf Coast country have recently been discussed by Deussen,[1] who recognizes three classes—shallow domes, domes of medium depth, and deep-seated domes. In the shallow domes the cap rock lies within 500 or 600 feet of the surface, and salt within 700 or 800 feet. Most of them are accompanied by superficial mounds, except where the mounds have been eroded. There is usually a little oil in the cap rock, but these domes as a rule are not very profitable commercially. They include Damon Mound, Pierce Junction, Blue Ridge, Hoskins Mound, Barber Hill and South Dayton.

The domes of medium depth have a cap rock about 1,000 to 1,200 feet below the surface, and salt at 1,200 to 1,600 feet. The mounds are not pronounced. The cap rock contains much oil; usually

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[1] DEUSSEN, ALEXANDER: Am. Assoc. Pet. Geol. *Bull.*, vol. 2, pp. 16-37, 1918.

gushers are developed in these domes. They include Spindletop, Humble, Sour Lake, and Saratoga.

The deep-seated domes have been drilled as deep as 3,000 feet, but no cap rock and salt have been encountered. Overlying mounds are absent. The oil produced in these domes comes from sands above the level of the cap rock, possibly leaking out of it. The deep-seated domes include Goose Creek, Edgerly, Terry, and Welch. These may be simply anticlines, or there may be underlying salt domes that supply oil to the sands.

A grouping of the wells of these three classes shows that the shallow ones and those of medium depth occur near together, and that the deeper ones lie southeast of the shallow ones, indicating a dip of the rock south and toward the Mississippi River. The persistence of limestone above the salt suggests that many of the deposits are at the same stratigraphic horizon. It is not unlikely that these salt beds are simply in anticlines and faulted flexures formed when the rocks of the region were less consolidated than they are now. The salt was probably folded and became thicker at the crests of anticlines, just as has been observed on the Englen anticline, at Stassfurt, and in other deposits of Germany.[1] The limestone, being stronger than the mud or clay, probably broke up into blocks, and the shattered limestone supplied reservoirs for the oil.

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[1] Van der Gracht, W. A. I. M. V. W.: The Saline Domes of Northwestern Europe. Southwestern Assoc. Pet. Geol. *Bull.*, vol. 1, pp. 85-92, 1917.

Rogers, G. S.: Intrusive Origin of Gulf Coast Salt Domes. *Econ. Geology*, vol. 13, pp. 447-485, 1918.

Geology + Oil + Coal [illegible]
Oregon Basin W.
D.F. Hewett U.S.G.S. prof. pap. # 145 - 1927

CHAPTER XX

ROCKY MOUNTAIN FIELDS

WYOMING

General Features.—Wyoming is made up of lofty mountain ranges and intermontane basins. In the northern part of the State there are three great anticlinal ranges, between which lie two great synclinal basins. The Black Hills, in the northeast corner, extend into Wyoming from South Dakota; west of them is the Big Horn Range; and west of it the Shoshone range of Yellowstone Park. Southwest of the Big Horn Mountains and nearly parallel to them is the Wind River Range. The Front Range, known in Wyoming as the Laramie Range, occupies a large area in the southeast quarter of the State. In the southwest corner is the Teton Range, about parallel to the Wasatch Range of northern Utah. The Owl Creek Mountains lie southeast of the Shoshone Mountains. In the central and southern part of the State are the Rattlesnake and Sweetwater mountains.

The mountains are, in the main, anticlinal folds, the tops of which are eroded, so that in some of them the strata from the pre-Cambrian to the Tertiary are exposed (Fig. 161). On the flanks of the mountain folds and in the interiors of the basins there are many subordinate folds, and on these are the principal oil fields. There are altogether more than 100 anticlines and domes (Fig. 162). Many of these have been drilled without yielding oil or gas. About a score have proved productive, and more than half of these have produced oil and gas in considerable quantities. Noteworthy among them are the Salt Creek, Grass Creek, Big Muddy, Greybull, Basin, Elk Basin, Pilot Butte, Byron, Rock River, Lost Soldier, Lance Creek, and Buck Creek fields.

A considerable part of Wyoming is underlain by Cretaceous beds, and these have supplied nearly all the oil produced. The principal productive strata of the Cretaceous are in the Colorado group, which includes the chief oil-producing sands in central Wyoming and in the Big Horn Basin. In the region north of Lusk, oil has been produced recently from the Muddy sand, a

Petroleum Marketed in the Rocky Mountain Field in 1916 and 1917, in Barrels

Year	1916			
	Colorado	Wyoming	Montana	Total
1916	197,235	6,234,137	44,917	6,476,289
1917	121,231	8,978,680	99,399	9,199,310

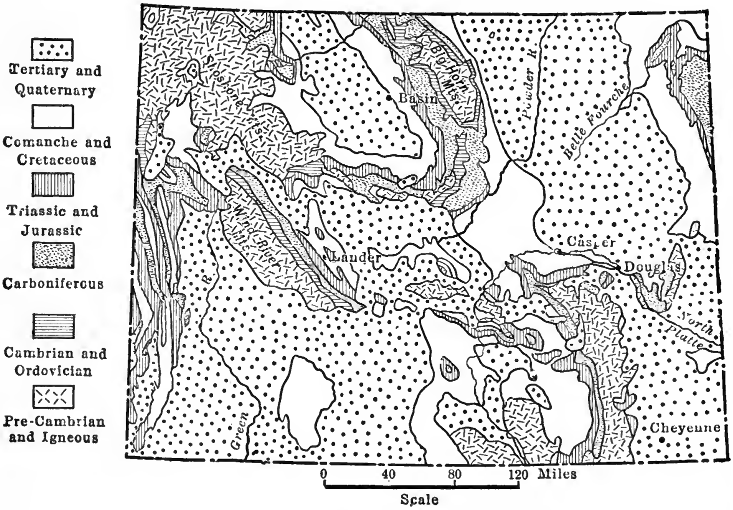

Fig. 161.—Sketch map of Wyoming.

short distance below the Mowry. Heavy black oil is found in the Embar of the Permian and Pennsylvanian. All the reservoir rocks are sandstones, except the Embar, which is a porous limestone. The saturation of the rocks is lower than in Oklahoma, and the folds are steeper.

With a few exceptions only closed folds yield noteworthy amounts of oil. The closed folds are mainly domes. In one or two localities oil occurs in fault traps. In the Upton-Thornton field the oil is on a terrace. A considerable number of plunging anticlines, terraces, and monoclines of low dip have been drilled, however, without finding oil.

The oil of the Douglas field, which is not very productive, has probably accumulated at or near an unconformity between steeply tilted Cretaceous rocks and flat-lying Tertiary beds. The Labarge and Spring Valley fields, in the southwestern part of the State, are along faults. None of these fields have produced much oil. Oil seeps are common, one or more being present in at least twelve of the fields.

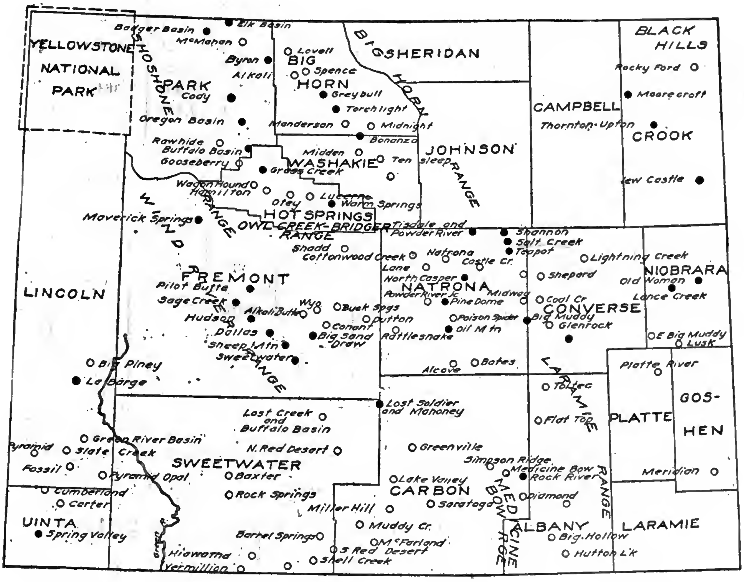

FIG. 162.—Map of Wyoming showing position of certain oil and gas pools (black dots) and prospects (circles.)

The water on which the oil floats is not all saline, although high salinity is noteworthy in parts of the Salt Creek field. The low salinity in the Grass Creek field is unusual for a productive field. Fresh water below the oil in the same strata generally suggests communication with superficial sources, a condition which may permit leakage of oil and gas. A little water, not highly saline, is found at a depth of 2,700 feet in a faulted area on the west edge of the Salt Creek dome. The strata dip steeply toward the Salt Creek field. Water circulating down the dip and rising in a fractured area would sweep the oil sand free of brine above that area.

PETROLEUM MARKETED, VALUE, AND AVERAGE PRICE PER BARREL IN WYOMING, 1914-1917, BY DISTRICTS

Year	Big Horn			Fremont			Natrona		
	Quantity (Barrels)	Value	Average Price per Barrel	Quantity (Barrels)	Value	Average Price per Barrel	Quantity (Barrels)	Value	Average Price per Barrel
1914	96,178	$96,178	$1.00	27,395	$21,362	$0,780	3,421,325	$1,541,494	$0.451
1915......	140,978	133,457	.946	27,660	15,051	.544	3,971,128	1,985,564	.500
1916......	139,854	150,884	1.079	62,564	87,275	1.395	3,933,403	3,363,364	.855
1917......	62,040	101,549	1.637	49,797	31,113	.625	3,910,511	3,723,291	.952

Year	Hot Springs			Park			Converse		
	Quantity (Barrels)	Value	Average Price per Barrel	Quantity (Barrels)	Value	Average Price per Barrel	Quantity (Barrels)	Value	Average Price per Barrel
1914......	....	....	......	....	....	......	(a)	(a)	......
1915......	98,723	$74,126	$0.751	....	....	......	(a)	(a)	......
1916......	1,369,807	1,336,840	.976	720,988	$695,571	$0.965	(a)	(a)	......
1917......	2,756,402	4,190,774	1.523	1,530,264	2,266,794	1.481	665,432	$726,738	$1.092

Year	Other Counties			Total		
	Quantity (Barrels)	Value	Average Price per Barrel	Quantity (Barrels)	Value	Average Price per Barrel
1914..........................	[b]15,477	[b]$20,158	$1.302	3,560,375	$1,679,192	$0.472
1915..........................	[c]7,038	[c]8,820	1.254	4,245,525	2,217,018	.522
1916..........................	[d]7,521	[d]10,146	1.349	6,234,137	5,644,080	.905
1917..........................	[e]4,234	[e]7,617	1.780	8,978,680	11,047,876	1.230

[a] Included in "Other Counties."
[b] Converse, Crook, and Uinta Counties.
[c] Converse, Park, and Uinta Counties.
[d] Converse and Uinta Counties.
[e] Uinta County.

SECTIONS SHOWING OCCURRENCES OF OIL AND GAS IN SOME OF THE ROCKY MOUNTAIN FIELDS

(After Hares. Correlations Approximate and Incomplete)
o, oil; g, gas; +, seeps or small production of oil or gas

System or Series	Spring Valley and Labarge[a]	Grass Creek[b] and Oregon Basin	Shoshone River.[b]	Greybull[c]
Tertiary.	Wasatch. +o.	Wasatch.	Wasatch.	
	Evanston.	Fort Union.	Fort Union.	Fort Union.
Tertiary (?).		Lance.	Ilo (Lance).	Ilo.
Cretaceous (Montana).	Adaville.	Meeteetse.	Meeteetse.	Montana, undifferentiated.
		Mesaverde.	Gebo.	Eagle.
				Pierre.
	Hilliard.	Cody.		
Cretaceous (Colorado).			Colorado.	Basin.
	Frontier. o.	Frontier. o.		Benton. Torchlight. Peay. o. g.
			+	
			+	
	Aspen. o.	Mowry.	o.	
		Thermopolis. g.	o.	
Cretaceous.	Bear River. o.	Cloverly.	"Cloverly." g.	Cloverly. o. g. Greybull.
	Beckwith.			
Cretaceous (?).		Morrison.	Morrison. g.	Morrison.
Jurassic.	Twin Creek.		Sundance.	
Triassic. Permian. Pennsylvanian.				

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[a] VEATCH, A. C.: Geography and Geology of a Portion of Southwestern Wyoming, with Special Reference to Coal and Oil. U. S. Geol. Survey *Prof. Paper* 56, pp. 157-158, 1907. SCHULTZ, A. R.: The Labarge Oil Field, Central Uinta County, Wyoming. U. S. Geol. Survey *Bull.* 340, p. 364, 1908.

[b] HEWETT, D. F.: The Shoshone River Section, Wyoming. U. S. Geol. Survey *Bull.* 541, pp. 89-113, 1914, and unpublished data.

[c] HINTZE, F. F.: Basin and Greybull Oil and Gas Fields. Wyoming State Geologist's Office *Bull.* 10, p. 40, 1914 (1915).

Fig. 162 is an outline map showing the position of the principal mountain ranges, the oil and gas fields, and certain domes or other

SECTIONS SHOWING OCCURRENCE OF OIL AND GAS IN SOME OF THE ROCKY MOUNTAIN FIELDS—*Continued*

(After Hares. Correlations Approximate and Sections Incomplete)

o, oil; g, gas; +, seeps or small production of oil or gas

System or Series	Big Horn Basin[d]	Lander[e]	Wyoming[f]	Central Wyoming[g]
Tertiary.	Wasatch Wind River White River			White River. +
		Wind River.	Wasatch. +	Wind River. +?
	Undifferentiated Fort Union and Lance.	Absent or concealed.	Laramie. Fort Union.	Fort Union.
				Lance.
Cretaceous (Montana).		[h]	Fox Hills.	Lewis.
	Mesaverde.	Mesaverde.		Mesaverde. Teapot. + Parkman.
	Cody.	Mancos.	Fort Pierre.	Steele. Shannon.
Cretaceous (Colorado).			Niobrara.	Niobrara.
				Carlile.
	Frontier. Torchlight. + + Peay. +g.		+	Frontier. Wall Creek. + + Peay. +
	Mowry. +o.	+o.	Fort Benton.	Mowry.
	Thermopolis. +			Thermopolis.
Cretaceous.	Cloverly.	Dakota.	Dakota. +	Dakota +
		Lower Cretaceous (?).	+	Lower Cretaceous. Shale. Conglomerate. +
Cretaceous (?).	Morrison.	Morrison.	Como.	Morrison. +
Jurassic.	Sundance	Sundance.	Shirley.	Sundance. +
Triassic.	Chugwater	Chugwater. +o.	Triassic.	Chugwater. +
Permian.	Embar	Embar. o.	Permian.	Embar.
Pennsylvanian.	Tensleep Amsden		Carboniferous.	Tensleep. +
				Amsden.
Mississippian	Madison			Madison.

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[d] LUPTON, C. T.: Oil and Gas Near Basin, Big Horn County, Wyoming. U. S. Geol. Survey *Bull*. 621, pp. 157-190, 1916.

[e] WOODRUFF, E. G.: The Lander Oil Field, Fremont County, Wyoming. U. S. Geol. Survey *Bull*. 452, 1911.

[f] KNIGHT, W. C.: A Preliminary Report on the Artesian Basins of Wyoming. Wyoming Univ. Exper. Sta. *Bull*. 45, 1900. KNIGHT, W. C., and SLOSSON, E. E.: The Dutton, Rattlesnake, Arago, Oil Mountain, and Powder River Oil Fields. Wyoming Univ. School of Mines, Petroleum ser., *Bull*. 4, 1901.

[g] HARES, C. J.: Anticlines in Central Wyoming. U. S. Geol. Survey *Bull*. 646, pp. 233-279, 1917.

[h] In a later paper (U. S. Geol. Survey *Bull*. 656, 1917) HEWETT and LUPTON place the Meeteetse above the Mesaverde.

SECTIONS SHOWING OCCURRENCE OF OIL AND GAS IN SOME OF THE ROCKY MOUNTAIN FIELDS—*Concluded*

(After Hares. Correlations Approximate and Sections Incomplete)

o, oil; g, gas; +, seeps or small production of oil or gas

System or Series	Salt Creek and Powder River[i]	Douglas[j]	Moorcroft and Newcastle[k]	Boulder, Colorado[l]	Florence, Colorado[m]
Tertiary.		White River, o. g.			
	Fort Union.	Fort Union.			
Tertiary (?).	Lance.	Lance.			Laramie (?).
Cretaceous (Montana).	Fox Hills.	Fox Hills.	Fox Hills.	Fox Hills.	Trinidad. (?).
	Pierre. Parkman. Shannon. o.	Pierre. Parkman (?). Shannon (?). +	Pierre.	Pierre. Hygiene. o. g. o.	Pierre. o.
Cretaceous (Colorado)	Niobrara. o.	Niobrara.	Niobrara.	Niobrara. o.	Niobrara.
	Benton. Wall Creek. o.	Benton. +o. g. Wall Creek (?).	Carlile.	Benton. o.?	Carlile.
			Greenhorn.		Greenhorn.
	Mowry. +	Mowry. (o?)	Graneros. Mowry. o.		Graneros.
Cretaceous.	Dakota (?). +	"Cloverly." o. +	Dakota. +	Dakota.	"Dakota." +
			Fuson. +		
			Lakota.		
Cretaceous(?).	Morrison. +	Morrison.	Morrison.	Morrison.	Morrison. +
Jurassic.	Sundance. +	Sundance.	Sundance.		
Triassic.		Chugwater.			
				Lykins.	
Carboniferous.		Forelle (?). Satanka (?). + Casper.		Lyons. Fountain.	

[i] WEGEMANN, C. H.: The Salt Creek Oil Field, Natrona County, Wyoming. U. S. Geol. Survey *Bull.* 452, pp. 37-83, 1911; The Powder River Oil Field, Wyoming. U. S. Geol. Survey *Bull.* 471, pp. 56-75, 1912. Compare with later and more detailed correlations, page — and —.

[j] BARNETT, V. H.: The Douglas Oil and Gas Field, Converse County, Wyoming. U. S. Geol. Survey *Bull.* 541, pp. 49-88, 1914.

[k] BARNETT, V. H.: The Moorcroft Oil Field and Big Muddy Dome, Wyoming. U. S. Geol. Survey *Bull.* 581, pp. 83-117, 1914. DARTON, N. H.: Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains. U. S. Geol. Survey *Prof. Paper* 32, pp. 334, 364, 379-388, 1905.

[l] FENNEMAN, N. M.: Geology of the Boulder District, Colorado. U. S. Geol. Survey *Bull.* 265, pp. 76-98, 1905.

[m] WASHBURNE, C. W.: The Florence Oil Field, Colorado. U. S. Geol. Survey *Bull.* 381, pp. 517-544, 1910.

structural features that are barren or have not yet been fully tested. A number of fields yield gas or gas with relatively little oil. The gas fields include Oregon Basin, Buffalo Basin, Bonanza, Big Sand Draw, Sweetwater, Sheep Mountain. Oil Mountain, Pine Dome and North Casper.

Salt Creek.—The Salt Creek field[1] is about 40 miles north of Casper and includes a productive area of 7 square miles. It is the most productive field in Wyoming and yields a high-grade paraffin oil, greatly prized on account of its gasoline content. Indications of oil in the Salt Creek field include several oil and gas seeps in shale, deposits of ozokerite along fault planes in shale, and oil seeps from the Shannon sandstone. Several oil and gas seeps from the shale were known prior to the drilling of the discovery well in the Salt Creek anticline.

Oil is found in four sands—the Shannon, of the Montana; and the first Wall Creek, second Wall Creek, and third Wall Creek of the Colorado. Each of these sandstones is capped by shale. The dominant feature of the structure is a broad anticline 18 miles long and about 6 miles wide on which there are two broad domes—the Salt Creek dome and the Teapot dome. The east limb of the anticline has a gradual dip, the west limb is more abrupt. Several faults strike across the domes; most of them are normal faults and have displacements ranging from 5 to 100 feet. Some thrust faults are present.

The wells produce both oil and gas. Some are gushers. On three sides of the Salt Creek dome (Fig. 37, p. 131) the variation in position of the oil is not over 50 feet, but on the north end, as stated by Wegemann, the oil extends downward about 150 feet lower, probably because the gathering area was greater in that direction. The oil is under pressure, and much gas is dissolved in it rather than segregated in pools above the oil.

Oil has been found also in the second Wall Creek sand, which is about 25 feet thick and lies 250 feet below the first Wall Creek sand. Wegemann states that the productive area in this sand is probably larger than the productive area in the first Wall Creek sand. In nearly all wells drilled in the Salt Creek field some oil is encountered in shale. (See p. 157.)

The Teapot dome, to the south, is included in a naval reserve.

At the crest of the dome the first Wall Creek sand is reached at a depth of about 1,000 feet. The first Wall Creek sand is about

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[1] Wegemann, C. H.: The Salt Creek Oil Field, Wyoming. U. S. Geol. Survey *Bull.* 670, 1917; also *Bull.* 452, pp. 37-84, 1911.

FORMATIONS IN SALT CREEK OIL FIELD, WYOMING
(After Wegemann)

System	Series	Group	Formation		Character	Thickness (Feet)
Tertiary.	Eocene.		Wasatch formation.		Yellow sandstone, gray shale and coal.	2,400
			Fort Union formation.		Fine-grained bluish-white sandstone and gray shale.	2,000
Tertiary (?)	(?)		Lance formation.		Concretionary buff sandstone and shale.	3,200
Cretaceous.	Upper Cretaceous.	Montana.	Lewis shale with thick sandstone at top and another sandstone in middle.		Sandstone, white to brown, and gray shale.	1,400
			Mesaverde formation, including Parkman, and Teapot sandstone members.		Shale, sandstone, thin coal beds.	845
			Steele shale, including Shannon sandstone member. Carries oil.		Buff sandstone and gray shale.	2,275
		Colorado.	Niobrara shale.		Light-colored shale, in parts somewhat arenaceous.	735
			Benton shale.		Dark shale.	220
				Wall Creek sandstone member and lower sands with interbedded shale. Carry oil.	Buff to white sandstone and gray shale.	685
					Dark shale.	250
				Mowry shale member.	Firm slaty shale, usually forming escarpment. Weathers light gray and bears fish scales.	280
					Dark shale.	205
	Lower Cretaceous.		Cloverly formation.		Thin sandstone and dark shale.	150
					Conglomerate.	
Cretaceous (?)	(?)		Morrison formation.		Variegated shale with several sandstone beds.	250
Jurassic.	Upper Jurassic.		Sundance formation.		Shale, limestone, and sandstone.	150

125 feet thick and consists of medium-grained dirty-gray sandstone containing thin calcareous beds and numerous lenses and layers of sandy shale ranging in thickness from a fraction of an inch to several feet. The distribution of the oil in the sand is dependent on

differences in the porosity of the layers composing it, due to differences in the sizes of the sand grains and the amount of cementing material between them. The porosity of the sand in the several layers of the formation differs greatly. A specimen of massive sandstone from the upper part of the Wall Creek, collected by Wegemann and tested by Van Orstrand, has a porosity of 25.8 per cent; another specimen, somewhat shaly, taken near the base of the formation, has a porosity of 20.4 per cent; and a specimen from one of the thin layers of calcareous sandstone, called by the drillers "shells," has a porosity of only 7.6 per cent.

Owing to variations in the character of the sand, oil is encountered in the wells in pay streaks; in some places the "pay" is found at the very top of the sand; in others it is some distance below the top, only small amounts of oil and gas being found when the sand is first struck. There are no dry holes within the known oil pool, some part of the sand being capable of commercial production wherever it is tapped.

The distribution of the oil about the Salt Creek dome is unusually regular. The line marking the contact of the oil pool with the water that occupies the sand on the flanks of the fold below the oil varies only about 150 feet in elevation in the entire circuit of the dome, lying between 3,425 and 3,575 feet above sea level.[1]

The first commercial wells in the Salt Creek field were drilled in the Shannon pool, which is at the north end of the dome, about 3 miles north of the present town of Salt Creek. The oil is obtained from the Shannon sand, which lies 2,000 feet above the Wall Creek and forms the rim rock of the Salt Creek pool. The Shannon sand is encountered in the wells at Shannon at depths ranging from 700 to 1,000 feet. It consists of two ledges separated by 30 or 40 feet of sandy shale. The upper ledge of sandstone is about 40 feet thick, and the lower one 50 feet. The oil is confined to the lower ledge, the upper being water bearing. The porosity of the sand, determined by Van Orstrand, is 26.7 per cent.

The Shannon wells are small, the average well producing daily from 5 to 15 barrels of heavy paraffin-base oil. The pool appears to contain not more than 160 acres. Some of the wells flowed slightly when first struck, but all of them were pumped. No oil is now being taken from them. The pool is on the pitching north

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[1] WEGEMANN, C. H.: The Salt Creek Oil Field, Wyoming. U. S. Geol. Survey *Bull.* 670, p. 27, 1917.

end or "nose" of the Salt Creek anticline, at a place where the fold is narrowed abruptly. The oil extends farther down the end of this fold than it does on the western flank. The limits on the east are not accurately determined.[1]

Powder River.—The Powder River or Tisdale field[2] is a dome southeast of the Big Horn Mountains. The strata in which the oil occurs are lower in the geologic column than those which bear oil at Salt Creek. The oil of the Powder River field is a heavy lubricating oil.

The Powder River dome is roughly outlined in plan by the outcrop of the Wall Creek sandstone. The dome is a somewhat irregular oval 16 miles long from north to south and 10 miles wide from east to west, its axis trending approximately north. About 15 miles north and a little west of the highest point of the dome is a smaller but similar dome, which lies just west of the village of Kaycee. The two domes are connected by a low anticlinal arch and may be considered parts of a single structural feature 30 miles long.

Oil has been found in five different beds in the Powder River field. Of these the lowest is in the Sundance, a small quantity of oil, along with brackish water, rising from the upper strata of that formation in the SW. ¼ sec. 33, T. 41 N., R. 81 W. A massive sandstone about 6 or 7 feet thick near the base of the Morrison formation contains a small quantity of oil in the NE. ¼ sec. 33, T. 41 N., R. 81 W., where a tunnel has been driven into the sandstone. In Oil Canyon a small oil seep was noted in a sandstone near the middle of the Morrison. In the Mowry shale member oil is reported in the well in Oil Canyon, where a few quarts was obtained at a depth of about 300 feet. The principal reservoir of oil in the field, however, is the coarse conglomeratic sandstone, 56 feet thick, which is probably the Cloverly. It has been prospected with results that are not encouraging.

The open wells in Trail Canyon, on the crest of a secondary fold, which here forms also the axis of the anticline, obtain oil from the Cloverly (?) sandstone. It has been suggested that the oil from the Embar formation has risen to the sandstone beds above.

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[1] Wegemann, C. H.: *Op. cit.*, p. 33.

[2] Wegemann, C. H.: The Powder River Oil Field, Wyoming. U. S. Geol. Survey *Bull.* 471, p. 56, 1912.

Big Muddy Dome.—The Big Muddy dome[1] is in Converse and Natrona Counties, near the North Platte River, about 15 miles east of Casper. The following generalized section shows the character and thickness of the Mesozoic and later formations and their relations to each other:

The Big Muddy dome is a slight arch of the strata extending over an area of about 72 square miles.

At the surface that part of the Pierre formation which lies below the Parkman sandstone member crops out. The outline of the dome is shown by the outcrop of the Teapot sandstone member. Oil is obtained from the Shannon sand, from a stray sand, and from the Wall Creek sand of the Colorado. The depth of the Shannon ranges from 950 to 1,150 feet; the Wall Creek is about 2,000 feet deeper.

In the field proper there are two anticlines—a northerly one trending east, on which oil is obtained, and another in the southwestern part of the field trending northeast and nearly east. These are separated by a shallow syncline. A well on the southwestern anticline obtained water. This fold may be cut off by a fault to the southwest.

Douglas.—The Douglas oil and gas field[2] (Brenning Basin) lies west of Douglas, in Converse County. Oil springs are found at many places in this region.

The White River formation in the Douglas field rests unconformably on the upturned edges of the older rocks, which include nearly all the beds of the Colorado and Montana groups, both of which are known to yield oil in the Salt Creek field and near-by areas. Hewett believes that the oil in migrating upward along bedding planes and through porous sandstone finds a barrier when it reaches the White River formation, so that oil and gas accumulate near this line, penetrating the White River only where they encounter lenses of porous material or fault planes.

Two grades of oil are produced—a heavy lubricating oil and a light oil of good quality. The gas is rich in propane and butane. The field, though extensively prospected, has not made a large production.

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[1] BARNETT, V. H.: Possibilities of Oil in the Big Muddy Dome, Converse and Natrona Counties, Wyoming. U. S. Geol. Survey *Bull.* 581, pp. 105-117, 1915.

[2] HEWETT, D. F.: The Douglas Oil and Gas Field, Converse County, Wyoming. U. S. Geol. Survey *Bull.* 541, pp. 89-113, 1914.

GEOLOGIC FORMATIONS IN OR NEAR POWDER RIVER OIL FIELD, WYOMING
(After Wegemann)

System	Series	Group	Formation		Description	Thickness (Feet)
Cretaceous.	Upper Cretaceous.	Montana (4,350 feet).	Fox Hills sandstone.		White sandstone and shale. Marine.	700?
			Pierre formation (3,650 feet).		Shale with several sandstone beds, including that which forms Little Pine Ridge. Marine.	1,000
				Parkman sandstone member.	Massive buff sandstone overlain by shale and thin coal beds. Marine and fresh water.	350
					Shale with sandstone stratum 250 feet above its base. Marine.	1,100
				Shannon sandstone lentil.	Oil-bearing horizon near base. Marine.	175
					Gray shale. Marine.	1,025
		Colorado (2,405 feet).	Niobrara shale.		Light-colored shale, in parts somewhat arenaceous. Marine.	735
			Benton shale (1,670 feet).		Dark shale, several calcareous beds. Marine.	220
				Wall Creek sandstone lentil.	Buff sandstone, ripple marked and cross-bedded. Petrified wood, marine shells, and fish teeth. The principal oil sand of Salt Creek.	80
					Dark shale, several sandstone beds. Marine.	800
				Mowry shale member.	Firm slaty shale, usually forming escarpment. Weathers light gray and bears fish scales. Marine.	300
					Dark shale with one thin, persistent, strongly ripple-marked sandstone.	270
			Dakota (?) sandstone.		Conglomeratic sandstone, oil bearing. Fresh water.	56
Jurassic (?).			Morrison formation.		Variegated shale with several sandstone beds which in certain localities bear oil. Fresh water.	250
Jurassic.			Sundance formation.		Shale and limestone in upper part; white sandstone in lower part.	275

This district has not produced profitable quantities of oil, and its importance is problematic.

GENERALIZED SECTION OF FORMATIONS INVOLVED IN THE BIG MUDDY DOME, WYOMING
(After Barnett)

System	Series	Group	Formation and Member		Character	Type of Topography and Soil	Thickness (Feet)
Quaternary.					Alluvium, gravel, and sand.	Sand dunes, gravel-topped hills, and valley flats.	25+
			–Unconformity–				
Tertiary.	Oligocene.		White River formation.		Clay, conglomerate, and sandstone.	Flat-topped hills and gentle slopes; thin soil.	1,000
			–Unconformity–				
Tertiary (?).	Eocene (?).		Lance formation.		Friable sandstone and shale, with local beds of coal.	Rolling hills and broad gentle slopes; thin, sandy soil and alkali flats.	200+
Cretaceous.	Upper Cretaceous.	Montana.	Fox Hills formation, base uncertain.		Friable sandstone and shale with local coal beds near top.	Ridges of sandstone and valleys in shale; sandy soil.	860
			Pierre formation.		Sandy shale.	Valleys; thin clay soil.	400
				Teapot sandstone member.	Gray and buff sandstone and carbonaceous shale.	Low ridges, barren rock slopes, and pine-clad hills.	160
					Sandy shale.	Valleys; thin clay soil.	320
				Parkman sandstone member.	Friable sandstone and beds of shale and coal.	Ridges of some prominence and broad, grassy slopes.	330
					Dark shale.	Broad valleys; thin soil.	2,000
		Colorado.	Niobrara shale.		Gray to buff calcareous shale.	Low rounded ridges and brown slopes.	100–650
			Benton shale.		Dark shale.	Narrow valleys; thin soil.	200
				Wall Creek sandstone member.	Gray and buff sandstone and beds of shale.	Ledges and hogback ridges covered with small pines.	100–200
					Dark shale including Mowry shale member.	Broad valley with low, rounded pineclad ridge of Mowry shale. Thin soil.	1,200
	Lower Cretaceous.		Cloverly formation.		Buff sandstone and shale with conglomerate in lower part.	Ledges, hogback ridges, and barren slopes of rock; thin sandy soil.	140
Jurassic or Cretaceous.			Morrison formation.		Green, buff gray, and maroon shale and thin beds of sandstone.	Gentle slopes below ridges of Cloverly rocks.	700
Jurassic.	Upper Jurassic.		Sundance formation.		Greenish-gray limestone and sandstone.		

Lander.—The Wind River Range lies southwest of the Big Horn Basin and its southwestern bordering range, the Owl Creek Mountains. The Wind River Range is an anticlinal uplift striking northwest. Northeast of it there is a foothill fold, the Shoshone anticline, 40 miles or more long, that strikes northwest, parallel to the Wind River Range. This anticline has an undulating crest, developing four elongated domes. These from northwest to southeast are the Sage Creek dome; the Plunkett dome (Big Popo Agie), near Lander; the Dallas dome (Little Popo Agie); and the Sweetwater dome. Along the crest of the anticline the Red Beds (Chugwater), of Triassic age, crop out. Wells drilled on the crest encounter the Embar (Carboniferous), which yields a heavy oil. The Embar[1] consists of limestone, some of it shaly and cherty, and of shale. Two members consist of very shaly sandstone containing a large percentage of lime carbonate and some bituminous matter which comes to the surface in oil seeps.[2] Woodruff considers the Embar the main source of oil in the region, although oil is found also in overlying formations. The Chugwater (Red Beds), above the Embar, consists of red shales and sandstones nearly 1,500 feet thick. It contains lenses of gypsum. Above the Chugwater are Mesozoic shale, sandstone, and limestone.

The oil is found along the top of the anticline. On the Little Popo Agie dome there is a thrust fault 2½ miles long with a throw of about 1,180 feet. No springs occur along the line of the fault, and neither oil seeps nor asphalt beds were noted near it. The fault is believed to extend downward to the oil-bearing strata, but the abundant shale in the Chugwater formation has probably sealed the break and prevented the escape of gas or oil. Several oil seeps and tar springs, however, occur along the axis of the anticline. It is these springs, together with the anticlinal structure, that led to the prospecting for oil. Most of the wells show gas. The oil flows from several wells, but some are pumped. The oil is a heavy oil with an asphalt base, and production is small.

Maverick Springs, Fremont County.—The Maverick Springs[3] district is in the Wind River Basin, just south of Owl Creek

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[1] Woodruff, E. G.: The Lander Oil Field, Fremont County, Wyoming U. S. Geol. Survey *Bull.* 452, pp. 1-36, 1911.

[2] *Op. cit.*, p. 12.

[3] Collier, A. J.: Anticlines Near Maverick Springs, Fremont County, Wyoming. U. S. Geol. Survey *Bull.* 711-H, pp. 149-166, 1920.

Mountains. Three domes are developed along an axis that strikes northwest. These are, from northwest to southeast, the Circle Ridge Dome, the Big Dome, and the Little Dome.

On the Circle Ridge, the top of the Embar formation is exposed. In the Big Dome the Chugwater, composed of sandstones, shales, and gypsum, covers the Embar, which consists of limestone, shale, and phosphate rock, with some sandy layers (Fig. 163). The oil is found in a sand in the Embar group and is developed on the Big Dome which has several hundred feet of closure. It is a heavy asphaltic oil like that obtained at Lander.

Pilot Butte.—The Pilot Butte field[1] is near the center of Fremont County, in the west-central part of the State, about 40 miles southwest of Thermopolis and 26 miles north of Lander. It is on an elongated dome that lies a little east of north of the north end of the Shoshone anticline and is an échelon fold or uplift on its basinward flank. The oil produced has a paraffin base and is obtained from Cretaceous sandstone. The oil is found in an interbedded sandstone about 1,500 feet above the base of the Pierre. A sandstone on Dry Creek in the Pierre about 1,450 feet above the base is correlated with the upper oil sand of Pilot Butte. The sandstone here is a friable, porous buff rock that has a few streaks of grit with grains as much as a quarter of an inch in diameter. It is overlain and underlain by sandy shales, and the total thickness of the sandy zone is 40 feet; the sand proper is about 15 feet thick. This horizon is approximately the same as that of the Shannon sandstone, which produced oil in the Salt Creek and Big Muddy fields. Other sands should be encountered below.

Central Wyoming.—The city of Casper is the most important center of refining in Wyoming and the headquarters of many producing and prospecting companies. The Salt Creek field is northeast of Casper, and the Big Muddy dome is about 15 or 20 miles to the east. To the west of Casper for about 100 miles extending nearly to Lander, there is a broad belt of Cretaceous, Tertiary, and Quaternary rocks. The Cretaceous is thrown into folds nearly all of which strike northwest. These folds have been mapped and described by Hares.[2]

[1] ZIEGLER, VICTOR: The Pilot Butte Oil Field, Fremont County, Wyoming. Wyoming Geol. Survey *Bull.* 13, p. 143, 1916.

[2] HARES, C. J.: Anticlines in Central Wyoming. U. S. Geol. Survey *Bull.* 641, pp. 233-279, 1917.

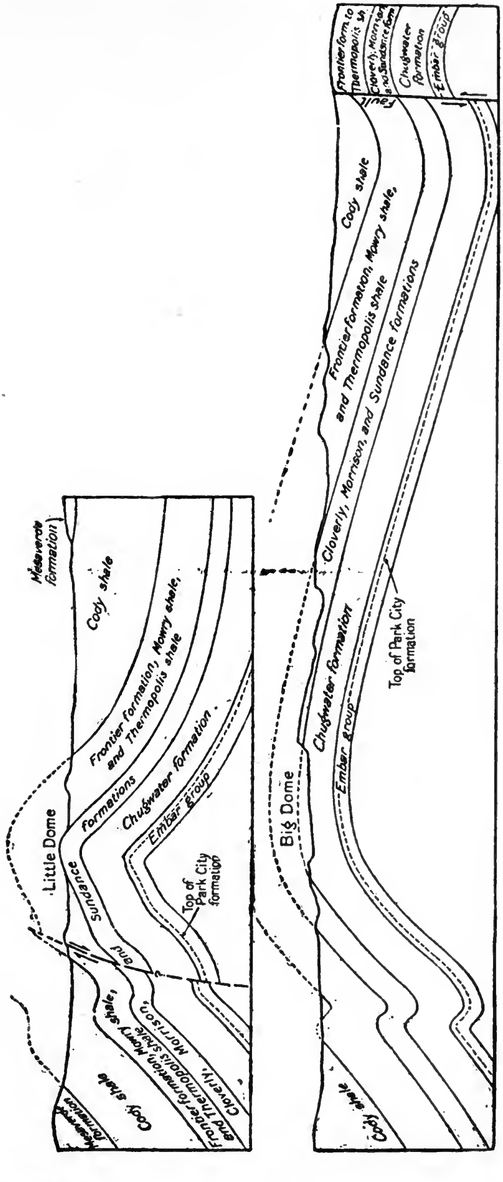

Fig. 163.—Sections of Big Dome and of Little Dome, Maverick Springs region, Fremont County, Wyoming. (*After Collier.*) Oil is discovered on the Big Dome in the Embar formation.

The Carboniferous and Cretaceous formations which produce oil in other Rocky Mountain fields are well developed in central Wyoming, and in places the oil seeps from them, but in only a few places are these formations covered by impervious shale and within reach of the drill in folds favorable for the accumulation of oil and gas. The noteworthy folds, according to Hares, are the Pine dome, the Oil Mountain anticline, the anticlines between Poison Spider and South Casper creeks, and the Emigrant Gap, Iron Creek, North Casper Creek, and Bates Hole anticlines. The Cretaceous oil sands are below the surface in the Big Sand Draw anticline, in the anticline southwest of Powder River, and in the dome (?) on Wallace Creek.

Rock River.—The Rock River field is near the eastern border of Carbon County. No reports showing the structure of this field have been published, but the stratigraphy and structure of areas between Rawlins and Medicine Bow, which lie just west of it, have been described by Veatch.[1]

Lost Soldier.—The Lost Soldier field is in northeastern Sweetwater County. It lies on an anticline,[2] on which the Niobrara is exposed. A light-gravity oil is obtained from the Wall Creek sandstone of the Frontier formation.

Moorcroft.—In eastern and northeastern Wyoming the regional dip is southward, away from the Black Hills uplift. The rocks outcropping are indicated in the accompanying table. At several places subordinate folds have been identified on the southward-dipping monocline, and some of these have been prospected for oil.

The Moorcroft oil field[3] lies 12 miles north of the town of Moorcroft. Seeps are found in the Fuson shale, the Dakota sandstone, and the Graneros formation. Prior to 1888 oil was pumped from a well and gathered from oil springs and sold in mining towns of the Black Hills. The district contains a heavy paraffin oil and also a heavy asphaltic oil. The sandstone of the Graneros shale (Benton) is the main oil-bearing bed. Numerous test wells have failed to reveal commercial supplies (1919).

[1] Veatch, A. C.: Coal Fields of East-Central Carbon County, Wyoming. U. S. Geol. Survey *Bull.* 316, pp. 244-263, 1907.

[2] Ziegler, Victor: Popular Oil Geology, p. 94, New York, 1918.

[3] Barnett, V. H.: The Moorcroft Oil Field, Crook County, Wyoming. U. S. Geol. Survey *Bull.* 581-C, pp. 83-105, 1915.

GENERALIZED SECTION OF ROCKS IN THE MOORCROFT OIL FIELD, WYOMING
(After Barnett)

System	Series	Group	Formation	Character	Thickness (Feet)	Character of Topography and Soil
Cretaceous.	Upper Cretaceous.	Montana.	Fox Hills sandstone.	Friable sandstone and sandy shale.		Rolling hills and rounded ridges; sandy soil with good grass.
			Pierre shale.	Dark shale with calcareous concretions.	2,000	Wide plains with shallow valleys; thin, clayey, and not very fertile soil, supporting fair growth of grass.
		Colorado.	Niobrara shale.	Gray calcareous shale.	100	Shale slopes; limy soil.
			Carlile shale.	Gray shale with oval concretions and thin sandstones.	500	Rolling hills with thin clay soil, mostly covered with grass.
			Greenhorn formation.	Shale with impure concretionary limestone.	175	Small bare ridges.
			Graneros shale.	Black shale with concretions. Hard gray shale containing many fish scales (Mowry shale member). Sandstone, oil bearing. Black shale with small concretions.	1,245	Wide valleys containing extensive alluvial deposits. Shaly ridges, partly wooded. Valleys with clay soil and badlands.
			Dakota sandstone.	Gray to buff sandstone, mostly very massive; weathers reddish brown.	50+	Plateaus, canyons, and high cliffs with rocky slopes; thin sandy soil.
	Lower Cretaceous.		Fuson shale.	Shale and sandy shale with local sandstone.	70	Slopes below cliffs of Dakota sandstone.
			Lakota sandstone.	Light-colored coarse massive sandstone.	25–50	Canyons with cliffs; thin sandy soil.
Jurassic or Cretaceous.			Morrison shale.	Massive pale greenish-gray to maroon shale with limestone nodules.	125 ±	Steep slopes below cliffs of Lakota sandstone; poor soil.

Newcastle.—The Newcastle field[1] is about 50 miles southeast of Moorcroft. The Graneros shale, which contains sandstone lenses, crops out in the district, and in places a heavy paraffin oil exudes from the sands. Drilling had not revealed commercial supplies of petroleum until 1920, when a heavily producing well was drilled.

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[1] KNIGHT, W. C., and SLOSSON, E. E.: The Newcastle Oil Field. Wyoming Univ. School of Mines Pet. Series, *Bull.* 5, 1902.

Upton-Thornton Oil Field.—The Upton-Thornton oil field[1] is in Weston and Crook Counties, eastern Wyoming. The rocks outcropping are of Cretaceous age and lie on the southwest flank of the Black Hills Uplift. An anticline strikes northwest through the district, and on its crest two domes are developed. One of them lies near Upton and the other about a mile southwest of Thornton. Neither of these domes produces oil. About three miles northwest of Thornton a small oil field is developed on a monocline that dips southwest and which lies west of the anticline on which the domes are located.

The oil has accumulated on or near a terrace-like slope where the dip of the monocline changes (Fig. 164). The oil occurs in the sandy members of the Colorado shale, one horizon being in the Graneros, another in the Carlile shale. The oil is obtained mainly from a sand which ranges in thickness from 29 to 47 feet and is reached at depths ranging from 448 to 843 feet. The oil near Thornton is light green in color and of light gravity. Northwest of the center of the dome, in sec. 4, T. 48 N., R. 66 W., several wells have been sunk to depths between 480 and 880 feet. These yield each from 5 to 10 barrels of light oil daily.[2] The wells are on a structural terrace, and the productive sand crops out within half a mile of the nearest producing well.

Buck Creek.—About 20 miles north of Lusk, near the center of Niobrara County,[3] there is a well-defined structural terrace, which Trumbull designates the Buck Creek field. The beds, which lie flat in the western part of the area, dip steeply eastward east of Buck Creek. In this region oil is said to be obtained from the Muddy sand a short distance below the Mowry.

Mule Creek.—The Mule Creek oil field is in eastern Wyoming, four miles from the South Dakota line, about 35 miles northeast of the Lande Creek field. About 10 wells sunk on an anticline tested 125 to 150 barrels of high grade oil daily in the autumn of 1919. The oil occurs in the Dakota sandstone of Cretaceous age,

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[1] Hancock, E. T.: The Upton-Thornton Oil Field, Wyoming. U. S. Geol. Survey *Bull.* 716-B, pp. 17-34, 1920.

[2] Hancock, E. T.: The Upton-Thornton Oil Field, Wyoming. U. S. Geol. Survey *Bull.* 716, p. 31, 1920.

[3] Trumbull, L. W.: Prospective Oil Fields. Wyoming State Geologist's Office *Bull.* 5, p. 8, 1913.

SECTION OF ROCK FORMATIONS IN THE UPTON-THORNTON FIELD

System	Series	Group	Formation and Member	Character	Thickness (Feet)
Cretaceous.	Upper Cretaceous.	Montana.	Pierre shale.	Dark shale including a zone of calcareous concretions near middle and a few thin beds of bentonite. Only lower 1,200 feet to top of zone of calcareous concretions is mapped.	2,500 ±
		Colorado.	Niobrara shale.	Chiefly light-yellowish to cream-colored calcareous shale, with some impure chalk, clay, and sand.	200
			Carlile shale.	Dark shale with thin beds of soft sandstone mainly near the base.	700
			Greenhorn limestone.	Impure, slabby limestone.	50
			Graneros shale.	Dark-gray to black shale, including many large calcareous concretions, especially in the upper part.	800
			Mowry shale member.	Hard, light-gray, sandy shales containing numerous fish scales. Bentonite beds near the top and to some extent near the base.	150
				Dark, sandy shale grading upward into typical Mowry shale.	50
				Reddish to light-yellow sandstone associated with black carbonaceous shale.	3 to 15
				Dark-gray to black shale.	225
			Dakota sandstone.	Thin-bedded to massive hard buff sandstone.	60
	Lower Cretaceous.		Fuson formation.	Shale and thin-bedded sandstone.	20
			Lakota sandstone.	Sandstone, in part conglomeratic, with some coal beds near the base.	200
Cretaceous(?).	(?)		Morrison formation.	Light-gray to pinkish shale.	130
Jurassic.	Upper Jurassic.		Sundance formation.	Light-gray to dark greenish-gray and pinkish, sandy shale with a 25-ft. sandstone near the base.	346
Triassic (?).			Spearfish formation.	Gypsum and red clay beds in alternating succession. Popularly known as the "Red Beds."	492
Carboniferous.	Permian (?).		Minnekahta limestone.	Light-gray to pinkish or purplish limestone.	34
			Opeche formation.	Red, sandy clay, purplish at the top.	74
	Pennsylvanian.		Minnelusa sandstone.	Light gray to buff calcareous sandstone.	851
	Mississippian.		Pahasapa limestone.	White, pale-buff, pinkish, and gray limestone.	398 ±

which lies about 1,400 feet deep. The Minnelusa sandstone (Carboniferous) which contains oil in the Old Woman anticline 15 miles away, is expected at a depth of 2,700 feet at Mule Creek wells.[1]

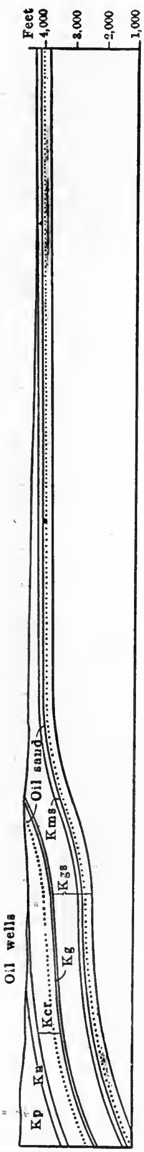

FIG. 164.—Section (northeast) through the Upton-Thornton oil field, Wyoming. (*After Hancock.*) Kms, Mowry shale; Kgs, Graneros shale; Kg, Greenhorn limestone; Kcr, Carlile shale; Kn, Niobrara shale; Kp, Pierre shale. The wells are on a structural terrace.

Spring Valley.—The Spring Valley field,[2] Uinta County, southwestern Wyoming, is an area of Mesozoic and later sedimentary rocks deformed by faulting and folding. The oil field is in the Absaroka fault zone, which is marked by reverse faulting. Numerous oil springs are found in this region, among them the Brigham Young, Carter, and White springs, which occur along a secondary fault east of the main Absaroka fault. The Aspen tunnel of the Union Pacific Railroad, which was driven through the Cretaceous Frontier formation, crossed a secondary fault in the Absaroka fault zone, and at the fault there was a considerable seep of oil. Many wells put down in this region found some oil, but not in paying quantities. The region is complexly deformed. At Hilliard the strata are overturned. Most of the oil found in the Spring Valley wells comes from sandy layers in the Aspen shale. The oil-bearing beds carry little water.

Labarge.—The Labarge field[3] is in Lincoln County, about 80 miles north of the Spring Valley field. The county is an area of faulted and folded strata of Cretaceous and Tertiary age. The dominant structural feature is the Absaroka fault zone. In the vicinity of

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[1] HANCOCK, E T : U. S. Geol. Survey *Bull.* 716-C. Press *Bull.* U. S. Geol. Survey No. 455, August, 1920.

[2] VEATCH, A. C.: Geography and Geology of Southwestern Wyoming. U. S. Geol. Survey *Prof. Paper* 56, p. 139, 1907.

[3] SCHULTZ, A. R.: The Labarge Oil Field, Central Uinta County, Wyoming. U. S. Geol. Survey *Bull.* 340, p. 364, 1907.

Labarge Ridge the oil formation is the Aspen (Mowry?), a division of the Colorado that consists of shale, sandstone, and limestone. Oil is supposed to have seeped from the deep-lying Aspen under the outcropping Tertiary beds. In a sketch of this field Trumbull[1] shows an anticline in the Cretaceous which includes the Aspen, overlain by the flat-lying Tertiary beds.

Big Horn Basin.—The Big Horn Basin[2] is a depression nearly surrounded by high mountain ranges. On the east lie the Big Horn Mountains, on the south the Owl Creek and Bridger ranges, and on the west the Shoshone Mountains (Fig. 165). The structure of the northeastern part has been described by Washburne, and that of the southern part by Hewett and Lupton.

The rocks dip from the mountains toward the center of the basin, where the older formations are deeply buried. The Big Horn Basin may be separated into two parts—an inner or central part, in which the surface rocks belonging to the Wasatch and younger formations are almost horizontal, and an outer or border part adjacent to the mountains, in which the beds older than the Wasatch are thrown into small folds. The Wasatch and younger beds of the central part are only locally horizontal, however, for they dip slightly toward the middle trough, which trends roughly N. 40° W.

Near the mountains there are two almost completely circular chains of anticlines and domes, one inside the other (Figs. 166, 167). The inner circle has yielded almost the entire production of the area. All of the producing folds are elongated domes, or

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[1] TRUMBULL, L. W.: Wyoming State Geologist's Office *Bull.* 5, p. 13, 1913.

[2] HEWETT, D. F., and LUPTON, C. T.: Anticlines in the Southern Part of the Big Horn Basin, Wyoming. U. S. Geol. Survey *Bull.* 656, 1917.

HINTZE, F. F., JR.: The Basin and Gray Bull Oil and Gas Fields, Wyoming. Wyoming State Geologist's Office *Bull.* 10, 1914.

DARTON, N. H.: Mineral Resources of the Big Horn Mountain Region. U. S. Geol. Survey *Bull.* 285, pp. 303-310, 1906.

FISHER, C. A.: Geology and Water Resources of the Big Horn Basin, Wyoming. U. S. Geol. Survey *Prof. Paper* 53, 1906.

WASHBURNE, C. W.: Gas Fields of the Big Horn Basin, Wyoming. U. S. Geol. Survey *Bull.* 340, pp. 348-363, 1908.

HEWETT, D. F.: The Shoshone River Section, Wyoming. U. S. Geol. Survey *Bull.* 541, pp. 89-113, 1912.

SCHULTZ, A. R.: Geology and Geography of a Portion of Lincoln County, Wyoming. U. S. Geol. Survey *Bull.* 543, 1914.

anticlines plunging at both ends. Their axes are rudely parallel to the axes of the mountain ranges, which almost encircle the basin. The domes and anticlines have large closures; that of the Grass Creek anticline, the most productive in the basin, is over 2,000 feet. Many of the oil-bearing folds are faulted, but moderate amounts of faulting do not seem to influence accumulation adversely in this region. For a productive region that is so much faulted, surface indications of oil are not numerous, although oil seeps have been found on or near the Bonanza, Sherard, and Lysite Mountain anticlines, and near the base of the Chugwater formation on the Red Spring anticline. The oil-bearing strata are all or nearly all marine. Salt water is found in many of the folds, but in some of them it is not very salty. The water below the oil on both limbs of the Grass Creek anticline is neither sulphurous nor

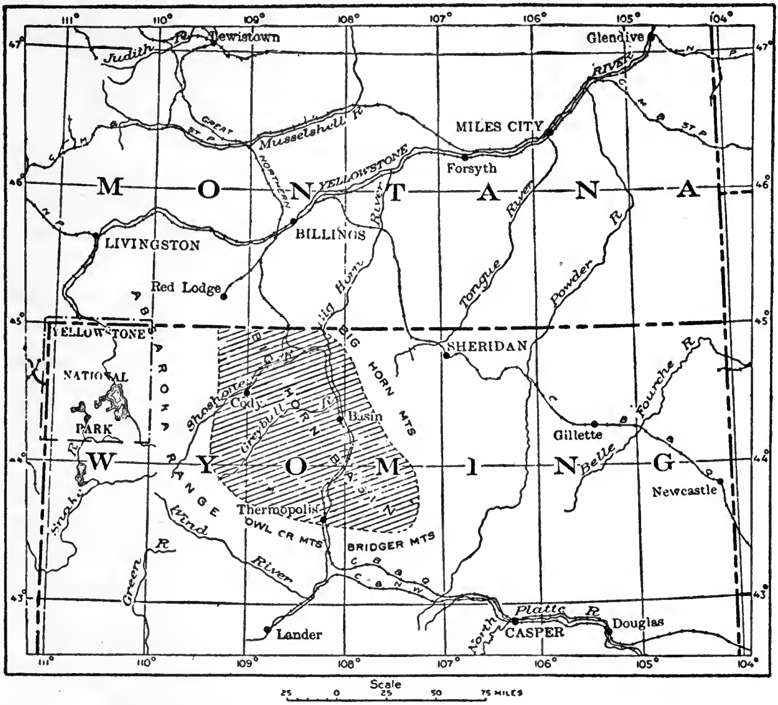

Fig. 165.—Sketch map showing Big Horn Basin, Wyoming.

FORMATIONS OF BIG HORN BASIN, WYOMING
(After Hewett and Lupton)

System	Formation		Thickness (Feet)	Character of Rocks
Quaternary.	Alluvium.		0–50	Valley and flood-plain deposits along streams.
	Hot-spring deposits.		....	Local deposits of calcareous tufa.
	Terrace gravels.		0–30	Gravels and boulders washed from adjacent mountains.
Tertiary.	Volcanic rock.		(?)	Andesitic tuffs and flows on west side of basin.
	Wasatch.		1,300+	Red and drab clay; buff and white sandstone with gravel lenses. Many areas of badlands around border of basin.
	— Unconformity —			
	Fort Union.		2,000–5,600	Buff and white gritty sandstone, with drab, red, and green clay; lenses of gravel and lenticular beds of coal.
	— Unconformity —			
Tertiary (?).	Lance.		840–1,800	Buff and drab sandstone with drab and green shale. No red shale or coal beds.
Cretaceous.	Montana.	Meeteetse.	250–1,400	Soft gray and brown shale; gray and buff sandstone and lenticular beds of coal.
		Mesaverde.	1,120–1,410	Buff and white sandstone, gray and brown shale and lenticular beds of coal near base.
		Cody.	1,900–3,400	Gray, green, and black shale, with calcareous concretions near base, merging with buff sandstone at top. No persistent sharply marked beds.
	Colorado.	Frontier.	494–648	West side: Seven or more beds of gray and buff sandstone with gray and brown shale and bentonite. East side: Two to six or more beds of sandstone.
		Mowry.	160–375	Hard gray shale containing fish scales with lenses of gravel-bearing sandstone.
		Thermopolis.	400–800	Gray to black shale with one persistent sandstone, the Muddy sand of the drillers.
	Cloverly.		110–300	Two beds of massive buff sandstone separated by gray or variegated shale. Upper sand is the Greybull.
Cretaceous (?).	Morrison.		150–580	Purplish and pale greenish-gray shales with sandstones interbedded.
Jurassic.	Sundance.		250–530	Greenish-gray sandstones and shales with a little limestone interbedded.
Triassic.	Chugwater.		700–1,100	Red Beds: Red sandstones and shales with a thick bed of gypsum near top.
Carboniferous.	Embar.		250–480	Gray limestone, with gray and red sandy shale and gypsum interbedded. Limestone very thin on east side of basin.
	Tensleep.		30–230	Massive gray sandstone, containing thin layers of limestone.
	Amsden.		150–200	Red sandy shales and sandstones, with layers of limestone and chert.
	Madison.		600–1,000	Gray massive limestones.
Ordovician.	Bighorn.		150–300	Siliceous gray limestone, very hard and massive.
Cambrian.	Deadwood.		700–900	Sandstone, shale, conglomerate, and limestone.

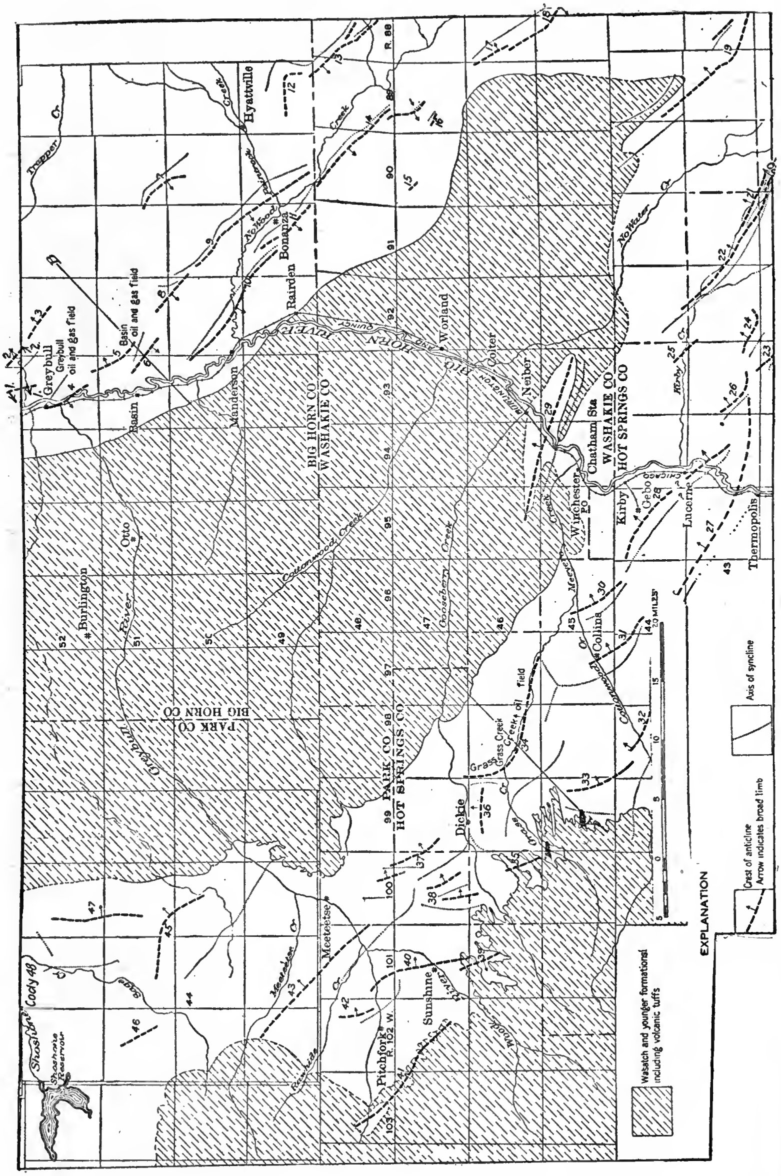

FIG. 166.—Geologic map of southern part of Big Horn Basin, Wyoming. For section along line *AB*, see Fig. 167. Numbers refer to descriptions in table on opposite page and page following. (*After Hewett and Lupton.*)

ANTICLINES AND DOMES IN THE SOUTH HALF OF THE BIG HORN BASIN, WYOMING (1917)
(After Hewett and Lupton)

No. on Map (Fig. 166)	Name	Wells			Formation Exposed at Top of Dome or Anticline	Formations		Anticline Cut By Faults
		Date of First Well	Number	Product of Wells (1917)		Oil-bearing [a]	Possibly Oil-bearing	
1	Sheep Mountain	....	....	....	Madison.	....	....	....
2	Shell Creek	1915	1	Nonproductive.	Morrison.	....	....	....
3	Cherry	1915	1	Do.	Sundance.	....	Embar.	....
4	Greybull	1907	53+	Oil and gas.	Mowry.	Cloverly.	....	X
5	Lamb	1907	11	Oil and gas.	Cody.	Frontier, Mowry.	Cloverly.	....
6	Torchlight	1904	53+	Do.	Frontier.	Do.	....	....
7	Mercer	1910?	1	Nonproductive.	Sundance.	....	Embar.	....
8	Dry	1914	1	Do.	Cody.	....	....	....
9	Paintrock	1888	3	Do.	Sundance.	....	....	....
10	Manderson	1900	3	Do.	Cody.	....	Frontier, Mowry, Cloverly.	....
11	Bonanza	1898? [b]	6	Do.	Thermopolis.	....	....	....
12	Ziesman	....	....	....	Tensleep.	....	Madison.	....
13	Brokenback	....	....	....	Do.	....	Do.	X
14	No Wood	....	....	....	Chugwater.	....	Embar.	X
15	Well area	....	....	....	Cody.	....	Frontier, Mowry, Cloverly.	?
16	Sherard [c]	1914	7	Oil and gas.	Frontier.	Frontier.	Mowry, Cloverly.	X
17	Tensleep	....	....	....	Mowry.	....	Mowry, Cloverly.	X
18	Bud Kimball	....	....	....	Chugwater.	....	Cloverly, Embar.	X
19	Mahogany Butte	....	....	....	Madison.	....	Frontier, Mowry, Cloverly.	X
20	Lysite Mountain [c]	....	....	....	Mowry.	....	Cloverly.	X
21	Black Mountain	....	....	....	Do.	....	Do.	X
22	Lake Creek	....	....	....	Frontier.	....	Mowry, Cloverly.	....
23	Wildhorse Butte	....	....	....	Chugwater.	....	Embar, Madison.	....
24	Blue Spring	....	....	....	Thermopolis.	....	Cloverly.	X
25	Zimmerman Butte	....	....	....	Cody.	....	Frontier, Mowry, Cloverly.	....
26	Red Spring [c]	....	....	....	Embar.	....	Embar, Madison.	X
27	Thermopolis	1910?	1	Nonproductive.	Do.	....	Embar.	X
28	Lucerne	1915	1	Do.	Morrison.	....	Frontier, Mowry, Cloverly.	....
29	Neiber	1915	1	Do.	Fort Union.	....	Mesaverde, Frontier.	....
30	Sand Draw	....	....	....	Cody.	....	Frontier, Mowry, Cloverly.	....
31	Waugh	1914	4	Nonproductive.	Do.	....	....	....

Anticlines and Domes in the South Half of the Big Horn Basin, Wyoming (1917)—*Concluded*

No. on Map (Fig. 166)	Name	Wells			Formation Exposed at Top of Dome or Anticline	Formations		Anticline Cut By Faults
		Date of First Well	Number	Product of Wells (1917)		Oil-bearing [a]	Possibly Oil-bearing	
32	Cottonwood	1912	2	Nonproductive.	Thermopolis.	....	....	X
33	Wagonhound	1915	3	Do.	Cody.	....	Cloverly.	X
34	Grass Creek	1913?	81 +	Oil and gas.	Do.	Frontier.	Do.	X
35	Enos Creek	1916	1	Nonproductive.	Do.	....	Do.	....
36	Little Grass Creek	....	....	....	Do.	....	Frontier, Mowry, Cloverly.	X
37	Buffalo Basin	1913?	4	Gas.	Do.	Frontier.	Do.	....
38	Gooseberry	....	....	Nonproductive.	Do.	....	Do.	....
39	South Sunshine	....	....	....	Morrison.	....	Cloverly.	....
40	Sunshine	....	....	....	Do.	....	Embar.	....
41	Fourbear	....	....	....	Frontier.	....	Mowry, Cloverly.	....
42	Pitchfork	....	....	....	Mowry.	....	Do.	X
43	Spring Creek	1915	1	Nonproductive.	Do.	....	Do.	....
44	Frost Ridge	....	....	....	Mesaverde.	....	Mesaverde, Frontier.	....
45	South Oregon Basin	1912	3	Gas.	Frontier.	Thermopolis.	Cloverly.	X
46	Halfmoon	....	....	....	Do.	....	Mowry, Cloverly.	X
47	North Oregon Basin	1912	3	?	Do.	....	....	X
48	Shoshone	1909	3	Oil and gas.	Do.	Mowry, Thermopolis, Cloverly.	....	....

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[a] "Oil" in the remainder of the table is intended to include both oil and gas.

[b] Oil was discovered in a seep here about 1884.

[c] Oil seep.

very salty, but is somewhat alkaline. Presumably the surface water has entered the oil-bearing sands down the dips of the beds and along faults and either diluted the water that had been stored in the sands or swept it out.

The beds that have yielded most of the oil and gas are of Cretaceous age and are parts of the Cloverly formation, Thermopolis shale, Mowry shale, and Frontier formation. Gas is reported also from a sand in the Morrison formation on the Shoshone anticline near Cody. It is uncertain whether any of the beds lower than the Cloverly formation will prove to be important sources of oil or gas. Only one well (on the Nieber anticline, has tested, under favorable structural conditions, beds higher than the Cody shale, which overlies the Frontier formation. The prospect that any of these higher beds will yield important quantities of either oil or gas, according to Hewett and Lupton, is uncertain.

The sands of the Frontier formation yield the greatest part of the oil, and the sands of the Mowry shale and the Greybull sand yield oil as well as most of the gas now produced in the basin. Where synclines or beds lying flat have been drilled they have struck little oil or gas or none.

In the three most productive fields in the area—the Greybull, Torchlight, and Grass Creek—the zone in the prolific sands that yields the oil extends much lower along a part of the flat basinward limb of the fold than on the steep mountainward limb. Thus at Grass Creek the sands are prolific at a lower altitude in the southeastern part of the field than in the southwestern or western part. As stated by Hewett and Lupton, every tested field in the Big Horn Basin which has yielded appreciable quantities of oil and gas lies toward the principal trough of

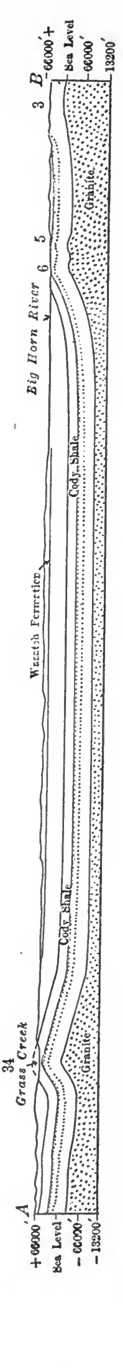

FIG. 167.—Section across the southern part of Big Horn Basin, Wyoming, on line *AB*, Fig. 166. Numbers at surface indicate anticlines numbered on Fig. 166. (*After Hewett and Lupton.*)

the basin, and every tested upfold which is separated from this trough by other folds has either yielded water and the merest traces of oil and gas or is barren. The side of the anticline or elongated dome that is more nearly flat is in general more productive than the steeply plunging side. The flatter dips are generally toward the basin, from which the accumulations came.

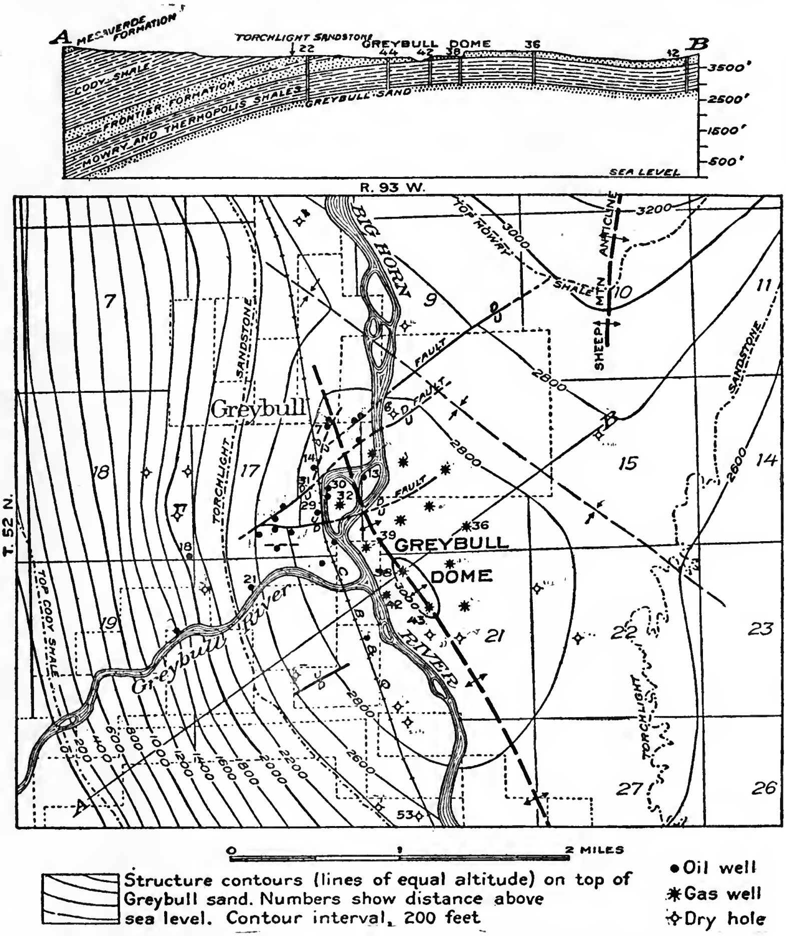

FIG. 168.—Structure contour map and section of Greybull dome, Wyoming. (*After Hewett and Lupton.*)

The Elk Basin pool, in the northern part of the oil district, is on the boundary between Wyoming and Montana. Structurally the field is a dome cut by cross faults. The oil is of light gravity and comes from sandstone of the Frontier formation.

The Byron dome, which lies southeast of Elk Basin, produces light oil that is refined at Cowley, near by. The productive sands are the Frontier, Mowry, and Morrison (?).

Greybull is southeast of Byron. It produces a high-grade paraffin-base oil and much gas. The Greybull sand is the upper sand in the Cloverly formation. Gas is found in the top of the dome, and oil lower down on the west and northwest sides (Fig. 168). Its accumulation there may be due in part to the presence of water in the Greybull sand close to the gas wells on the north, east and southeast sides, the water having pushed the oil toward the west and northwest. Water can easily enter the oil and gas sand at its outcrop around the south end of Sheep Mountain, 3 to 4 miles north of the Greybull dome.

The Torchlight dome (Fig. 169), also termed the Basin dome, is only about 10 miles southeast of the Greybull dome and 2 or 3 miles east of the town of Basin. It is an elliptical upfold in the rocks trending northwest, with its broad end facing southeast. It is about 3 miles long and 2 miles wide and is separated from the Lamb anticline by a shallow syncline, a depression in the rocks 200 to 300 feet deep. Along the crest of the dome the beds lie nearly flat, dipping gently outward. On the north limb the maximum dip of the rocks (11°) is reached about a quarter of a mile away from the crest line; beyond this the beds gradually flatten to the axis of the syncline. The dips are comparatively low, averaging 3° to 4° at the northwest and southeast ends of the dome. The rocks at the surface in the center of the Torchlight dome belong to the upper part of the Frontier formation, which in this locality is a little more than 550 feet thick. A prominent sandstone (the Torchlight) of this formation encircles the central part of the dome in a line of cliffs. A thicker and more prominent sandstone, the Peay, in the lower part of the Frontier formation, is not exposed in this dome but is well shown along Big Horn River near Greybull. Directly under the Frontier formation is the Mowry shale, which contains two sands—the Kimball and Octh Louie—that yield oil. The entire formation yields some oil. Under the Mowry shale is the Thermopolis shale, about 700 feet thick; the Muddy sand, which contains a little gas in some wells, is about 300 feet above its base. Directly beneath the Thermopolis shale is the Cloverly formation, about 125 feet thick, the top

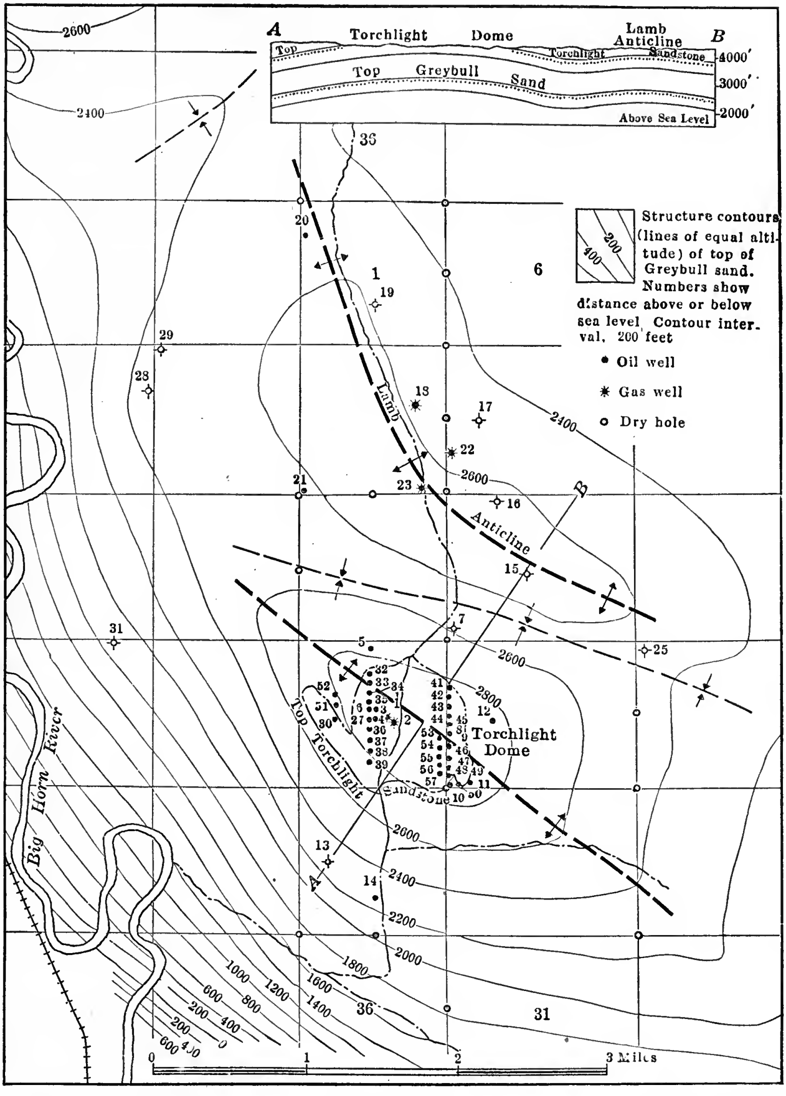

FIG. 169.—Contour map and cross section of Lamb anticline and Torchlight dome, Bighorn Basin, Wyoming. Numbers with symbols refer to descriptions in U. S. Geol. Survey Bull. 656. (*After Lupton.*)

sandstone of which is about 20 feet thick and is known as the

Greybull sand. In the Greybull field[1] this bed of sand yields nearly all the oil and gas.

The Bonanza dome is about 18 miles southeast of Torchlight. Oil seeps from a sand in the Mowry shale exposed near the crest of the dome, and the oil was used by early settlers. The Thermopolis shale is exposed on the crest. The dome has yielded little or no oil.[2]

The Warm Springs dome, southwest of Bonanza, on the opposite side of the basin, yields oil.

The Grass Creek anticline,[3] about 28 miles northwest of Thermopolis, is the most productive fold in the Big Horn basin. It plunges at both ends, giving ample closure. In three wells oil flowed over the casing, but none of the wells were strong gushers. Although most of the wells are pumped they have a long life. The water below the oil is not salty but is said to be alkaline. The outcropping rock is the Cody shale. The sandstones of the Frontier formation which yield the oil in this anticline do not outcrop but are struck in wells at a minimum depth of 365 feet.

The contours show a relatively simple but sharp anticline broken by a few faults. The fold is unsymmetrical, with a steep limb on the southwest wide and a very gently dipping limb on the northeast side. The dips on the northeast side increase from zero at the crest line to a maximum of 34° on the outcrop of beds of the Meeteetse formation, 4 miles distant. The rim rock of Mesaverde sandstone dips from 12° to 24° along the northeast limb. On the southwest side the beds descend sharply into the adjacent syncline and dip from 50° to 60° across a wide belt. The anticline is limited on the northwest by a short syncline, west of which is the Little Grass Creek dome.

The Buffalo Basin anticline is about 10 miles northwest of the Grass Creek field. The Cody shale crops out, and gas is found in the sands of the Frontier.

The Oregon Basin field is about 20 miles northwest of the Buffalo Basin field. It produces gas from sands below the Frontier.

The Cody field is northwest of the Oregon Basin field and produces some gas and a little light oil from sands below the Frontier.

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[1] Hewett, D. F., and Lupton, C. T.: *Op. cit.*, pp. 76-77.

[2] *Idem*, p. 93.

[3] *Idem*, p. 153.

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MONTANA

General Features.—The Cretaceous and later rocks that cover extensive areas in Wyoming are present in force also in Montana. The mountain areas are in the main anticlinal, and as a rule igneous and metamorphosed rocks form their central masses, as in Wyoming. In Montana, however, there are larger and more numerous bodies of post-Cretaceous igneous rocks, whereas in Wyoming the larger central mountain masses were formed in general before the Cretaceous sediments were laid down, and the sedimentary rocks rest upon the eroded igneous bodies. For that reason Montana contains more numerous metalliferous veins, which are associated with the great post-Cretaceous intrusive rocks. Such veins are very sparingly developed in Wyoming. The basin areas in Montana exhibit minor folds, like the basin areas of Wyoming, especially away from the centers of the basins and around their rims. Although the rocks present and the structure are favorable for oil and gas prospecting in Montana, the production thus far is very small. Some of the sands are tight. The State has not been fully prospected, however, and there are reasons for supposing that productive oil or gas fields may yet be discovered. The structure of the Big Horn Basin, Wyoming, extends northwestward into Montana. The outcrops of Cretaceous rocks expand in central and northern Montana, covering broad areas between the Rocky Mountain front and the great Tertiary areas in the eastern part of the State (Fig. 170). Here and there they are raised around small uplifts of older rocks, such as the Judith Mountains, and Little Rocky Mountains, and other outlying ranges.

Although few large fields have been discovered in Montana, the Elk Basin oil pool, about 55 miles south and a little west of Billings, lies partly in Wyoming and partly in Montana. The portion of this field lying in Montana produced 44,917 barrels of oil in 1917. Commercial quantities of gas have been found very near Baker and Glendive, Dawson County. Two oil wells were brought in in Devil's Basin,[1] near Roundup, Montana, in 1919. One of them, the Van Duzen well, yielded a heavy black oil of 23° Baumé. In eastern Fergus County, near Mosby, on the Cat Creek dome (Fig. 171), several wells were brought in in 1920 that yielded a high gravity oil. One of these was reported to yield over 1,000 barrels a day.

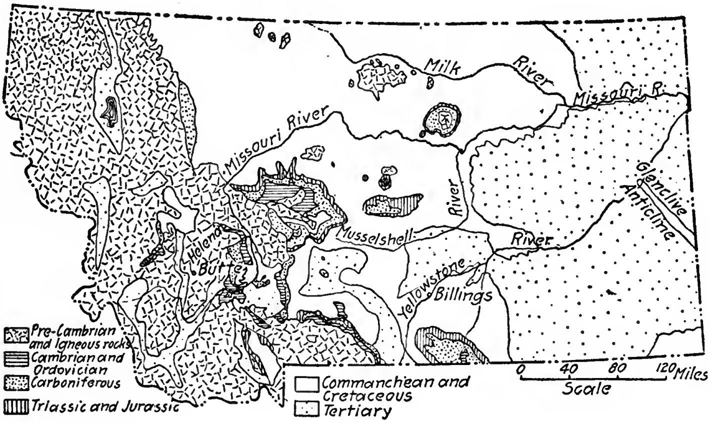

FIG. 170.—Geologic sketch map of Montana. Silurian and Devonian rocks are included in other series.

A little oil was found, probably in the Ellis formation, of Jurassic age, in the Woman's Pocket. The Kootenai produces the high grade oil of Cat Creek dome and is generally regarded as a

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[1] BOWEN, C. F.: Coal Discovered in a Reconnaissance Survey Between Musselshell and Judith, Montana. U. S. Geol. Survey *Bull.* 541, part 2, pp. 328-337, 1914.

possible producer in many parts of the area. The Kootenai[1] consists of an upper and a lower sandstone member separated and overlain by shale that is generally red. It is in general about 500 feet thick and the lower sand is 30 to 40 feet thick. The upper sand is water soaked and the lower one is oil bearing.

The Colorado shale, about 1,800 feet thick, lies above the Kootenai. It is composed of black shale with a sandstone member at its base. In north central Montana it shows oil seeps, and in Wyoming it produces oil in the Big Horn basin, but thus far (1919) has not proved productive in Montana.

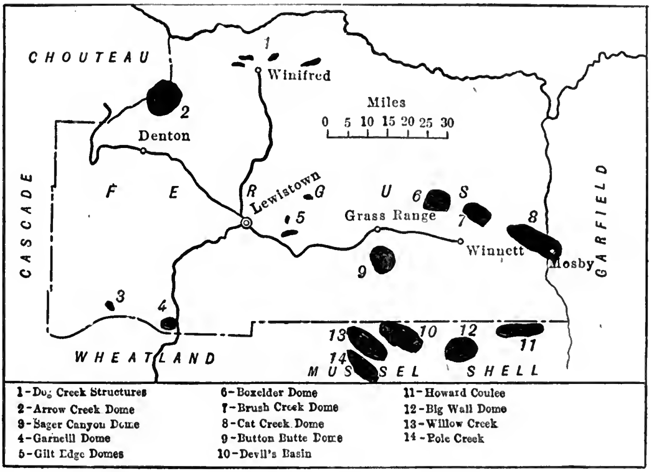

FIG. 171.—Sketch of Fergus and parts of adjoining countries, Montana, showing position of domes, oil fields and prospects. (*After Freeman.*)

Stillwater Basin.—In the Upper Stillwater Basin, southwest of Billings and northwest of Red Lodge,[2] drill holes have been sunk for oil at several places. The rocks in this area range from the coal measures of lower Montana (Upper Cretaceous) age to the Fort Union formation (Eocene). Older sedimentary formations and crystalline rocks are exposed in the Beartooth Mountains, along whose north base there is a profound fault that brings Pale-

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[1] FREEMAN, O. W.: Oil Fields in Central Montana. *Eng. and Min. Jour.*, vol. 109, pp. 936-938, 1920.

[2] CALVERT, W. R.: Geology of the Upper Stillwater Basin, Stillwater and Carbon Counties, Montana. U. S. Geol. Survey *Bull.* 641, pp. 199-214, 1917.

GEOLOGICAL SECTION IN CENTRAL MONTANA

(After Freeman[a])

Quaternary (Travertine, terrace gravel, alluvium, glacial drift).
Tertiary (Lance, shale and sandstone, 700 to 800 feet).

				Feet
Mesozoic	Cretaceous	Montana	Bearpaw shale	1,100 ±
			Judith River formation (sandstone and shale)	250–500
			Claggett shale	700 ±
			Eagle sandstone	200–300
			Gas sand at Havre	
		Colorado shale with thin beds of sandstone (contains gas, possibly oil) +		1,800 ±
		Kootenai sandstone, coal, and shale (lower sand oil bearing) ++		500 ±
	Jurassic	Morrison shale and sandstone		125 ±
		Ellis formation, shale and sandstone (possibly contains oil) +		400 ±
Paleozoic	Carboniferous	Pennsylvania—Quadrant shale and sandstone (oil bearing) +		100–200
		Mississippian—Madison limestone		800
	Siluro-Devonian limestone			300
	Cambrian	Alternating shale and limestone		500–700
		Flathead quartzite and sandstone		100
Pre-Cambrian	Algonkian—Belt series—black and green shale			1,000
	Archean—Gneisses and schists; exposed in Little Belt Mountains			

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[a] FREEMAN, O. W.: *Op. cit.*, p. 938.

ozoic rocks into contact with Tertiary formations south of Red Lodge and with successively older strata to the west. Drilling in 1916 was done on the axis of an anticline, but the absence of oil in the rock section in commercial amounts, according to Calvert, is inconclusive, because the holes were of insufficient depth and because they were put down on the pitching end of the anticline. The absence of water in the drill holes, however, suggests that the beds penetrated are not charged with oil higher in the anticlinal arch. If oil is present at any horizon through which the drill has passed it has accumulated at that horizon lower down on the flanks of the anticline.

In sec. 32, T. 6 S., R. 18 E., according to Calvert, there is more justification for prospecting. Indications of oil were reported in several holes, and it is said that in one hole small amounts of oil were obtained. At three points near by small pools of asphalt occur. These pools are augmented by asphalt oozing from the ground.

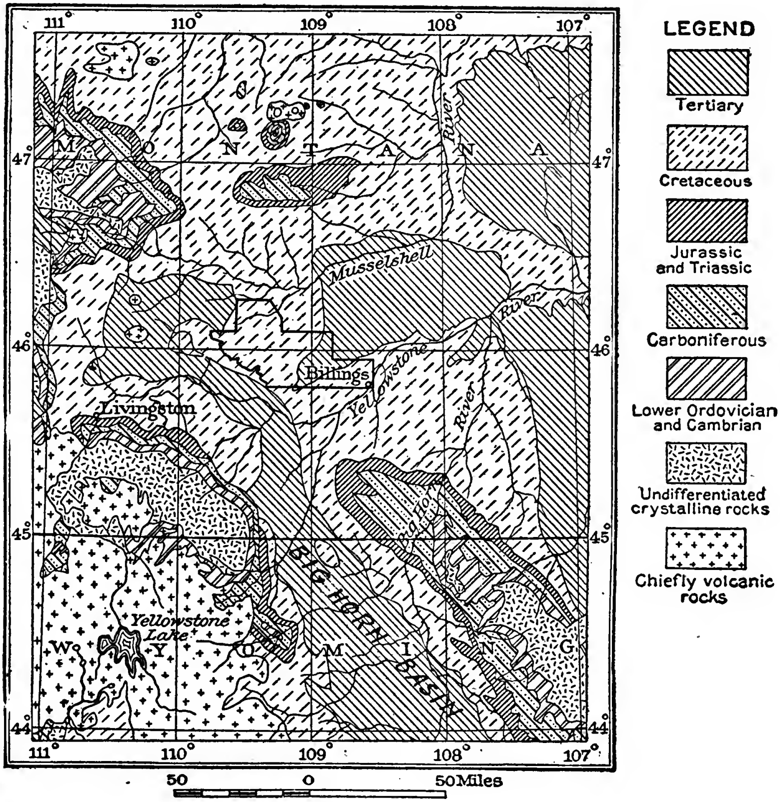

Fig. 172.—Geologic sketch or key map showing relation of Lake Basin field, Montana to major structural features of the region. (*After Willis, Hancock and others.*)

Lake Basin.—The Lake Basin field is northwest of Billings, in south-central Montana, and includes portions of Sweet Grass, Stillwater, Musselshell, and Yellowstone Counties. The rocks outcropping in this region (Fig. 172) are of Cretaceous and Tertiary age. The formations exposed and those that will probably be encountered in depth are as follows:

ROCK FORMATIONS EXPOSED IN LAKE BASIN OIL FIELD (After Hancock)

Era	System	Series	Group and Formation		Character	Topographic Expression	Thickness (Feet)
Cenozoic.	Tertiary (?).	Eocene (?).	Lance formation.		Light-yellow to light-gray sandstones and bluish to gray shales interbedded. Also occasional thin beds of dark carbonaceous shale. The formation, as a whole, presents a decidedly light-gray aspect.	Commonly weathers down to rather even elevated ridges. Where the sandstones overlie the Bearpaw directly they form rather prominent escarpments.	Several hundred feet.
Mesozoic.	Cretaceous.	Upper Cretaceous.	Montana group.	Lennep sandstone.	Generally consists of a lower member of massive light-colored, in places false-bedded sandstone, a middle member consisting of brown andesitic beds, and an upper member containing abundant tufaceous material.	Commonly forms a prominent escarpment bordering broad valleys underlain by Bearpaw shale.	300–350
				Bearpaw shale.	Bluish and light to dark grayish marine shale, including lenses and fingers of sandstone containing numerous plant remains.	Erodes rapidly, forming low, broad valleys and basins.	500–600
				Judith River formation.	Beds of soft, massive light-yellow sandstone interbedded with layers of light bluish-gray to black carbonaceous shale, including an occasional thin seam of coal. Many of the beds yield numerous plant remains.	In areas of low relief commonly forms even ridges. Where highly dissected by streams it forms badlands.	300–400
				Claggett formation.	Belts of thin-bedded sandstone alternating with those consisting mainly of soft, sandy shale.	Commonly forms long dip slopes from the top of the Eagle sandstone back to the ridges formed by the basal sandstone of the Judith River formation.	300–400
				Eagle sandstone.	This formation includes a belt of thin-bedded to massive sandstone at the top and a massive, ledge-making sandstone from 50 to 100 feet thick at the base. The upper and lower sandstones are separated by a belt of softer beds including sandy and carbonaceous shales and locally thin seams of coal. The upper sandstone is commonly capped by a thin layer of black chert pebbles.	Usually characterized by an abrupt escarpment surrounding the low depression eroded out of the underlying shale.	150–250
			Colorado shale.		Composed mainly of light to dark gray shale, including thin layers and lenticular beds of sandstone. About 90 feet below the base of the Eagle sandstone is a soft sandstone entirely without bedding planes but including innumerable small joint planes. This sandstone is capped by a thin layer of hard brown sandstone separated into rectangular blocks by two sets of parallel joints.	Commonly forms broad valleys and basins.	Several hundred feet exposed.

There are in the field two dominating folds—the Big Coulee-Hailstone dome and the northwest end of the Big Horn Mountain anticline. The Broadview dome is a local uplift about 7 miles southwest of Broadview.

The most striking feature of the structure of the Lake Basin field is the long, narrow belt of shearing that crosses the field from the northwest corner southeastward about 8 miles north of Billings. The most intense shearing occurred along the steeply dipping south flank of the Big Coulee-Hailstone dome and around the southeast side of the Broadview dome.

In this field surface indications of petroleum are not prominent. There seems to be no evidence of oil or gas having escaped along any of the fault planes, but it is difficult to ascertain to what extent the lower sands have been faulted. It appears possible that well-defined sandstones such as those present in most of the productive Wyoming fields are lacking in the Lake Basin field. It may be, however, that the available drill records fail to represent the true nature of the Colorado sands and that future drilling will establish the existence of sandstones under parts of the Lake Basin field similar to those underlying certain portions of the Musselshell Valley, farther north.

The Huntley field,[1] northeast of Billings, is in Yellowstone and Bighorn Counties, Montana, just east of Lake Basin field. The rocks are of Cretaceous and later ages, are thrown into folds, and are faulted.

The Colorado formations, that are productive in Wyoming, are under cover in this region. There are no pronounced oil seeps.

Porcupine Dome.—The Porcupine Dome,[2] Rosebud County, Montana, lies north of Forsyth on the Chicago, Milwaukee & St. Paul Railway.

The formations exposed at the surface in this area extend from the Lance formation down to the upper part of the Colorado shale.

The dominant structure of this area is that of an elongate, roughly triangular dome whose outline is indicated by the inner margin of the Judith River formation. Within that margin the

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[1] HANCOCK, E. T.: Geology and Oil and Gas Prospects of the Huntley Field, Montana. U. S. Geol. Survey *Bull.* 711-G, pp. 105-148, 1920.

[2] BOWEN, C. F.: Possibilities of Oil in the Porcupine Dome, Rosebud County, Montana. U. S. Geol. Survey *Bull.* 621-F, pp. 61-70, 1915.

ROCK FORMATIONS EXPOSED IN THE HUNTLEY FIELD, MONTANA (After Hancock)

Era	System	Series	Group and Formation		Character	Topographic Expression	Thickness (Feet)
Cenozoic.	Tertiary.	Eocene.		Fort Union formation.	Yellowish to buff sandstone and sandy shale. Lebo shale member. Dark olive-green to brown sandy shale and thin-bedded arkosic sandstone; contains a thick bed of carbonaceous shale, including thin layers of coal near the middle.	Forms broad, more or less gentle slope extending back from the Lance formation to the massive sandstones forming the upper part of the Fort Union formation.	100 ± 200–300
(?)	Tertiary(?).	Eocene(?).		Lance formation.	Light yellowish-gray sandstone; gray, yellow, and drab clays and shales; and grayish, sandy shale. The upper part contains some thin streaks of coal.	Basal beds of the Lance formation commonly form a prominent escarpment along the margin of the depressed area underlain by the Bearpaw shale. Higher sandstones form scarps along the low ridges.	700–1,500
Mesozoic.	Cretaceous.	Upper Cretaceous.	Montana group.	Bearpaw shale.	Dark marine shale containing numerous calcareous concretions. Abundantly fossiliferous.	In many places weathers down to broad valleys and shallow basins between the more resistant sandstones of the Judith River and Lance formations. Also forms the sides of elevated ridges where protected by a cap of gravel and conglomerate.	Undetermined; 500 to 600 feet in the adjoining Lake Basin field.
				Judith River formation.	Light-yellow, soft massive sandstones containing considerable dark carbonaceous material and dark shale. At the base is a brown, irregularly jointed and hackly sandstone, alternating with zones of greenish-gray sandy shale, which seems to be the approximate equivalent of the sandstone included in the upper part of the Claggett formation in its type area; but for convenience of mapping and because of lithologic similarity this sandstone is here included in the Judith River formation.	If dipping rather steeply the beds form rather prominent ridges between the valleys eroded out of the Bearpaw above and the Claggett below. Where nearly flat lying the hard basal sandstones form rather prominent escarpments around the broad valleys eroded out of the Claggett formation.	100–500
				Claggett formation.	Dark-gray marine shale, including zones of thin-bedded sandstone which locally become very massive and form prominent cliffs. The sandy zones are generally characterized by a growth of evergreens.	Commonly occupies broad valleys and low depressions between the escarpment formed by the basal sandstone here included in the Judith River formation and that formed by the massive Eagle sandstone.	550 ±
				Eagle sandstone.	The upper 100 feet consists of moderately soft light-yellow sandstone alternating with beds of sandy shale. The lower 100 feet is massive sandstone.	The massive basal sandstone forms a vertical cliff for several miles east of Billings.	200
				Colorado shale.	The upper 200 or 300 feet exposed in this field is composed of dark marine shale containing scattered calcareous concretions.	Is eroded into a deep valley southwest of the prominent Eagle sandstone escarpment.	200 or 300 exposed.

Op. cit., p. 110.

GEOLOGIC FORMATIONS EXPOSED IN THE PORCUPINE DOME, MONTANA
(After Bowen)

System	Group	Formation	Thickness, Feet	Character
Quaternary				Alluvial sand, gravel, and silt along Yellowstone and Musselshell rivers and some of the smaller streams.
Tertiary (?).		Lance formation.		Brown, irregularly bedded sandstone, alternating with "somber" gray shale.
Cretaceous.	Montana.	Bearpaw shale.	900–1,000 ±	Dark, gray shale in which occur calcareous concretions containing marine invertebrate fossils.
		Judith River formation.	100–200 ±	Upper sandstone member, light-brown to light-gray massive sandstone. Middle member, light-gray to dark-gray shale. Lower member, sandstone which weathers brown and gives rise to large, boulder-like masses. The formation is of fresh-water origin in the western part of the field and of marine origin in the eastern part.
		Claggett and Colorado shales.	3,000	Dark gray to black shale; upper part highly plastic when wet, and contains fossils characteristic of the Claggett formations; lower part slightly darker in color, more fissile and less plastic when wet, and contains fossils of Colorado age.

dome has a maximum north-south diameter of about 33 miles and a maximum east-west diameter of 27 miles. Along the east and north sides of the dome the Judith River formation dips away from the axis of uplift at angles ranging from 1° to 8°, the steeper dips being on the east side.

No oil or gas seeps are known in this region. The sandstones of the Judith River formation are not probable receptacles of oil or gas, as these sandstones are well exposed in the field and show no indications of the presence of any bituminous substance. Oil or gas, according to Bowen, may or may not occur in the sandstones at the base of the Colorado and in the underlying Kootenai (?). Elsewhere sandstones at simlar stratigraphic positions are oil bearing.

In 1920 oil was found in wells near Mosby on an anticline west of the Porcupine dome.

Musselshell Valley.—The Musselshell Valley,[1] about midway between Billings and Lewiston, is occupied principally by Cretaceous rocks, with subordinate exposures of Tertiary sediments and of igneous rocks. The Cretaceous rocks are folded into gentle anticlines and synclines. Although no commercial production of oil in this region has been recorded, the region is regarded by Bowen as affording favorable prospects.

The same formations that produce the oil in the Elk Basin and Big Horn Basin of Wyoming are found here. In those fields the oil comes chiefly from the Mowry and Frontier formations, and at Basin, Wyoming, oil is obtained from the Greybull sand, the upper member of the Cloverly. Sections indicate that the sands in the Colorado shale in the Musselshell Valley occupy, in a general way, the same stratigraphic position as the productive sands in the Elk and Big Horn basins.

Sandstones that would serve as suitable reservoirs for the accumulation of oil occur at several horizons. (1) Near the top of the Colorado shale there is a transition zone of thin sandstones and sandy shale beds. (2) About 1,200 feet below the top of the Colorado a thick porous sandstone, slightly conglomeratic at the top, is well developed in the western part of the field but seems to be nearly or quite absent in the eastern part. This sandstone has approximately the same stratigraphic position as some of the sandstones in the Frontier formation. (3) About 250 to 300 feet lower in the section is another sandstone of similar character but much thinner and more distinctly conglomeratic. (4) Associated with and underlying the Mowry shale member, in the eastern part of

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[1] Bowen, C. F.: Anticlines in a Part of the Musselshell Valley, Montana. U. S. Geol. Survey *Bull.* 691, pp. 185-209, 1918; The Stratigraphy of the Montana Group. U. S. Geol. Survey *Prof. Paper* 90, pp. 95-153, 1916.

GENERALIZED SECTION OF GEOLOGIC FORMATIONS IN A PART OF THE MUSSELSHELL VALLEY, MONTANA (After Bowen)

System and Series	Group and Formation		Average Thickness (Feet)	Characteristics
Quaternary.	Alluvium.			Unconsolidated deposits along stream courses.
	-Unconformity-			
Tertiary (Miocene(?)	Terrace gravels.		0–80	Terrace gravel of well-rounded pebbles.
	-Unconformity-			
Tertiary(?) (Eocene(?).	Lance formation.		Not determined.	Yellowish-brown sandstones and buff to gray shales with a thick, massive sandstone at base.
Upper Cretaceous.	Montana group.	Bearpaw shale.	1,000 ±	Dark-gray to black marine clay shale containing large calcareous concretions. Heavy band of sandy concretions near base.
		Judith River formation.	550 ±	An upper part, chiefly sandstone and shale, forming ridges; a middle part, chiefly light-buff to gray or white clay shale with interbedded sandstone; a lower part, included in the Judith River because of lithologic similarity, chiefly sandstone with a thick bed of massive ledge-making sandstone at the base. The sandstones become andesitic in western part of field.
		Claggett formation.	350–490	In eastern part of field a dark-drab shale. It becomes more sandy toward the west.
		Eagle sandstone.	300 ±	Three members. Upper member moderately thick sandstones interbedded with shale; middle member shale and thin-bedded sandstones; lower member (Virgelle sandstone) thick, massive white sandstone. In western part of field lower member is thinly bedded. The sandstones become andesitic toward the west.
	Colorado shale.		2,200 ±	In eastern part of field lower 400 to 500 feet contains three conglomeratic sandstones 5 to 20 feet thick, above which is 10 to 30 feet of sandy shale which contains fish remains. This represents the Mowry shale. The probable representative of the Frontier formation is a zone of thin shaly sandstones about 30 feet thick. Farther west, the Mowry shale can not be recognized. The lower 700 or 800 feet of the formation consists of alternating black fissile shale and thin sandstones. Above this zone is the Big Elk sandstone member, 200 feet or more thick. Remainder of formation chiefly shale.
Lower Cretaceous.	Kootenai formation.		250 +	Mainly sandy shale, containing concretionary sandstone in the upper part. At the top is about 50 feet of thin-bedded sandstone in which are markings resembling worm trails; at base of exposed section is a coarse sandstone.

the field, are several thin, finely conglomeratic sandstones. (5) At the top of the Kootenai there is 40 to 50 feet of platy, rather fine grained sandstone in approximately the same position as the Greybull sand of the Big Horn Basin, Wyoming. (6) Near the base of the Kootenai there is another coarse, porous sandstone of undetermined thickness.

North-central Montana.—Interest has recently been attracted to northern Montana by a large gas well brought in near Havre,[1] which is estimated to have had an initial yield of about 10,000,000 cubic feet, but proved short-lived. The rocks of north-central Montana are sedimentary beds lying almost flat that have been

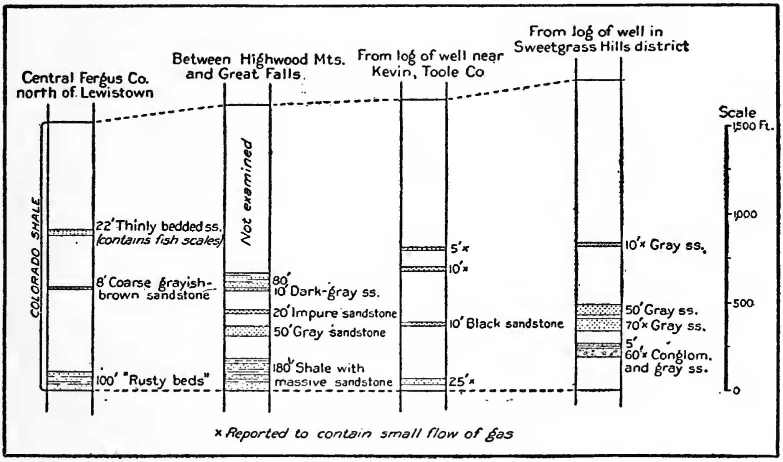

Fig. 173.—Section showing sandstones in lower part of Colorado shale, north-central Montana. (*After Stebinger.*)

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[1] Stebinger, Eugene: Possibilities of Oil and Gas in North-Central Montana. U. S. Geol. Survey *Bull.* 641, pp. 49-91, 1917; The Montana Group of Northwestern Montana. U. S. Geol. Survey *Prof. Paper* 90, pp. 61-68, 1915.

Fisher, C. A.: Geology of the Great Falls Coal Field, Montana. U. S. Geol. Survey *Bull.* 356, 1909; Geology and Water Resources of the Great Falls Region, Montana. U. S. Geol. Survey *Water-Supply Paper* 221, 1909.

Pepperberg, L. J.: The Milk River Coal Field, Montana. U. S. Geol. Survey *Bull.* 381, pp. 82-107, 1910; The Southern Extension of the Milk River Coal Field, Chouteau County, Montana. U. S. Geol. Survey *Bull.* 471, pp. 359-383, 1912.

Bowen, C. F.: The Cleveland Coal Field, Blaine County, Montana; The Big Sandy Coal Field, Chouteau County, Montana. U. S. Geol. Survey *Bull.* 541, pp. 338-378, 1914.

intruded by igneous rocks and uplifted in isolated mountain groups. Faults are numerous. In the plains surrounding the Bearpaw Mountains for 30 to 40 miles on all sides there are many folds and faults in the Cretaceous rocks. These are irregular in their trend and distribution. The faulting is probably related to the igneous intrusions in the Bearpaw Mountains. The faults are all of the thrust type, older formations having been carried upward beside younger rocks that lie for the most part undisturbed. Some of these faults are about 12 miles long.

The strong flow of gas encountered at Havre, as stated by Stebinger, comes from the Eagle sandstone. The gas produced at Medicine Hat, in Alberta, according to some investigators, is found at the same horizon. Sections of the Colorado shale are shown on Fig. 173.

As shown by the tables given above differences between the geologic sections of the eastern and western parts of the region occur in the Montana group in the interval between the Virgelle sandstone and the Bearpaw shale. This is due to the fact that the marine invasion during which the Claggett shale was deposited in the east did not extend westward beyond the 112th meridian.

Birch Creek-Sun River Area.—The Birch Creek-Sun River area[1] in northwestern Montana, lies adjacent to the front range of the Rocky Mountains, between Great Falls and Kalispell. The Cretaceous formations which have yielded oil and gas in Wyoming, Colorado, and at Medicine Hat, Alberta, are present in this area, where they are thrown into folds along axes parallel to the front range. Some wells have yielded gas, but no oil field has been developed. The section is stated below.

Blackfeet Reservation.—The Colorado shale and Kootenai formations are present also in the Blackfeet Reservation,[2] where locally they are folded and faulted (Fig. 174). The Colorado and Bearpaw shales are of marine origin and were laid down in separate

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[1] STEBINGER, EUGENE: Oil and Gas Geology of the Birch Creek-Sun River Area, Northwestern Montana. U. S. Geol. Survey *Bull.* 691, pp. 149-184, 1919.

[2] STEBINGER, EUGENE: Anticlines in the Blackfeet Indian Reservation, Montana. U. S. Geol. Survey *Bull.* 641, pp. 281-305, 1917; Possibilities of Oil and Gas in North-Central Montana. U. S. Geol. Survey *Bull.* 641, pp. 49-91, 1916; Geology and Coal Resources of Northern Teton County, Montana. U. S. Geol. Survey *Bull.* 621, pp. 117-156, 1916.

FORMATIONS EXPOSED IN THE PLAINS OF NORTH-CENTRAL MONTANA EAST OF THE 112TH MERIDIAN

(After Stebinger)

System	Series	Group	Formation	Thickness (Feet)	Character
Quaternary.	Recent.		Alluvium.		Silt, sand, and gravel along flood plains of larger streams.
	Pleistocene.		Glacial drift.	0–200	Boulder clay, gravel, and lake silt and clay. Contains boulders and cobbles of granite, gneiss, quartzite, etc., transported from the northeast.
Tertiary.	Eocene.		Fort Union formation.	[a]700 +	Clay shale, sandstone, and coal beds. Present only in small areas. Poorly exposed.
Tertiary (?).	Eocene (?).		Lance formation.	700–800	Alternating gray clay shale and sandstone with irregular coal beds. Present in relatively small areas only.
Cretaceous.	Upper Cretaceous.	Montana group.	Bearpaw shale.	500–800	Dark-gray clay shale with a few limestone concretions. Contains many marine shells. Forms a subdued, rounded topography and gumbo soil.
			Judith River formation.	450–550	Light-gray clay and clay shale with irregular beds of gray or brown sandstone, and coal beds. Contains many oyster and other shells besides fossil bones.
			Claggett shale.	350–500	Like the Bearpaw in character of rocks and fossils, except for the occurrence of sandy beds near the top.
			Eagle sandstone with Virgelle sandstone member at base.	250–400	Upper part gray clay shale and sandstone with coaly shale and thin coal. Lower part white to buff thick-bedded, massive sandstone, Virgelle sandstone member. Contains gas in the Havre district.
			Colorado shale.	1,500–1,700	Bluish-gray to black shale with a few limestone concretions. Contains many marine shells. Includes three or four sandy beds 5 to 70 feet thick in lower 800 feet. Probably contains gas and oil in some localities of favorable structure.
	Lower Cretaceous.		Kootenai formation.	400–600	Red clayey shale and irregular gray sandstone with a few thin beds of limestone. Contains coal near the base and fossil plant remains of fresh-water origin. Probably contains gas and oil in some localities of favorable structure.

[a] Estimated.

FORMATIONS EXPOSED IN THE PLAINS OF NORTH-CENTRAL MONTANA WEST OF THE 112TH MERIDIAN
(After Stebinger)

System	Series	Group and Formation		Thickness (Feet)	Character
Quaternary.	Recent.	Alluvium.			Silt, sand and gravel along flood plains of larger streams.
	Pleistocene.	Glacial drift.		0–200	Boulder clay, gravel, and lake silt and clay. Contains boulders and cobbles of granite, gneiss, quartzite, etc., transported from the northeast.
Cretaceous.	Upper Cretaceous.	Montana group.	Bearpaw shale.	450–550	Dark-gray clay shale with a few limestone concretions. Contains many marine shells. Forms a subdued, rounded topography.
			Two Medicine formation.	1,900–2,100	Gray to greenish-gray clay and soft, irregular sandstone, which is most abundant in the lower 250 feet. In places thin beds of red clay and nodular limestone. Contains an abundant reptilian fauna of Judith River types, besides leaves and shells. Contains coal beds near the base and at the top.
			Virgelle sandstone.	200–290	Gray to buff coarse-grained, much cross-bedded massive sandstone, with many ferruginous concretions in upper half. In lower half slabby gray sandstone, becoming shaly toward the base.
		Colorado shale.		1,600–1,750	Bluish-gray to black shale with a few limestone concretions. Contains many marine shells. Includes three or four sandy beds 5 to 70 feet thick in lower 800 feet. Probably contains gas and oil in some of the areas of favorable structure.
	Lower Cretaceous.	Kootenai formation.		600–700	Shale, red in upper part, but remainder grayish to black. Contains irregular sandy beds up to 100 feet thick. Fresh water. Probably contains gas and oil in some of the areas of favorable structure.

FORMATIONS EXPOSED IN THE BIRCH CREEK-SUN RIVER AREA, MONTANA (After Stebinger)

System	Series	Group and Formation	Thickness (Feet)	Character
Quaternary.	Recent.	Alluvium.		Silt, sand, and gravel, chiefly along stream bottoms.
	Pleistocene.	Glacial drift.	0–150	Boulder clay, gravel, and sand. Contains boulders of various rocks derived from the mountains.
Tertiary.	Pleistocene and late Tertiary.	Terrace gravels.	5–50	Limestone gravels on terraces and plains.
Tertiary (?).	Eocene (?).	St. Mary River formation.	650 +	Clay, clay shale, and soft sandstone, gray to greenish gray.
Cretaceous.	Upper Cretaceous.	Montana group. Horsethief sandstone.	250–400	Chiefly massive gray to buff and greenish-gray coarse-grained sandstone with slabby sandstone and shale in lower half. Contains one or more shell beds.
		Bearpaw shale.	0–500	Dark-gray shale with a few thin beds of gray sandstone. Marine shells of Pierre types. Present only in northern part of area. To south grades into brackish and fresh water clays and sandstones.
		Two Medicine formation.	1,800–2,200	Gray, greenish-gray, and red clay and clay shale with subordinate irregular sandstones, mainly in lower half. Bones of reptiles of Judith River types and fragments of wood are abundant. Thin beds of coal near base.
		Virgelle sandstone.	200–380	Upper part, massive coarse gray sandstone, much cross-bedded, and with heavy, irregular beds of magnetite sandstone at top. Lower part, interbedded sandstone and shale. Contains gas at Medicine Hat and elsewhere in Alberta and at Havre, Montana.
		Colorado shale with Blackleaf sandy member at base.	1,800 +	Upper part, dark shale with bituminous shale and thin, maltha-bearing limestones near base. Blackleaf sandy member, coarse sandstones locally conglomeratic in beds 20 to 75 feet thick, alternating with dark marine shale; thickness 610 to 700 feet.
	Lower Cretaceous.	Kootenai formation.	890–920	Red and green shales and clay shale with many beds of coarse gray sandstones. Contains a few fresh-water shells.
Jurassic.	Upper Jurassic.	Ellis formation.	240–310	Black to gray calcareous shale with thin limestone and sandstone. Many fossil shells. Marine.
		–Unconformity–		
Carboniferous.	Mississippian.	Madison and later limestones.	1,200 +	Massive white limestone, cherty in middle and lower beds; coralline limestone in upper beds.

FORMATIONS OCCURRING EAST OF THE MOUNTAINS ON THE BLACKFEET INDIAN RESERVATION, MONTANA

(After Stebinger)

System	Series	Group and Formation		Thickness in Feet	Character of the Rocks
Quaternary.	Recent.		Alluvium.		Deposits of small extent found along flood plains of the larger streams.
	Pleistocene.		Glacial drift.		Boulder clay, gravel, and lake silt and clay. Contains boulders and cobbles of granite, gneiss, quartzite, etc., transported from other regions. Deposits are of several stages not distinguished in this report.
Tertiary (?).	Eocene (?).		Willow Creek formation.	720+	Variegated clay and soft sandstone, chiefly maroon to chocolate-brown. Fragments of fossil bones common. Clay in places contains thin, lenticular beds of limestone. Forms a red soil. Top not seen.
			St. Mary River formation (coal bearing).	980	Alternating clay, shale, and sandstone much cross-bedded and ripple marked. Gray to greenish gray; a few layers are red. Contains thin lenticular limestones, fragments of dinosaur bones, and fossil shells.
Cretaceous.	Upper Cretaceous.	Montana group.	Horsethief sandstone.	225–375	Gray to greenish-gray sandstone. Thin bedded and shaly in lower half. In upper half generally massive and concretionary. In places near the top contains titaniferous magnetite. Has many shell beds, mainly of oysters.
			Bearpaw shale.	490	Dark-gray clay shale with a few limestone concretions. Contains abundant marine shells. Forms subdued, rounded topography.
			Two Medicine formation (coal bearing).	1,950	Gray to greenish-gray clay and soft sandstone, most abundant in the lower 250 feet. In places beds of red clay and nodular limestone. Contains a reptilian fauna, besides leaves and shells. Coal beds near base and at top.
			Virgelle sandstone.	220	Gray to buff coarse-grained sandstone, with ferruginous concretions in upper half. In lower half slabby, gray sandstone, shaly toward the base. Contains gas in the Havre field and at Medicine Hat.
			Colorado shale.	1,500 ±	Bluish-gray shale with a few limestone concretions. Contains an abundance of marine shells. Forms a subdued and rounded topography. Complete undisturbed section not present. May contain oil and gas in areas of favorable structure.
	Lower Cretaceous.		Kootenai formation.	2,000 ±	Gray sandstone and shale, alternating with maroon clay shale. Some of the sandstone massive. Conglomerate 6 to 50 feet thick near center. Carries a few leaves and fresh-water shells. Complete undisturbed section not found. May contain oil and gas in areas of favorable structure.

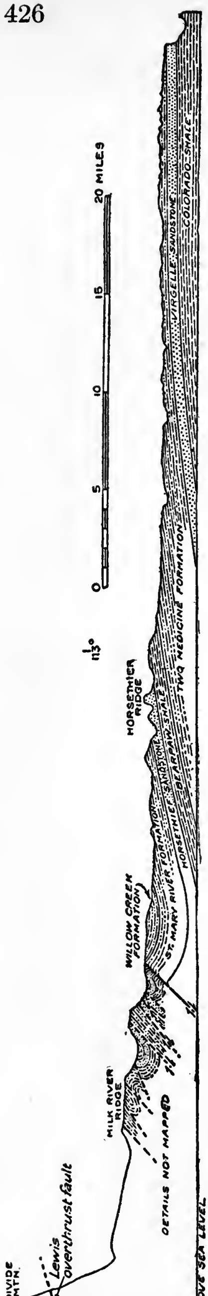

FIG. 174.—Section from Divide Mountain eastward. Blackfeet Indian Reservation, Montana. (*After Stebinger.*)

epochs, during which a comparatively shallow sea covered the entire region. The remaining formations are mainly of continental origin—that is, they are irregularly bedded rocks that were for the most part deposited by streams and winds on land areas that were only slightly above sea level. The most promising areas for prospecting are those containing marine formations gently folded and not too highly faulted.

Bowdoin Dome.—The Bowdoin dome[1] is on Milk River, in northeastern Montana, on the Great Northern Railway, between Malta on the west and Hinsdale on the east. A well drilled here for water several years ago yielded a small flow of gas. The sedimentary rocks range in age from Cambrian to Recent, but only the Upper Cretaceous Claggett shale, Judith River formation, and Bearpaw shale and some of the more recent surficial deposits are exposed in the immediate vicinity of the dome. The Claggett shale crops out in the Little Rocky Mountains, about 50 miles to the southwest. The surface of the Bowdoin dome is covered by the Claggett shale, below which, according to Collier, are four sandstones within 3,000 feet of the surface. Of these four the Eagle sandstone yields gas at Havre.

Eastern Montana.—Small amounts of gas have been encountered at several places in eastern Montana or western North Dakota, most of them in wells sunk for water. In the southeastern part of Dawson County the Glendive anticline is well defined. It extends into North Dakota and is one of the most

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[1] COLLIER, A. J.: The Bowdoin Dome, Montana, a Possible Reservoir of Oil or Gas. U. S. Geol. Survey *Bull.* 661, pp. 133-209, 1917.

GENERAL SECTION OF THE ROCKS OF THE BOWDOIN DOME, MONTANA
(After Collier)

System	Series	Group	Formation	Thickness (Feet)	Character
Quaternary.	Recent.				Silts in the flood plains of streams.
	Pleistocene.				Scattered crystalline boulders; glacial moraines.
					Silt, sand, and gravel deposited along the old channels of the Missouri, Musselshell, and other streams before the end of the glacial epoch.
					Gravel interstratified with yellowish silt at an altitude of 300 feet above Milk River valley. May possibly be late Pliocene.
Cretaceous.	Upper Cretaceous.	Montana.	Bearpaw shale.	800–1,000	Dark-gray shale; forms gumbo soil.
			Judith River formation.	400	Light-gray clay and irregular beds of gray and brown sandstone.
			Claggett shale.	750	Dark-gray shale; forms gumbo soil. About 500 feet exposed in Bowdoin dome.
			Eagle (?) sandstone.	100 ±	Light-gray sandstone; forms a low ridge; contains limestone concretions in its upper part.
		Colorado.		875	Bluish-gray to black shale; contains limestone concretions and marine fossils.
				60 ±	Light-gray sandstone, capped by a thin limestone containing numerous gastropods.
				485 ±	Bluish-gray to black shale.
			Mowry shale.	100 ±	Platy shale or sandstone, which is in places dark-colored but weathers white; contains numerous fish scales; yields traces of oil by distillation.
	Lower Cretaceous.		Kootenai (?) formation.	825 ±	Mainly shale but includes some poorly defined sandstone. In lower part red and purple shales were noted. A bed of fresh-water sandstone and carbonaceous shale with fragments of woody stems near the base.
Jurassic.	Upper Jurassic.		Ellis formation.	200 ±	Massive white and yellow sandstone.
				200 ±	Shale containing *Belemnites.*
Carboniferous.	Mississippian.		Madison limestone.		Massive limestone.

prominent structural features in the region. It exposes a belt of Cretaceous rocks about 100 miles long, flanked on both sides by Tertiary deposits. On this anticline gas is obtained, probably from sands of the Judith River group of the Montana. It is used to supply Glendive and Baker. Gas is found in the Eagle sands near Hinsdale, Valley County. Several low anticlines near Wolf Point and Poplar, Valley County, are reported. These are probably part of the Glendive system, and they expose near their crests the upper parts of the Upper Cretaceous.

NORTH DAKOTA

At Williston and Minot, North Dakota, wells have been drilled in search of oil, but at neither place have commercial accumulations been found, though small samples resembling gasoline are said to have been obtained from the Minot well. The towns of Westhope and Lansford, in Bottineau County, are supplied with natural gas from shallow wells in the glacial drift above the Pierre shale. At Edgeley, Lamoure County, artesian wells drilled to the Dakota sandstone yield a small quantity of gas which is separated from the water by mechanical means and used by the residents.[1]

The rocks of North Dakota in general lie nearly flat; anticlines or domes are not easily detected. Underlying the area the shale and fine-grained sandstone of the Fort Union (Eocene) and Lance (Eocene?) formations reach a depth estimated at about 1,700 feet. The Lance carries dinosaur fossils and is of fresh-water origin. Beneath the Lance formation is the Pierre, composed almost entirely of dark-gray shale. No sandstone layers are known to be present in the upper part of the Pierre.

The Nesson anticline,[2] named from a small village in Williams County, in the northwest corner of North Dakota, is about 30 miles east of Williston, 13 miles southeast of Ray, and 80 miles west of Minot. It was discovered in 1917 by a United States Geological Survey party which mapped outcrops of the lignite beds in the Ray quadrangle.

[1] Leonard, A. G.: Natural Gas in North Dakota. U. S. Geol. Survey *Bull.* 431, pp. 7-10, 1911.

[2] Collier, A. J.: The Nesson Anticline, Williams County, North Dakota. U. S. Geol. Survey *Bull.* 691, pp. 211-217, 1919.

COLORADO

General Features.—The production of oil in Colorado has never been large and now is dwarfed in comparison with that of Wyoming. The principal producing areas are the Florence and Boulder fields, in both of which the oil comes from the Pierre shale. In the San Juan field, Utah, oil has been found in the Goodridge formation (near top of Pennsylvanian). In the De Beque field oil is found probably in the Mesaverde or at the base of the Wasatch. In the Rangely district, Rio Blanco County, some oil is found in the Mancos formation. At Urado, near Black Dragon station, near the western boundary of Rio Blanco County, a little oil comes from a horizon not far below the base of the Green River oil shales.

Petroleum Marketed in Colorado, 1908–1917, By Districts

Year	Boulder			Florence			Total		
	Quantity (Barrels)	Value	Average Price per Barrel	Quantity (Barrels)	Value	Average Price per Barrel	Quantity (Barrels)	Value	Average Price per Barrel
1908........	84,174	$124,794	$1.482	295,479	$221,609	$0.750	379,653	$346,403	$0.913
1909........	85,709	129,812	1.514	225,062	187,900	.834	[a]310,861	318,162	1.023
1910........	42,186	63,420	1.503	193,482	174,332	.901	[b]239,794	243,402	1.015
1911........	37,973	50,393	1.327	187,341	175,763	.938	[b]226,926	228,104	1.005
1912........	15,304	19,130	1.250	190,498	180,281	.946	[c]206,052	199,661	.969
1913........	11,796	15,366	1.303	176,693	159,103	.900	[c]188,799	174,779	.926
1914........	6,515	9,117	1.399	215,548	191,067	.886	[d]222,773	200,894	.902
1915........	6,376	9,679	1.518	202,069	173,506	.859	[a]208,475	183,485	.880
1916........	5,749	9,902	1.722	191,486	207,237	1.082	197,235	217,139	1.101
1917........	5,847	11,510	1.969	114,664	115,150	1.004	[a]121,231	128,100	1.057

[a] Includes a small production in Garfield County.
[b] Includes production in Garfield and Rio Blanco Counties.
[c] Includes production in Rio Blanco County.
[d] Includes production in Mesa and Rio Blanco Counties.

Florence.—The Florence field,[1] in south-central Colorado, is in a synclinal reentrant of the Rocky Mountain front, between the fold made by the Front range on the northeast and the Wet Mountains on the southwest. This reentrant is commonly called Cañon City embayment. The rocks are Paleozoic and Mesozoic sediments. Solid bitumen is found in the Dakota sandstone near Cañon City, and about 7 miles northeast of Cañon City there is an oil spring, running less than 20 gallons of oil a day. It issues from Pleistocene gravel but probably rises from the Morrison beds.

[1] Washburne, C. W.: The Florence Oil Field, Colorado. U. S. Geol. Survey *Bull.* 381, pp. 517-544, 1910.

Two other oil springs have been noted in Morrison beds. The producing wells are in the Pierre shale (Upper Cretaceous), which is a remarkably uniform rock. Underground it is firm and easily broken along the bedding planes.

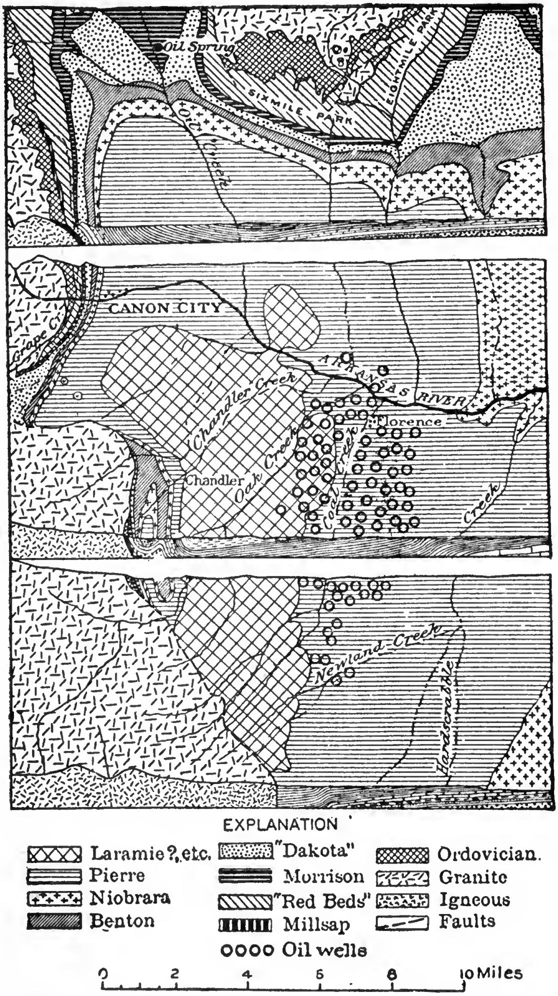

FIG. 175.—Geologic sketch map of the Canyon City embayment, Colorado. (*After Dorton.*)

The syncline on which the field is situated (Fig. 175) has generally low dips, on which there are small folds passing into faults with a general east-west trend and a throw of less than 50 feet. These folds and faults probably indicate the fissures below them in the oil-bearing zone. The oil occurs in fissures having the same direction as the flexures; and the presence of east-west fissures and flexures at the surface is a favorable indication of the productive character of the locality. The Pierre, which crops out in the region of the wells, is productive through a zone 2,500 feet thick. It carries marine fossils. The oil is rather light (30° Baumé), has a paraffin base, and is free from sulphur. It is associated with gas, and the deep wells encounter salt water. As a rule, however, water does not follow the oil when the well is pumped dry.

Boulder.—The Boulder oil district[1] lies a few miles north of Boulder, east of the Front range. The rocks dip eastward, away from the mountains. Locally small foothill folds are developed. The section includes the following strata.

Quaternary	Alluvium and terrace gravels
Cretaceous	Laramie Fox Hills Pierre Niobrara Benton Dakota
Jurassic	Morrison
Triassic (?)	Lykins Lyons Fountain
Algonkian	Quartzite of South Boulder Canyon
Archean	Granites, etc.

The Pierre is more than 5,000 feet thick and is mainly shale with a little limestone and sandstone. It contains also the Hygiene sandstone member and other lower sandstones. Near Boulder the Hygiene sandstone is within less than 1,000 feet of the base of the Pierre and is itself a very thin stratum. It thickens greatly toward the north, as do the shales which lie below it. Oil springs are found about 10 miles from Boulder, and one some 17 miles north is noteworthy. Oil development appears not to have been suggested by the springs, however, but the bituminous odor of the Benton and Niobrara shales led to the exploration. Later, in

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[1] Fenneman, N M.: Geology of the Boulder District, Colorado. U. S. Geol. Survey *Bull.* 265, 1905.

prospecting for coal, oil was found in the Pierre, much higher than these formations. The beds from which the oil is obtained are sands or sandstones in the Pierre. Such beds may be encountered at any depth, but there is no depth at which they are certain to be found. Some of the wells are dry; others yield salt water. In the part of the field near Boulder that had been developed when the field was described by Fenneman the oil accumulations appear to have no very definite relation to the structure. Later an anticline in the area to the north, shown in Fenneman's report by the position of the Hygiene sandstone member in the Pierre, was drilled. The first well, a gusher, was brought in on the south end of this anticline. It had an initial flow of 250 barrels a day. Eight other wells drilled, pumped from 5 to 170 barrels a day, two encountered traces of oil, and two were dry. All the productive wells are on the anticline. They derive their oil from a sandstone in the Pierre shale, 2,000 to 2,500 feet deep. The wells sunk near the crest of the anticline produce gas and a light oil of about 42° Baumé. The wells farther down the limbs of the anticline produce heavier oil (40° Baumé), mixed with water.[1]

DeBeque.—The DeBeque oil field[2] is on the Grand River in Mesa County. The country is a high plateau deeply dissected. The rocks are nearly flat-lying, and the formations exposed are the Wasatch and Green River. Below the Wasatch is the Mesaverde formation, and below that the Mancos shale is probably present. The section is stated on page 433.

Structurally the region is a saucer-like basin that extends from the Uncompahgre Plateau on the southwest to the Grand Hogback on the northeast. In the part of the region near De Beque the rocks generally dip northeast or lie horizontal. Due west of De Beque, however, there is an anticline which extends westward for about 8 miles or more. South of the axis the rocks dip 2°-3° S.; north of it they dip 3°-5° N. Oil is encountered in wells on the anticline not far from its crest. It is a light-gravity oil (37° Baumé) with a paraffin base, free from asphalt.

Oil was discovered in the area in 1902, and in the next two years ten wells were drilled. The first well was 614 feet deep. Most

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[1] Washburne, C. W.: Development in the Boulder Oil Field, Colorado. U. S. Geol. Survey *Bull.* 381; pp. 514-516, 1910.

[2] Woodruff, E. G.: Geology and Petroleum Resources of the DeBeque Oil Field, Colorado. U. S. Geol. Survey *Bull.* 531, pp. 54-68, 1913.

STRATIGRAPHIC RELATIONS OF FORMATIONS IN THE DE BEQUE REGION, COLORADO
(After Woodruff)

System	Series	Formation	Character
Quaternary.			Alluvium in valleys and gravel on terraces, variable thickness.
Tertiary.	Eocene.	Green River formation.	Shale and sandstone, locally calcareous. The shale is sandy, fine grained, and evenly bedded; faded olive-green in color. The sandstone is thin bedded and fine grained.
		Wasatch formation.	Shale and sandstone, irregularly bedded. The shale is variegated, shades of gray and pink predominating. The sandstone is coarse grained and variegated.
Cretaceous.	Upper Cretaceous.	Mesaverde formation.	Sandstone, thick bedded, and sandy shale. Not exposed in this region.

of the wells found small quantities of oil and gas, but no clearly defined oil sand was encountered. Woodruff believes that the oil and gas are in the upper part of the Mesaverde formation, or possibly in the lower Wasatch. He states that the Mancos shale, which underlies the Mesaverde, is probably the original source of the oil rather than the Green River, which is high above the oil-bearing strata.

Rangely.—The Rangely district is in Raven Park, Rio Blanco County, about 33 miles northeast of Dragon, Utah.[1] Attention was directed to this field by the discovery of an oil seep. There are about 20 wells each capable of producing 2 or 3 barrels of oil a day. Most of the wells are 400 to 600 feet deep; one is said to be

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[1] GALE, H. S.: Geology of the Rangely Oil District, Rio Blanco County, Colorado. U. S. Geol. Survey *Bull.* 350, 1908.

over 3,000 feet deep. The oil is a high-grade yellow oil, with a gravity of 44° Baumé, and according to report is burned directly in an engine. The district is structurally a dome or quaquaversal which exposes the Mancos shale and is superimposed on the great structural basin that lies south of the Uinta Mountains. The oil is found in thin sand lenses in the Mancos formation. Both the sands and shales are said to be dry; no adequate oil sand has yet been encountered. The Dakota sandstone, which lies 3,500 or 4,000 feet below the surface, has not been tested. In general it is not petroliferous in this region.

White River.—The White River field is on Blacks Gulch, 40 miles east of Rangely and 20 miles west of Meeker. It is on the crest of a minor anticline that lies across the White River Valley.[1]

The dips are low, being about 3° toward the east, about 10° south of the river, and about 5° toward the west. A well was put down 400 feet where a cowboy had discovered a flow of gas by lighting a match. Another well sunk 538 feet struck gas under sufficient pressure to destroy the derrick. The gas burned six months and then ceased to issue. No oil was found. The strata are Wasatch at the surface, flanked by Green River escarpments.

Urado.—About 8 miles south of Dragon station, Utah, at Urado, Rio Blanco County, on the Uintah Railway, 1½ miles east of the Colorado-Utah line, the Urado Co. operates an oil well and a small refinery. It produces lubricating oils of high quality which are sold in the Uinta Valley region. The plant is said to be capable of producing between 5 and 10 barrels a day. A well 505 feet deep is sunk in beds that lie at a horizon below the oil shales of the Green River formation, possibly in the upper beds of the Wasatch. Drilling was suggested by the presence of an oil spring. The beds are practically flat or dip 2°-3° NW. Oil is present in three sands penetrated. A tunnel 375 feet long is run in on the upper sand the entire distance. This tunnel was bulkheaded a short distance in, and the structure beyond the bulkhead is concealed. Mr. J. T. Pope, manager, says that the oil sand forms a shallow syncline. There is little or no gas pressure, and no gas was encountered in driving the tunnel. The oil sand and the oil lie in shallow sags which are 4 or 5 feet deep. The oil comes into the sags from the southeast and issues at the portal of the tunnel.

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[1] GALE, H. S.: *Op. cit.*, p. 48.

UTAH

Green River District.—In the Green River district of Utah, near the town of Green River, on the Denver & Rio Grande Railroad, sandstones saturated with petroleum crop out, and small amounts of oil have been found in several wells. Oil seeps on the surface are fairly common. The geology has been described by Lupton,[1] who visited the field in 1912. The rocks exposed are of Cretaceous and Jurassic age.

The oil and gas are in the McElmo formation. Of wells drilled prior to 1912, three were dry, four showed gas, and three showed traces of oil. Gas is associated with salt water in a well 1,980 feet deep. The wells passed through the McElmo formation and penetrated the upper part of the La Plata. The McElmo contains no persistent oil sand, although it may include numerous small lenses of petroliferous sandstone.

Structurally the region is a monocline dipping northeast, on which there is a shallow anticline broken by faults. The dips are low. According to Lupton there are no good-sized domes or persistent petroliferous beds in the McElmo in this region.

Hanksville.—Near Hanksville, 45 or 50 miles southwest of Green River, two wells were being drilled in 1912. Lupton,[2] who made a reconnaissance of this district, states that the structure appears to be favorable to oil accumulation, providing the rocks contain a sand and oil. A broad, low, flat east-west anticline connects the San Rafael Swell on the west with another anticline reported to be near the junction of the Grand and Green rivers.

Salt Lake Basin.—Gas has been found at several places in the lake deposits of Salt Lake basin by drilling near small gas seeps.[3] Several wells about 12 miles north of Salt Lake City supplied gas for domestic use for a time, but these are now abandoned. At Farmington gas was found under heavy pressure at several horizons in the unconsolidated material, but no oil was discovered, although in a well 2,000 feet deep some oil was found at Fillmore, Utah, south of Salt Lake.

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[1] Lupton, C. T.: Oil and Gas Near Green River, Grand County, Utah. U. S. Geol. Survey *Bull.* 541, pp. 115-133, 1914.

[3] Lupton, C. T.: *Op. cit.*, pp. 120, 133.

[2] Richardson, G. B.: Natural Gas Near Salt Lake City, Utah. U. S. Geol. Survey *Bull.* 260, pp. 480-483, 1905.

GENERAL SECTION OF ROCKS OUTCROPPING IN THE GREEN RIVER FIELD, UTAH (After Lupton)

System	Formation	Member	Character of Strata	Thickness (Feet)	Economic Value
Cretaceous.	Mancos shale.		Yellow to bluish drab sandy shale; the upper part is very sandy and contains beds and lenses of sandstone; the middle and lower parts are mainly shale.	About 2,500 (after Richardson)	
		Ferron sandstone member.	This sandstone contains in places concretions which are fossiliferous. It forms a hogback through the field.	50–100	Possibly this sandstone is a reservoir for the gas that has been obtained in some of the wells.
			Bluish drab sandy shale; sandy material is most plentiful near the base and top of this part of the formation.	About 400.	
	Dakota sandstone.		Yellowish-gray sandstone with thin beds of shale alternating. Sandstones, coarse, soft, and in places very conglomeratic.	0–40	Contains a little coal in places, but none was observed in this field.
			——Unconformity——		
Jurassic (?).	McElmo formation.		Gray conglomerate, variegated sandy shale, and clay, and a few feet of limestone about 175 feet from the top.	325–350	A few lenses of sandstone contain pockets of gas. Other lenses are partly saturated with petroleum.
		Salt Wash sandstone member.	Gray conglomeratic sandstone which outcrops in cliffs. The sandstone in places is lenticular, soft, and friable.	150–175	Water-bearing in places. Probably contains a little gas and a trace of oil.
			Red sandstone, thin-bedded above and massive below.	About 700.	Gypsum and manganese in the upper part.
Jurassic.	La Plata sandstone.		Coarse gray sandstone very much cross-bedded	Estimated 700.	Water-bearing in many places.

Asphalt is found near the Rozel Hills, on the north shore of Salt Lake.[1] The occurrence appears to be restricted to the shallow littoral portion of the lake, one-fourth to one mile out from the present shore line, immediately southeast of the Rozel Hills. The asphalt exudes through the unconsolidated material on the bottom of the lake and bubbles up into the water in the form of hollow spherical or tubular masses 1 to 2 inches long and threads and hairs 6 to 18 inches long. These small masses spot the bottom in great numbers throughout this area. At certain points the emissions are concentrated into considerable seeps or "pitch springs," 1 to 2 feet in diameter. The source of these seeps appears to those

Section of Strata Exposed in the San Juan Oil Field, Utah
(After Woodruff)

System	Formation	Member	Thickness (Feet)	Description
Jurassic.	La Plata sandstone.		[a]500 ±	Massive, tan sandstone.
Triassic.	Dolores shale.		1,330	Very sandy, variegated shale. This formation contains saurian remains.
Unconformity?-				
Permian?	Moencopie formation.	Oljato sandstone.	20–380	Massive, tan sandstone.
			1,260	Red, sandy shale and massive, tan sandstone beds.
Pennsylvanian	Goodridge formation.		1,542	Massive-bedded, crystalline limestone, soft, sandy shale and sandstone. Oil near top.

[a] Only lower part exposed.

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[1] Boutwell, J. M.: Oil and Asphalt Prospects in Salt Lake Basin, Utah. U. S. Geol. Survey *Bull.* 260, p. 474, 1905.

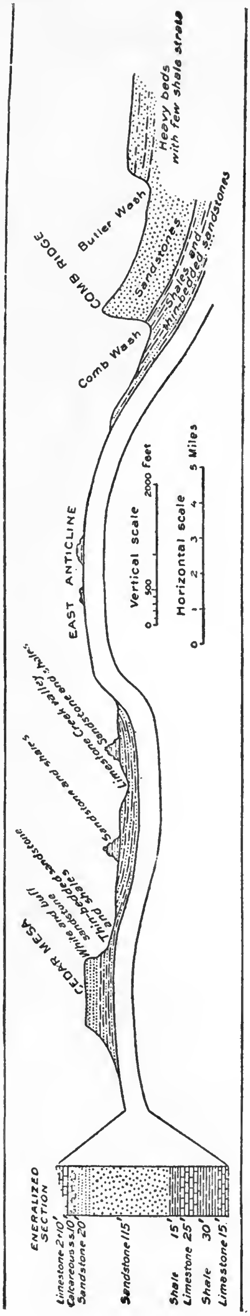

FIG. 176.—East and west section across San Juan oil field, Utah. (*After Woodruff.*)

who have prospected this ground to be a bed of asphalt 2 or 3 feet thick, which was encountered 80 feet below the present lake bed, and an underlying series of asphaltic beds 3 to 5 feet thick, which alternate with beds of clay to a depth of at least 140 feet. In the vicinity of these seeps the asphaltic matter cements the calcareous oolitic deposits of the lake bottom into a bituminous limestone. This forms numerous low islets, 1 to 50 feet in diameter, which are distributed in rough alinement. This alinement and the presence of brecciated zones in the limestone on the mainland suggest the possibility that the seeps may occur along zones of fracture. These zones may have served merely to open exits for the fluid asphalt in unconsolidated lake beds, or they may have also delivered it from deeper reservoirs in underlying bedrock to its present position.

San Juan Field.—The San Juan oil field[1] is in southeastern Utah, about 20 miles west of Bluff, where several oil seeps occur along the San Juan River. The strata of this region are indicated on page 437.

The rocks are thrown into gentle folds, whose axes trend nearly north. The principal structural feature is a broad, gentle syncline, flanked by anticlines on either side. There are several oil sands, all near the top of the Good-

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[1] WOODRUFF, E. G.: Geology of the San Juan Oil Field, Utah. U. S. Geol. Survey *Bull.* 471, p. 76, 1912.

GREGORY, H. E.: The San Juan Oil Field. U. S. Geol. Survey *Bull.* 431, pp. 11-25, 1911.

ridge formation, where they are interbedded with shale. Where not exposed the Goodridge is overlain by the lower shales of the Moencopie. All the oil found is in the broad syncline (Fig. 176). There is very little water in the oil-bearing sands, and the gas pressure is not high. The oils are light (37° Baumé) and carry high percentages of gasoline and burning oil, with considerable paraffin wax. Numerous wells have encountered oil, and one well drilled in 1908 sprayed oil 70 feet above the derrick floor. The pressure in general is low, however, and the sands are generally dry. Developments thus far are not particularly promising.

Virgin City.—Virgin City is on Virgin River, in the southwest corner of Utah,[1] about 90 miles by road from Lund, the nearest railroad station, which is on the Los Angeles & Salt Lake Railroad. This portion of the Plateau Province is underlain by almost flat-lying strata which range in age from Carboniferous to Eocene.

Carboniferous limestone crops out a few miles west of Virgin City, and the town is immediately underlain by the Permian (?) Red Beds. An oil seep led to drilling a well in 1907. The first well struck oil. Six wells drilled afterward did not find oil in appreciable amounts.

NEW MEXICO

In Eddy and Chaves Counties, New Mexico, in the Pecos River basin, petroleum has been discovered in about twenty deep wells drilled for artesian water. In most of these wells only conspicuous showings of oil are present. In one a considerable flow of gas was encountered. Two wells have produced oil in small quantities.

The country is a broad, nearly level valley irrigated by artesian water, of which there are good flows at Artesia, Dayton, and Lakewood. In this area hundreds of wells have been drilled, ranging in depth from 300 feet to more than 1,100 feet. In most of them water rises to points near the surface or flows out under pressure.

In 1910 gas was struck in a well 896 feet deep, drilled for water about 1½ miles southeast of Dayton. The flow is said to have burst a 300-pound gage when gas was first encountered. This well is now fitted with a gas trap, and when the valve is opened a strong jet of inflammable gas issues.

The Williams or Belt well, 2½ miles east of Dayton, is about 1,000 feet deep. Oil and gas flow out with the water. The oil is

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[1] Richardson, G. B.: Petroleum in Southern Utah. U. S. Geol. Survey *Bull.* 340, pp. 343-347, 1908.

allowed to settle from the water in a tank, where about half a barrel a day is recovered. The largest well in this region is the Brown well, about 2 miles northeast of Dayton. It was sunk in 1909 and was then 950 feet deep. Water was encountered at a depth of about 660 feet and oil at about 920 feet. The water was partly cased off, and the well is said to have yielded about 10 barrels of oil a day.

The oil of this region is a heavy black fuel oil of about 25° Baumé. It has an asphalt base and is high in sulphur. According to analyses made by David T. Day, it contains no gasoline and carries about 29 to 33 per cent of kerosene. Sulphur gases issue with the oil and from some of the water wells that produce little or no oil. The oil from the Brown well carries 2.3 per cent of sulphur. The water carries sulphates but is essentially free from sodium chloride.

The rocks[1] are all of sedimentary origin and dip eastward from the Guadalupe Mountains to the Pecos River. Near the mountains the rocks dip steeply; in the valley the dips are lower. In the mountains there is exposed a series of Pennsylvanian limestones, estimated to be about 10,000 feet thick. In the Pecos Valley these beds are covered by a series of shales, limestones, and sandstones with gypsiferous beds containing native sulphur which belong to the Red Beds, of Permian age. This series is 1,600 feet thick. Farther east the Permian is covered by Triassic and Tertiary rocks, but these are probably absent in the oil district. Quaternary gravels, sands, and clays cover the older rocks in the Pecos Valley. Locally this unconsolidated material is hundreds of feet thick, effectively covering the bedrock in the valley region.

In the Pecos Valley fractured limestones are overlain by shales. Water enters the fractured limestone in the higher country, where precipitation is greater, and flows eastward underground. Its escape is prevented by the overlying impervious shales and "gumbo." The limestone is very permeable locally, owing to fractures. Near Artesia many wells flow 1,000 gallons a minute or more. At places the limestone is probably impermeable. In

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[1] FISHER, C. A.: Preliminary Report on the Geology and Underground Waters of the Roswell Artesian Area, New Mexico. U. S. Geol. Survey *Water-Supply Paper* 158, 1904.

RICHARDSON, G. B.: Petroleum Near Dayton, New Mexico. U. S. Geol. Survey *Bull.* 541, pp. 135-140, 1914.

the area north of Artesia, in Cottonwood Draw, several wells have encountered the limestone without finding a water supply.

In this great eastward-dipping series of rocks there are probably small domes superimposed on the monocline. One such dome is said to be present near Dayton.

IDAHO AND OREGON

Near Payette, Idaho, and Vale, southeastern Oregon,[1] gas and some oil are found, and hot springs carry inflammable gas. The rocks of the area are of fresh-water origin and are mainly lake beds, consisting of clays and sands and river gravel with some intrusive basalt and rhyolite. The sedimentary rocks, which include the Payette formation (Eocene or Oligocene) and the Idaho formation (Pliocene) are thrown into gentle folds, the dips being as a rule less than 7°. There is very little faulting. Traces of oil and gas seeps are found at many places in southeastern Oregon and on the Snake River plains of Idaho, and small mud volcanoes have formed where gas seeps issue. About 10 miles southwest of Vale a hard band of petroliferous sandstone runs along a low cliff. It has a strong odor of petroleum, especially near some faults that cut across the cliff. A similar sandstone is found about 3 miles southeast of this point, and oil is present at several other places. Several wells have been put down in this region, and one of them is 3,650 feet deep. Gas under heavy pressure was encountered in several wells at moderate depth. One well encountered rock salt; another salty water. Some of the wells are said to encounter sulphur-bearing rock. No oil had been found in marketable quantity. Washburne considers as possible the hypothesis that the gas and oil have an abyssal or solfataric source.

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[1] Washburne, C. W.: Gas and Oil Prospects Near Vale, Oregon, and Payette, Idaho. U. S. Geol. Survey *Bull.* 431, pp. 26-57, 1910.

CHAPTER XXI

PACIFIC COAST FIELDS

CALIFORNIA

General Features.—Petroleum is found in California (Fig. 177) in a belt about 225 miles long extending from the Coalinga district, in Fresno County, at the north, to the Puenta Hills district, in Orange County, at the south. The fields in this belt, which are among the most prolific in the United States, produce mainly oils of medium to heavy grade, with asphaltic base. The rocks containing the oils are partly unconsolidated and in most of the oil-

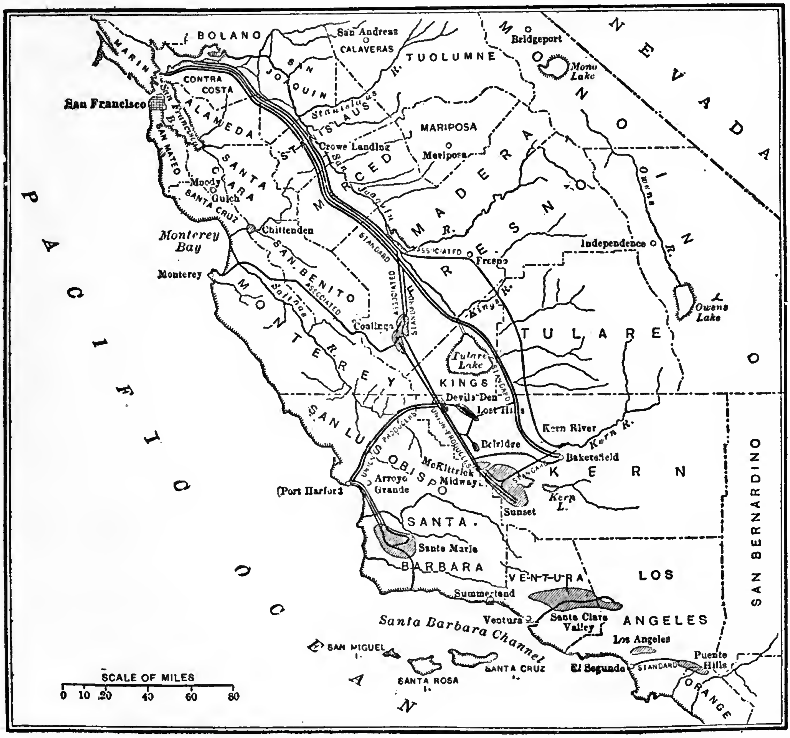

Fig. 177.—Map of part of California, showing oil districts and pipe lines. (*After Arnold and Garfias.*)

PETROLEUM MARKETED IN CALIFORNIA IN 1916 AND 1917

District and County	1916			1917		
	Quantity (Barrels)	Value	Price per Barrel	Quantity (Barrels)	Value	Price per Barrel
Coastal and southern:						
Los Angeles County:						
Los Angeles city	299,781	$180,386	$0.602	261,348	$227,572	$0.871
Montebello	....	....	......	829,428	860,258	1.037
Newhall	108,590	89,947	0.828	121,879	132,557	1.088
Salt Lake	1,457,471	867,319	0.596	1,170,213	1,177,446	1.066
Coyote Hills	1,973,882	1,336,713	0.677	2,156,655	2,066,484	0.958
Puente						
Whittier						
Orange County:						
Coyote Hills	12,095,819	7,721,779	0.638	14,515,060	14,021,289	0.966
Fullerton						
Ventura County:						
Santa Paula	932,028	705,543	0.757	963,422	1,044,904	1.084
Santa Barbara County:						
Lompoc	4,439,619	2,321,186	0.523	4,801,065	4,193,557	0.873
Los Alamos						
Santa Maria						
Summerland	42,223	29,267	0.693	47,036	42,673	0.909
Monterey County	45,603	25,792	0.566	98,715	89,140	0.903
San Luis Obispo County						
Santa Clara County						
San Joaquin Valley:						
Fresno County:						
Coalinga	14,231,251	8,460,623	0.595	15,984,766	14,211,319	0.889
Kern County:						
Kern River	8,226,788	4,528,711	0.550	8,144,348	6,998,867	0.859
Lost Hills	3,433,034	1,829,710	0.533	4,249,039	4,044,013	0.951
McKittrick [a]	4,467,668	2,692,120	0.603	5,024,320	3,691,904	0.734
Midway	31,840,361	18,570,505	0.583	28,829,674	27,095,565	0.939
Sunset	7,357,818	4,242,432	0.577	6,680,581	6,264,216	0.937
	55,325,669	31,863,478	0.576	52,927,962	48,094,565	0.908
Grand total	90,951,936	$53,702,733	$0.590	93,877,549	$86,161,764	$0.918

[a] Includes Belridge.

PETROLEUM MARKETED IN CALIFORNIA, 1908–1917, BY COUNTIES, IN BARRELS

Year	Fresno	Kern	Los Angeles	Orange	Santa Barbara	Ventura	San Mateo	Santa Clara	Total
1908	10,386,168	18,132,893	4,692,495	3,358,714	7,816,682	379,044	[a]88,741		44,854,737
1909	14,795,459	23,831,768	16,774,195				[a]70,179		55,471,601
1910	18,387,750	37,896,727	16,665,678				[b]60,405		73,010,560
1911	18,483,751	45,921,712	16,708,466				[b]20,462		81,134,391
1912	19,911,820	50,245,255	[c]17,095,395				[b]20,123		87,272,593
1913	19,302,654	58,278,966	20,164,689				[b]42,216		97,788,525
1914	15,692,733	62,429,243	3,150,892	13,260,226	4,363,797	857,685	[d]20,751		99,775,327
1915	12,851,034	53,886,181	2,732,250	11,885,150	4,290,944	908,359	[d]37,617		86,591,535
1916	14,231,251	55,325,669	3,839,724	12,095,819	4,481,842	932,028	[b]45,603		90,951,936
1917	15,984,766	52,927,962	4,539,523	14,515,060	4,848,101	963,422	[b]98,715		93,877,549

[a] Includes oil produced in San Luis Obispo County.

[b] Production of Santa Clara and San Luis Obispo Counties.

[c] Includes small quantity from Alaska.

[d] Includes Monterey County.

producing areas, are intensely deformed, so that the beds lie at high angles. In some of the districts the strata are overturned. Oil seeps are numerous, and asphalt beds cover wide areas. In no other region in North America is oil found in commercial quantities where the structure is so complicated, nor are surface indications so abundant in any other American fields. In most respects the California fields resemble the fields of Europe and Asia more closely than they resemble other fields in America.

Commercial quantities of petroleum are found in California in every important geologic formation from the Chico (Upper Cretaceous) to the Fernando (Pliocene) and also in the Quaternary deposits as tar springs and asphaltum. The principal formations of the oil fields, in order of age, are Jurassic or pre-Jurassic crystalline rocks; the Franciscan (probably late Jurassic); the Knoxville-Chico rocks (Cretaceous); the Tejon (Eocene); the Sespe (probably Oliogocene); the Vaqueros and Monterey (lower Miocene); the Fernando or equivalent (largely upper Miocene and Pliocene); and the Quaternary. Commercial quantities of oil are found chiefly in the Miocene.[1]

Coalinga.—The Coalinga oil district,[2] which is the northernmost great field, is an area 50 miles long and 15 miles wide lying along the northeastern base of the Diablo Mountains, in western Fresno and Kings Counties, on the southwest side of San Joaquin Valley. The productive area of this district is a strip 13 miles long and 3 miles wide in the north end of the district and a narrow strip along the southwest boundary along the slopes of the Kreyenhagen Hills. The district is an area of Cretaceous and Tertiary strata, only slightly consolidated, intricately folded, and not extensively faulted. The dominant structural feature is the monocline that dips eastward from the Coast Range to the valley. On this is developed the Coalinga anticline, and bordering it the Coalinga syncline and a great monoclinal area that forms the west limb of the syncline. The oil is found principally near the top of the anti-

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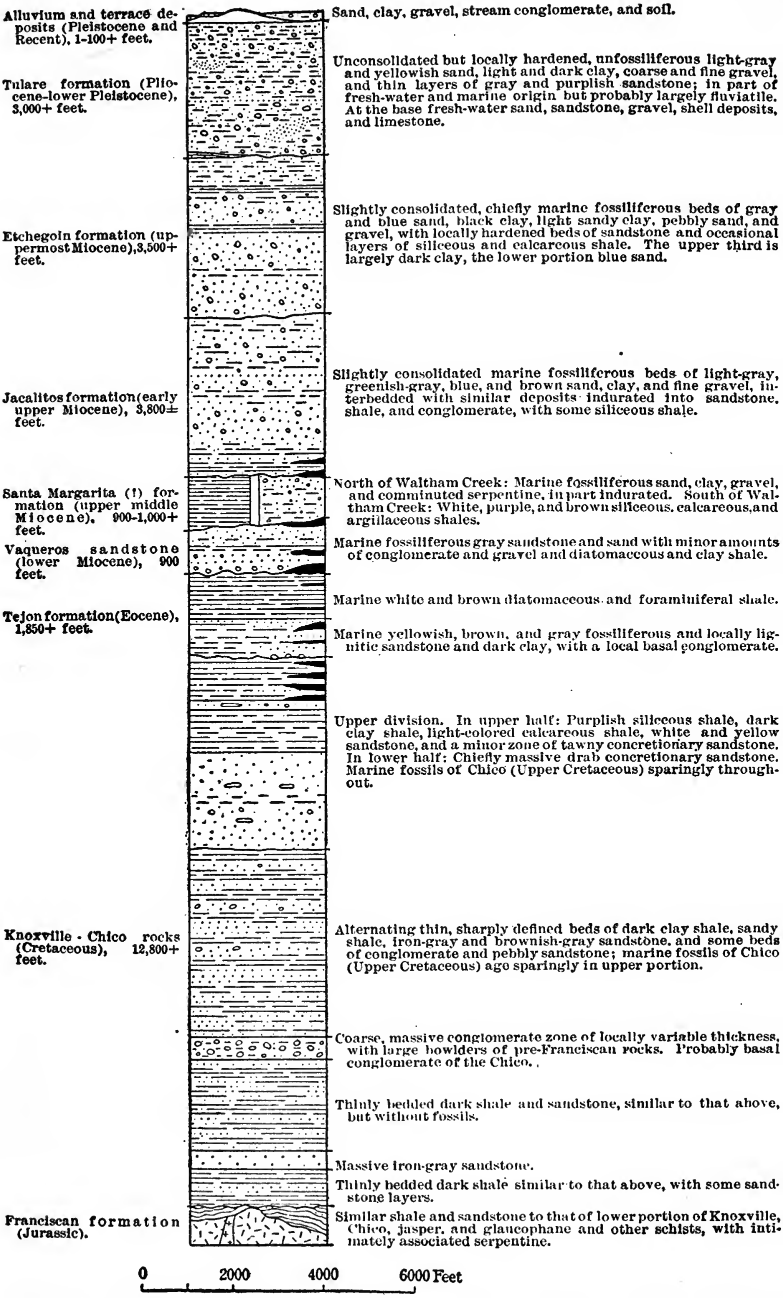
[1] ARNOLD, RALPH and GARFIAS, V. R.: Geology and Technology of the California Oil Fields. Am. Inst. Min. Eng. *Bull.* 87, p. 405, 1914.

[2] ARNOLD, RALPH, and ANDERSON, ROBERT: Geology and Oil Resources of the Coalinga District, California, with a Report on the Chemical and Physical Properties of the Oils by IRVING C. ALLEN. U. S. Geol. Survey *Bull.* 398, 1910; Preliminary Report by ARNOLD and ANDERSON. U. S. Geol. Survey *Bull.* 357, 1908.

TENTATIVE CORRELATION OF FORMATIONS OF COALINGA DISTRICT WITH THE STANDARD CALIFORNIA COAST RANGE SECTION AND THOSE OF OTHER LOCALITIES IN CALIFORNIA (After Arnold and Anderson)

Era	System	Series	Standard Coast Range Section	Coalinga District Section	Santa Maria District Section	Santa Clara Valley (Ventura Co.) Section	Los Angeles and Puente Hills Section
Cenozoic.	Quaternary.	Recent.	Alluvium.	Stream conglomerate and alluvium.	Alluvium.	Alluvium.	Alluvium.
		Pleistocene.	San Perdo. —Unc.— -Unc.—	Streamdeposits, valleyfillings, and raised beach. —Unconformity—	Terrace deposits and dune sand. —Unconformity—	Terrace deposits, sand, and gravel. —Unconformity—	Terrace deposits, sand, and gravel. —Unconformity—
	Tertiary.	Pliocene.	Merced. San Diego.	Tulare. —Unconformity—			
		Miocene.	San Pablo. -Unconformity (?)— Santa Margarita. -Unconformity — Monterey. Temblor -Unconformity — Vaqueros. -Unconformity —	Etchegoin. —Unconformity— Jacalitos. —Unconformity— Santa Margarita (?) —Unconformity— Lacking (with possible exception of a small part). Vaqueros. —Unconformity—	Fernando. —Unconformity— Monterey. Vaqueros.	Fernando. —Unconformity— Modelo. { Shale. Upper sandstone. Shale. Lower sandstone. } Vaqueros.	Fernando. —Unconformity— Puente.[a] { Upper shale. Sandstone. Lower shale. }
		Oligocene.	San Lorenzo. -Unconformity (?)—	Wanting (?)	Sespe and Tejon undifferentiated.	Sespe. { Upper beds. Red beds. Lower beds. } Topatopa.	
		Eocene.	Tejon. Martinez.	Tejon. —Unconformity—			
Mesozoic.	Cretaceous.		-Unconformity— Chico. -Unconformity— Horsetown. -Unconformity — Knoxville. -Unconformity —	Chico. Knoxville. —Unconformity—	(?) Knoxville. —Unconformity—		
	Jurassic (?).		Franciscan. -Unconformity — Granitic rocks, schist, etc. -Unconformity —	Franciscan.	Franciscan.	—Unconformity— Granitic rocks, gneiss, etc.	—Unconformity— Granitic rocks, gneiss, etc. —Unconformity—
	(?)		Schist; limestone				Black schist.

[a] Lower part probably Vaqueros in Los Angeles field.



Alluvium and terrace deposits (Pleistocene and Recent), 1-100+ feet.

Sand, clay, gravel, stream conglomerate, and soil.

Tulare formation (Pliocene-lower Pleistocene), 3,000+ feet.

Unconsolidated but locally hardened, unfossiliferous light-gray and yellowish sand, light and dark clay, coarse and fine gravel, and thin layers of gray and purplish sandstone; in part of fresh-water and marine origin but probably largely fluviatile. At the base fresh-water sand, sandstone, gravel, shell deposits, and limestone.

Etchegoin formation (uppermost Miocene), 3,500+ feet.

Slightly consolidated, chiefly marine fossiliferous beds of gray and blue sand, black clay, light sandy clay, pebbly sand, and gravel, with locally hardened beds of sandstone and occasional layers of siliceous and calcareous shale. The upper third is largely dark clay, the lower portion blue sand.

Jacalitos formation (early upper Miocene), 3,800± feet.

Slightly consolidated marine fossiliferous beds of light-gray, greenish-gray, blue, and brown sand, clay, and fine gravel, interbedded with similar deposits indurated into sandstone, shale, and conglomerate, with some siliceous shale.

Santa Margarita (?) formation (upper middle Miocene), 900-1,000+ feet.

North of Waltham Creek: Marine fossiliferous sand, clay, gravel, and comminuted serpentine, in part indurated. South of Waltham Creek: White, purple, and brown siliceous, calcareous, and argillaceous shales.

Vaqueros sandstone (lower Miocene), 900 feet.

Marine fossiliferous gray sandstone and sand with minor amounts of conglomerate and gravel and diatomaceous and clay shale.

Tejon formation (Eocene), 1,850+ feet.

Marine white and brown diatomaceous and foraminiferal shale.

Marine yellowish, brown, and gray fossiliferous and locally lignitic sandstone and dark clay, with a local basal conglomerate.

Knoxville - Chico rocks (Cretaceous), 12,800+ feet.

Upper division. In upper half: Purplish siliceous shale, dark clay shale, light-colored calcareous shale, white and yellow sandstone, and a minor zone of tawny concretionary sandstone. In lower half: Chiefly massive drab concretionary sandstone. Marine fossils of Chico (Upper Cretaceous) sparingly throughout.

Alternating thin, sharply defined beds of dark clay shale, sandy shale, iron-gray and brownish-gray sandstone, and some beds of conglomerate and pebbly sandstone; marine fossils of Chico (Upper Cretaceous) age sparingly in upper portion.

Coarse, massive conglomerate zone of locally variable thickness, with large bowlders of pre-Franciscan rocks. Probably basal conglomerate of the Chico.

Thinly bedded dark shale and sandstone, similar to that above, but without fossils.

Massive iron-gray sandstone.

Thinly bedded dark shale similar to that above, with some sandstone layers.

Franciscan formation (Jurassic).

Similar shale and sandstone to that of lower portion of Knoxville, Chico, jasper, and glaucophane and other schists, with intimately associated serpentine.

Fig. 178.—Generalized section of Coalinga district, California. (*After Arnold.*)

cline and on the monocline. The geologic formations are shown in Fig. 178.

The oil is found (1) in sandy zones of the purple shale of the Chico; (2) in the porous sandstone of the Tejon, which consists mainly of diatomaceous and foraminiferal shale; (3) in three zones in the Vaqueros, which is the most productive formation in the area; (4) in the sandstone above the Tejon in the Santa Margarita; and (5) in the Jacalitos, particularly where it rests on or is near the Tejon. Arnold and Anderson[1] consider the oil in the Chico and Tejon to be original; in the later formations it has probably come from some outside source.

The oil is found mainly along the Coalinga anticline and in the monocline in the west part of the area (Fig. 179). On this monocline tar springs or oil seeps occur mainly in the Tejon and Vaqueros and especially along an unconformity between these two formations. The bituminous matter on oxidation and drying has sealed up the beds more or less completely, and this has preserved the oil remaining. Where water is present with the oil, the oil rises to crests of anticlines or to the higher parts of the monocline. Where the oil zone does not carry water the distribution of oil depends upon the distribution of the rocks rather than on the details of structure.

Where no water exists in or is associated with an oil zone, as in the deeper portions of the west side of the field and in by far the greater part of the east side, the structure apparently plays but a minor part in the accumulation of the oil, the presence or absence of the petroleum in the porous strata of the zone apparently depending entirely upon the presence or absence of the oil-yielding shales of the Tejon (Eocene) below or near the porous strata. If the Tejon is present under any particular sand or zone, then the abundance or scarcity of the oil depends largely upon (1) the proximity of the particular sand to the Tejon; (2) the state of disturbance of the underlying shale of the Tejon, or its relative position (whether unconformable or conformable) to the overlying beds; (3) the degree of porosity and grain of the sands of the zone; and (4) the effectiveness of the barriers hindering the escape of the hydrocarbons (oil and gas) from the oil sands.

Within the tested territory of the Coalinga district it has been found that the areas of Miocene sediments (either Vaqueros, Santa

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[1] *Op. cit.*, p. 183.

Margarita (?), or Jacalitos) immediately underlain by the shales

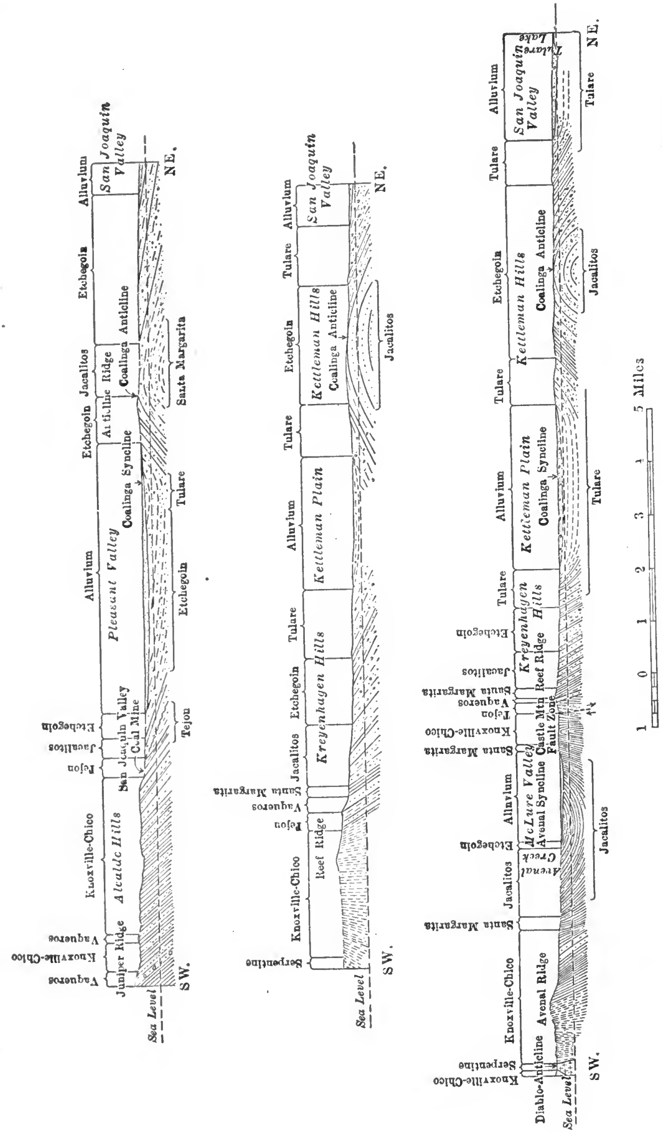

FIG. 179.—Geologic sections across the Coalinga district, California. (After Arnold and Anderson.)

of the Tejon are oil bearing; that the productiveness of these beds varies roughly inversely with their distance from the shales of the Tejon; that the productiveness is greatest where the Tejon occupies a position of angular unconformity with the Miocene sands or is more or less disturbed, as near the axis of an anticline such as the Coalinga anticline.

The few small faults are so situated as not to affect the oil zones greatly, and they are not marked by the presence of escaping hydrocarbons. There are two types of oil, a paraffin oil which appears to have originated in foraminiferal shales in the Upper Cretaceous and an asphalt oil which is believed to have its original source in diatomaceous and foraminiferal shales of upper Eocene age. The former is accumulated in sandy zones interbedded with the shales that are supposed to have given rise to it; the latter, which is the chief product of the district, is accumulated to some extent in the Tejon formation but chiefly in sands of the Vaqueros (lower Miocene), Santa Margarita (?) (upper middle Miocene), and Jacalitos (upper Miocene) formations. The Vaqueros is the principal producer of the district. The oil wells range in depth from 600 to more than 4,000 feet and penetrate from 20 to over 200 feet of productive sands. The product ranges from a black oil of 14° or 15° Baumé to a greenish oil of 35° Baumé or lighter. The yield ranges from 3 or 4 barrels a day for individual wells in the Oil City field to as much as 3,000 barrels a day for the deeper holes in the Eastside field.

Lost Hills.—The Lost Hills district[1] is in Kern County, 50 miles southeast of Coalinga. The strata include the Santa Margarita (marine), Jacalitos, and Etchegoin, of upper Miocene age, and the Tulare, a fresh-water formation of Pliocene age.

The Santa Margarita consists of a series of diatomaceous shales from 2,000 to 3,000 feet thick, the entire series interbedded with fine sandstone and sandy shales. It is believed to be the parent formation of the oil in this district, and the sandy members in the upper part of the formation also act as reservoirs for the oil toward the southern part.

Unconformably overlying the Santa Margarita is a series of blue clay shales interbedded with bluish sands having a total thickness in this district of over 3,000 feet, the whole believed to be the equivalent of the Jacalitos and Etchegoin formations that are well

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[1] Arnold, Ralph, and Garfias, V. R.: Geology and Technology of the California Oil Fields. Am. Inst. Min. Eng. *Bull.* 87, p. 422, 1914.

developed in the Coalinga district, to the north. The Jacalitos shales form an impervious cover to the underlying oil reservoirs, and where the Santa Margarita is eroded and the oil is allowed passage along the crest of the anticlinal fold, the sands at the base of the Jacalitos become the oil reservoirs. This is the case in the northern part of the district, where the lower sandy members range between 75 and 100 feet thick, generally in two different bodies.

The Tulare formation, 300 to 500 feet thick, follows the topography of the region and lies nearly horizontal throughout the Lost Hills district. In the northern part of the field the oil from the underlying formations has migrated upward and collected in the Tulare in minor quantities.

The dominant structural feature of the Lost Hills district is the Coalinga anticline, which extends southeastward from Anticline Ridge, in the Eastside Coalinga field, through the Kettleman Hills to the Lost Hills, where it runs in a southeasterly direction, finally plunging under the valley filling with an axial dip of about 150 feet to the mile. The folding, which has had a controlling influence on all the formations and on the accumulation and migration of the oil in the district, has been more or less intermittent along the Coalinga anticline, as is attested by the unconformable position of the Jacalitos on the Santa Margarita. The erosion which took place before the deposition of the Jacalitos was more intense toward the northern part of the district, thus exposing lower members of the Santa Margarita formation in this direction. It was from these eroded members that the Santa Margarita oil migrated to the lower sandy beds of the overlying Jacalitos. In the southern part of the district the impervious Santa Margarita shales were not disturbed or eroded to the extent of allowing the escape of the oil, which was retained within its sandy members. The gravity of the oil in the Santa Margarita averages about 35° Baumé, while that of the oil in the base of the Jacalitos, presumably also once indigenous to the Santa Margarita, has a gravity of only 18°.

McKittrick, Sunset, and Midway.—The McKittrick, Sunset, and Midway fields[1] are in Kern County, south of the Coalinga dis-

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[1] Arnold, Ralph, and Johnson, H. R.: Preliminary Report on the McKittrick-Sunset Oil Region. U. S. Geol. Survey *Bull* 406, 1910.

Arnold, Ralph, and Garfias, V. R.: Geology and Technology of the California Oil Fields. Am. Inst. Min. Eng. *Bull.* 87, pp. 383-470, 1914.

trict. Bakersfield is some 40 miles to the east of the oil fields. The district mapped by Arnold and Johnson is 60 miles long and 30 miles wide, and the petroleum-bearing formations trend northwset through its entire length. The southern half of the district, however, supplies almost the whole output of oil and includes the Midway and Sunset fields. Oil is produced also in the Devil's Den, which adjoins and is a continuation of a sub-district of the Coalinga field.

The oil fields lie on the east slope of the Temblor Range, which rises some 4,000 feet above the sea. The San Emigdio Range lies to the south, on the border of the Sunset field. The country is an area of hills and plains east and north of the mountain ranges.

The Temblor Range, which trends northwest, is a great monocline dipping northeast on which are developed many minor folds, the axes of which make small angles with the major range. In general they strike a few degrees more to the west than the major monocline. On the southwest the Temblor Range is bordered by the great San Andreas fault zone, which has been traced from Point Arena, on the Pacific Coast north of San Francisco, for over 600 miles, nearly to Salton Sea.[1] The faulting and folding on the side of the range give in effect a huge anticlinorium, which is most clearly shown in the northwestern part of the area. There are also several smaller faults in the region, some of them thrust faults.

The wells in the McKittrick district, including Belridge, range in depth from about 600 to 1,800 feet or more. The oil is dark colored, most of it is heavy, from 12° to 20° Baumé. The production from individual wells ranges from 2 to 1,000 barrels a day.

The McKittrick field[2] lies on the flanks of three more or less local and highly complex folds subsidiary to the great northeastward dipping monocline of the Temblor Range. Thrust faulting and overturning have so complicated the folding as to place the older beds above the younger. (See Fig. 64.)

The oil is believed to have originated in the diatomaceous shales of the Monterey and Santa Margarita formations and to have migrated to the porous layers intercalated with them or to the

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[1] Lawson, A. C.: Report of the Earthquake Investigation Committee on the California Earthquake of April 18, 1906. Carnegie Inst. Washington, *Pub.* 87, 1908.

[2] Arnold, Ralph, and Johnson, H. R.: *Op. cit.*, p. 111.

sands and gravels of the unconformably overlying McKittrick formation.

There are two productive zones in the McKittrick district. In the northern part of the district one zone, the lower one, lies nearly horizontal and is usually between 100 and 240 feet thick; in the southern part the zone is overturned and stands nearly vertical. The upper zone is only moderately productive. Where the oil sand reaches the surface, west of the town of McKittrick, enormous deposits of asphalt have formed. The structure of this area is exceedingly complicated. (See Fig. 180.)

The Sunset-Midway field has recently been described by Pack[1] and Rogers.[2] The area covered in their reports overlaps the area mapped by Arnold and Johnson, and extends farther southeast.

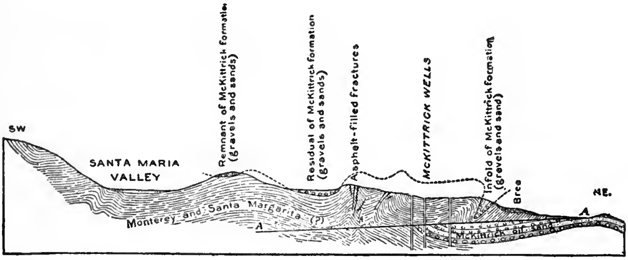

Fig. 180.—Ideal cross-section of north end of McKittrick field, California. The McKittrick oil sand lies below an overthrust fault, *AA*. (*After Arnold and Anderson.*)

The Tertiary formations range in age from Eocene to Pliocene and are altogether 18,000 feet thick (Fig. 181). They consist of sands, gravels, and clays, poorly consolidated, and in the central part of the section are 4,800 feet of material of Miocene age that consists largely of remnants of diatoms. There are numerous unconformities in the section.

The foothill region of the Temblor Range is closely folded and is faulted. The oil, according to Pack,[3] originated in the diatomaceous shale formations, chiefly from the alteration of organic

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[1] Pack, R. W.: The Sunset-Midway Oil Field, California. U. S. Geol. Survey *Prof. Paper* 116, part 1; Geology and Oil Resources, pp. 1-179, 1920.

[2] Rogers, G. S.: The Sunset-Midway Oil Field, California. U. S. Geol. Survey *Prof. Paper* 116, part 2; Geochemical Relations of the Oil, Gas, and Water, pp. 1-103, 1919.

[3] Pack, R. W.: *Op. cit.*, p. 70.

matter contained in diatoms and foraminifers, but probably in part also from the alteration of terrestrial vegetal débris.

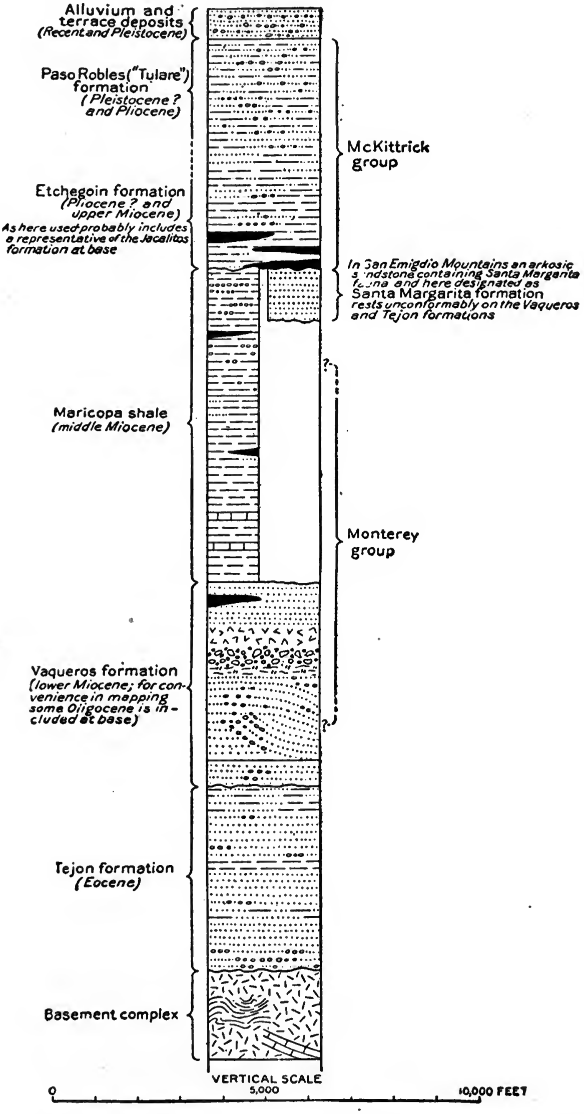

FIG. 181.—Generalized columnar section of the rocks in the Sunset-Midway oil field and in the north flank of the San Emigdio Mountains. Position of oil-bearing beds indicated by solid black. (*After Pack.*)

Some of the oil now contained in the productive pools has originated in the part of the region in which these pools occur, but much of it has been formed in the shale that lies beneath San Joaquin Valley. The oil has migrated from the beds beneath the valley to the foothills and collected in the small anticlines that extend from the hills out into the valley.

The reservoirs from which the wells derive their oil are chiefly Miocene or Pliocene sandy beds that rest unconformably upon the diatomaceous shale. Sandy lenses within the shale yield some of the oil.

The oil-bearing beds in the late Tertiary sequence are coarse and fine sands that range in thickness from a few feet to a few hundred feet. These beds crop out in the foothills of the Temblor Range, and their line of outcrop marks the western limit of the main productive field. Toward the east the productive oil sands are buried progressively deeper beneath the surface. In the eastern part of the field the productive sands, which are usually 10 to 50 feet thick, are interspersed with barren beds of equal thickness through a section 600 to 800 feet thick. Near the outcrop the total thickness of the zone containing oil sands is rarely more than 200 or 300 feet but the portion of it composed of oil sand is greater there than in the parts of the field where the sands lie deeper.

The richest sands lie close to the contact with the diatomaceous shale. These oil-bearing beds are, however, not of the same age throughout the field, for the formation of which they are a part rests unconformably on the shale, and younger beds that abut against the shale in the western part of the field are younger than those against the shale in the eastern part.

The oil has evidently moved chiefly through the lowest part of the formation that rests upon the diatomaceous shale, as these beds are fairly porous and offer less resistance to the movement of the oil than the shale. The movement is therefore chiefly parallel to the plane of unconformity—that is, to the top of the shale. Near the outcrop, either by fractionation or by reaction with alkaline water, the oil becomes very viscous and seals the beds through which the oil is moving.

The tarrification of the oil is caused chiefly by the addition of sulphur derived from the sulphate-bearing surface waters. In places this same reaction has caused the formation of deposits of sulphur.

When the avenue of escape to the surface is closed the oil moves out from the plane of unconformity through the more porous of the beds in the formation that rests upon the shale. Movement in this manner is rendered easy by the fact that the younger formation was laid down in a transgressing sea and the different beds in it abut against the shale just as horizontal layers of sand held in a huge bowl would rest against the sides of the bowl (Fig. 182). The distance that the sands which extend out from the unconformity are filled with oil is variable, but each sand beyond the point at which it contains oil, according to Pack, is filled with water.

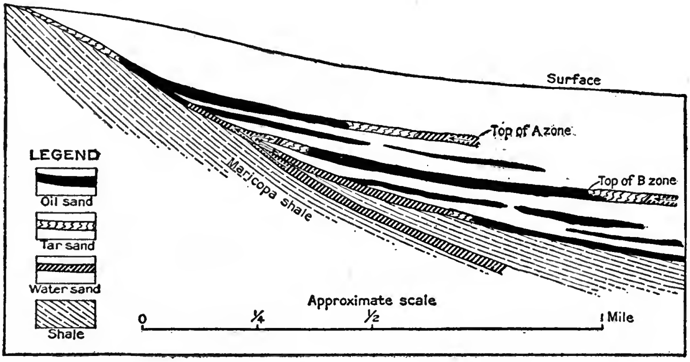

Fig. 182.—Diagram illustrating probable occurrences of water, oil and tar sand in part of Sunset-Midway oil field, California. Arrows indicate direction of movement of edgewater. (*After Pack.*)

Viewed in cross-section the arrangement of the oil sands near the outcrop may be compared to a branch from one side of which parallel twigs extend, the oil sands along the unconformity being the branch and the oil sands in the formation that rests upon the diatomaceous shale the twigs (Fig. 182).

Along the anticlines that are separated by synclines from the outcrop of the oil sands the oil has collected in sands that lie some distance above the plane of unconformity (Fig. 183.) This oil has evidently moved vertically through the lenticular sands. In any sand that contains oil and gas in these outer anticlines there is a notable tendency for the gas to occupy the higher parts of the fold and the oil the lower parts or saddles of the same fold. In the outer anticlines dry gas has collected 200 or 300 feet above the oil.

In some parts of the field where the oil is buried more than 2,000 feet a zone of tar-filled sand lies less than 1,000 feet below the surface. This zone is believed to mark the place where the upward-moving hydrocarbons have met and been oxidized by surface waters. The evidence indicates that these hydrocarbons have moved more or less vertically through the intervening beds. Pack states that they were probably in a gaseous state.

The gravity of the oil varies with the grain of the sand, the oil being lighter in the fine-grained beds; with the distance from the outcrop; with the relation of the oil to mineralized water, the oil in contact with water of certain types being tarry; and with the position on the fold, the oil being lighter on the higher parts of the anticline.

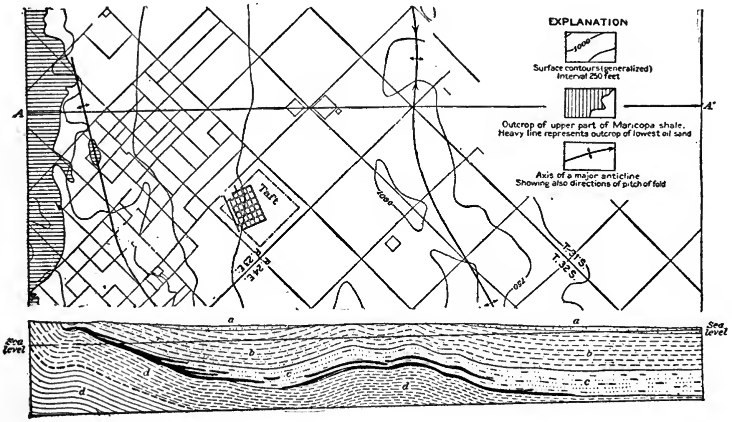

FIG. 183.—Upper figure is a plan of part of Sunset-Midway field, near Taft, California. Each large square is one square mile. Contour interval is 250 feet. The lower figure is a section on line *AA'*. *a*, Alluvium; *b*, Paso Robles ("Tulare") formation; *c*, Etchigoin formation (contains chief petroleum reservoirs of the district); *d*, Maricopa shale. (*After Pack.*)

The oil ranges in gravity from less than 11° Baumé near the outcrop to 31° or 32° Baumé in the part of the field where the oil comes from great depths. The average gravity of the oil obtained from the sands near the outcrop is between 14° and 18° Baumé; that of the oil obtained in the Buena Vista Hills and other parts of the field where the sands lie deep is 21° to 28° Baumé. The oil normally carries but little gasoline, the proportion distilling at a temperature of less than 150° C. being usually less than 4 per cent.

In the Buena Vista Hills the beds lying above the oil-bearing sands contain "dry" gas under heavy pressure, commonly as much as 1,000 pounds to the square inch and in one well reported to be more than 2,000 pounds to the square inch.

Gasoline is "squeezed" from the gas at a number of plants in the field, and the average amount recovered in 1916 was between 1 and 3 gallons from 1,000 cubic feet of gas.

Kern River.—The Kern River field is in Kern County, about 4 miles north of Bakersfield, near the southeastern extremity of San Joaquin Valley.[1] It was discovered in 1900 and produced 18,000,000 barrels in 1904. Its great production is due to the great thickness of its sands, which range from 200 to 500 feet. The productive territory covers 155 square miles, and its long axis extends northwest. The productivity of the wells within this area varies with the distance from the center in a more or less uniform ratio, the more productive wells being near the central portion. The depth to the productive oil sands ranges from 400 feet on the northeast part of the fold to 1,100 or 1,200 feet on the south and west borders. The average depth of all the wells is approximately 900 feet, and the gravity of the oil averages about 14° Baumé. The oil is used mainly for fuel and for the manufacture of asphalt.

The formations of the Kern River district consist of a basement of granitic rocks overlain by a series of Tertiary strata which attain a thickness of about 5,000 feet in the oil field. The granite of the Sierra Nevada is continuous around the south end of San Joaquin Valley, and in the vicinity of Kern River the escarpment of the mountain front is believed to mark a normal fault along which the granite on the east has been raised and the Miocene beds on the west depressed.

Tertiary formations include an upper and a lower division. The upper division is made up of coarse, unconsolidated sands, gravels, and boulders. These beds are supposed to correspond to portions of the Tulare, Etchegoin, and possibly Santa Margarita formations of the west side of the valley. The lower division, composed

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[1] ARNOLD, RALPH, and GARFIAS, V. R.: Geology and Technology of the California Oil Fields. Am. Inst. Min. Eng. *Bull.* 87, p. 436, 1914.

mostly of clays and soft diatomaceous shales grading up from a basal sandstone, represents the Monterey. The lower division is regarded as the source of the oil, and the upper is the main zone of accumulation.

There is, according to Eldridge,[1] a body of sands and gravels from the surface to varying depths, the maximum, 200 feet. Beneath this there is usually a stratum of blue clay, which ranges in thickness from a few feet to 100 feet. This clay is impermeable to the waters which nearly everywhere are present in the sands above. Below the clay is an alternation of sands and clays without regularity and varying in thickness. These sands constitute the oil reservoirs of the field, and as much as 400 or 500 feet of them has been encountered in a single well. In a great many wells 200 or 300 feet of oil-bearing sand is found. Below the oil sands is another thin blue clay. Although the sands are exceedingly irregular, the short lenses overlap and interlock, permitting a movement of oil.

The district is a low dome and presents a symmetrical arrangement as regards its productive territory. Minor folds occur throughout the productive portion of the monocline, and these control accumulation. The productive area is an ellipse. The production and quality of the oil are best northeast of the center and gradually decrease toward the perimeter.

Santa Clara.—The Santa Clara district,[2] in Ventura and Los Angeles Counties, is the oldest oil-producing area in California. This district is in the hilly country bordering on the Santa Clara Valley, a structural depression modified by erosion. The rocks of the region are all Tertiary and Quaternary, except a small area of pre-Cretaceous granite and gneiss at the southeast corner.

The Tejon, or Topatopa formation, as it is called locally, is the oldest of the sedimentary series and is of Eocene age. It consists of 3,000 to possibly 9,000 feet of alternating shale and hard sandstone and quartzite and so far has proved to be the least important of the commercially productive oil formations in the district.

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[1] Eldridge, G. H.: Petroleum Fields of California. U. S. Geol. Survey *Bull.* 212, p. 310, 1903.

[2] Eldridge, G. H.: The Santa Clara Valley Oil District, Southern California. U. S. Geol. Survey *Bull.* 309, 1907.

Arnold, Ralph, and Garfias, V. R.: Geology and Technology of the California Oil Fields. Am. Inst. Min. Eng. *Bull.* 87, pp. 447-452, 1914.

The Sespe formation, supposed to be of Oligocene age and characterized by its reddish color and wide distribution throughout the Santa Clara Valley district, overlies the Topatopa and consists of about 3,500 feet of alternating hard sand and shale layers. It has yielded oil of 11° to 37° Baumé gravity and is the chief producer of oil in the district.

The Sespe formation is conformably overlain by the Vaqueros or lower Miocene, which consists of 800 to 3,000 feet of dark-colored shale that carries organic remains and minor amounts of sandstone. At most localities in this region the sandstone members of this formation carry petroleum, so that the formation, where available to the drill, offers inducements for exploitation, especially where the structural conditions are favorable.

The Monterey series (locally called the Modelo), also of lower Miocene age, overlies the Vaqueros and consists of four principal members as follows:

	Feet
Upper shale	200 or more
Upper sandstone	100 to 900
Lower shale	400 to 1,600
Lower sandstone	300 to 1,500

Certain beds have burned red to considerable depths by fire, evidently supported by the petroleum they contained.

The lower sandstone yields a high-grade oil in the Modelo Canyon wells, and at other points throughout the series there is evidence of petroleum. The lower shale is well exposed along Pole and other canyons, where it lies in sharp contrast to the upper Modelo sandstone above it.

The Fernando formation, from 5,000 to 8,000 feet thick, extending from the upper Miocene to the Quaternary, lies in an unconformable position with relation to the older beds, and locally is largely made up of their waterworn fragments. It is commonly incoherent, although in places it contains layers of hard conglomerate or sandstone. The Fernando carries oil in the Newhall field, in the region east of Piru Creek, and at several isolated places along the south side of the Santa Clara River.

The general structure in this district is dominated by an overturned anticline, which makes up the mountain range to the north parallel to the productive oil fields. The local structure affecting the accumulation of oil in any particular region is very complicated, sharp folds, faults, cross folds, and overturned folds being common. These conditions account for the lack of continuity of the productive areas, particularly north of the river. The structure south of the river is controlled by an asymmetric anticline, the axis of which roughly parallels the Santa Clara Valley for 15 miles. The accumulation of oil is by no means uniform throughout this fold, commercial quantities occurring only in certain favorable areas resulting from undulations in the fold itself—for example, in the Montebello and Bardsdale fields, between which are apparently unproductive local areas. Owing to the lack of uniformity in structural and sedimentary conditions, the productive zones are encountered at varying depths and at different horizons, and an exact correlation of the zones, even in near-by properties, is almost impossible. This irregularity probably accounts also for the diversity of the product obtained, the oil ranging in gravity from 10° to 35° Baumé.

Seeps of oil and oil springs are found at several places in the region. One of the fault zones appears to be marked by strong seeps.[1]

In Placerita Canyon, oil was discovered in contorted micaceous granitic schist that overlies the San Gabriel granite, by miners who were sinking a shaft to prospect for gold. Six wells are within 200 yards of the contact with the Fernando (Pliocene) sandstone, but one is said to be a quarter of a mile away. The deposits are unique; the oil probably occurs in the fractures of the schist. It is very light (50° to 60° Baumé). Doubtless it has seeped into the schist from outside sources.

Summerland.—The Summerland district is in Santa Barbara County, about 80 miles northwest of Los Angeles. The field is small, the producing wells being confined to the vicinity of Summerland, 6 miles southeast of Santa Barbara. The field is of no great importance economically, having produced from 1895 to 1906 only 1,373,980 barrels. In 1899, its year of maximum yield, it produced 208,000 barrels. The wells have small initial yield. The oil is dark brown or black and ranges in gravity from 9° to 18° Baumé, the average being about 14°. It is used principally for the manufacture of asphalt, for fuel, or for road dressing.

The district is in an area of complexly folded Tertiary sediments,

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[1] Eldridge, G. H.: *Op. cit.*, p. 45.

including about 9,000 feet of conglomerate, sandstone, and shale of the Topatopa (Eocene); 4,300 feet of conglomerate, sandstone, and shale of the Sespe (Eocene or Oligocene); 2,400 feet of sandstone and shale of the Vaqueros (lower Miocene); 1,900 feet of shale and volcanic ash of the Monterey (middle Miocene); 1,000 feet of conglomerate, sandstone, and clay shale of the Fernando (upper Miocene-Pliocene); and 50 feet of gravel, sand, and clay of the Pleistocene—in all about 18,650 feet of sediments, practically all of Tertiary age. Unconformities occur between the Monterey and Fernando formations and between the Fernando and the Pleistocene.[1]

The beds in the vicinity of Summerland dip south from the Arroyo Parida fault, which is also the crest of an anticline. Small folds are developed on the south limb of this anticline in the region of the oil wells. The Monterey has been eroded from the top of the anticline. Resting unconformably on the truncated edges of the Monterey are the Fernando beds which are steeply tilted.

The oil wells are put down on the terrace on which the town is situated, on the beach in front of this terrace, and on wharves that extend out into the ocean, some of them nearly a quarter of a mile. They range in depth from 100 to more than 600 feet; the shallowest are the northernmost wells on the terrace, the deepest those farthest south on the wharves. The oil is obtained from sands alternating with clay beds in the Fernando formation, which dips almost due south at angles ranging from nearly 90° at the north end of the field to nearly horizontal at the south end. Only one productive sand, from 10 to 45 feet thick, is penetrated by the terrace wells, but in the wharf wells two or three oil sands occur.[2]

The oil of the Summerland field has originated by a slow process of distillation from the diatoms and other organisms in the Monterey (middle Miocene) shale, which is abundant in the region. After its formation quantities of the oil migrated upward, largely through joint cracks, under gas or hydrostatic pressure, and accumulated in the Fernando formation in porous sandstones under relatively impervious clay layers. The oil did not continue its upward migration through the Fernando to the surface because the plastic condition of certain clay beds in that formation pre-

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[1] Arnold, Ralph: Geology and Oil Resources of the Summerland District, California. U. S. Geol. Survey *Bull.* 321, p. 21, 1907.

[2] *Idem*, p. 39.

cluded the formation of cracks that could act as channels for the oil. In certain places, however, notably at the north end of the field, the Fernando beds have been so steeply tilted that some of the oil has migrated along the sandy layers and accumulated, with a loss of volatile constituents, in the unconformably overlying Pleistocene sands and gravels.

Santa Maria.—The Santa Maria oil district,[1] comprising the Santa Maria, Lompoc, and Arroyo Grande fields, lies in the central and northern parts of the Lompoc and Guadalupe quadrangles, in western Santa Barbara County, and the southern part of the San Luis quadrangle, in southern San Luis Obispo County.

The area is occupied mainly by sedimentary rocks thrown into long and moderately gentle folds that trend principally northwest and west. Several faults of small displacement trend nearly parallel to the folds. The rocks present in the petroliferous region include the Monterey (middle Miocene) diatomaceous and clay shale, limestone, and volcanic ash; Fernando (Miocene-Pliocene-Pleistocene) conglomerate, sandstone, and shale; and Quaternary gravel, sand, clay, and alluvium. At the surface there are oil and tar seeps, asphalt, and bituminous shale. The asphalt occurs as a mixture of bituminous material with sand resulting from the absorption by overlying sand deposits of seeps from the shale, as hardened fillings of asphalt in cavities along joints, and as saturated shale. The burnt shale is the rose-colored or slaglike rock observed within the Monterey shale at many places in this and other oil-bearing regions. It is the result of the burning of the hydrocarbons that have impregnated the shale.

The wells range in depth from 1,500 to more than 4,000 feet. In the Santa Maria and Lompoc fields they obtain their oil from zones of fractured shale or sandy layers in the lower portion of the Monterey shale. The production of the individual wells ranges from 5 to 3,000 barrels a day, and the average is between 300 and 400 barrels. The gravity of the oil ranges from 19° to 35° Baumé. In the Arroyo Grande field the oil comes from sandstone at the base of the Fernando and has a gravity of 14°.[2]

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[1] ARNOLD, RALPH, and ANDERSON, ROBERT: Preliminary Report on the Santa Maria Oil District. U. S. Geol. Survey *Bull.* 317, 1907.

ARNOLD, RALPH, and GARFIAS, V. R.: *Op. cit.*, pp. 439-444.

[2] ARNOLD, RALPH, and ANDERSON, ROBERT: *Op. cit.*, p. 66.

Concerning the relations of oil to structure in this region, Arnold and Anderson[1] say: "Although oil accumulation is affected by a complication of other circumstances, the anticline seems to be the chief favorable factor and affords a tangible and fairly trustworthy clue. Close folding appears to play a part in depriving beds of their oil, and excessive disturbance and fracturing is unfavorable to its retention. Furthermore, the position of the beds in the formation is regarded as important, since there is less likelihood that the oil-bearing strata, which seem to lie mainly low in the Monterey, were able to retain their contents when denuded of the greater part of the overlying formation or when themselves exposed or partially removed."

Los Angeles.—The Los Angeles city field[2] extends westward for 6 miles from a point about 4½ miles west of the business center of Los Angeles. It was discovered in 1892 when a shaft was sunk near a brea deposit. The wells are 500 to 1,200 feet deep or more and the gravity of oil from 12° to 19° Baumé. The wells are small producers and are pumped. The Salt Lake field is a few miles west of the city field. The wells are between 1,200 and 3,000 feet deep, and the average gravity of the oil is between 16° and 18° Baumé. Considerable gas under strong pressure accompanies the oil, which causes the wells to gush during their early life. Between 1894 and 1912 the district, including the Salt Lake field, produced 38,860,136 barrels.

Enormous deposits of brea or impure asphalt have formed along the outcrop of the upper Puente sand and in the wash above the oil sand. Some of the oil has apparently risen through cracks in the shaly beds above the oil sand and has escaped to the surface.

The formations, in the order of age, comprise more than 2,000 feet of indurated sandstone, believed to be largely of Vaqueros (lower Miocene) age; about 2,000 feet of shale and soft, thin-bedded sandstone of Monterey (Puente), also of lower Miocene age; pre-Fernando basalt and diabase intrusions cutting the Monterey; 3,000 feet or more of soft, thin and thick bedded sand-

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[1] *Idem*, pp. 29-30.

[2] Eldridge, G. H., and Arnold, Ralph: The Santa Clara Valley, Puente Hills, and Los Angeles Oil Districts, California. U. S. Geol. Survey *Bull.* 309, p. 138, 1907.

Arnold, Ralph, and Garfias, V. R.: Geology and Technology of the Oil Fields of California. Am. Inst. Min. Eng. *Bull.* 87, pp. 455-458, 1914.

stone, thin-bedded shale, and heavy-bedded conglomerate composing the Fernando formation, of upper Miocene and Pliocene age; and a capping of Pleistocene gravels and sands of variable thickness. The oil in the Los Angeles district is derived largely from the upper 500 feet of the Puente or Monterey and the basal beds of the Fernando.

The most prominent structural feature in the district is the great flexure which lies northeast of the business portion of Los Angeles and trends N. 60° W. This fold is known as the Elysian Park anticline. This anticline (Fig. 184) is almost an elliptical structural dome, as it appears to plunge at both its northwest and southeast ends. Not far from the northwest extremity of the anticline, where it approaches the fault zone lying along the southern base of the Santa Monica Mountains, the fold develops into a fault. The City field is developed in strata at the top of the Monterey and possibly the base of the Fernando formation, on the south limb of the Elysian Park anticline. The trend of the productive belt, however, instead of conforming to the axis of the main fold, follows the strike of the formations on the south side of a divergent subordinate line of disturbance and hence has a direction about east. The oil appears to have accumulated in the

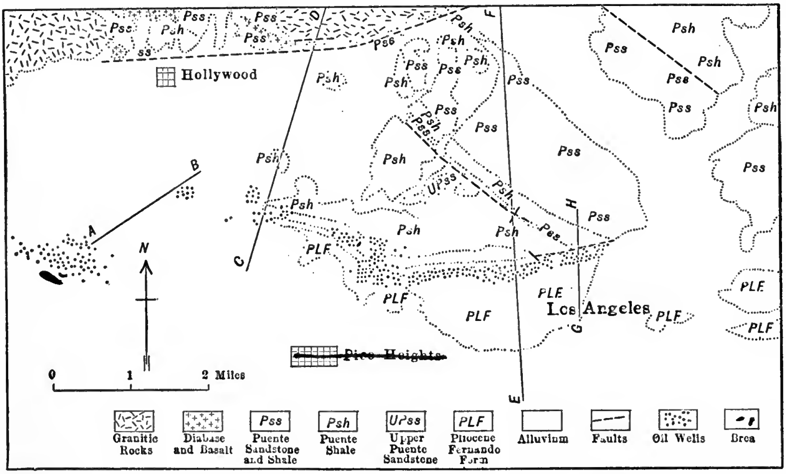

FIG. 184A.—Sketch of part of Los Angeles oil field, California, showing position of certain wells and of sections shown in Fig. 184B. (*Data from Eldridge and Arnold, U. S. Geol. Survey.*)

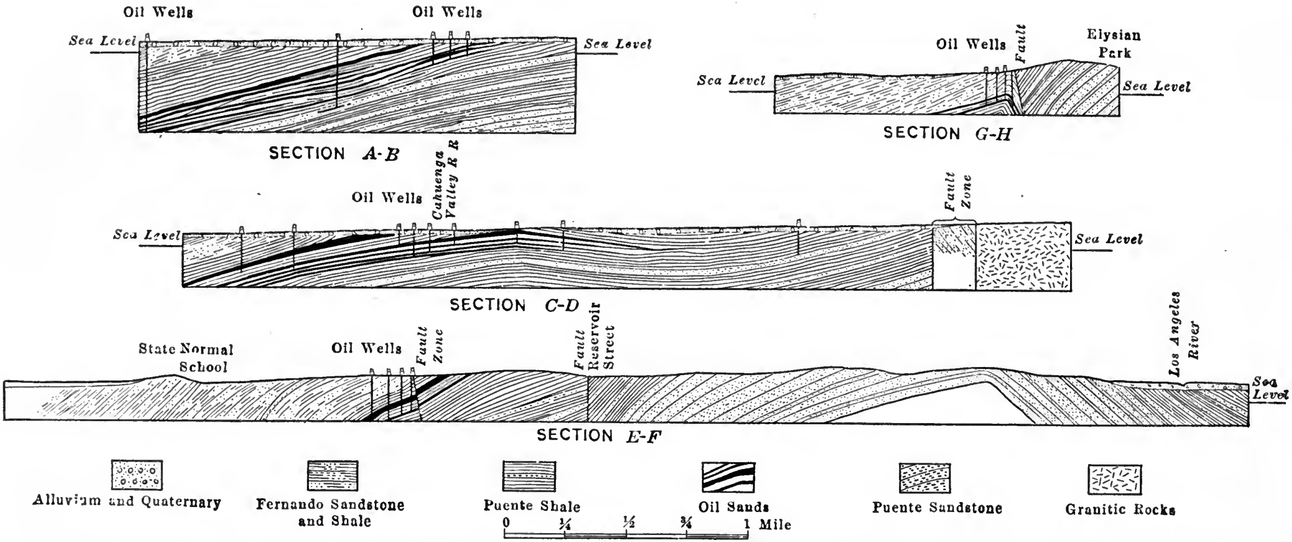

FIG. 184B.—Geologic sections through Los Angeles oil field, California. Positions of sections shown on Fig. 184A. (*After Eldridge and Arnold, U. S. Geol. Survey.*)

sands of the southern limb of the anticline just below the point where the steeply dipping beds bend toward the horizontal before passing over the axis of the fold. The structure in the Salt Lake field appears to be that of a minor flexure on the flanks of the fold along whose southern limb the other Los Angeles fields are situated.

Puente Hills.—The Puente Hills,[1] about 12 miles southeast of Los Angeles, extend east-southeastward for about 22 miles. This region, which includes several oil fields, is one of the most persistent producers in the State, having yielded 40,943,205 barrels between 1882 and 1912.

The wells in the Whittier field are small producers and range in depth from 600 to 3,500 feet, the average depth being close to 1,650 feet. The oil produced runs between 15° and 24° Baumé.

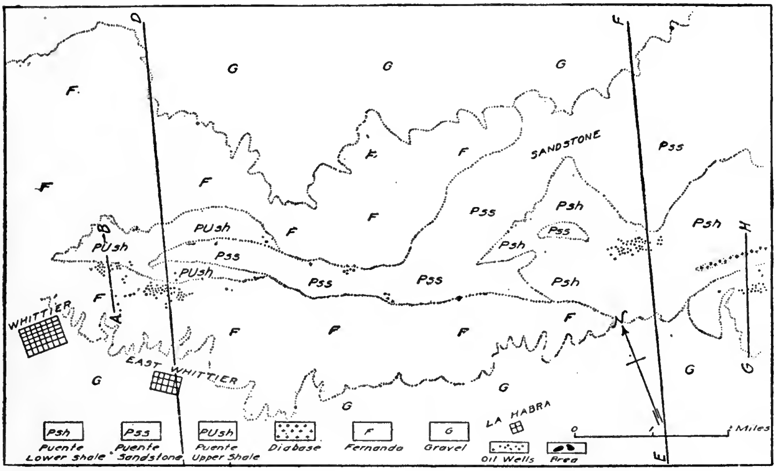

FIG. 185A.—Sketch showing geology of Puente Hills oil field, California. (*After Eldridge.*) Sections along lines *AB*, *CD*, etc., are shown on Fig. 185B.

The Coyote field is "deep territory," the wells producing large quantities of oil by natural flow. The average depth of the wells is about 3,300 feet, and the maximum about 4,500 feet. The gravity of the oil is between 20° and 33° Baumé. The average daily production per well in the Whittier and Coyote fields is about 22.8 barrels; that of the Coyote field alone probably several times

[1] Eldridge, G. H.: The Puente Hills Oil District, Southern California. U. S. Geol. Survey *Bull.* 309, pp. 102-137, 1907.

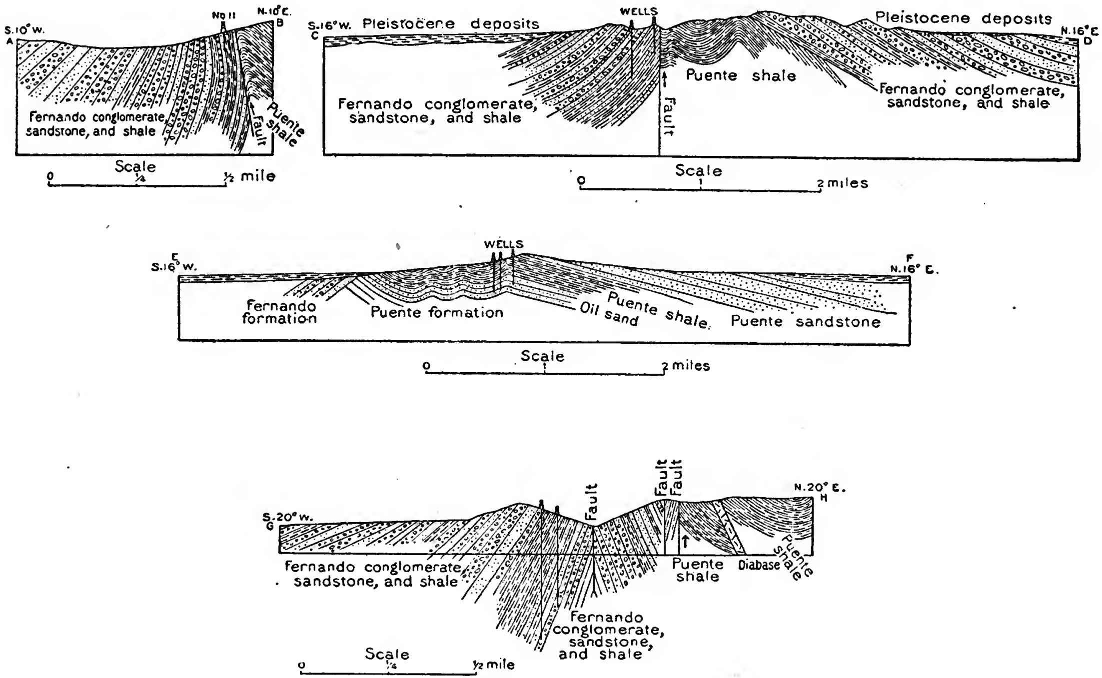

FIG. 185B.—Sections showing geology of Puente Hills oil field, California. (*After Eldridge.*)

this, as certain of the wells produce from 1,500 to 3,000 barrels daily.

In the Puente field the first well was drilled in 1880, and wells drilled in 1886 and 1887 are still being pumped. The average depth of the wells in this field is somewhat over 1,300 feet; the average life has been about 16 years; the gravity of the oil ranges between 21° and 32° Baumé. Individual wells yield an average of 1.4 barrels a day.

The Olinda or Fullerton field began producing in 1900. In the Olinda and Brea Canyon areas there is a wide diversity in gravity and output for the different localities. The wells range between 1,500 and 3,500 feet in depth and produce oil ranging in gravity between 15° and 34° Baumé. In certain areas great quantities of gas containing commercial quantities of gasoline are produced with the oil, the gasoline being extracted by compression or freezing. The average daily production per well in this field is about 71.5 barrels.

The rocks of the area are folded and faulted Tertiary sediments (Fig. 185, A and B). The oldest formation is the Puente (Miocene, approximately equivalent to the Monterey and Modelo); this is overlain by the Fernando (Pliocene) and the Pleistocene gravel. Both the Puente and the Fernando are productive. The Puente consists of sandstone and shale and is unconformable with the Fernando. The dominant structural feature of the Puente Hills is an anticlinorium, in which the main fold trends N. 65° W. The axes of the greater anticlines are locally faulted. The conditions are almost a repetition of those in the McKittrick district. The oil fields of the Puente Hills have been developed in the zone of sharp crumpling and in proximity both to the trace of the fault and to the line of unconformity; the most productive wells of the McKittrick district have been drilled along the fracture and adjacent to the unconformity. Development in the Puente Hills region has been guided by the numerous seeps that occur along the belt of severely disturbed strata, but not all of these have proved reliable indications of large accumulations of oil. The significant factors appear to be the anticlines, the sharply disturbed zone along the south side, the fault that seems to be located within this zone, and the unconformity between the Fernando and the Puente formations.[1]

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[1] Eldridge, G. H.: *Op. cit.*, p. 109.

Near Whittier, in the northwest end of the Puente Hills, the oil seems to be confined to the zone of fracturing and faulting; presumably the shattering of the rocks facilitated the accumulation of the oil or permitted it to rise from lower beds.

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ALASKA FIELDS

Oil is found at several places along the Pacific coast in Alaska. The Katalla field (Fig. 186) skirts the north shore of Controller Bay, about 30 miles east of the Copper River delta.[1] The rocks are mainly Tertiary sandstones and shales that contain coal beds and are intruded by basic dikes. Under the Tertiary rocks are graywackes, shales, and igneous rocks of unknown age. The pre-Quaternary rocks have a steep dip throughout the greater part of the region and are folded and faulted. Some of the folds are overturned. Oil and gas seeps are numerous in a belt about 25 miles long from east to west and 4 to 8 miles wide.

The oil of the seeps reaches the surface through a variety of rocks. The seeps west of Katalla are associated with metamorphic rocks, the oil reaching the surface either through the joints and bedding or cleavage planes of the slate and graywacke or through surficial deposits which probably overlie such rocks. The position of the seeps with reference to the structure is uncertain. Those west of Katalla are on steeply folded and metamorphosed rocks in which the structural features have not been determined in detail. Those on Redwood Creek and Katalla Slough are apparently near a fault. The Burls Creek and Redwood Creek seeps are near the axes of

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[1] MARTIN, G. C.: Geology and Mineral Resources of the Controller Bay Region, Alaska. U. S. Geol. Survey *Bull.* 335, p. 42, 1908; Petroleum Fields of Alaska. U. S. Geol. Survey *Bull.* 225, p. 368, 1904.

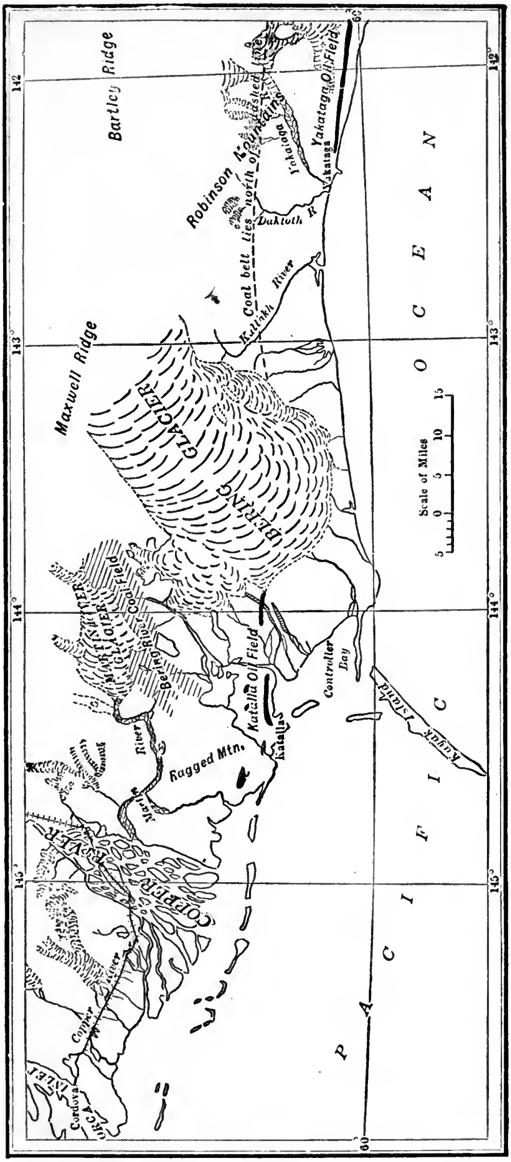

FIG. 186.—Map showing location of Katalla and Yakataga oil fields, Alaska. (*After Brooks.*)

anticlines, the Redwood Creek anticline being probably broken near or west of its axis by a fault. The upper part of the valley of Burls Creek contains many seeps at which the oil oozes directly from steeply dipping shales that contain a large amount of glauconite grains, which gives the rock a bright green color. Thin sections show abundant casts of Foraminifera and diatoms.

The age of the oil of the Katalla field is not determined. It is probably Tertiary. Brooks[1] suggests that the metamorphic rocks that have oil seeps may be thrust over the younger petroliferous beds. Several wells have been drilled, but the production is small. The oil has a gravity of 39° Baumé and is rich in gasoline.

The Yakataga field[2] (Fig. 186) lies about 60 miles east of Katalla. Here a series of seeps marks a zone about 20 miles long, half a mile to 2 miles from the beach. So far as determined, all the seeps lie along a sharp anticline whose southern limb is about vertical and whose northern limb dips inland at 15° to 45°. The exposed rocks consist of sandstone overlain by fine-textured shale of Oligocene or lower Miocene age.

Iniskin Bay (Fig. 187) is an indentation which, with Chinitna Bay on the north, blocks out an irregular-shaped peninsula on the west shore of Cook Inlet. The shore line of this peninsula is broken on the southwest by two small indentations—Oil Bay and Dry Bay. Petroleum seepages have been found in this field near Iniskin, Oil, and Dry Bays.

The bedrock of the field is a fine-grained sandstone with which are interbedded clay shales. Some beds of conglomerate occur in the sandstone, and one of them forms the basal member of the formation and near the head of Iniskin Bay rests on sheared igneous rocks. The sandstone and the associated sediments, which are of Middle Jurassic age, have a thickness of about 1,100 feet. They are overlain by a shale formation with intercalated conglomerate. The seeps occur in the eastern limb of a broad anticlinal arch which has been faulted.[3]

Cold Bay (Fig. 187) is an indentation on the Pacific shore nearly opposite Kodiak Island. The area is untimbered and consists of hills rising less than 1,000 feet above the sea. Oil seeps occur in a Middle Jurassic series consisting of sandstone and shale with a little limestone. This series is underlain by Triassic shales,

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[1] Brooks, A. H.: The Petroleum Fields of Alaska. Am. Inst. Min. Eng. *Trans.*, vol. 51, p. 613, 1915.

[2] Brooks, A. H.: The Petroleum Fields of Alaska. Am. Inst. Min. Eng. *Bull.* 98, p. 202, 1915.

[3] Brooks, A. H.: *Op. cit.*, pp. 202-203.

limestones, and cherts and overlain by Middle Jurassic arkose conglomerate, sandstone, and shale. The youngest rocks of the district are volcanic, chiefly andesites and basalts. The oil-bearing member is Middle Jurassic of the same age as that of the

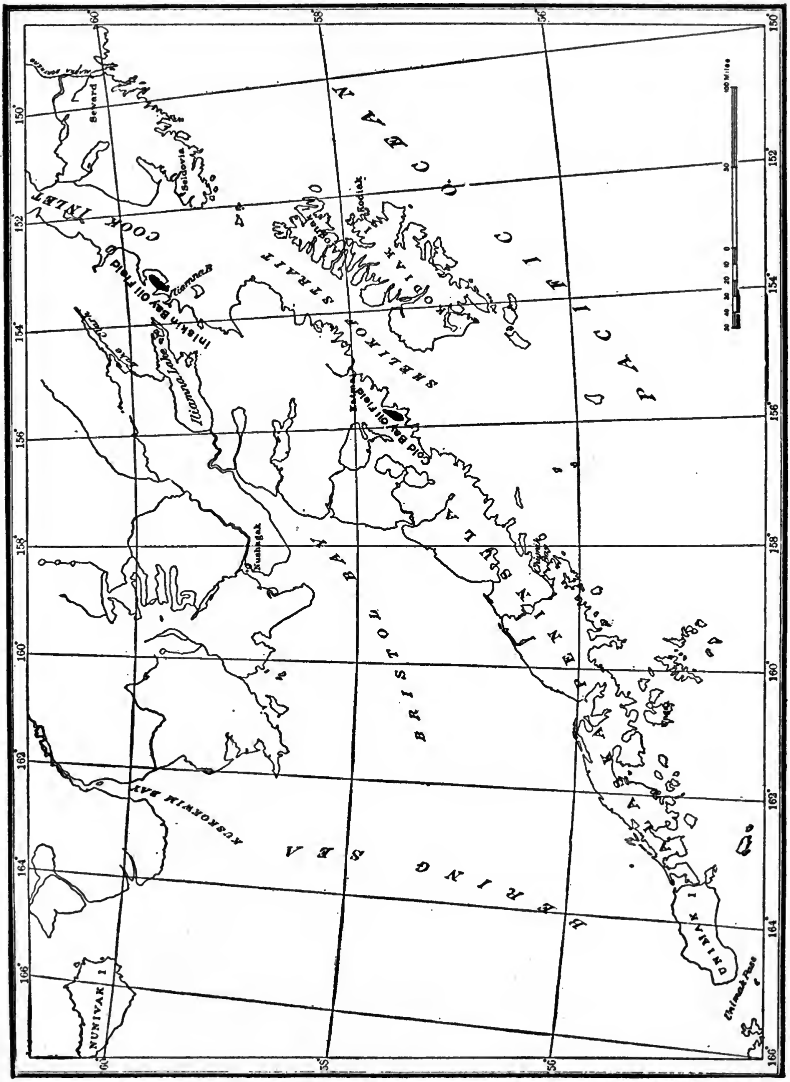

FIG. 187.—Map showing location of Iniskin Bay and Cold Bay oil fields, Alaska. (*After Brooks.*)

Iniskin Bay field. The main structural features are broad, open folds whose axes parallel the coast, trending about northeast. The dips of the strata in few places exceed 15°.[1]

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[1] BROOKS, A. H.: The Petroleum Fields of Alaska. Am. Inst. Min. Eng. *Trans.*, vol. 51, p. 615, 1915.

CHAPTER XXII

CANADA AND NEWFOUNDLAND

Oil and gas are found at many places in Canada,[1] but thus far oil has been produced on a considerable scale only in Ontario. Gas has been produced in Ontario, Quebec, New Brunswick, and southern Alberta. There is a large area between Hudson Bay and the Canadian Rockies, extending northward to the Arctic region, over which surface indications consisting of oil and gas seeps and tar sands are found. This area has yielded gas at several places and a little light oil near Calgary. It is regarded by many as the most promising region in Canada. An oil seep has been found east of this area, south of James Bay. Oil occurs also in eastern

FIG. 188.—Sketch map of Canada and Newfoundland, showing occurrences of petroleum, natural gas and tar sand. (*After Clapp.*)

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[1] CLAPP, F. G., and others: Petroleum and Natural Gas Resources of Canada. Canada Dept. Mines. Mines Branch, *Pub.* 291, 2 vols., 1914.

Canada, in Nova Scotia, in New Brunswick, and on Gaspé Peninsula, Quebec. In this region the rocks are consolidated Paleozoic sediments and are rather closely folded and faulted at many places. The prospecting that has been done has resulted in only a small production. Fig. 188 shows occurrences of petroleum and natural gas and of tar sands in Canada.

ONTARIO

Practically all the petroleum produced in Canada has come from Ontario,[1] from the district lying between Lake Huron and Lake Erie (Fig. 189). Nearly all the Ontario petroleum has come from Lambton County, at the western edge of this district, and from Middlesex County, just east of it. The principal structural features are the domes at Petrolia, at Oil Springs, and in Mosa Township. The oil is derived from the Delaware and the Onondaga limestone of the Devonian, and a little comes from the Trenton limestone.

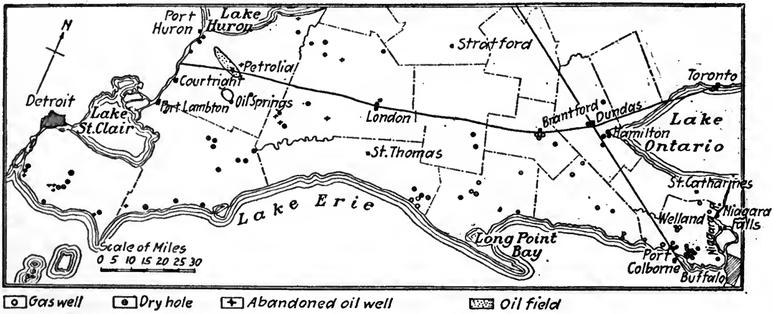

FIG. 189.—Sketch showing location of oil fields and wells in South Ontario. (*After Clapp.*) The heavy lines indicate lines of sections given in Figs. 190 and 191.

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[1] BRUMELL, H. P. H.: Natural Gas and Petroleum in Ontario. Canada Geol. Survey *Ann Rept.*, vol. 5, part Q, pp. 1-94, 1892.

STAUFFER, C. R.: The Devonian of Southwestern Ontario. Canada Geol. Survey *Mem.* 34, pp. 1-341, 1915.

CLAPP, F. G., and others: Petroleum and Natural Gas Resources of Canada. Canada Dept. Mines, Mines Branch, *Pub.* 291, vol. 2, pp. 172-185, 1915.

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WINCHELL, ALEXANDER: Sketches of Creation. *Appendix*, New York, 1870.

At Oil Springs, Lambton County, oil issues at the surface along Black Creek just north of the springs. In 1859 attempts were made to utilize oil which exuded from the "gum beds" that formed in the drift. Wells were dug 4 or 5 feet deep into the gravel, and the oil would flow into the wells. The principal development, however, began in 1862. At first the arrangements were not adequate to take care of the flow. It is estimated that 5,000,000 barrels of oil was carried off in the streams. One well is said to have flowed 6,000 barrels the first day.

The production of the Ontario fields is shown below. The Ontario oil is of good grade but carries considerable sulphur. That of Petrolia runs from 28° to 31° Baumé and that of Oil Springs from 35° to 36°.

Oil Produced in Ontario, 1918[a]
(After Waddell)

District	Gallons	Barrels of 35 Gallons
Petrolia and Enniskillen	2,291,356	65,467
Oil Springs	1,563,487	44,671
Moore Township	222,834	6,366
Sarnia Township	120,322	3,437
Plympton Township	14,409	411
Bothwell	1,019,060	29,116
Tilbury (including Dover Township)	882,971	25,227
Dutton	65,635	1,875
Onondaga	41,513	1,186
Belle River	15,645	447
Mosa Township	3,814,591	108,988
Thamesville	54,972	1,565
	10,106,615	288,760

[a] Williams, M. Y.: *Op. cit.*, p. 41.

In general the rocks of the district dip at low angles. The axis of the Cincinnati arch branches in Ohio, as already noted; one branch extends westward into Indiana and another eastward to northeastern Ohio. The eastern branch of the axis almost disappears in the region of Lake St. Clair, but an axis of a very gentle

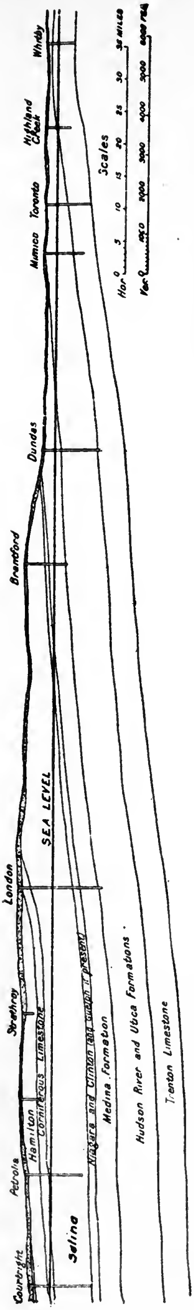

Fig. 190.—Section from Whitby to Courtright, Ontario. (*After Brumell.*) The position of the section is shown on Fig. 189.

folding occurs near Port Lambton, Ontario. It strikes northeast and extends to the Petrolia dome, about 23 miles distant. The dip from Petrolia to Port Lambton is 600 feet. Southeast of this anticline a synclinal axis plunges southwestward from a point near Shetland, Euphemia Township, Lambton County, for about 30 miles to a point near Wallaceburg, the average dip being 20 feet to the mile. Part of this area is shown on the contour map, Fig. 27 (p. 122). A generalized section from a point near Courtright to Whitby, approximately along the east-west line drawn on Fig. 189 is shown by Fig. 190.

Another section, from Port Colborne northwestward, crossing the section shown by Fig. 190, near Dundas, is shown by Fig. 191. The direction of this section is indicated on Fig. 189 by the line drawn northwestward through Port Colborne, but the section extends northwestward beyond the area of Fig. 189 to Kincardine, on Lake Huron. From St. Catharines, in the eastern part of the area, near Niagara Falls, the rocks dip south at low angles (see Fig. 94, p. 210), away from the ancient rocks that are extensively exposed around Hudson Bay, to the great Appalachian geosyncline.

In Lambton and Middlesex Counties oil is found in what is popularly called the Big lime, Lower lime, or Corniferous limestone of the Devonian. This limestone is subdivided into the upper or Delaware limestone and the lower or Onondaga limestone. Oil occurs in both divisions. The largest oil pools of the Corniferous occur at the tops of rock domes, only smaller accumulations of oil being found on terraces. Because erosion has eaten stratigraphically deeper into domes than elsewhere the black shale has been stripped from nearly all the oil fields. Knowing this, drillers rarely continue drilling where black shale is found (Fig. 13, p. 66.)

The Petrolia field has been the largest producing field in Canada and is still the largest except Mosa Township, recently developed. The Petrolia field is a flat-topped, elliptical dome whose longer axis extends northwest (Fig. 27, p. 122). The custom has been to drill the oil wells about 475 to 490 feet deep. On page 480 is a typical log.

The porous limestone near the bottom of the wells supplies most of the oil. Some oil is obtained also from what is known as a "mud vein." On the Dennis property in Petrolia three wells forming a triangle about 150 feet to the side pump oil from a depth of 459 to 460 feet, and the pumping of any one affects the other two. That there is a porous horizontal stratum containing free channels is thus established. The greatest production is obtained from the porous limestone.

The Oil Springs field may be considered the pioneer Canadian oil field and is remarkable not only for its large initial production, but for the size of its present production, considering its small area. The rocks lie in a typical eccentric dome. The oil production is fairly even over the dome except on the northwest side, which appears to be barren of oil at elevations that are productive elsewhere.

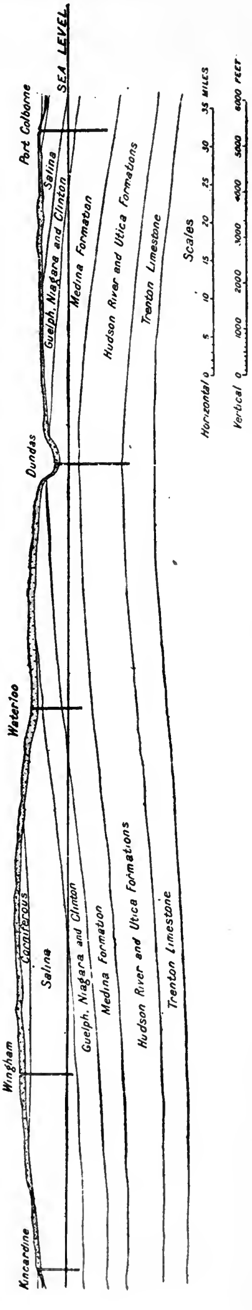

FIG. 191.—Section from Port Colborne to Kincardine, Ontario. (*After Brumell.*) The position of the southeastern part of this section from Port Colborne to Dundas and beyond is shown on Fig. 189. The section extends, however, to Kincardine on Lake Huron.

LOG OF WELL ON LAWSON PROPERTY, PETROLIA

	Thickness	Depth
	Feet	Feet
Surface drift	100	100
Ipperwash limestone, or "top rock"	50	150
Petrolia shale, or "upper soap"	134	284
Widder beds, or "middle lime"	15	299
Olentangy shale, or "lower soap"	45	344
Delaware limestone, or "lower" or "big lime"	50	394
Onondaga limestone, penetrated; oil-bearing rock reported to extend from 462 to 471 feet	82	476

Oil Springs has produced oil from beds at three different horizons, all of which, however, are probably supplied from the deepest source. Surface oil or "gum beds" in low swampy areas early attracted attention. Today a fine lubricating oil is obtained from wells that penetrate unconsolidated gravels just above the solid formations.

The oil from the gushing wells of the early days came from a "mud vein" or "crevice" about 7 to 12 feet from the top of the Delaware limestone, as stated by Williams. The main production of the present day is from porous limestone 100 to 120 feet below the top of the Delaware.

The following is a typical log:

LOG OF A WELL BELONGING TO C. O. FAIRBANK, IN ENNISKILLEN TOWNSHIP

	Thickness	Depth
	Feet	Feet
Surface	76	76
Petrolia shale, or "upper soap"	113	189
Widder beds, or "middle lime"	17	206
Olentangy shale, or "lower soap"	25	231
Delaware and Onondaga limestone penetrated	163	394
Oil crevice at 240 feet; oil rock between 331 and 351 feet		

The gushing wells tapped a porous stratum from 7 to 12 feet below the top of the Delaware limestone. The drill is said to drop about 4 inches in most wells when this stratum is reached. The "crevice" apparently consists of a very porous bed of limestone, in which are numerous interlacing channels.[1]

The Mosa oil pool, about 4 miles northwest of Glencoe, Middlesex County, produced more oil during 1918 than any other field in Canada. The main oil production comes from the crest of the dome and very few wells produce from terraces or structurally lower portions. The porous oil stratum of the older fields appears to be absent in the Mosa field. The oil is obtained mainly from the crevices or shattered zones in the Delaware formation.

The following log is typical of the center of the Mosa field:

		Thickness	Depth
		Feet	Feet
Surface		77	77
Petrolia shale	"Soap"	58	135
	Limestone	6	141
	"Soap" with streaks	73	214
Widder beds or middle limestone		19	233
Olentangy shale	"Lower soap"	20	253
	Streaks of limestone	4	257
	Streaks of "soap"	2	259
Delaware and Onondaga limestone penetrated		55	314
Oil at 264 feet.			

Oil in this field generally occurs in the upper 20 feet of the Delaware limestone, but it occurs also in a few wells in the "middle lime" or Widder beds.[2] Fig. 192 shows a model of this field.

As the Silurian produces gas from the Medina sand ("Clinton") in Ohio, and as oil is obtained from the Trenton in Ohio and Indiana, the rocks below the Devonian have naturally been regarded as possible sources of oil and gas below the domes in Lambton County. A well drilled on the Petrolia dome to a depth of 3,770 feet has failed to reach a productive stratum. At Oil Springs, according to report, some oil has been obtained from the Trenton, but the production is not mentioned by Williams in his report, already cited, published in 1919.

[1] Williams, M. Y.: *Op. cit.*, p. 34.

[2] Williams, M. Y.: *Op. cit.*, p. 37.

RECORD OF DEEP WELL ON R. I. BRADLEY ESTATE, PETROLIA POOL

		Feet
Pleistocene	Surface	0–90
Hamilton	Streaks of limestone and shale	90–330
Onondaga.[a]	Limestones	330–520
Salina	Streaks of brown, gray, and black dolomite	520–1,210
	Salt strata and streaks of dolomite	1,210–1,640
	Salt strata and streaks of dolomitic limestone	1,640–1,747
	Salt strata and gray dolomitic lime and shale	1,747–2,105
Guelph and Niagara	Guelph and Niagara dolomitic limestone	2,105–2,380
	Niagara shale (red and dark)	2,380–2,440
Clinton	Clinton	2,440–2,530
Medina	Red Medina	2,530–2,805
Utica	Lorraine shales (light)	2,805–3,010
	Utica shales (dark)	3,010–3,175
Trenton	Trenton	3,175–3,345
	Birdeye	3,345–3,460
	Chazy (Canadian)	3,460–3,770

[a]Probably includes Delaware formation.

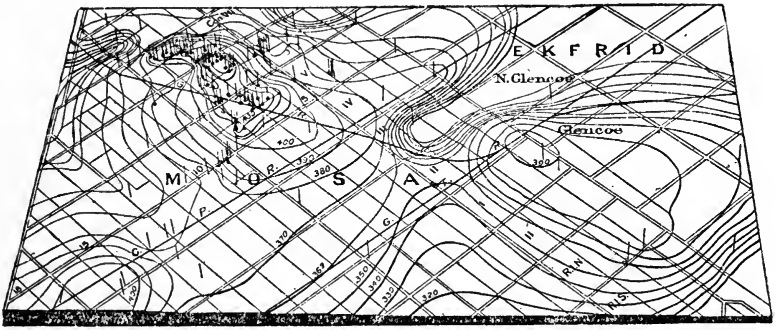

FIG. 192.—Model of Mosa oil field, Ontario, representing the top of the Delaware (Corniferous) limestone. The edges of the cardboard used in making the model may be considered as lines of equal elevation or contour lines. The wells are marked by pins and beads represent the oil wells producing in October, 1918. (*After Williams.*)

Two wells about 40 miles southwest of Petrolia, in Kent County, Dover West, obtained oil from the Trenton.

In the second producing well the main oil and gas appear to be floating on salt water, as considerable salt water is produced with the oil.[1]

No gas is produced from the "Clinton" in Lambton County. East of the Mosa field there is a broad, shallow syncline, and still farther east the rocks rise to the northeast on a broad, low anticline[2] that plunges southwest. On the flank of the anticline near Port Colborne (see Fig. 191) gas is obtained in the "Clinton" sand, and gas wells are found at several places as far west as 90 miles west of Niagara Falls.

NOVA SCOTIA

In Nova Scotia, according to Brumell,[3] oil is frequently seen on the waters of Lake Ainslee. The oil-bearing strata are so complicated by folding and faulting that conditions are not favorable for accumulation.[4]

NEW BRUNSWICK

In New Brunswick oil seeps are found in the Albert shales, and albertite has been mined in large quantities. Although many wells have been drilled the amount of oil produced is very small. Pools of gas have been developed and have supplied several towns in New Brunswick. The most important of these is the Stony Creek field, where the rocks are of Paleozoic age. Where the Devonian and lower Carboniferous rocks abut against the pre-Cambrian rocks in Albert and Kings Counties, they dip steeply to the north, but this inclination flattens out northward and the middle Carboniferous rocks of the central basin are thrown into a system of gentle folds. The Stony Creek field is about 9 miles south of Moncton and about 4 miles north of Hillsboro. The oil and gas are found in sands of the Albert series.

The sands are reported to be dry of water, and the gas has collected in them at points of local undulations.[5] The oil is a clear dark-green oil of 39° Baumé. The gas is a wet gas, estimated to contain half a gallon of gasoline to 1,000 cubic feet.[6]

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[1] Williams, M. Y : *Op. cit.*, pp. 39-40.

[2] Stauffer, C. R.: *Op. cit.*, outline map.

[3] Brumell, H. P. H.: Petroleum and Natural Gas in Canada. Geol. Soc. America *Bull.*, vol. 4, pp. 225-240, 1893.

[4] Clapp, F. G.: *Op. cit.*, vol. 2, p. 5, 1915.

[5] Clapp, F. G.: *Op. cit.*, vol. 2, p. 45.

[6] *Idem*, p. 48.

Geologic Column for Eastern Albert County, New Brunswick
(After Clapp)

Age	Series	Thickness (Feet)	Character
Middle Carboniferous.	Millstone grit (Pottsville).	500	Gray quartz conglomerate and freestone with coal streaks.
Lower Carboniferous (Mauch Chunk and Pocono).	Upper conglomerate	1 ,950	Red and gray conglomerate, gray limestone and gypsum.
	Red shale.	450	Red and gray calcareous shale with thin sand and conglomerate.
	Lower sandstone and conglomerate.	700	Gray micaceous, and petroliferous sandstone with some reddish conglomerate.
Lower Carboniferous or Devonian.	Albert.	850	Gray and brown calcareous or bituminous shales and sands.
	Basal conglomerate.	200	Greenish conglomerate with slate fragments, etc., often absent.

QUEBEC

Gaspé, the most northeasterly county of the peninsula of Gaspé, is the only county in Quebec that has produced oil in commercial quantity, and this field was never profitable.[1] The total production is about 2,000 barrels. The country is an area of Paleozoic limestones, sandstones, slates, and shales, thrown into sharp folds, locally almost on edge, the dips ranging from 10° to 80°. These strata are cut by igneous intrusions. The anticlines expose Silurian and Devonian limestone, and the flanks of the anticlines and synclines expose the Gaspé sandstone, which is Devonian. Oil seeps are numerous, and many wells have been drilled, some of

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[1] Clapp, F. G.: *Op. cit.*, vol. 2, p. 64.

Malcolm, Wyatt: The Oil and Gas Fields of Ontario and Quebec. Canada Geol. Survey *Mem.* 81, pp. 92-238, 1915.

them to great depths. The wells drilled on anticlines found no oil, all the productive wells being in synclines. This seems to be an indication that the breaking of the strata has long ago caused leakage of most of the oil.[1] The oil from sandy portions of the strata is of a light amber color; that from the lower Calciferous rocks is a heavier dark oil.[2]

WESTERN CANADA

A large area in western Canada and the United States, east of and in the Rocky Mountains, exhibits indications of petroleum. (See Fig. 188, p. 475.) The rocks exposed are largely of Cretaceous age. The Cretaceous formations carry oil in Wyoming, Colorado, and Montana and have yielded some oil at Calgary, in Alberta. The Cretaceous yields gas also in Alberta and contains a very extensive body of tar sands on the Athabasca River. The Upper Cretaceous formations of southern Alberta are shown in the table below,[3] together with correlations of formations in Manitoba, Montana, and South Dakota.

This great area is underlain at many places by the Dakota sandstone. This formation carries artesian water in a large part of the plains region east of the Rocky Mountains and has been encountered in many wells. It is so extensive and its position is known at so many places that it has served as a key rock to plot the structure over a wide area. A paper by Darton[4] recently issued shows by contours the structure of a large portion of the area in the United States, embracing parts of Kansas, Colorado, Nebraska, Wyoming and South Dakota.

In western Canada the Dakota sandstone is extensively developed in Manitoba, Saskatchewan, and Alberta. A little oil has been found in Canada in a sand that has been classed by some as Dakota and by others as the Cloverly, above the Dakota. The Cretaceous, in or near the Dakota, carries gas at Bow Island, at Viking, and at Pelican, Alberta. The tar sands of the Athabasca River are in the Dakota. The Dakota crops out at many places

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[1] Clapp, F. G.: *Op. cit.*, p. 68.

[2] *Idem*, p. 69. Ells, R. W.: The Oil Fields of Gaspé. Canada Geol. Survey *Fifteenth Ann. Rept.*, new ser., p. 362A, 1903.

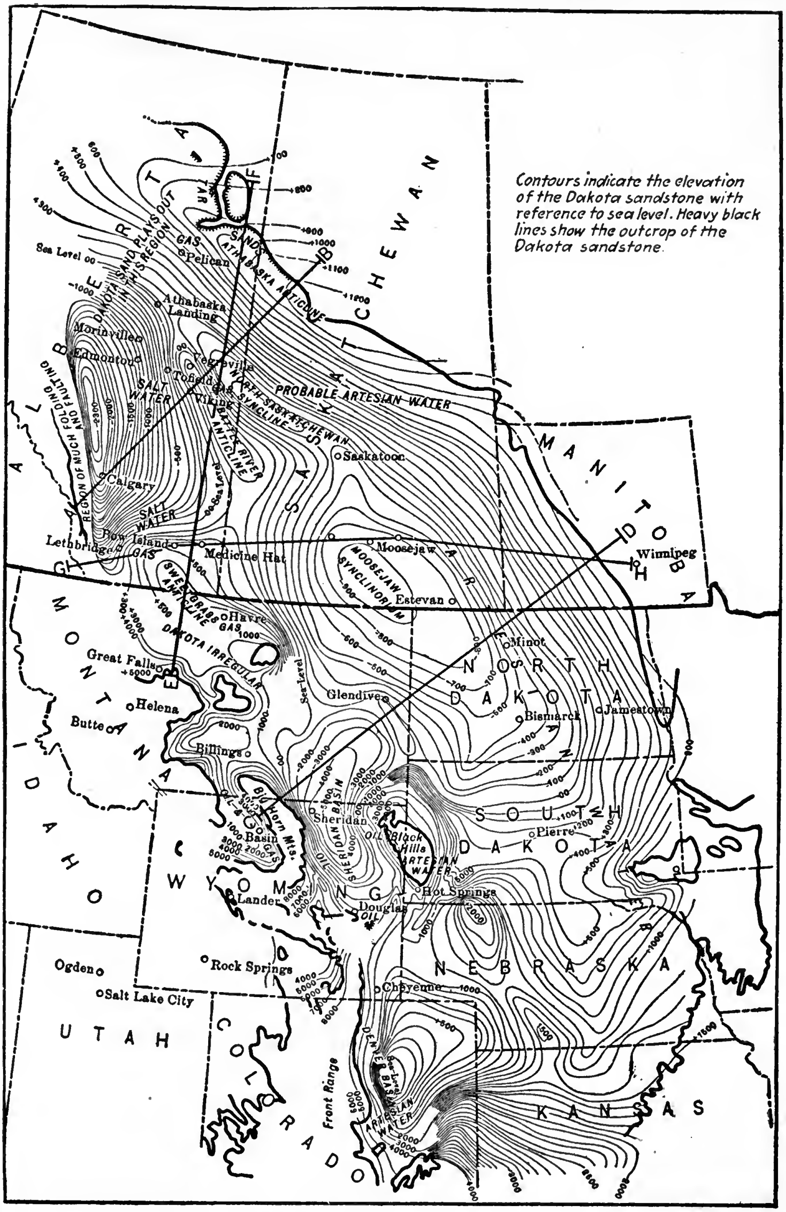
[3] Dowling, D. B.: Correlation and Geologic Structure of the Alberta Oil Fields. Am. Inst. Min. Eng. *Trans.*, vol. 51, pp. 353-363, 1915.

[4] Darton, N. H.: The Structure of Parts of the Central Great Plains. U. S. Geol. Survey *Bull.* 691, pp. 1-26, 1919.

CORRELATION OF UPPER CRETACEOUS FORMATIONS OF CANADA AND THE UNITED STATES IN THE AREA EAST OF THE ROCKY MOUNTAINS

(After Dowling)

	Western Montana	Southern Alberta			Central Montana	Manitoba	South Dakota
			West Forks of Milk River	East Near Pakowki Coulee			
Montana group.	Bearpaw shales. (marine).	Fox Hills Pierre.	Bearpaw shales. (marine).	Bearpaw shales. (marine).	Bearpaw shales. (marine).	Odanah shales. (marine).	Fox Hills.
	Two Medicine formation (fresh and brackish).	Belly River formation.	"Pale" and "Yellow" beds. Sandstones and clays (fresh and brackish).	"Pale" and "Yellow" beds. Sandstones and clays (fresh and brackish).	Judith River formation (mainly fresh water).		Pierre.
			Shale at Forks.	Shale in Coulee. (marine).	Claggett shales. (marine).	Millwood shales. (marine).	
	Virgelle sandstone.		"Castellated" rocks.	"Castellated" rocks of Milk River.	Eagle sandstone.		(Marine).
Colorado group.	Benton shales (marine).	Lower Dark shales (marine).			Benton shales (marine).	Niobrara shales (marine). Benton shales (marine).	Niobrara shales (marine). Benton shales (marine).
Dakota group.		Exposures of sandstones in the Sweet Grass Hills, and also reached by drilling in Alberta.			Exposures in Sweet Grass Hills.		



Contours indicate the elevation of the Dakota sandstone with reference to sea level. Heavy black lines show the outcrop of the Dakota sandstone.

FIG. 193.—Map showing generalized structure of the Dakota sandstone in the United States and Canada east of the Rocky Mountains, with relation to the oil, gas, and water reservoirs. Sections along lines *A-B*, etc., are given on Figs. 194-197. (*After Huntley.*)

along the mountain front and almost continuously along the eastern edge of the structural basin. It is represented as a heavy black line in Fig. 193. Over most of the area it is covered by later beds of Cretaceous and Tertiary age.[1] The principal formations are shown in the section on p. 490. The symbols in the second column correspond to those used in Figs. 194 to 197.

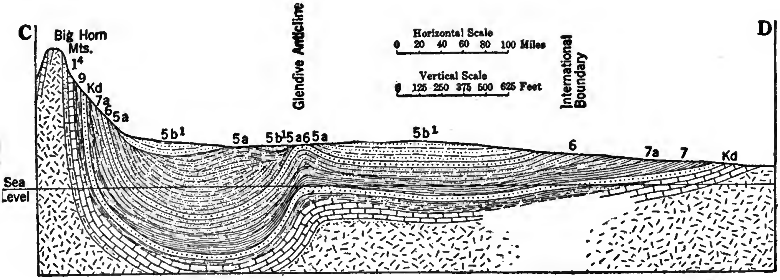


FIG. 1 94.—Section along line *CD*, Fig. 193.

The beds form a huge synclinorium on which many large anticlines are superimposed. These conditions are illustrated by the contours in Fig. 193, p. 487. The synclinorium is comparable to the Appalachian synclinorium (see Fig. 93), but the folds are generally of greater amplitude. Unlike the sands of the West Virginia-Pennsylvania region the Dakota formation is generally a continuous sheet rather than a group of more or less isolated lenses. It is possible, however, that some of the sand mapped as Dakota in this region is of Kootenai age.

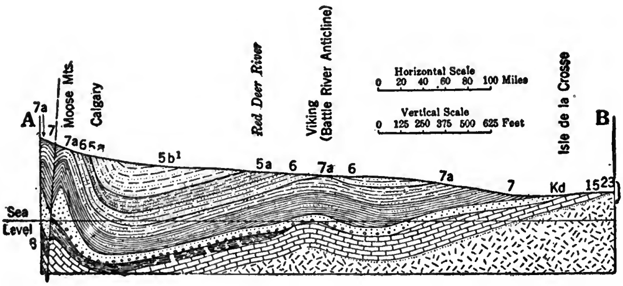


FIG. 195.—Section along line *AB*, Fig. 193. (*After Huntley.*)

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[1] HUNTLEY, L. G.: Oil, Gas, and Water Content of Dakota Sand in Canada and United States. Am. Inst. Min. Eng. *Trans.*, vol. 52, pp. 329-345, 1915.

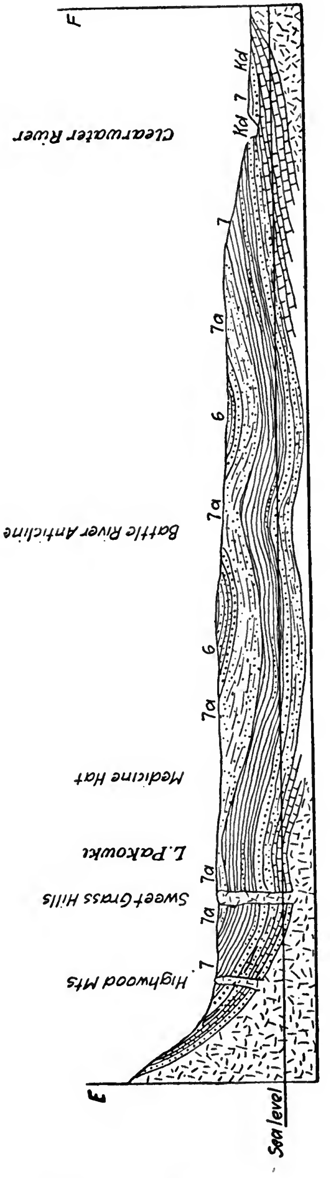

Fig. 196.
Section along line *EF*, Fig. 193.
(*After Huntley.*)

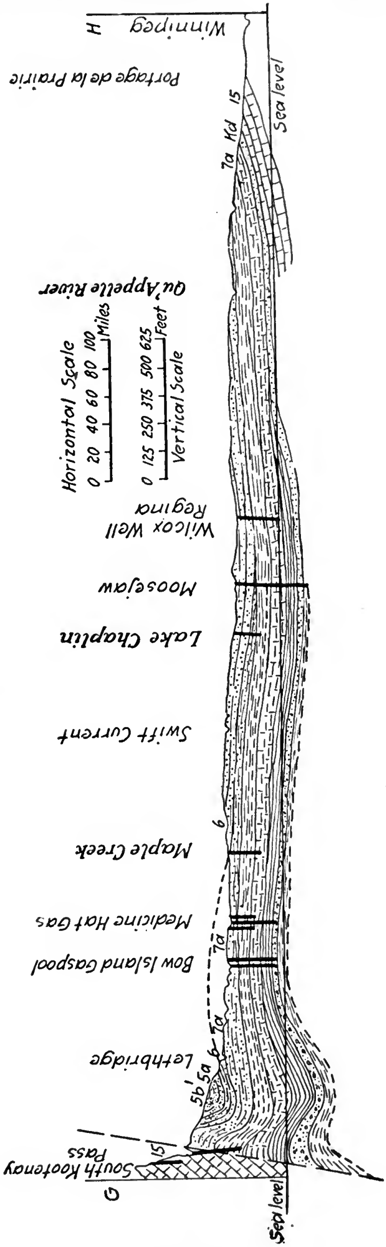

Fig. 197.
Section along line *GH*, Fig. 193.
(*After Huntley.*)

Except in northern Alberta, the Dakota sandstone contains generally a fresh-water fauna. In northern Alberta marine and brackish-water conditions prevailed when it was laid down. Nearly everywhere above the Dakota is a great thickness of Cretaceous shales, largely marine. In southern Montana and Wyoming the overlying shales include a number of sands, some of which have yielded oil and gas. Among these are the Shannon sand of the Pierre and the Wall Creek sand of the Benton in the Salt Creek and Powder River pools in Wyoming; and the Frontier, Torchlight, Peay, Cloverly, and Greybull sands in the Big Horn Basin.

Lower Tertiary.	5b1	Laramie—Paskapoo series.	Fresh-water sands, clays, and shales.
Upper Cretaceous.	5a	Laramie—Edmonton series (coal bearing).	Sand and shales.
	6	Bearpaw (Pierre-Fox Hill).	Gray-brown shales, sand shells.
	7a	Belly River and Lower Dark shales.	Sand and shale in upper portion, black shale below.
		Niobrara (cardiom).	Sand lenses and dark shales.
		Benton.	Black and gray shales.
	Kd	Dakota sandstone.	Soft, porous sand (250 to 950 feet), conglomeratic at base.
Lower Cretaceous.	8	Kootenai shales (coal bearing).	
Devonian.	15	Devonian.	Limestones, shale, and salt or gypsum.
Cambrian.	18	Cambrian.	Reddish sand and shales.
Archean.	23	Laurentian.	Granite.

The gas pool in the vicinity of Bow Island, in southern Alberta, has yielded a large production. The gas is used at Medicine Hat and Lethbridge. The total capacity of the wells was estimated to be 75,000,000 cubic feet a day. A well drilled 5 miles north of Viking, Alberta, obtained a considerable flow of gas.

Gas was encountered at Pelican Rapids in 1897-98. The gas escapes with a roaring noise through a 4-in. pipe. For many years the noise was so great that it could be heard at a distance of 2 miles or more, especially in the winter. After nine years the pressure appeared to be lessening.[1]

So far as is indicated by available analyses[2] the gases of Alberta fields are "dry." They are composed essentially of methane and nitrogen.

Fig. 198 is a sketch of part of the foothill region of southern Alberta.[3] Sections are shown in Fig. 199.

The interest shown in the fields of western Canada is due largely to the presence of the "tar sands" on the Athabasca River. These sands constitute one of the largest deposits of asphaltic material known, if not the largest. They crop out along the river for 100 miles and occupy an area estimated to cover 2,000 square miles or more. They were deposited on an irregular floor and range in thickness from 13 to 200 feet.[4] The sands are at the base of the Cretaceous (Dakota) and rest on Devonian limestones.[5] The sands are either white or reddish. At some places they are incoherent; at others they are cemented by a calcareous matrix. The tar-sand formation grades up into a light-green sandstone with which are commonly interstratified thin bands of light-green shale. The shale covers the sands where it has not been eroded. The sands, which are saturated with asphaltum and heavy oil, are said

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[1] Bell, Robert: The Tar Sands of the Athabasca River, Canada. Am. Inst. Min. Eng. *Trans.*, vol. 38, p. 843, 1907.

[2] Clapp, F. G.: *Op. cit.*, vol. 1, p. 64 and table opposite p. 62, 1914.

[3] Dowling, D. B.: Correlation and Geologic Structure of the Alberta Oil Fields. Am. Inst. Min. Eng. *Trans.*, vol. 51, pp. 353-363, 1915.

[4] Clapp, F. G.: *Op. cit.*, vol. 2, p. 237, 1915.

[5] McConnell, R. G.: Report on an Exploration in the Yukon and McKenzie Basins. Canada Geol. Survey *Rept.*, new ser., vol. 4-D, pp. 1-163, 1889; Report on a Portion of the District of Athabasca, Comprising the Country Between Peace River and Athabasca River North of Lesser Slave Lake. Canada Geol. Survey *Rept.*, new ser., vol. 5-D, pp. 1-67, 1891.

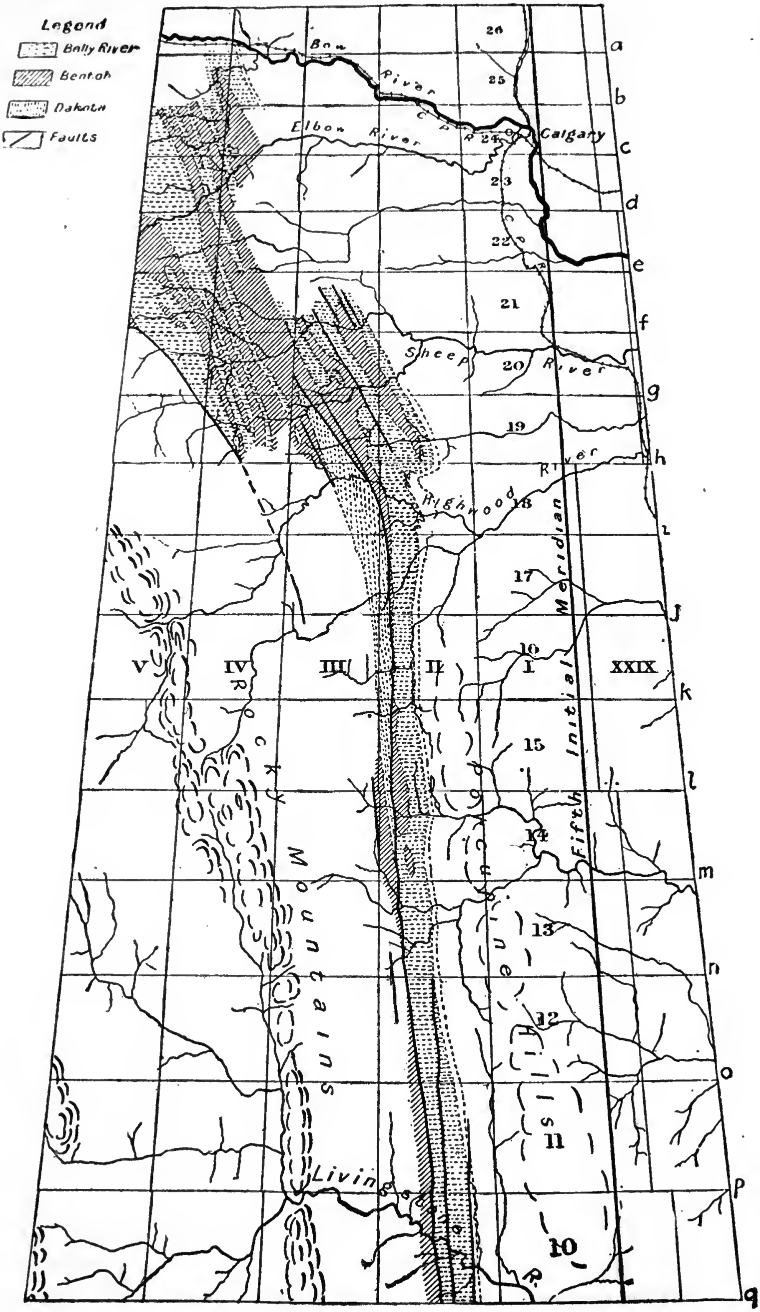

FIG. 198.—Perspective diagram of part of foothill region of southern Alberta, Canada. (*After Dowling.*) Sections along lines *a*, *b*, *c*, etc., as shown in Fig. 199.)

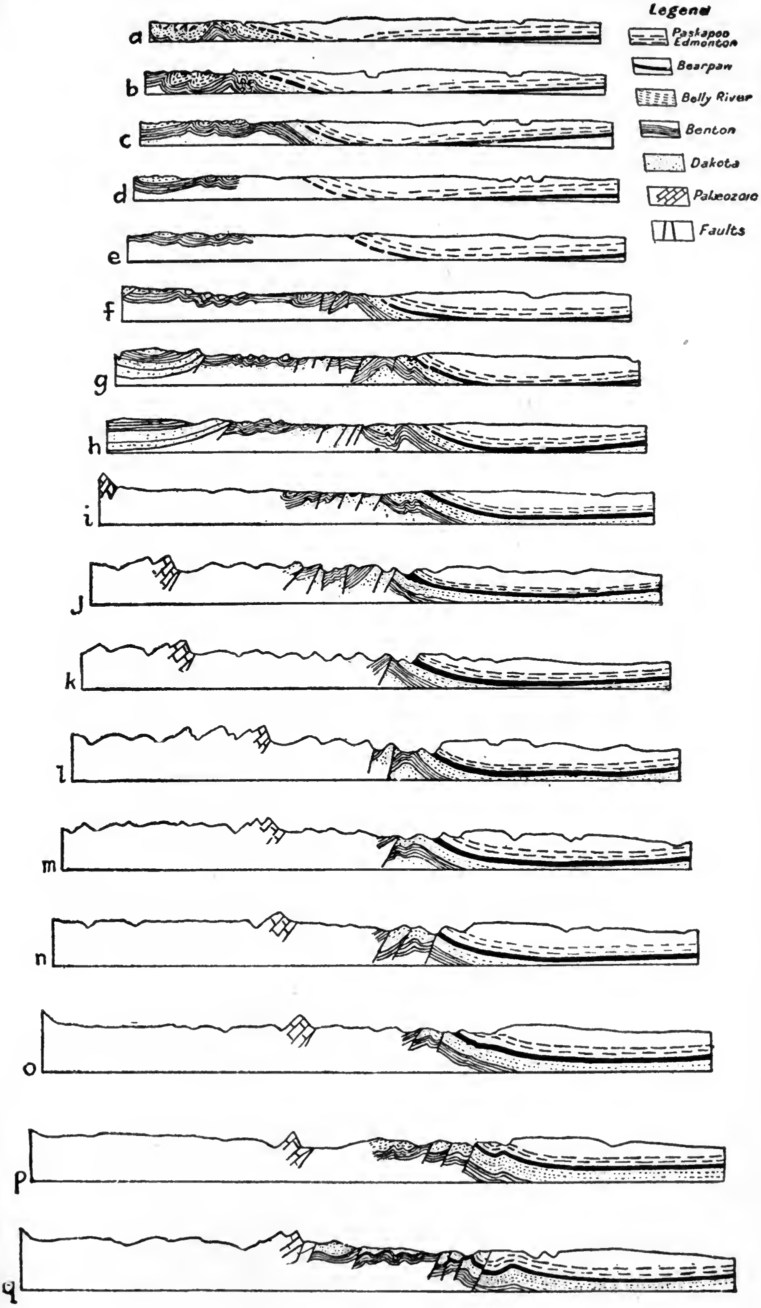

Fig. 199.—Structure sections across part of foothill region of northern Alberta, Canada, along lines *a*, *b*, *c*, etc., Fig. 198.

to contain 14 gallons of oil to the ton.[1] According to Bell[2] the petroleum that saturated the Cretaceous sand came up from the Devonian limestones on which it rests. Hardened tar or pitch may be seen in the cracks and joint planes of these limestones, showing that petroleum has passed through them at a remote period. The numerous exposures of Devonian limestone seen under the tar sands show little evidence of containing bitumen, except as black incrustations in joint planes, cracks, and vugs. The tar may have come from a lower formation, but it is so generally diffused in the sand that it probably came from the formation immediately below it.[3]

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[1] Bell, E. C.: Geology and History of Canadian Fields. *Oil and Gas Jour. Suppl.*, May, 1919.

[2] Bell, Robert: The Tar Sands of the Athabasca River, Canada. Am. Inst. Min. Eng. *Trans.*, vol. 38, p. 838, 1907; Canada Geol. Survey *Rept. Prog.*, 1882-1884, part CC; also *Summary Rept.* for 1889, pp. 103-110.

[3] Bell, Robert: *Op. cit.*, p. 843.

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NEWFOUNDLAND

Oil seeps have been known on the west coast of Newfoundland for many years. A well sunk in 1867 to a depth of 700 feet obtained traces of oil. A well sunk in 1895 struck oil at 700 and 900 feet and a larger flow at 1,230 feet. The beds are Ordovician shales and sandstones with some limy layers. They dip eastward, away from the pre-Cambrian rocks across the bay. The wells are sunk in the Ordovician where the strata are highly folded and faulted and at many places mashed and on edge.

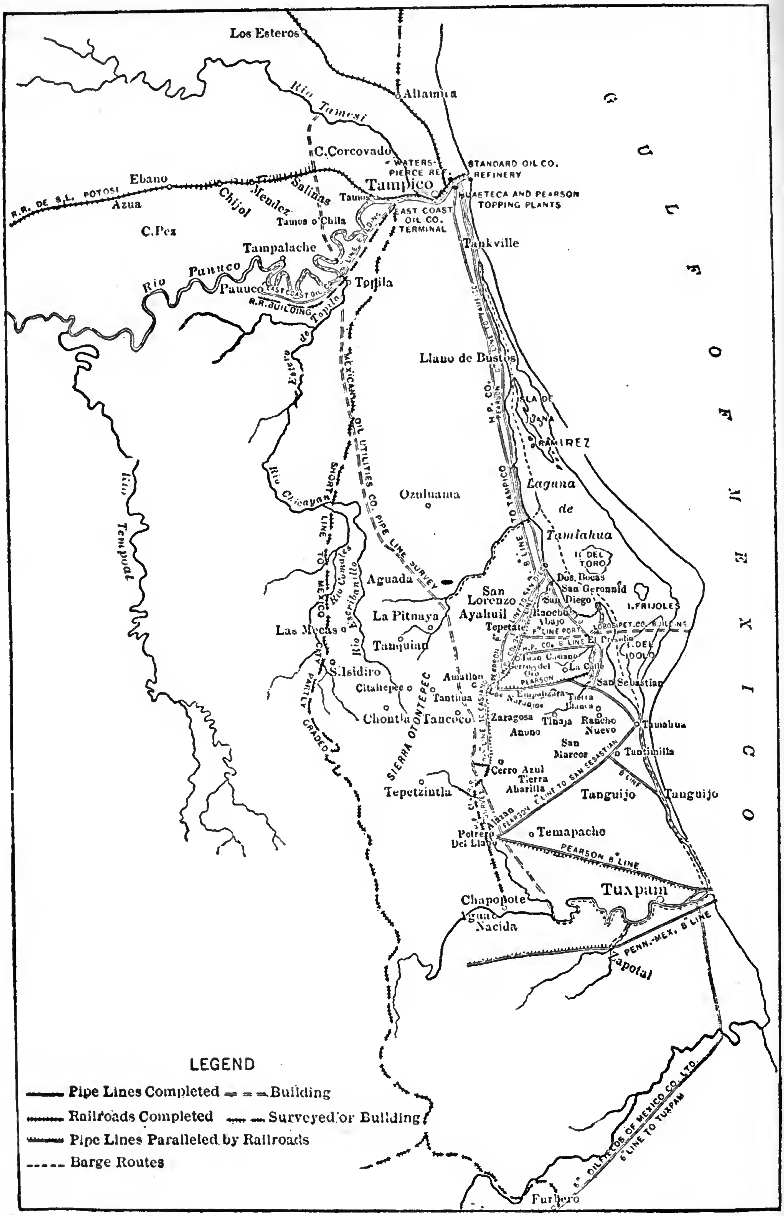

FIG. 200.—Sketch map of the northern Vera Cruz oil region, Mexico, showing pipe lines and railroads. (*After Huntley.*)

CHAPTER XXIII

MEXICO

The oil fields of Mexico[1] are on the Gulf coast in the States of Vera Cruz, Tamaulipas and Tabasco. The northern Vera Cruz region (Fig. 200), which includes the ports of Tampico and Tuxpam, supplies almost the entire production.

The output in 1917 was distributed among the various fields as follows:[2]

	Barrels of 42 Gallons
Tampico-Tuxpam zone:	
Panuco River valley region:	
San Pedro field	1,955
Ebano-Chijol field	1,125,702
Topila field	815,954
Panuco field	14,955,940
Total region	16,899,551

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[1] Garfias, V. R.: The Oil Region of Northeastern Mexico. *Econ. Geology*, vol. 10, pp. 195-224, 1915; Effect of Igneous Intrusions on the Accumulation of Oil in Northeastern Mexico. *Jour. Geology*, vol. 20, pp. 666-672, 1912.

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[2] De Golyer, E.: The Petroleum Industry of Mexico. *Evening Post* Oil-Industry *Suppl.* New York, Aug. 31, 1918, p. 17.

	Barrels of 42 Gallons
Tuxpam region:	
Casiano-Tepetate field	8,153,692
Tanhuijo-San Marco field	3,093
Cerro Azul field	9,171,478
Potrero-Alazan field	16,893,717
Alamo field	4,112,899
Furbero field	34,689
Total region	38,369,663
Total zone	55,269,214
Tehuantepec-Tabasco zone	23,556
Total Mexico	55,292,770

This output came principally from five large wells,[1] of which the Juan Casiano No. 7 and Potrero del Llano No. 4, two famous gushers drilled in 1910, supplied a large amount. In all there were at the end of 1917 in Mexico 339 productive wells, with a daily estimated capacity of 1,337,213 barrels of oil. Some of the wells in Mexico have unusually long life, especially for gushers of such magnitude. Most of the oil produced in Mexico is a heavy fuel oil, but recently lighter oil yielding considerable gasoline has been found. Salt water is associated with the oil, and at some places the water is hot. Some of the large wells recently have gone to salt water.

In northern Vera Cruz the coastal plain is about 60 miles wide. The country is comparatively flat and is forested. It is an area of sedimentary rocks intruded by many dikes and plugs of basic igneous rocks. Along the plain the rocks are nearly flat-lying except where disturbed locally by intrusions. To the west, along the east flank of the Sierra Madre Oriental, the sediments are closely folded. The rocks are of Cretaceous and later age. A table of formations is given on p. 499.

The principal oil-bearing rock is the Tamasopa, a series of limestones which make up the core of the Sierra Madre Oriental along the western rim of the coastal plain. These limestones are 3,000 feet thick and are for the most part gray and massive. This series is placed by some in the Lower Cretaceous and by others in

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[1] Blardone, George: Mexico's Petroleum Production in 1917. *Oil and Gas Jour.* (Tulsa, Okla.), vol. 16, No. 34, pp. 28, 32, 1918.

TENTATIVE CORRELATION OF THE TERTIARY AND CRETACEOUS FORMATIONS OF NORTHEASTERN MEXICO

(After Garfias)

Tertiary:	
Pliocene:	
Miocene:	Later Tertiary clays, limestones, and sands, about 700 feet.
Tuxpan	
Oligocene:	
San Fernando (yellow clays, limestones, and sands)	
Eocene:	Cretaceous-Eocene shales, about 3,000 feet.
Alazan shales	
Mendez shales (in part)	
Cretaceous:	
Upper:	
Papagallos shales	
Mendez shales (in part)	
San Felipe limestones and shales	Upper Cretaceous limestones and shales, about 500 feet.
Cardenas	
Lower:	Lower Cretaceous limestones, about 3,000 feet.
Middle:	
Tamasopa limestone	
Lower:	
El Abra limestone	

the Upper Cretaceous. It is named after the Tamasopa Canyon, where a section is exposed. The limestones vary in different localities, are fossiliferous, and have a slight petroliferous odor. The oil occurs in solution cavities and in other openings in the limestone and is associated with salt water.

Overlying the Lower Cretaceous limestones is the San Felipe[1] formation, a series of interbedded limestones and shales in which the shale increases toward the top. The San Felipe limestones and shales form some of the principal sources of oil in the region. These rocks constitute ideal reservoirs, particularly where they are fractured or folded, as near intrusions. The oil occurs to some extent in the porous limestones, but more generally, perhaps, in interstices in the shales. Wells that are apparently finished in the

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[1] Others place these rocks higher in the geologic column than is shown in the table by GARFIAS.

San Felipe draw their major oil supply from the Tamasopa limestone through fissures. According to Arnold,[1] the Potrero No. 4 was finished in the San Felipe, but a great number of blocks of Tamasopa rocks were blown out when the well came in.

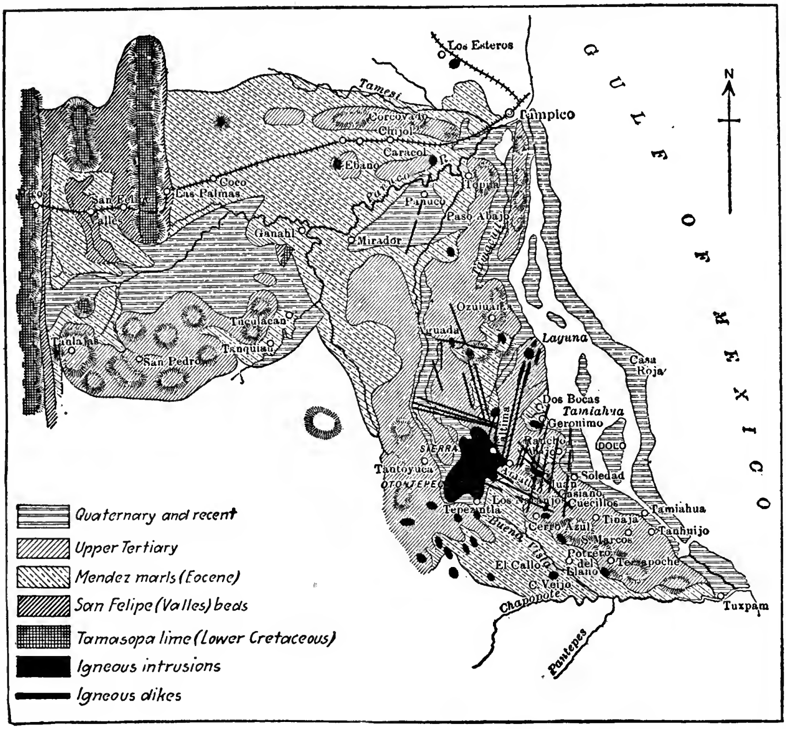

FIG. 201.—Generalized sketch map of the oil fields in the Northern Vera Cruz region, Mexico, showing areal geology, location of main basaltic intrusions and strike of the main dikes in the central district. (*After Jeffreys.*)

Unconformably above the San Felipe beds is a series of uniform marls and clays, the Mendez, 2,000 to 3,000 feet thick. This formation is impervious and forms the cap rock of the main oil reservoirs; it is also a reservoir rock where conditions are favorable. Some of the wells derive oil from the Mendez, partic-

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[1] ARNOLD, RALPH: Conservation of Oil and Gas Resources of the Americas. Second Pan American Sci. Cong. *Proc.*, vol. 3, pp. 217-218, 1917.

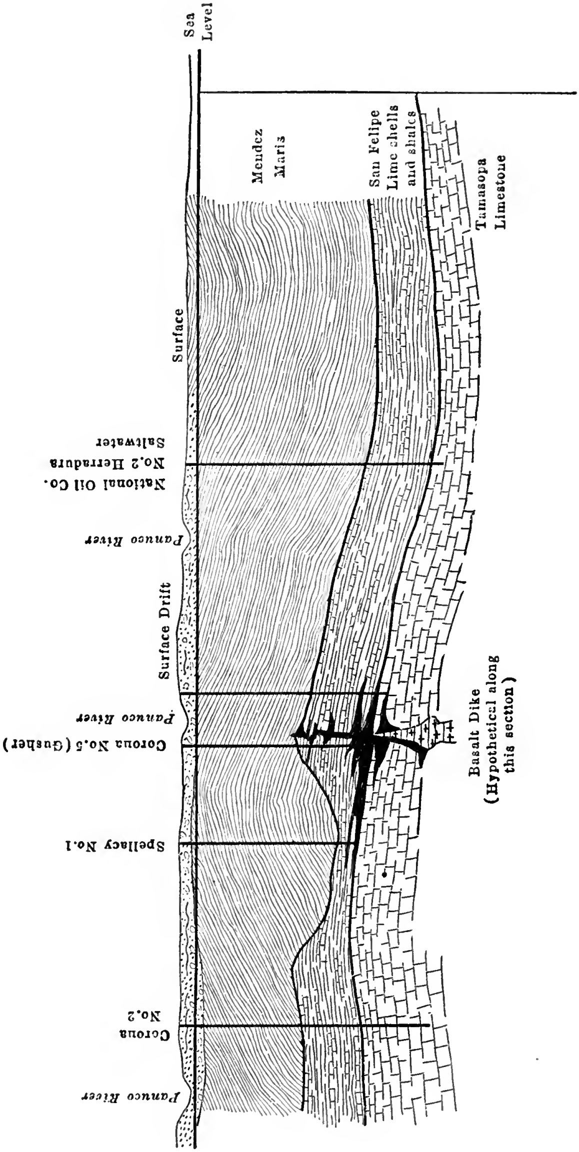

FIG. 202.—Hypothetical geological section through Panuco field, Mexico. (*After Huntley.*)

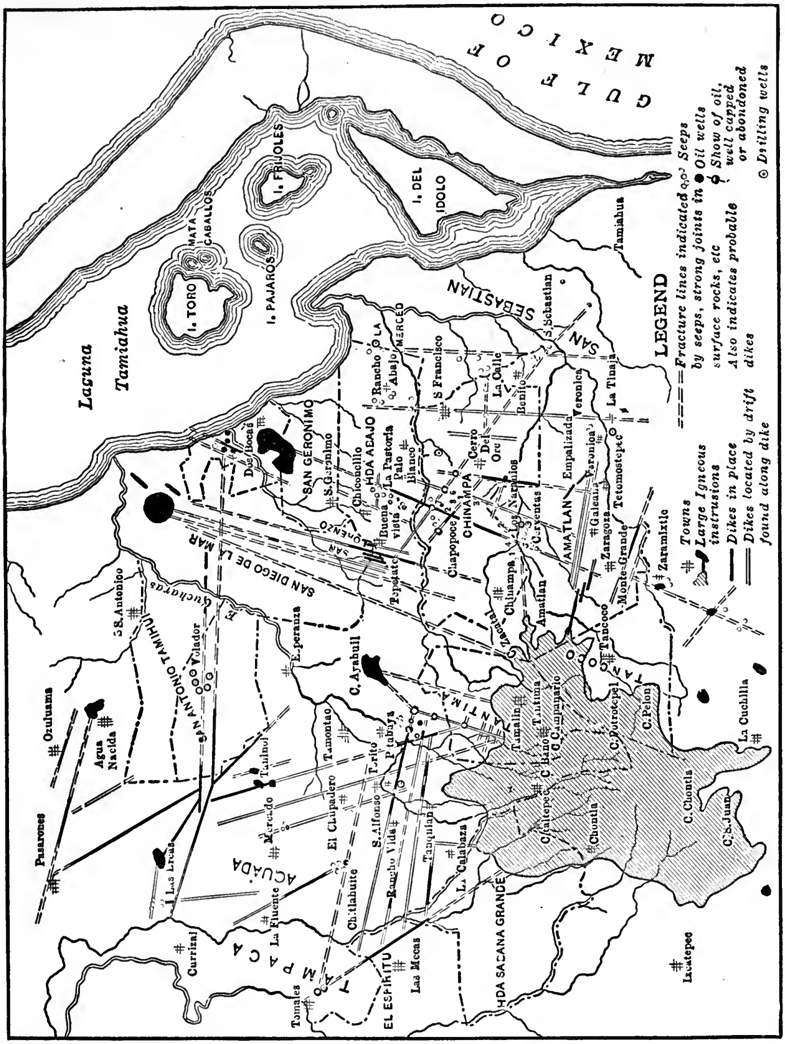

Fig. 203.—Map of a portion of Vera Cruz oil field. Shows the relations of the principle igneous intrusions to oil seeps and gushers that have been drilled at Dos Bocas, Juan Casiano and Los Naranjos. (*After Huntley.*)

ularly its lower members, without reaching the Upper Cretaceous limestones and shales.[1]

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[1] Garfias, V. R.: The Effect of Igneous Intrusions on the Accumulation of Oil in Northeastern Mexico. *Jour. Geology*, vol. 20, pp. 666-672, 1912.

Unconformably overlying the marls is a succession of fossiliferous grayish limestones and shales with minor amounts of conglomerate and sand having an average thickness of about 700 feet. These beds are of little importance in connection with the commercial accumulation of oil in this region, and they form a rather porous covering over the impervious Eocene-Cretaceous shales. Under favorable conditions, however, where the shales have been fractured, allowing the oil to migrate to the overlying porous beds, accumulations of oil have been formed.

Dikes, sills, and stocks of basaltic rock intrude the sedimentary beds (Figs. 201 and 202). Most of the surface indications of oil are closely associated with the basalts, and hundreds of them occur throughout the plain. Among the localities where oil seeps are abundant are Panuco, Dos Bocas, Casiano, Tres Hermanos, Ojo de Brea, Chapopotillo, Monte Grande, and many others.

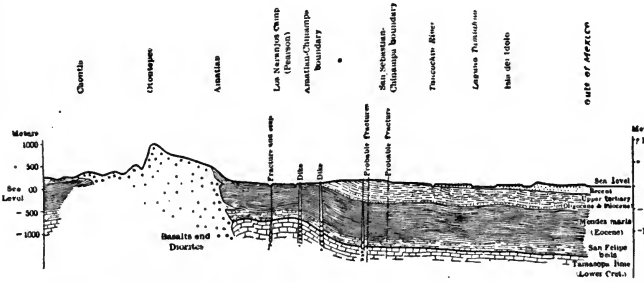

FIG. 204.—Diagrammatic geological section across southern part of area shown in Fig. 203. (*After Huntley.*)

The strata dip eastward from the Sierra Madre Oriental at low angles. This low monoclinal structure has been modified to the south by volcanic intrusions, which, trending in a southeasterly direction, have in this region upturned the monocline slightly to he northeast. Huntley[1] states that all the large wells are located where there is anticlinal or dome structure and pronounced fracturing of the rock. The fractures are usually accompanied by basaltic intrusions and seeps of asphalt and gas[1] (Figs. 203 and 204).

According to Garfias, three anticlines running approximately

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[1] HUNTLEY, L. G.: Mexican Oil Fields. Am. Inst. Min. Eng. *Trans.*, vol. 52, pp. 281-322, 1915.

north and south have been traced—one near Ebano, another between Mendez and Chila, and the third between Tamos and Ochoa. In the area between Panuco and Topila there are at least two such folds, and a well-defined line of weakness marked at the surface by oil seeps extends from Otontopec to Tantima and thence to Dos Bocas. Faults are numerous but are difficult to trace owing to the surface cover.

Arnold states that the San Diego, Casiano, Naranjos, Tierra Amarilla, Potrero, and Alamo fields are clearly anticlinal. The structure of the Topila, Panuco, Chijol, and Chila Salinas fields is not clearly marked, but it is probable that they are the result of the filling of porous beds in the San Felipe formation through fissures that extend to the Tamasopa.

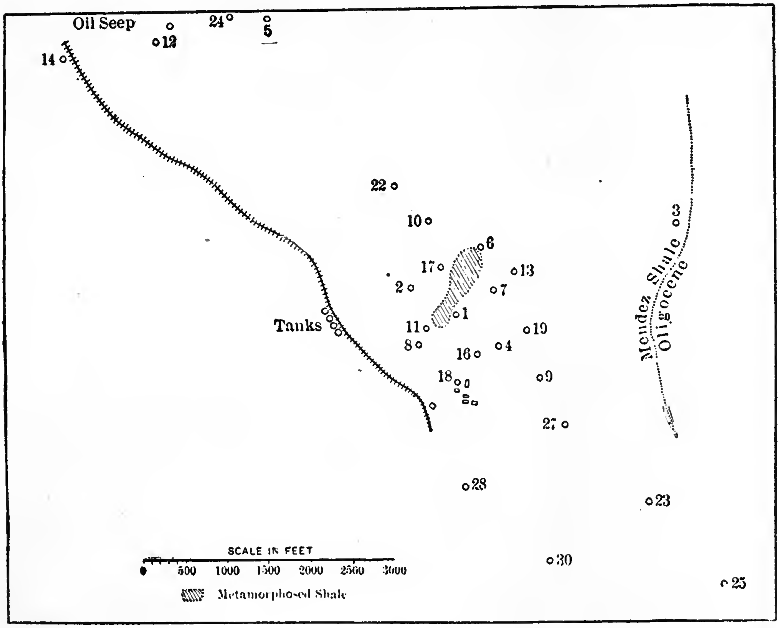

FIG. 205.—Sketch map of Furbero oil field, Mexico. Numbers refer to wells shown on Fig. 206. (*After De Golyer.*)

In the Ebano field, which was one of the first drilled, the outcropping rocks are the upper Tertiary and the Mendez marls. The sedimentary rocks dip toward an igneous plug near the plug but dip away from it a short distance away, thus showing anticlinal ring and funnel structure. Evidently the plug thrust the rocks up; then on cooling and contracting it dragged them down around the edges. This phenomenon, according to Garfias, is not uncommon in Mexico. (See p. 136.)

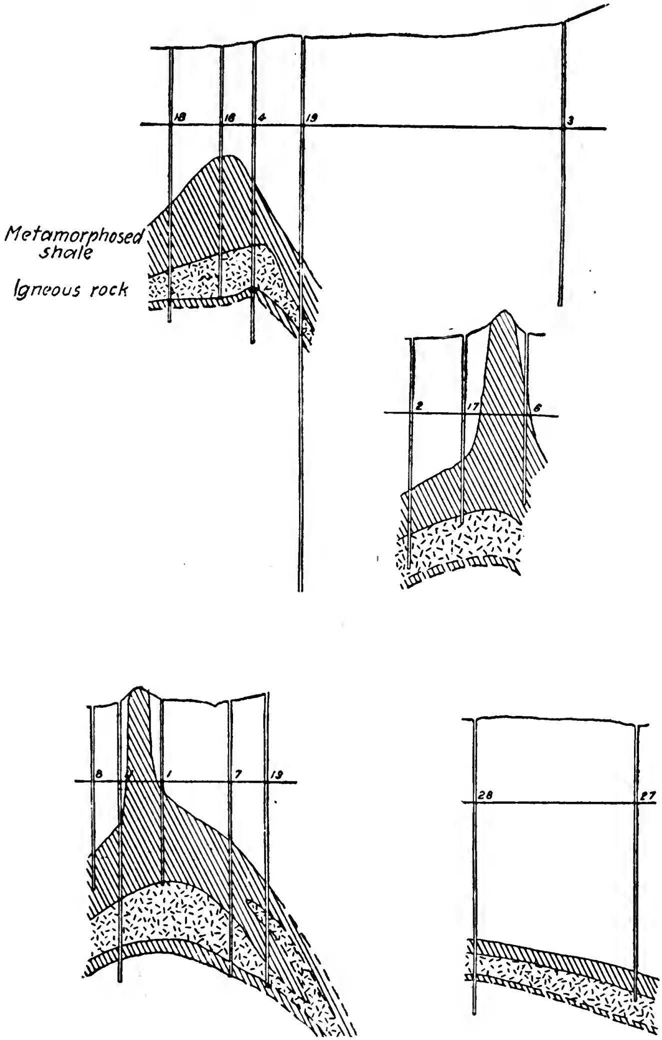

FIG. 206.—Geological cross section of the Furbero oil field. Position of wells shown on Fig. 205. (*After De Golyer.*)

The Furbero district[1] lies in the Gulf coastal plain of Mexico, between Tampico and Vera Cruz, and is the southernmost district developed in the Tampico-Tuxpam region. The country is for the most part a flat-lying tropical jungle with comparatively few outcrops. Oil seeps have long been recognized in the region (Fig. 205). The surface rock over most of the region is the Mendez shale. Below this the San Felipe and Tamasopa are believed to be present. The igneous rocks in the region consist of basalts, dolerites, basalt-gabbros, and various products of volcanic activity, such as volcanic sands and ash. A ridge of indurated fractured shale is found within the area of the Mendez shale. Underground exploration has shown that this is the top of a pipelike body of hydrothermally altered and indurated rock, lying above a thick dome of gabbro or dolerite which is a part of a great sill (Fig. 206). The sedimentary rocks bend upward, forming an anticline. Both the igneous rock and the indurated part of the Mendez shale contain openings and form the reservoir for the oil. In several wells salt water was encountered below the oil. The crest of the laccolith or dome lies altogether outside the most productive area, though some oil has been encountered in every well drilled to a depth at which it might reasonably be expected. DeGolyer believes that the porosity of the beds rather than the anticlinal fold was the controlling feature. A sample of the igneous rock, according to DeGolyer, showed a porosity of 6 per cent. He believes that the oil was originally in the Tamasopa (Cretaceous) beds. The Mendez shale is generally impervious and not productive, but in the Furbero field part of it has been thoroughly baked and metamorphosed into a hard brown to black porous shale and forms, together with the crystalline igneous rock, the oil reservoir of the field. Apparently much of the metamorphism has been due to the action of ascending thermal waters associated with the igneous rock after its intrusion. The thickness of this formation at Furbero is approximately 4,000 feet. Overlying the Mendez shale is a thick series of sandstones, shales, impure fossiliferous limestones, and conglomerates of Oligocene age.

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[1] DeGolyer, E. L.: The Furbero Oil Field, Mexico. Am. Inst. Min. Eng. *Bull.* 105, pp. 1,899-1,911, 1915.

CHAPTER XXIV

EUROPE, EXCEPT RUSSIA.

GREAT BRITAIN

Oil seeps, bitumens, and pitch are found at many places in Great Britain, but there was no production of oil until 1919, when a flowing well was brought in at Hardstoft, Derbyshire. A variety of bitumen, known as "mineral india rubber" on account of its elastic properties, was found at an early date in the Odin mine, near Castleton, Derbyshire, and was called elaterite[1] by Hausmann. Bituminous deposits are known in Shropshire, Lancashire, and other counties.

Natural gas has been reported from Wigan, England, also from Scotland and Wales. During the construction of the Thames Tunnel inflammable gas was encountered in such quantities that it exploded on coming into contact with the lights used by the workmen. The principal source of gas in England is at Heathfield, Sussex. There it was first discovered in 1893 at a depth of 228 feet in a bore-hole sunk for water close to the railway station. No water was found, and as the gas was considered dangerous, the well was sealed. In 1896 another boring for water was made near by, and at a depth of 312 feet gas was found in considerable quantities. The boring was carried to 377 feet and abandoned, as no water was found. The well was capped, and the gas was utilized for illuminating and heating. About 1,000 cubic feet was used daily for a period begun in 1896. The gas is said to be richer in hydrocarbons than American natural gas, and to burn with a more brilliant flame. Other wells have been bored in the neighborhood, in which gas is said to have been met at a depth of 400 feet with a pressure of 200 pounds to the square inch, and the aggregate output for 1904 is officially reported to have been 774,800 cubic feet. In 1909 236,800 cubic feet was obtained.[2]

Practically all the oil produced in Great Britain to 1919 was obtained from the distillation of the oil shales of Scotland.

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[1] Redwood, Boverton: A Treatise on Petroleum, vol. 1, p. 34, 1913.

[2] Redwood, Boverton: *Op. cit.*, p. 36.

The dominating feature of north England is the anticline of the Pennine Hills, which extends from Scotland southward to Derbyshire. Along the axis of this anticline, in the center of England, the Mountain limestone (Mississippian) is exposed. It contains numerous seeps of petroleum. The upper 100 to 150 feet of this limestone is dolomitic. Overlying the Mountain limestone are the Yoredale shales and sandstones, which in the area to the east of the axis have a thickness of 400 to 700 feet, and in the area to the west 2,000 to 2,500 feet. Above the Yoredale shales are the Millstone grits, a series of shales and porous sandstones with a total thickness on the east of 700 to 900 feet and on the west of about 300 feet; these in turn are succeeded by the productive coal measures. On each side of the main Pennine fold, subsidiary folds produce a series of local domes, anticlines, and terraces in the regions where the limestone is overlain by the Yoredale and succeeding rocks.[1] There is considerable faulting, but although the oil produced in the limestone has a paraffin base, it oxidizes, according to Veatch, more rapidly than an asphaltic oil. There are no surface exudations of oil on either side of the main limestone mass, but for the last century the coal mines on both sides have encountered flows of oil on fault planes.

The discovery well is on a faulted dome at Hardstoft, Derbyshire. It started in the coal measures, found wax in drilling through a fault, and a commercial supply of gas in the Millstone grits, which was muddied off. Oil was found in the top of the limestone at a depth of 3,078 feet. This well flowed at the rate of 12 barrels a day from June 1919, to the end of the year, and is estimated by Veatch to have a pumping capacity in excess of 50 barrels.

The oil from the Hardstoft well has the following characteristics: Specific gravity, 0.823; sulphur, 0.26 per cent; gasoline, 7.5 per cent; kerosene, 39.0 per cent; wax, 6.0 per cent; gas oil, 20.0 per cent; lubricating oil, 30.0 per cent. The oil is particularly rich in very high-grade lubricants.

The area in central England that has possibilities of producing petroleum is, according to Veatch, between 20,000 and 30,000 square miles.

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[1] Veatch, A. C.: Petroleum Resources of Great Britain, pamphlet issued by Am. Inst. Min. Eng., January, 1920. *Mining and Metallurgy*, No. 157, sec. 3, pp. 1-4, 1920.

GENERALIZED GEOLOGIC SECTION OF PENNINE REGION, ENGLAND[a]

Coal measures:

- Red and gray sandstones, clays, and at some places breccias, with occasional seams and streaks of coal.
- Middle or chief coal-bearing series of yellow sandstones, clays, and shales, with numerous workable coals.
- Ganister beds, flagstones, shales, and thin coals, with hard, siliceous (ganister) pavements.

Millstone grit:

- Grits, flagstones, and shales with thin seams of coal.

Carboniferous limestone series:

- Yoredale group of shales and grits, passing down into dark shales and limestones.
- Thick (Scaur or Main) limestone in south and center of England and Ireland, passing northward into sandstones, shales and coals (abundant corals, polyzoans, brachiopods, lamellibranchs, etc.)
- Lower limestone shale of south and center of England (marine fossils like those of overlying limestone). The Calciferous sandstone group of Scotland (marine, estuarine, and terrestrial organisms), represents the lower limestone shale and lower part of the English Mountain limestone, and graduates downward insensibly into the upper Old Red sandstone.

[a] GEIKIE, ARCHIBALD: Text-book of Geology. P. 737, London, 1882.

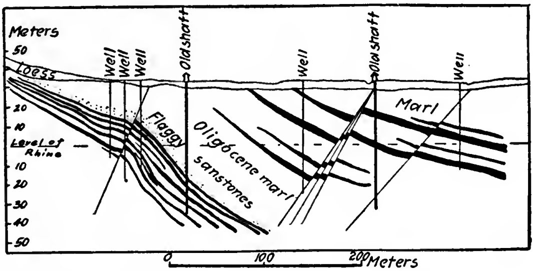

FIG. 207.—Geological cross section through the Schwabweiler oil field, Alsace. The dark beds are petroliferous. (*After Andreae.*)

FRANCE

The oil fields of Alsace[1] were among the earliest exploited. The

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[1] VON WERVEKE, L.: Vorkommen, Gewinnung und Entstehung des Erdöls in Unter-Elsass. *Zeitschr. prakt. Geologie,* vol. 13, pp. 97-114, 1895; Die Entstehung der Unterelsaessischen Erdoellager Erlaeutert an der Schichtenfolge im Oligocaen. Philomat. Gesell. Elsass-Lothringen, Band 4, pp. 697-721, 1913; (review by W. H. BUCHER, *Econ. Geology,* vol. 12, p. 203, 1917).

ANDREAE, A.: Notiz Ueber das Tertiär im Elsass. *Neues Jahrb.*, 1882, Band 2, pp. 287-294.

Pechelbronn field has been worked on a commercial scale since 1742. In the early days shafts were sunk to depths of 300 feet. In 1880 drilling methods were introduced, and since that date the fields have yielded a small but steady supply. Nearly 1,800 wells have been drilled, reaching depths as great as 1,300 feet. The oil comes from the Tertiary strata; the Mesozoic rocks have yielded only negligible quantities. The oil ranges from 0.880 to 0.900 in specific gravity. Figs. 207 and 208 are cross-sections of the fields.

The youngest Mesozoic rocks of the region are Jurassic. Upon them rest unconformably Eocene fresh-water limestones and brown coal. These are overlain by upper Eocene nonfossiliferous conglomerates, upon which lie the extensive thick marl beds of the lower Oligocene, the most productive oil-bearing formation of the region. The bulk of this formation consists of gray, gray-green, brown, or red marl, interstratified with sands and sandstones and subordinate limestones, with lenses of anhydrite, gypsum, and pyrite. The sands are lens-shaped, many of them curved and branching. They rarely exceed 12 feet in thickness and have a maximum length of 2,500 feet and a width of 100 to 200 feet. The oil is confined almost exclusively to these sands. Near Schwabweiler the marl beds pass gradually into the middle Oligocene sandstones; at some other places they are overlain by limestone, some of which contains as much as 18 per cent of bitumen. The individual beds are from 4 to 8 feet thick. They alternate with coal seams 20 inches or less thick.

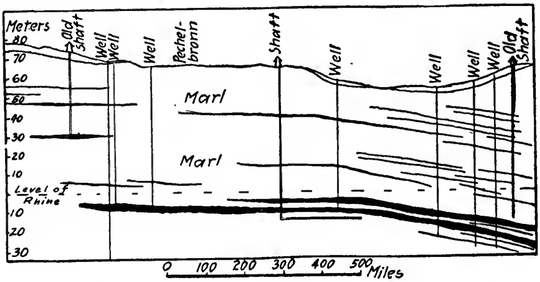

FIG. 208.—Longitudinal section through the upper oil sands of Pechelbronn, Alsace. The dark beds are petroliferous. (*After Andreae.*)

The section of the petroliferous series, as worked out from cores of deep bore holes by Von Werveke, is as follows:

	Meters
Gray marls	375
Alternating beds of marls (with numerous sun-cracked layers). Upper part, variegated marine marls containing anhydrite alternating with gray, green, red, and brown fresh-water marls, containing sandstone layers with *Limnaeus* and *Planorbis*. Lower part, variegated highly fossiliferous marine marls, with *Mytilus, Pecten, Mactra, Thracia, Hydrobia, Euchilus*, etc., alternating with colored fresh-water marls, with *Limnaeus*, containing sandstone layers, locally rich in bitumen	475
Red marls, locally green, and sandstone, with *Limnaeus*, containing bitumen	100
Gray and green fresh-water marls, red or brown in lower part, and numerous sandstone layers, with sun cracks and *Limnaeus*	150
Gray and black marine marls with anhydrite (no sandstone)	80

Locally, where fresh-water and marine strata alternate, oil and bitumen occur in varying amounts. The oil field is in the great fault trough of the upper Rhine Valley. All the strata mentioned above were involved in the post-Oligocene movements which created the great trough. Small faults are closely spaced. The direction of the major faults is north-northeast. The beds dip toward the Rhine. The oil fields lie in the disturbed area on the downthrown side.

The structural features that influence accumulation are the faults and the sandy lenses in the marl beds, rather than folds. At Pechelbronn a number of oil sands are encountered at depths of 250 to 270, 350 to 450, 550 to 600, 750, and 1,000 feet.

The yields of the different beds admit of no conclusion as to which are the most prolific. In some wells only gas and water are struck. Near Schwabweiler a number of successful wells were sunk. Here the oil sands are of great areal extent and are probably connected. The dip of the beds is comparatively steep, and minor faulting is common. South of the Zorn River oil was encountered in younger beds (middle Oligocene). Whether or not it entered these beds from the lower main oil zone is uncertain.

PETROLEUM PRODUCED IN THE GERMAN EMPIRE, 1908-1917

Year	Alsace-Lorraine	Prussia	Total	
	Metric Tons	Metric Tons	Metric Tons	Barrels (42 Gallons)
1908	[a]28,898	113,002	141,900	1,009,278
1909	[a]29,726	113,518	143,244	1,018,837
1910	....	....	145,168	1,032,522
1911	....	....	142,992	1,017,045
1912	....	....	144,961	1,031,050
1913[b]	....	....	140,000	995,764
1914[b]	....	....	140,000	995,764
1915[b]	....	....	140,000	995,764
1916[b]	....	....	140,000	995,764
1917[b]	....	....	140,000	995,764

[a] Includes Bavaria.
[b] Estimated.
1 metric ton, crude=7.1126 barrels.

As pointed out by Von Werveke, and as noted above, the oil-bearing series is in part marine and in part nonmarine. During the period of its deposition conditions changed from salt water to fresh water, terrestrial, and arid. In the 150 meters of exclusively fresh-water strata in the lower part of the section oil is absent, although these beds contain numerous porous sandstones. At the base of the fresh-water strata, where they alternate with marine sediments, some oil occurs. Where anhydrite is present oil is absent. The arid conditions that permit anhydrite to form are evidently unfavorable to life and to the development of material from which oil may be derived. The greatest yield of oil is obtained from strata composed of fresh-water beds alternating with highly fossiliferous marine beds. Von Werveke concludes that the oil originated essentially where it is found, and that it was derived from animal remains along a shore line where conditions repeatedly changed from marine to nonmarine. As the Jurassic black shales below the oil strata are not much altered he concludes that distillation has played a small part in the formation of the oil, which he attributes to polymerization. He cites the high heat gradient of the district and connects it with the exothermic process of polymerization.

GERMANY

The north German or Prussian oil field is a belt lying between the Weser and Elbe rivers north of the Harz Mountains, including the Wietze, Steinförde, Oelheim, and other pools of Hannover. The production of petroleum comes chiefly from limestones and sandstones of the Upper Jurassic or from transitional beds between the Jurassic and Cretaceous.

In 1897, according to Redwood,[1] 80 wells yielded an average of 20 barrels a day. In 1899 wells were sunk to depths of 140 to 200 meters, and a more abundant supply was reached, as much as 400 barrels a day being obtained from a single well. The oil was of a dark reddish-brown color, with a specific gravity of 0.930, and was rich in lubricants. In 1901 wells drilled deeper found an oil-bearing stratum containing green oil, with a specific gravity of 0.890.

Oelheim[2] or Eddesse is the chief center of the production of oil, which fills crevices in the Cretaceous clay, saturates the Wealden sandstones, and occurs scantily in the Lower Jurassic, upon which these beds rest. Across the upturned edges of these beds lies a sandstone of upper Tertiary age, charged with tar and known as the Tarpits rock. About 15 kilometers to the northwest of Oelheim, at Häningsen and Obbershagen, the lignitiferous Tertiary deposits are impregnated with tar, and oil occurs in the subjacent Triassic. The same conditions exist at Steinförde, Wietze, Hornbostel, Winsen, and Eickeloh, northwestward of Celle.

An asphalt deposit occurs west of Limmer,[3] on the highway from that village to Harenberg. The asphalt-bearing beds are Upper Jurassic and lie between the *Pteroceras* beds and the Eimbeckhäuser Plattenkalke (thin beds of limestone). The beds in the southern part of the deposit strike northeast and dip 24° SE. (See Figs. 209 and 210.) A fault nearly parallel in strike in the southern part but diverging toward the northeast, with the fault plane dipping 45° NW., cuts off the asphalt-bearing beds, and not very far below the surface the formation ends in a wedge. Two minor faults also are indicated on the accompanying cross-section (Fig. 210). The barren footwall belongs to another formation, the Hils clay. All the asphalt beds have a strong bituminous odor

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[1] Redwood, Boverton. A Treatise on Petroleum, vol. 1, p. 29, 1913.

[2] *Idem*, p. 146.

[3] Hoffmann, F. A.: Asphalt-Vorkommen von Limmer bei Hannover und von Vorwohle am Hils. *Zeitschr. prakt. Geologie*, 1875, pp. 370-379.

and upon fracturing become quickly covered with brown drops of bitumen. Weathered pieces are white. The bitumen content averages 12 to 14 per cent, and some beds carry as high as 18 per cent. The asphalt rock is extracted chiefly by open-pit mining.

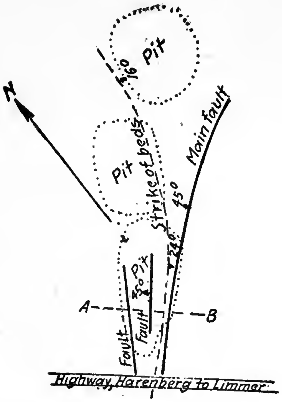

Fig. 209.—Plan of asphalt deposit near Limmer, Hanover, Germany. For section along line *AB*, see Fig. 210. (*After Hoffman.*)

Asphaltic beds are found at Vorwohle on the southwest slope of Hils Mountain. They belong to the Upper Jurassic. The only bed of economic importance is an asphaltic limestone about 22 feet thick. It contains about 6 per cent of bitumen which is concentrated in little oolitic grains. A faint odor of bitumen is noticeable in the rock. Overlying the asphalt limestone are thinly bedded calcareous and marly strata. The asphaltic rock is quarried and used for paving.

ITALY

The oil fields of Italy include the Emilia field, the Chieti field, and the Liris Valley fields between Rome and Naples (Fig. 211).

The Emilia and Chieti fields are on the northeast slope of the Apennine Range. This range is made up of a central core consisting chiefly of Cretaceous, Eocene, and Miocene rocks, which dip northeast toward the River Po and the Adriatic and which are covered at places by Pliocene sediments.[1] The sediments are nearly related to the Flysch of Galicia. The Oligocene in general is lacking.

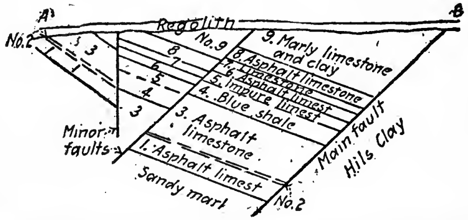

Fig. 210.—Section of asphalt deposit near Limmer, Hanover, Germany. The position of the section is shown on Fig. 209.

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[1] Thiel, Georg: Das Asphaltkalkgebiet des Pescaratales am Nordabhange Majella (Abruzzen). *Zeitschr. prakt. Geologie*, vol. 20, pp. 169-196, 1912.

The Emilia area occupies parts also of the provinces of Piacenza, Parma, Modena and Bologna, in northern Italy. This area has yielded oil in commercial quantities from Eocene, Miocene, and Pliocene rocks, which are thrown into folds. The structure is complicated and, according to Redwood[1] it is uncertain at some places what strata yield the oil. Near Piacenza oil was obtained by piercing the horizontal beds of gypsum and clay and drawing off the water and oil that collected. At Montechino gas issued from calcareous rocks associated with beds of bluish clay of the Subapennine formation. On the Neviano de Rossi property, near the Taro River, shallow wells have penetrated a bluish clay, interstratified with beds of sandy rock and thin beds of sandstone. In another well at Neviano oil was found at a depth of 60 meters. No sandstone was encountered in drilling this well to a depth of 110 meters, but the clay was interstratified with bands of sand at a depth of 60 meters and was sandy at a greater depth.

Fig. 211.—Outline map of Italy, showing position of oil fields.

At Rivanozzana, Pavia, artesian wells have been drilled to a depth of 180 meters, and from some of them salt water and petroleum were ejected. Other wells in the same region yield oil, gas, and salt water from soft sandy beds.[2]

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[1] Redwood, Boverton: A Treatise on Petroleum, vol. 1, p. 131, 1913.

[2] Clapp, F. G.: Petroleum and Natural Gas Resources of Canada, vol. 1, p. 10, 1914.

GEOLOGIC SECTION IN THE PROVINCE OF CHIETI, ITALY[a]

		German Classification	French Classification	Strata in Region of Asphalt Deposit, Chieti
Pliocene.		Levantinische Stufe. Pontische Stufe.		
Miocene.	Upper.	Sarmatische Stufe.	Sarmatien.	Clay, conglomerate, gypsum.
	Middle.	II. Mediterranstufe. Schlier.	Tortonien. Helvétien.	Marl, lithographic limestone, asphalt. Limestone, asphalt, Bryoyoa.
	Lower.	I. Mediterranstufe.	Burdigalien.	Lower marl.
Oligocene.			Ludien. Tongrien. Aquitanien.	Absent.
Eocene.			Bartonien. Lutétien. Yprésien. Landénien.	Nummulitic limestone.

[a] THIEL, GEORG: *Op. cit.*, pp. 179, 182.

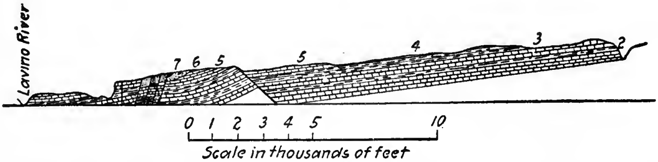

FIG. 212.—Geologic section at Majella, Abruzzo, Italy, showing region bearing asphaltic limestone. 1, Nummulitic limestone; 2, older marl; 3, Bryozoa limestone; 4, younger marl; 5, lithographic limestone; 6, cloes; 7, asphalt. (*After Thiel.*)

Asphaltic rocks are exploited in the province of Chieti. In the Majella region the asphaltic deposits are associated with faults.[1] (Fig. 212).

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[1] THIEL, GEORG: *Op. cit.*, p. 173.

SICILY

The Tertiary beds of Sicily are petroliferous at several places, and the oil has been used for illuminating for many centuries, but no extensive industry has been developed. The most valuable deposits both of oil and asphalt lie in the region of Ragusa, Modica, and the Val di Noto. Asphalt beds are found also near Leonporte. The Cretaceous limestones of the Ragusa region are bituminous, as well as the Miocene. Some of the vesicles of the basaltic lava of Etna are filled with petroleum, others with crystalline paraffin, taken up by the molten rock in its passage through and partial absorption of the Tertiary (or lower) carbonaceous strata.[1]

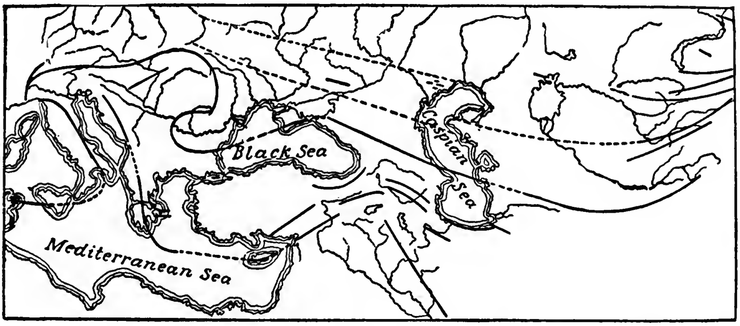

Fig. 213.—Sketch map showing structural axes in parts of Europe and Asia (*Based on map by Suess.*)

GALICIA

General Features.—The Carpathian Mountains constitute a long S-shaped uplift, anticlinal in structure, formed at a late geologic period. This axis, according to Suess (Fig. 213), probably extends across the Black Sea to the region of Taman and Kerch and in Russia becomes the Caucasus Range, at the end of which lies the well-known Baku field. The principal oil fields of Galicia, Rumania, and Russia are on minor folds that are connected generically with the Carpathian and Caucasus ranges and were probably formed at about the same time.

The production of the principal Galician fields is shown in the

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[1] Redwood, Boverton: A Treatise on Petroleum, vol. 1, p. 132, 1913.

following table. The positions of the principal oil fields are shown in Fig. 214.

PETROLEUM PRODUCED IN GALICIA, 1913-1917, IN METRIC TONS[a]
(After Northrop)

Field	1913	1914	1915	1916	1917
East Galicia:					
Tustanowice..........	691,382	[b]356,447	578,388	483,840	403,212
Boryslaw.............	205,904	[b]116,613		254,095	247,926
Schodnica............	190,000			....	....
Urycz................				....	....
Mraznica.............				32,172	51,929
Other fields.........				....	6,562
West Galicia:					
Potok................				128,563	
Rogi.................		....			
Rowne................					
Krosno...............					
Tarnawa-Wielopole-Zagorz............					[c]120,000
Kobylanka, Kyrg, Zalawie, Lipinki, Lubusza, etc................					
	1,087,286	[b]700,000	578,388	898,670	829,629

[a] 1 metric ton=7.1905 barrels of crude petroleum of 42 gallons=2,204.62 pounds.

[b] Figures for first six months only.

[c] Estimated.

In the axis of the Carpathian Mountains[1] beds of Cretaceous and Eocene age ("Flysch") crop out. There is a narrow sub-Carpathian zone of the same rocks, and northeast of that are the Galician plains, which are covered with Miocene and later beds.

[1] DALTON, L. V.: A Sketch of the Geology of the Baku and European Oil Fields. *Econ. Geology*, vol. 4, pp. 89-113, 1909.

UHLIG, V.: Ergebnisse Geologische Aufnahmen in den Westgalizischen Karpathen. K. K. Geol. Reichsanstalt *Jahrb*, vol. 38, pp. 83-264, 1888; and other papers in the same publication by PAUL, TIETZE, UHLIG, and others.

GRZYBOWSKY, J.: On the Foraminifera of the Oil Sands of Krosno District. Internat. Acad. Sci. Cracovie *Bull.* 1897, pp. 180-186; Polish text in Rozpr. Akad. Umiej. Krakow, ser. 2, vol. 12, pp. 256-302.

PETROLEUM PRODUCED IN GALICIA, 1908-1917

Year	Metric Centners[a]	Barrels of 42 Gallons	Year	Metric Centners[a]	Barrels of 42 Gallons
1908........	17,540,220	12,612,295	1913.........	10,872,860	7,818,130
1909........	20,767,400	14,932,799	1914.........	[b]7,000,000	5,033,350
1910........	17,625,600	12,673,688	1915.........	5,783,880	4,158,899
1911........	14,629,400	10,519,270	1916.........	8,986,700	6,461,706
1912........	11,870,070	8,535,174	1917.........	8,296,290	5,965,447

[a] 1 metric centner or quintal=100 kilograms (220.462 pounds); 1 metric centner or quintal of crude petroleum=0.71905 barrel of 42 gallons.

[b] Estimated.

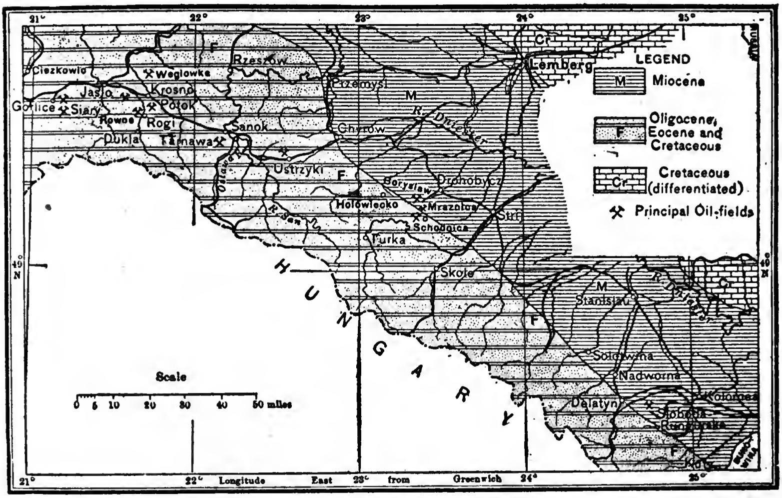

FIG. 214.—Geologic sketch of part of Galicia. (*After Dalton.*)

The series, including the lowest petroliferous strata, is as follows:

Miocene:

Sarmatian shales, clays, sandstones, limestones, etc., above; gypsiferous and saliferous clays below.

Oligocene:

Upper, Magura sandstone, Bonarowka beds, shales and hieroglyphic[1] sandstones, *Eburna*, *Melania*, *Cytherea*, etc., Dobrotow beds, sandstones and shales, with carbonized plant remains in parts, and abundant Foraminifera, generally[2] petroliferous.

Lower, Menilite[2] shales, light chocolate-colored, black or blue bituminous shales with fish remains and Foraminifera.

Eocene:

Upper, hieroglyphic (Ciekowic) sandstones, greenish and red shales, etc., Foraminifera, Mollusca, Bryozoa, and petroleum.

Lower, red clays and nummulitic beds.

Cretaceous:

At top, Jamna sandstone, thick-bedded or massive, with "ruin" sandstones.

Below, Ropianka beds, dark shales and sandstones at top, with Neocomian ammonites, *Inoceramus*, fucoids, and petroleum. Lower part, bluish calcareous hieroglyphic sandstones (petroliferous) with *Inoceramus*, fucoids, etc. All these beds have an abundant microscopic fauna.

[1] So called from the peculiar markings on the bedding planes.

[2] So called from the presence of highly siliceous bands ("Hornstein").

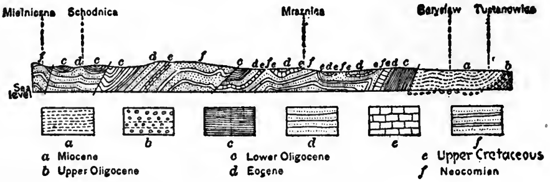

FIG. 215.—Section through Schodnica and Boryslaw fields, Galicia. (*After Zuber.*)

The oil fields of eastern Galicia are the most productive. These include the Boryslaw-Tustanowice field and the Opaka-Schodnica-Urycz field. The positions of the principal fields with respect to one another are indicated in the section (Fig. 215).

Boryslaw.—The Boryslaw field, as described by Zuber,[1] lies close to the Carpathian Mountains between the valleys of the Dniester and Stryj. In this region the older formations are covered by a layer of unconsolidated alluvial clay and gravel, at some places of considerable thickness. Beneath the alluvial deposits are saliferous and associated beds which consist chiefly of thick ash-gray clay or shales. It is in part arenaceous and in part marly.

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[1] ZUBER, RUDOLF: Die Geologischen Verhältnisse von Boryslaw in Ostgalizien. *Zeitschr. prakt Geologie*, vol. 12, pp. 41-48, 1904.

Interbedded with these strata are irregularly distributed flaggy beds of sandstone, both fine and coarse grained, some of which contain gas and oil besides carbonized and bituminous plant remains. The plant remains are found also in the shales. The clays and shales are impervious and so form effective barriers to the migration of oil. The whole formation is rich in gypsum and salt, which occur as loose crystals, veins and lenses, and also in regular beds. All the spring waters from these beds are salty, and some contain sulphur. The oil that occurs in the sandstone beds and lenses of this formation is very irregularly distributed. Layers that are dry and barren of oil are found in the immediate vicinity of others that are richly impregnated with petroleum and in places with ozokerite. Ozokerite occurs also in thin-bedded lenses and as a filling of crevices and veins. The veins are by far the more abundant. (See Fig. 216.) They have been encountered at depths of 2,200 feet in drilling for oil.

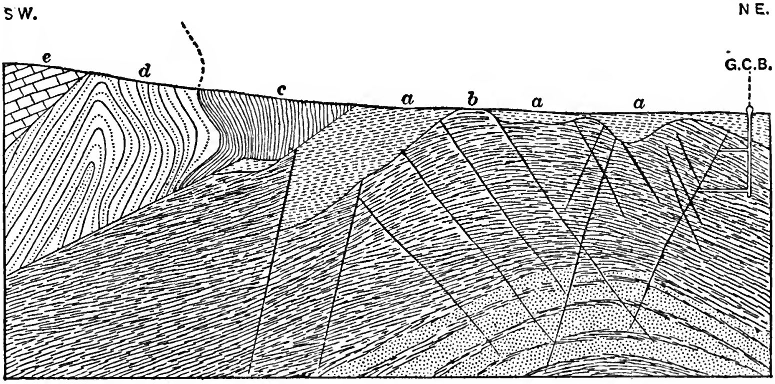

FIG. 216.—Section through Boryslaw oil field, Galicia. (*After Grzybowsky.*) *a*, Miocene; *b*, Upper Oligocene; *c*, Lower Oligocene; *d*, Eocene; *e*, Upper Cretaceous; *G.C.B.*, Ozokerite mine of Galician Credit Bank.

Drilling operations are difficult because tremendous pressure prevails in the formation. The whole earth to a considerable depth seems to move and shift constantly. The strongest timbers and steel pipes are broken like matches. Whole shafts are sometimes twisted in corkscrew-like fashion. In the western part of the field the oil is heavy, viscous, and very dark; in the eastern part it is lighter in gravity and color and is rich in benzene.

Below the Miocene salt formation lie the Dobrotow conglomerates, sandstones, and shales, of late Oligocene age. Beds of platy, well-hardened argillaceous micaceous sandstone predominate. These show characteristic ripple marks. Here and there darker lenses of shale are interstratified with them. The whole formation is rich in carbonized plant remains and constitutes the richest oil zone of the region. In places lenses and accumulations of conglomerate are interbedded, and these may become so extensive vertically and horizontally that they displace the fine-grained beds entirely. The distribution of the oil in the Dobrotow formation is very irregular and sporadic. Some parts of the formation are absolutely barren; other parts have delivered large quantities of petroleum. The drill records show a change in the formation from sandstone to quartzite, graywacke, and chlorite slate in a northeasterly direction. Finally the conglomerates dominate throughout the formation and form a conspicuous outcrop in a row of hills that trend southeast.

Underlying the Dobrotow formation are the Menilitic shales, of early Oligocene age. They are of no economic importance unless they are regarded as a warning to drillers. They include lenses and beds of sandstone that contain much water, which might flood the wells if these beds were penetrated.

Although the Menilitic shales have not been penetrated in the oil district (1904), it is known that they overlie the Carpathian Eocene beds, which consist of red and green shales and clays with interbedded sandstones and conglomerates and which constitute some of the richest strata in other fields. It is highly probable that these Carpathian Eocene beds are oil bearing in this district, but they lie at depths of perhaps 5,000 to 6,000 feet.

The structure of the district is indicated by Figs. 215 and 216. The older formations, including the Menilitic shales, have been intensely folded and partly faulted and thrust over the younger beds along the edge of the Carpathian Mountains. The overlying formations have also undergone extensive folding and faulting, but generally these folds are short along the strike and others partly overlap them.

Noteworthy features of this district are the large amount of ozokerite that has been formed from the oil and the great depth at which the ozokerite is found. The oil apparently occurs in both anticlines and synclines, as is not unusual where beds, in part incoherent, have been intensely deformed.

Opaka-Schodnica-Urycz.—The Opaka-Schodnica-Urycz district[1] lies about 8 miles southwest of Boryslaw. Oil is found in Tertiary and Cretaceous rocks complexly folded and faulted. The following formations are mentioned:

5. Tertiary. Menilitic shales. Dark bituminous shales with fish remains interbedded with sandstones. At the base of the formation are beds of banded hornstone.

4. Eocene. Chiefly green and red shales with lenses of hard "hieroglyph" sandstone. Conglomerates and large exotic boulders are present. The thick sandstone lenses in the shale form one of the most important oil zones in the Carpathian Mountains.

3. Cretaceous. Jamna sandstone. A very massive light-colored sandstone, weathering into grotesque forms. Interbedded with it are subordinate dark and black shales.

2. Upper *Inoceramus* beds. Well-bedded calcareous sandstones with "hieroglyphs" alternating with dark shales. There are also thick conglomerates with limestone. Some of the beds contain carbonized remains and some of the sandstones carry petroleum.

1. Lower *Inoceramus* (Ropianka) beds. The lower part of the formation consists of bedded marls. These are overlain by dark shales containing "hieroglyph" sandstones and conglomerates, in places with saline clay shales and thick sandstone lenses. Some of the sandstone lenses carry petroleum.

With the exception of the recent diluvial and alluvial deposits, no rocks younger than the Menilitic shales are known in this district. No unconformities are observed between the different formations, and all the transitions are gradual.

Intense orogenic movement has thrown the strata into a number of folds and faults which strike northwest, parallel to the main axis of the Carpathians. Fig. 217 is a plan of the field showing the positions of faults and wells and the lines of the cross-sections given in Figs. 218 and 219. In the vicinity of the line of section A-B there are no indications of oil. Near the line of section C-D three bore holes yield oil from the Eocene sandstones and conglomerates. The structure along the line E-F was revealed by the dry well drilled to a depth of 1,700 feet. At points marked by old shafts

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[1] Zuber, Rudolf: Die Geologischen Verhältnisse der Erdölzone Opaka-Schodnica-Urycz in Ostgalizien. *Zeitschr. prakt. Geologie*, vol. 12, pp. 86-94, 1904.

oil springs are found. A widening of the productive zone is evident on section G-H. Oil indications along this line are very numerous. The Eocene oil sands have been almost drained, but a well struck a third sand in the Upper *Inoceramus* formation (Cretaceous) at a depth of nearly 2,000 feet (in 1903). Some of the wells were very productive, and one yielded about 80,000 tons (575,200 barrels), an unusual quantity for this field. Section I-K cuts through the so-called Zhar field of Schodnica. Most of the wells in this field are not prolific, but they are more persistent in yield. Section L-M shows the Eocene oil zone nearer the surface. In the deeper beds much salt water has been struck. Along the line of section N-O the Eocene beds lie at greater depth. Southeast of Urycz they sink still lower.

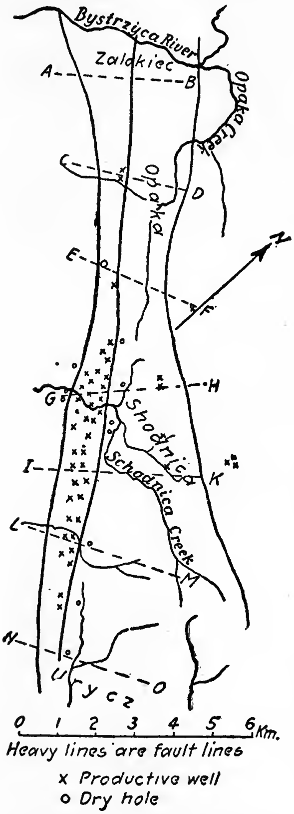

FIG. 217.—Plan of Opaka-Schodnica - Urycz oilfields, Galicia. The sections, *AB*, etc., are shown on Figs. 218 and 219. (*After Zuber.*)

Nowhere in the district has oil been found in the Menilitic shales, although the shales are rich in bituminous matter and fish remains and inclose a number of thick sandstone beds. Everywhere in this region the oil-bearing beds (Eocene and Cretaceous) are separated from the Menilitic shales by massive impervious beds. According to Zuber the hypothesis that the parent rock of the oil is the Menilitic shale appears to be without foundation.

Western Galicia.—In western Galicia there are a number of fields, among them Potok, Rogi, Rowne, and Krosno. The oil deposits are in Mesozoic and Tertiary rocks and are generally concentrated in anticlines. On an anticline at Potok gushers of high-grade light-gravity oil have been brought in. At Rowne an anticline in Oligocene beds yields oil of light gravity.

RUMANIA

Rumania, except Russia, is the largest producer of petroleum in Europe. Oil is found at many places, but the principal deposits are north of Bucharest, east and south of the Carpathian Mountains. As the oil is of high grade it is in great demand in European refineries. Before the European war Rumania produced about 12,000,000 barrels annually.

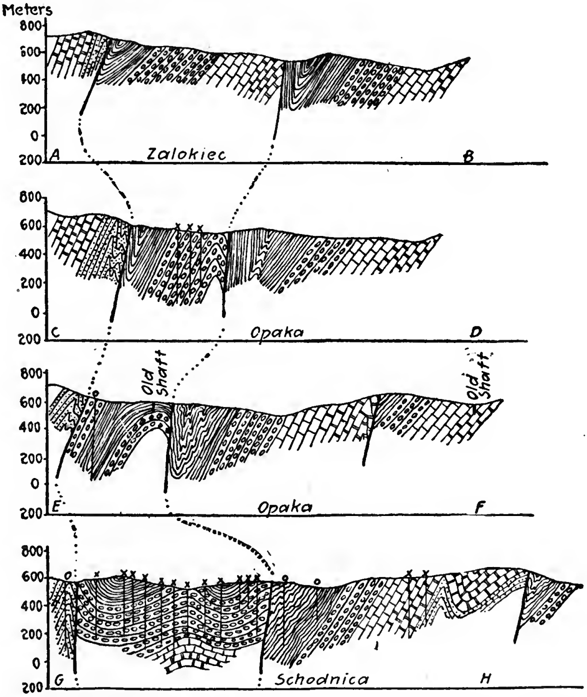

Fig. 218.—Sections showing geology of Zalokiec, Opaka and Schodnica, Galicia. The position of the sections is shown on Fig. 217. (*After Zuber.*)

Petroleum Produced in Rumania in 1915, in Metric Tons

Prahova:			
Bustenari-Calinet-Bordeni	286,035	Dambovitza	100,824
Campina Poiana	120,657	Buzeu	112,098
Moreni	741,163	Bacau	28,931
Other	283,437	Grand total	1,673,145
Total	1,431,292		

Rumania is divided into three physiographic zones—the Carpathian Mountains, the foothills, and the plains. The Carpathian zone[1] falls into two divisions—an inner one occupied by Mesozoic metamorphic and igneous rocks, and an outer one occupied by early Tertiary or Paleogene deposits (Flysch zone.)[2] The foothills are formed by later Tertiary beds. The Rumanian plain is composed of Levantine (Pliocene) strata and the Sarmatian or Moldavian plateau of Sarmatian (Miocene) strata. The oil fields are in the Flysch and foothill regions.

Remains of marine organisms, both animal and vegetable, abound in the early Tertiary (Paleogene) and later Tertiary (Neogene) strata. Petroleum[3] is found in both the Eocene and Miocene rocks. A map of the oil region is shown as Fig. 220, and a cross-section as Fig. 221.

The following is a table of formations:[4]

Pliocene:

Levantine. Marls, clays, and sands with *Unio*, *Vivipara*, *Bythinia*, etc.

Dacian. Gray shales and arenaceous marls, yellow-red sandstone lenses, fossiliferous, 3,000 to 3,500 feet thick (Preiswerk).

Pontian. Sandstones, gravels, andesitic tuffs, sands, and marls; *Vivipara bifarcinata*, *Dreissensia polymorpha*, *Congeria rhomboidea* above; *Valenciennesia annulata* and fish remains below; petroleum in places (perhaps from secondary infiltration) and some beds of lignite.

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[1] Dalton, L. V.: Geology of the Baku and European Oil Fields. *Econ. Geology*, vol. 4, p. 101, 1909.

[2] "Flysch zone" is a somewhat misleading term, for it includes beds of widely varying age.

[3] Zuber, R.: Kritische Bemerkungen ueber die Modernen Petroleum-Entstehungs Hypothesen. Zeitschr. prakt. Geologie, vol. 6, pp. 84-94, 1898.

Murgoci, G. M.: Tertiary Formations of Oltenia, with Regard to Salt, Petroleum, and Mineral Springs. Jour. Geology, vol. 13, pp. 670-712, 1905; with additions and corrections in Inst. Geol. Roman. An., vol. 1, 1907.

Aradi, V.: Erdöl-Studien. Allgem. oesterr. chem. techn. Zeitung, vol. 26, 1908; Ueber die Bildung der Rumaenischen Petroleumlagerstätten. Organ. Verein Bohrtechniker, vol. 15, 1908.

Andrusov, N.: Die Schichten von Kamischburun und der Kalkstein von Kertch in der Krim. K. k. Geol. Reichsanshalt *Jahrb.*, vol. 36, pp. 127-140, 1886; Maeotische Stufe. Russ. k. min. Gesell. *Verh.*, ser. 2, vol. 43, pp. 289-450, 1905.

Stefanescu, S.: Etude sur les Terrains Tertiaires de Roumanie, Lille, 1897.

[4] Dalton, L. V.: *Op. cit.*, p. 102, with modifications to conform with later descriptions of Preiswerk and others.

Miocene:

Maeotic. Limestone with *Dosinia exoleta*, sandy clays, fine sand and blue clays with *Hydrobia*, etc., and small *Congeriae* at top. Petroliferous.

Sarmatian. Marls and oolitic limestones with *Tapes gregaria*, *Buccinium duplicatum* or *Ervilia podolica*, *Mactra podolica*, etc.

Tortonian. Limestones, marls, conglomerates, sands, and tuffs, in places with *Ostrea cochlear*. Gypsum and some petroleum.

Helvetian. Marls, laminated micaceous sandstones, gypsum, salt, and tuffs. *Ostrea*, *Lithothamnium*. Petroleum.

Burdigalian. Clays, conglomerates, tuffs. *Cerithium margaritaceum*, *C. plicatum*, *Ostrea crassissima*, etc. Lignite in parts, petroleum.

Oligocene:

Sands, sandstones, conglomerates, shales, varying in different parts of the country, with *Nodosaria*, *Cerithium*, fucoids. Petroleum.

Eocene:

Ordinary marine facies found in the Dobrudja and here and there in the Carpathians, as limestones with *Nummulites distans*, *N. irregularis*. Represented by upper parts of Flysch.

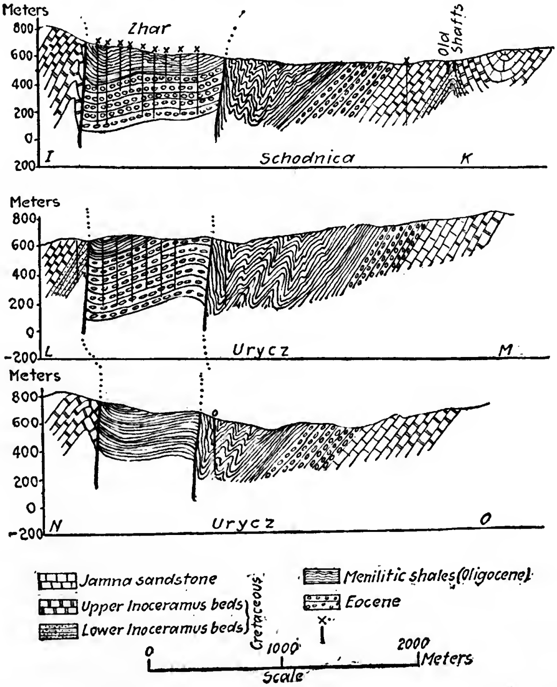


FIG. 219.—Sections showing geology of Schodnica and Urycz, Galicia. The position of the sections is shown on Fig. 217.

In the Rumanian Carpathians five earth movements have taken

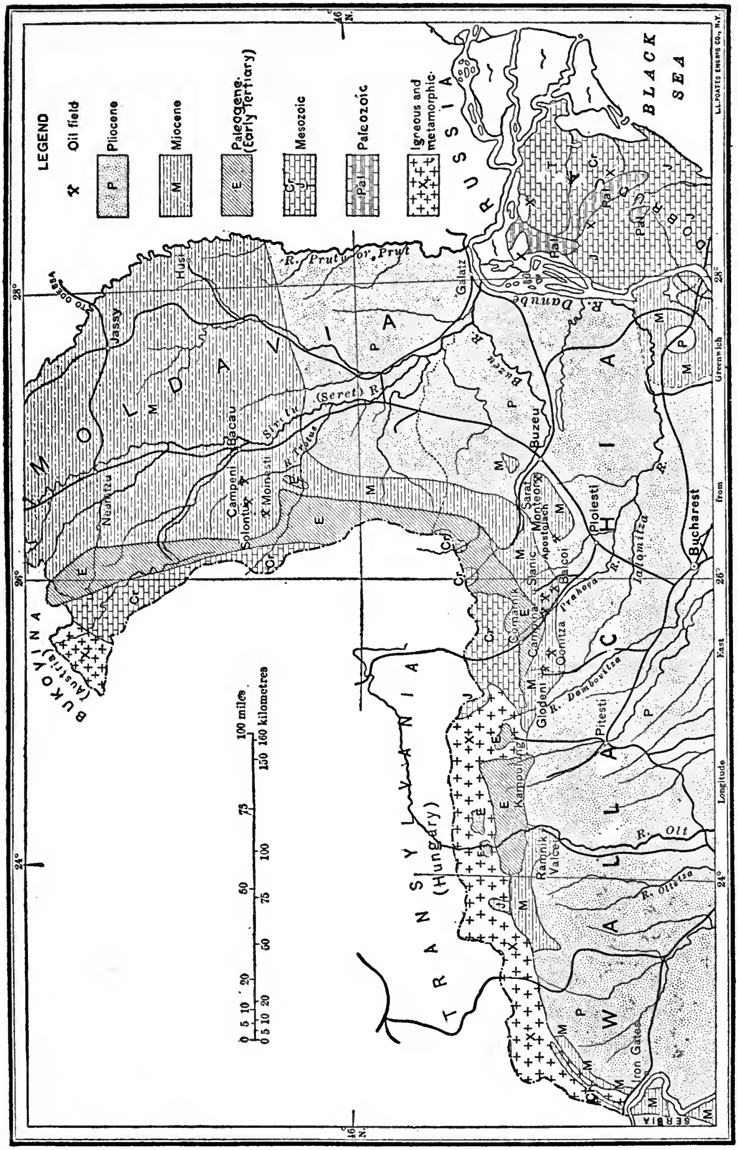


FIG. 220.—Map of part of Rumania. (*After Dalton.*) Since this map was made oil fields have been developed between Buzeu and Bacau.

place—(1) at the end of the Cretaceous, so that the lower parts of the Flysch are unconformable on the upper parts; (2) between Oligocene and Tortonian time; (3) after the Tortonian, when the sea advanced over the older rocks; (4) in Pontian time, when the present higher lands began to form; and (5) in post-Levantine time. There are extensive overlaps, the Pontian resting on the Tortonian at one place and on the crystalline rocks at another.

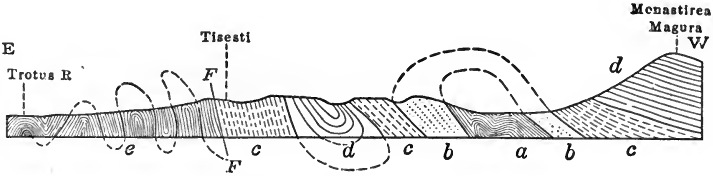


Fig. 221.—Section through "Flysch" zone, Trotus Valley, Moldavia. *a*, Paleogene salt beds; *b*, Jargu Ocna beds; *c*, Lower Menilite shales, Schipot beds; *d*, Upper Menilite shales, Jisesti sandstone; *E*, Miocene (Helvetian) salt beds. (*After Zuber.*)

In general, however, as the beds dip away from the Carpathian chain, they occupy belts, the outermost being the youngest. There is also a southward dip from Moldavia into Wallachia, the younger beds lying to the southeast. The beds are complexly folded and faulted, and the folds lie parallel to the Carpathian chain. As a rule the folds are asymmetric, the gentler dips lying on the sides toward the plains. Overturned folds are common.

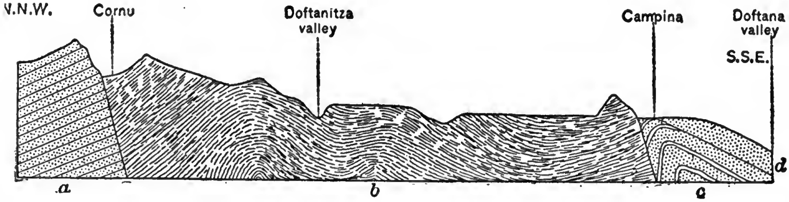
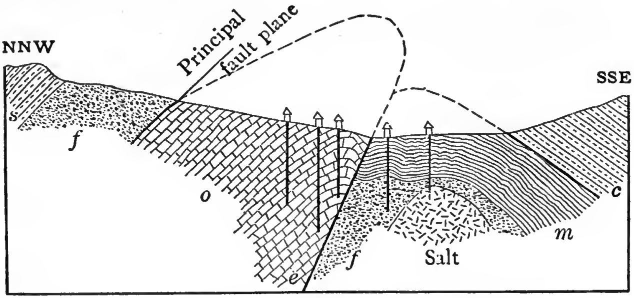


Fig. 222.—Section along Prahova River, Cornu and Doftanitya Valley. *a*, Flysch: *b*, Helvetian (Miocene salt series); *c*, Sarmatian; *d*, Pontian. (*After Stefanescu.*)

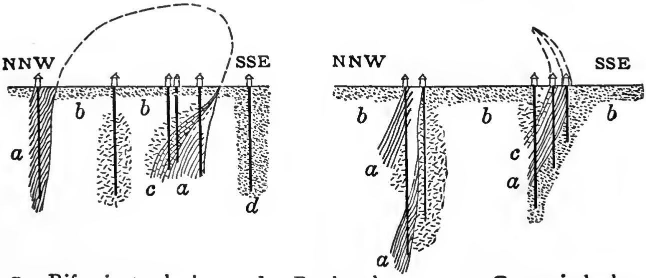
In the Prahova district the principal folds are those of Bustenari-Campina-Draganeasa (Figs. 222 and 223) and the one on which are the fields of Tzintea, Baicoi (Fig. 224), and Moreni (Fig. 225). The Bustenari fold is an overturned fold of the Maeotic (Miocene); the axial plane dips south, and the whole is faulted down on the north side at Campina against the Helvetian. The oil of Campina is believed to be derived from the Sarmatian. At Bustenari, according to Andrusov, the wells started in the Maeotic pass into unconformable Oligocene below. Thick salt deposits are found in some of the domes.



s, Sarmatian; *f*, Sub-Carpathian salt formation; *o*, Oligocene; *e*, Eocene; *m*, Meotic; *c*, Congeria beds;

FIG. 223.—Section across Faget Bustenari, Rumania. (*After Thompson.*)

The Berca and Beciu fields[1] are 20 kilometers from the city of Buzeu, in a region which is well known for its active mud volcanoes. They are on an anticline that strikes north-northeast and has been traced for 30 kilometers. The mud volcanoes themselves are confined to a stretch of 12 kilometers in the central part of the anticline (Fig. 226), where oil seeps and efflorescent salts are common.



a, Bifarcinates beds; *b*, Rock salt; *c*, Congeria beds; *d*, Cȃndesti beds,

FIG. 224.—Section through Baicoi oil field, Rumania. (*After Thompson.*)

The outcropping rocks of the region are all of middle or late

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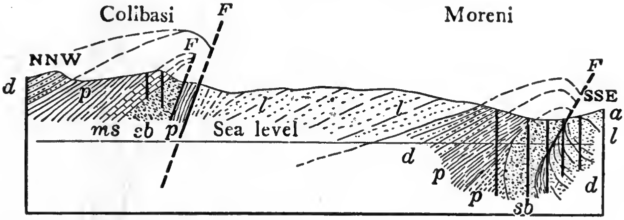
[1] PREISWERK, H.: Ueber den Geologischen Bau der Region der Schlammvulkane und Ölfelder von Berca und Beciu bei Buzeu in Rumänien. Zeitschr. prakt. Geologie, vol. 20, pp. 86-95, 1912.

Tertiary age, beginning with the youngest formation, the Levantine, through the Dacian and Pontian, to the oldest, the Maeotic. The Levantine consists of sands and marls with numerous seams of lignite, which reach a thickness of 6 to 7 inches, in the lower part of the formation.

The underlying Dacian is estimated to be 3,000 to 3,500 feet thick. Gray shales and arenaceous marls prevail. Interbedded with them occur lenses and beds of hard yellow-red sandstone that is rich in fossils. The abundance of fossils in the whole formation makes its recognition in the field relatively easy.

Beneath the Dacian lie the Pontian sediments, which occupy large areas in this district. Four groups are distinguished, as follows: Yellow sandstones, more or less consolidated, 200-300 meters; gray clay marl, 200 meters; yellow sands and sandstones, the latter with spherical concretions and ripple marks, 100 meters; gray clay marls, 100 meters. All these divisions contain fossils.



a, Quaternary; *l*, Levantine; *d*, Dacian; *p*, Pontian; *m*, Meotic; *s*, Sarmatian; *sb*, Miocene salt formation

FIG. 225.—Section through Moreni oil field, Rumania. (*After Thompson.*)

The oil-bearing strata are in the Maeotic, which has a thickness of about 600 meters. Marls and sands constitute the main mass of the formation. Interbedded with these are fairly hard sandstones, which make good horizon markers on account of their superior resistance to erosion. Toward the base of the formation they become more calcareous.

The Maeotic formation is the lowest of the series described by Preiswerk as cropping out. Underlying it is the Sarmatian formation of *Mactra* limestone and rather coarse sandstones and conglomerates, so far unexplored in this district.

The structure of the district is shown in the accompanying sections (Fig. 226). The anticline is steep and asymmetric. The mud volcanoes are situated in the central depression which suggests a fault or rupture of some sort in the strata. The principal oil zone in the Maeotic formation lies about 250 meters below the top bed of the formation. Up to 1912 no attempt had been made to drill into the Sarmatian, the Miocene salt formation beneath, although the Miocene has proved highly productive in other Rumanian fields.

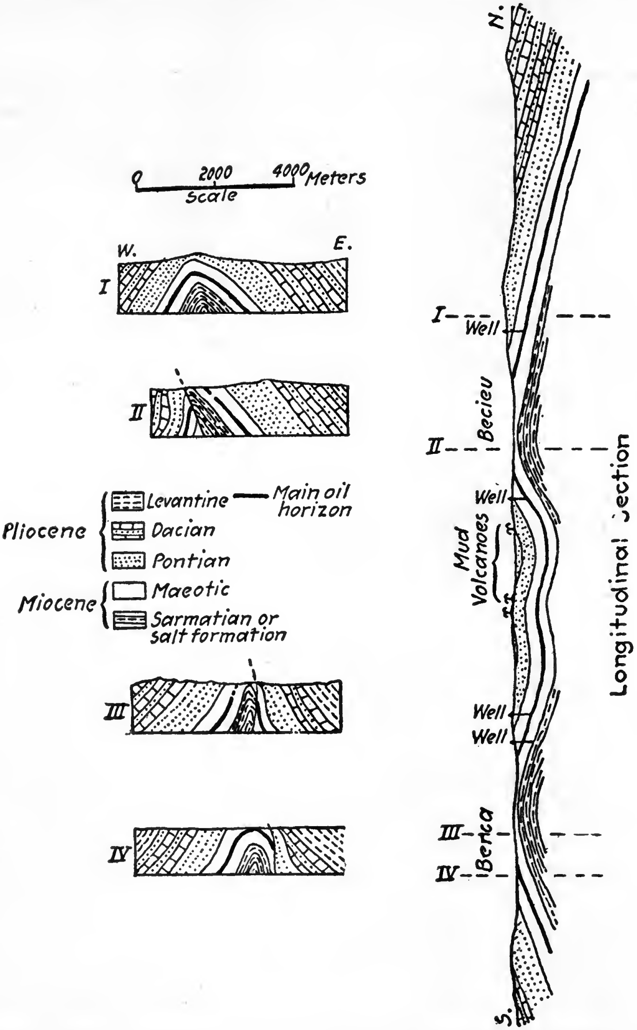


Fig. 226.—Sections through Berca and Becieu oil fields, Rumania. (*After Prieswerk.*)

CHAPTER XXV

RUSSIA, MESOPOTOMIA, PERSIA AND EGYPT

RUSSIA

General Features.—In Russia oil occurs in many widely separated fields. These, named from north to south, as listed by Adiassevich,[1] are as follows:

1. Basin of Petchora River, northern Russia.
2. Volga basin, in governments of Samara and Saratoff.
3. Astrakhan and Ural governments, northeast shore of Caspian Sea.
4. Grozny and Maikop.
5. Derbend district, Daghestan, north of Baku, on Caspian Sea.
6. Baku fields.
7. Sviatoi (Holy Island) and Cheleken islands, in Caspian Sea.
8. Neftianoia Gora (Oil Hill), in Transcaspian territory.
9. Ferghana Valley, Russian Central Asia.
10. Kertch and Taman peninsulas, Black Sea.
11. Sakhalin and Transbaikal, Siberia.

Of these districts the Baku fields are by far the most productive, although considerable oil is produced also in Grozny and Maikop. These fields are on the flanks of the Caucasus Mountains, which constitute a high range north of the Black Sea, extending southeastward to near the Caspian. The range is anticlinal in structure[2] and is practically in line with the Apsheron peninsula. The central mass of the range is granite, which is skirted by diabase, and that in turn by Paleozoic metamorphosed rocks. The sedimentary rocks that rest upon the ancient rocks are, in order, the Triassic, Jurassic, Lower Cretaceous, Upper Cretaceous, and Tertiary (Flysch, etc.) The fields of Taman and Kertch peninsulas, on the north shore of the Black Sea, are at the west end of the range. The Baku fields are at the east end, Maikop and Grozny on the north slopes, and Tiflis on the south slope.

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[1] ADIASSEVICH, A.: Oil Fields of Russia. Am. Inst. Min. Eng. *Trans.*, vol. 48, p. 613, 1914.

[2] Carte géologique internationale de l'Europe.

PETROLEUM PRODUCED IN RUSSIA, 1907-1917
(After Northrup)

Year	Baku		Grosny		Maikop	
	Poods[a]	Barrels	Poods	Barrels	Poods	Barrels
1907	476,002,000	57,143,097	39,214,612	4,707,637	....	....
1908	465,954,221	55,936,880	52,058,895	6,249,567	....	....
1909	492,500,000	59,123,650	57,033,015	6,846,700	....	....
1910	508,456,121	61,039,149	74,048,358	8,889,359	1,304,800	156,640
1911	454,206,853	54,526,633	75,189,591	9,026,361	7,933,936	952,453
1912	473,200,000	56,806,723	65,400,000	7,851,140	9,200,000	1,104,442
1913	404,538,000	48,563,985	73,659,265	8,842,649	4,802,926	576,582
1914	412,246,851	49,489,418	98,445,187	11,818,150	3,956,906	475,019
1915	431,139,305	51,757,419	88,159,052	10,583,320	7,582,000	910,204
1916[b]	464,902,000	55,810,564	102,731,246	12,332,683	2,000,000	240,096
1917[c]	413,000,000	49,560,000	123,000,000	14,760,000	([d])	([d])

[a] 61.05 poods=1 metric ton crude; 8.33 poods crude=1 United States barrel of 42 gallons; 8 poods illuminating oil=1 United States barrel of 42 gallons; 8.18 poods lubricating oil=1 United States barrel of 42 gallons; 9 poods residuum=1 United States barrel of 42 gallons; 7.50 poods naphtha=1 United States barrel of 42 gallons; 8.3775 poods other products=1 United States barrel of 42 gallons, estimated; 1 pood=36.112 pounds; 1 kopeck=0.515 cents.

[b] Estimated in part.

[c] Estimated.

[d] Included in other.

Year	Emba		Other		Total	
	Poods	Barrels of 42 Gallons	Poods	Barrels of 42 Gallons	Poods	Barrels of 42 Gallons
1907	....	....	....	....	515,216,612	61,850,734
1908	....	....	....	....	518,013,116	62,186,447
1909	....	....	....	....	549,533,015	65,970,350
1910	....	....	[a]2,094,381	251,426	585,903,660	70,336,574
1911	....	....	[b]13,979,771	1,678,244	551,310,151	66,183,691
1912	....	....	[c]18,800,000	2,256,903	566,600,000	68,019,208
1913	7,182,000	862,184	[d]33,228,000	3,988,956	523,410,191	62,834,356
1914	16,675,000	2,001,801	26,957,000	3,236,134	558,280,944	67,020,522
1915	16,632,000	1,996,639	27,493,000	3,300,480	571,005,357	68,548,062
1916[e]	15,200,000	1,824,730	21,600,000	2,593,037	606,433,246	72,801,110
1917[f]	15,000,000	1,800,000	16,000,000	1,920,000	575,000,000	69,000,000

[a] Includes as follows: Sviatoi, 1,392,306 poods; Ferghana, 610,500 poods, and Taman, 91,575 poods.

[b] Includes as follows: Sviatoi, 2,515,363 poods; Cheleken, 10,205,740 poods; and Ferghana, 610,500 poods; other districts, 648,158 poods.

[c] Includes as follows: Sviatoi, 3,300,000 poods; Cheleken, 13,300,000 poods; and Ferghana, 2,200,000 poods.

[d] Includes as follows: Sviatoi, 4,733,000 poods; Balakhani, 13,860,000 poods; Berekei, 6,000,000 poods; Ferghana, 1,406,000 poods; and Cheleken, 7,229,000 poods.

[e] Estimated in part.

[f] Estimated.

PETROLEUM PRODUCED FROM PUMPING AND FLOWING WELLS IN RUSSIA IN 1916 AND 1917 (After Northrup)

District	1916[a]		1917[b]	
	Barrels	Poods	Barrels	Poods
Apsheron Peninsula or Baku:				
Balakhany	10,204,082	85,000,000	33,000,000	275,000,000
Sabunchy	12,004,802	100,000,000		
Romany	6,962,785	58,000,000		
Bibi-Eibat	10,768,307	89,700,000		
Binagady	4,141,056	34,495,000	3,360,000	28,000,000
Surakany	11,729,532	97,707,000	13,200,000	110,000,000
	55,810,564	464,902,000	49,560,000	413,000,000
Grosny	12,332,683	102,731,246	14,760,000	123,000,000
Emba	1,824,730	15,200,000	1,800,000	15,000,000
Sviatoi	840,336	7,000,000	960,000	8,000,000
Maikop	240,096	2,000,000	1,920,000	16,000,000
Ferghana	240,096	2,000,000		
Cheleken	360,144	3,000,000		
Balakhany (hand wells)	1,152,461	9,600,000		
Schubany (hand wells)				
Grand total	72,801,110	606,433,246	69,000,000	575,000,000

Baku.—Baku,[1] on the Apsheron Peninsula (Fig. 227), lies approximately on the line of the axis of the Caucasus Mountains. All its outcropping rocks are of Tertiary age. The oldest rocks, which are Eocene, are exposed in the western part of the peninsula. East of them to the vicinity of Balakhany, Miocene rocks are exposed. Still farther east are Pliocene rocks, consisting of the Baku group and the underlying Apsheron group. The north and east coasts of the peninsula are covered with alluvium. The Tertiary beds are folded and locally faulted. As summarized by Dalton, the formations are given below:[2]

[1] This description of the Baku fields is a digest of the papers cited below. The data are drawn principally from ADIASSEVICH, DALTON, SJÖGREN, THOMPSON, and REDWOOD. I have not had access to the paper by SJÖGREN published in the Geol. Fören. Stockholm Förh. 14, p. 387, 1892. A good abstract of this paper appeared in the Zeitschr. prakt. Geologie, 1894, pp. 286-289. I have added a number of other references to papers cited by DALTON, which were not accessible to me.—W. H. E.

[2] DALTON, L. V.: A Sketch of the Geology of the Baku and European Oil Fields. *Econ. Geology,* vol. 4, 89-117, 1909.

ANDRUSOV, N.: Beiträge zue Kenntniss des Kaspischen Neogen. Com. Géol. *Mèm.,* vol. 15, No. 4, 1902.

ANDRUSOV, N.: Die Südrussischen Neogenablagerungen. Russ. k. min. Gesell., *Verh.,* ser. 2, vols. 34, 36, 39, 1897-1902. On the Paleogene, SOKOLV, N., Com. géol. *Mèm.,* vol. 9, No. 2, 1893.

ADIASSEVICH, A : The Russian Oil Fields. Am. Inst. Min. Eng. *Bull.* 89, pp. 855-868, 1914.

THOMPSON, A. B.: The Oil Fields of Russia, London, 1904.

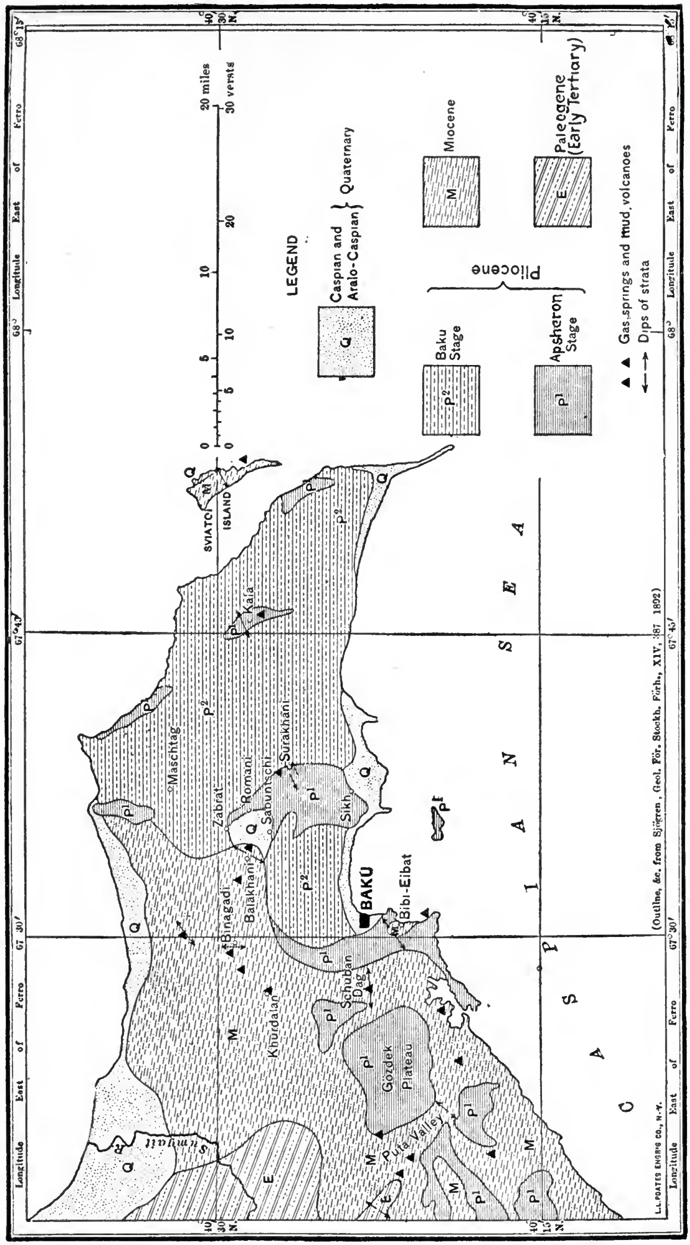

FIG. 227.—Geologic sketch map of Apsheron peninsula, Baku field, Russia. (*After Sjögren.*)

Quaternary:

Caspian beds (sands) above, with *Cardium edule, Helix* limestones near the top. Aralo-Caspian below, with *Cardium*, etc.

Pliocene:

Upper. Shell limestones; marls and sands, with *Cardium crassum, Dreissensia polymorpha.*

Lower (unconformable to above). Grits, shales and volcanic sands passing up into limestones (*Cardium, Micromelania, Cypris, Dreissensia*) in east; in west, limestones with *Congeria, Dreissensia*, etc. In places unconformable to Miocene below.

Miocene:

Mæotic. Sandy limestones, marls, and petroliferous sands, with Aktchagil fauna, small *Mactra, Cardium, Cerithium*, and calcareous algæ.

Sarmatian. Calcareous petroliferous sandstones, gypseous marls, sands, etc., *Cardium*, ostracodes. Overlaps the Helvetian and Tortonian.

Helvetian and Tortonian. *Spaniodon* beds (marls, sands, and sandstones with *S. barboti*, etc.) above Tchokrak beds, sandy and marly deposits, with *Dentalium, Lucina*, etc., and limestones with *Pecten, Chama*, and Bryozoa.

Burdigalian. Upper part of series of shales, etc., with *Meletta, Spirialis*, etc., and in Kertch Burdigalian fossils.

Oligocene:

On north side of Caucasus, continuous series of shales, few fossils, Burdigalian at top, Tongrian lower.

On south, tuffs, breccia, conglomerate (Aquitanian), clayey and calcareous sandstones with Mollusca (Tongrian), calcareous and clayey sandstones with marine fossils (Ligurian).

Eocene:

Bartonian. White marls with Mollusca and Foraminifera in Crimea and northwest Caucasus; shaly clays with fish remains, etc., elsewhere.

Parisian. Dark-gray foraminiferal clays in west and north; yellowish calcareous clayey marine sandstones on south.

Londinian. Marls and limestones with nummulites, fucoids, etc., in north and west; clayey fucoidal sandstones, dark-gray shales, and marls and limestones on south.

In the Baku field (Fig. 228),[1] on the mainland, the post-Tertiary deposits comprise loess, loam, sands, gravels, and silts, with marine deposits of friable shelly limestone. The Pliocene has a total thickness of 1,225 feet and is divided into the lower and upper stages. The Miocene deposits, mainly sands, clays, and marls, belong to the Aktchagil series.

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[1] Adiassevich, A.: The Russian Oil Fields. Am. Inst. Min. Eng. *Bull.* 89, pp. 855-868, 1914.

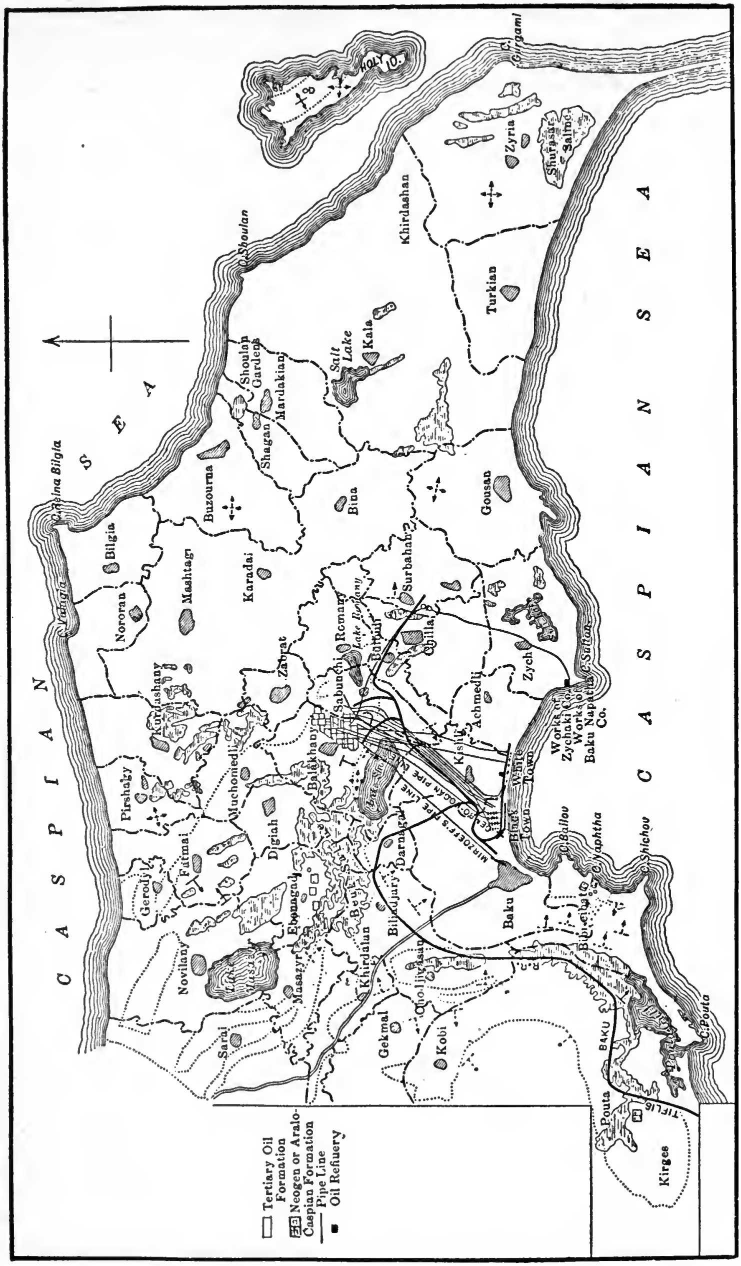

FIG. 228.—Map of Baku oil field, Russia. (*After Adiassevich.*)

Under these series lie the oil measures, some 5,600 feet thick. They consist of gray, blue, and brown clays, with sands and thick marls interstratified with sands. The upper part of these deposits contains marine and lacustrine fauna; in the lower part no fossils have been found. The oil measures are underlain by sandy clays and striated clays. The oil is heavy and is accompanied by much gas. The greater portion of the oil produced has come from gushers, although pumped wells also have been profitable. Some of the gushers yield large quantities of sand along with the oil, and the removal of the sand at the mouths of wells is a serious problem.[1]

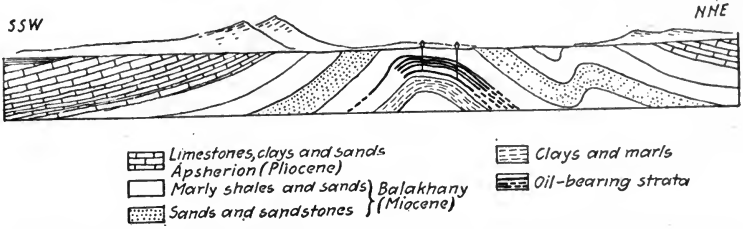

FIG. 229.—Anticline between Pouta and Perin-Agit Hill, Baku oil field, Russia.

The Tertiary beds, which form anticlinal and synclinal folds and dome-shaped uplifts, are cut in several directions by faults. The general trend of uplifts on the peninsula corresponds to the direction of the main Caucasus Range, from northwest to southeast. (See Figs. 229, 230.)

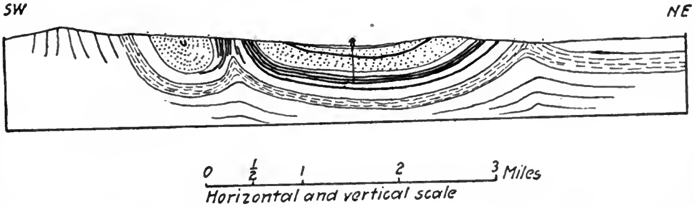

FIG. 230.—Synclinorium crossing the village of Khirdalan, Baku oil field, Russia. (*After Redwood.*) Legend same as in Fig. 229.

West of Holy Island, on the mainland, is the Kala anticline, and west of that the Balakhany-Sabunchy-Romany anticline. According to Adiassevich the Balakhany fold is an elongated dome.

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[1] KNAPP, A.: Problems Connected with the Recovery of Petroleum from Unconsolidated Sands. Am. Inst. Min. Eng. *Bull.* 123, p. 385, 1917.

Along the line of the main uplift is a series of mud volcanoes, many of which, even at the present time, spout mud and water, gases, and petroleum. The mud volcano Bog-Boga is one of the highest points in the region. Oil, gas, and mud still issue from little cones on it,[1] and solid pitch is dug from one side of it. These fields have borne the names of the three villages, although they have long since merged into one continuous field covering some 1,978 acres. From this territory has come the main part of the Russian oil.

In the Balakhany-Sabunchy-Romany field the producing strata are Oligocene and Miocene. There are three divisions of oil-bearing sands. The topmost has a thickness of 1,225 feet including the interbedded clays; the thickness of the pay sands alone is about 600 feet,[2] and individual pay sands range from several feet to 70 feet. This first division is separated from the second by thick water-bearing sands and sandstones. The second oil division has a total thickness of some 600 feet and comprises 280 feet of oil sands. Below these is the lowest and thickest division.

A short distance east of the Balakhany field lies the Surakhany field, which ever since the fire worshippers days has been known as a gas field. In late years large amounts of light oil have been discovered and many big gushers brought in. Nearly all wells sunk below 1,400 feet are gushers. The field is a dome-shaped anticline striking north.

At Binagady, about 5 miles northwest of Balakhany, marine Miocene shales and sands are exposed near the center of a faulted anticline. The sands are sealed by faulting, and oil accumulates near the faults (Fig. 53, p. 146).

The Bibi-Eibat field, which is also one of the most productive in the world, lies 3 miles south of Baku and covers an area of about 1,000 acres. Oil and gas seeps mark the surface, and mud volcanoes are found near by. Structurally the field is an almost symmetrical anticline.[3] The arching beds of the Miocene just reach the surface[4] (Fig. 231) and are flanked by imposing escarp-

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[1] Thompson, A. B.: Oil-field Development, p. 187, London, 1916.

[2] Other estimates are considerably lower.

[3] Thompson, A. B.: Oil-field Development, p. 226, London, 1916.

[4] Thompson, A. B.: The Relationship of Structure and Petrology to the Occurrence of Petroleum. Inst. Min. and Met. *Trans.*, vol. 20, p. 220, 1911.

ments of the Apsheron limestones. The anticline plunges downward on its landward side and is believed to plunge downward on a fourth side where covered by the sea. The Bibi-Eibat field has produced petroleum since 1880. In 1912 it had yielded 280,500,000 barrels. All the deep waters in the district are brines.

Grozny.—The Grozny[1] oil field is west-northwest of Grozny,in the Terek basin, on the north side of the Caucasus Mountains. It is in a range of hills 15 miles long that strike west-northwest and do not exceed 660 feet in elevation. This range is regarded by some as a spur of the Sunzha massif. It is a sharp anticline, the crest of which lies along the northeast flank of the range. The oldest beds crop out in the center of the range and dip away from it quaquaversally, the steepest dips being north and south. The north limb dips 40° to 90°; the south dip is considerably lower (Fig. 40, p. 134). The oil is found in the Miocene sands of the Chokrak. The section of the rocks, after Kalitzky, follows:

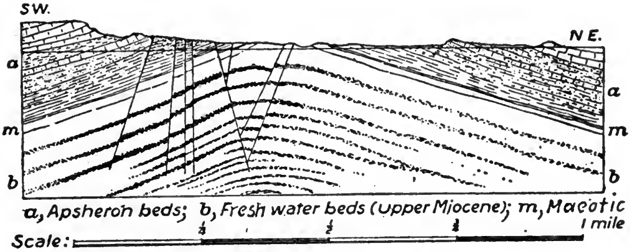

FIG. 231.—Section of the Bibi-Eibat oil field, Baku, Russia. (*After Thompson.*)

SECTION OF STRATA IN GROZNY FIELD, CAUCASUS, RUSSIA

	Feet
Mæotic stage:	
Aktchagil beds, limestone, limestone conglomerates,, calcareous sandstones, clayey sands, and calcareous clays	1,395
Break.	

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[1] KALITZKY, K.: Das Naphtagebiet von Groznyj. Com. géol. Russie *Mèm.*, new ser., No. 24, pp. 1-40, 1906; Abstract in Inst. Min. Eng. *Trans.*, vol. 35, pp. 743-744, London, 1908. (The original paper is not accessible to me.—W. H. E.)

	Feet
Middle Sarmatic stage:	
Gray shales, with occasional thin flaggy limestones	130–1,050
Calcareous clays, with limestones in the upper portion of the group	312
Lower Sarmatic stage:	
Calcareous clays with intercalations of chalklike marl	56
Calcareous and shaly clays, with interbedded limestones	141
Passage beds:	
Spaniodontella beds, shaly and sandy clays, clayey limestones, calcareous clays and sandstones, pure sandstones (all sandstones water bearing), and limestones	164
Chokrak beds, shaly and sandy clays, petroleum-bearing sandstones (clayey, calcareous, etc.), limestones (in places nodular), dolomites	1,214
Mediterranean stage:	
Spirialis beds, black shaly clays, limestones, black nodular limestones, dolomites	(?)

There are several oil-bearing sands sealed by clays. The axial plane of the dome dips south. The greatest accumulations are on the flat limb of the fold, especially in the lower beds.

Maikop.—The Maikop[1] oil field, in the Kuban province, Russia, is about 300 miles west of Grozny, on the north slope of the Caucasus Mountains. It is about 50 miles northeast of Tuapse, on the Black Sea. Cretaceous beds are thrown into gentle folds and resting unconformably upon them are Tertiary beds which dip uniformly at low angles.

The lower Oligocene is composed chiefly of Foraminifera beds, which are said to be unfavorable for oil.[2] Above the Foraminifera beds are lenses of sand, as much as 56 feet thick, that contain light oil. One lenticle 70 acres in extent yielded 400,000 tons of oil. The two heavy-oil zones in the Maikop strata crop out in places. The lower zone has yielded a gushing well. The sands are thick, and where they crop out they are so impregnated with oil that when the sand is squeezed in the hand oil oozes out like water from a sponge.[3] In places the oil rises to the contact of the oil sand with the Cretaceous beds (Fig. 57, p. 150).

[1] Calder, William: The Maikop Oil Field, South Russia. Inst. Min. Eng. *Trans.*, vol. 48, pp. 321-347, 1915.

[2] Thompson, A. B.: Inst. Min. and Met. *Trans.*, vol. 20, p. 258, 1911.

[3] Trench, R. H.: Discussion of Thompson's paper. *Op. cit.*, p. 247.

TERTIARY FORMATIONS AT MAIKOP, RUSSIA
(After Rappoport)[a]

Series	Stage	Lithologic Character and Subdivision of Strata	Fossils
Lower Miocene. Upper Oligocene.	Maikopstage.	1. Dark laminated noncalcareous clays. 2. Neftyanoya heavy-oil zone, alternating sands and clays, outcropping in parts of the field. 3. Alternating thick clays and water-bearing sands. 4. Shirvanskaya heavy-oil zone, alternating sands and clays, outcropping in parts of the field.	Fish remains.
Middle Oligocene.	Foraminifera beds.	5. Light-oil lenticles in the hanging wall. 6. White clays and marls, with bituminous streaks. 7. Green marls.	*Globigerina* and *Orbulina.*

[a] RAPPOPORT, F. G.: Discussion of CALDER'S Paper. *Op. cit.*, pp. 342-346.

From the region south of Maikop, parallel to the axis of the Caucasus, petroliferous strata extend northwestward along a belt nearly 200 miles long. Many of the rivers in this region carry oil films on water.

Taman and Kertch.—In the Crimean district oil is found on the Taman and Kertch peninsulas, at the south side of the Sea of Azov. On the Taman peninsula there are many sharp ridges rising from swampy plains. The tops of these ridges are marked by volcanoes carrying oily mud. The Kertch peninsula is made up of Oligocene and Miocene beds[1] forming numerous anticlines, on which mud volcanoes are found. The structure of the region is shown by Fig. 232.

Sviatoi.—Sviatoi or Holy Island, lies in the Caspian Sea off

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[1] REDWOOD, BOVERTON: A Treatise on Petroleum, vol. 1, p. 150, 1913.

Apsheron Peninsula, about 30 miles from Baku.[1] Practically all of the island except the center and small patches near the shore is covered with beds as late as Pliocene. These beds overlie sandstones, sands, and sandy clays of Miocene age, which crop out in the center of the island and form an asymmetric dome with its long axis running northwest. On the northeast flank there is much faulting in the Miocene beds. About 2,100 feet or more northeast of the dome, according to May, the oil-bearing Miocene beds rise again, forming an anticline. Along the axis of the main dome, for a distance of about a mile, there are 10 or 12 mud volcanoes and seeps, most of which occur where the beds are faulted. The soil contains enormous deposits of pitch. Parallel to the zone of mud volcanoes and east of them are springs of salt water, and still farther east is a bed of asphalt covering more than 200,000 square yards. Small lakes of oil are forming to-day. From wells drilled southwest of the anticline water spouted above the derrick. The oil, all of which comes from lower Miocene beds, has a specific gravity of 0.92 to 0.94.

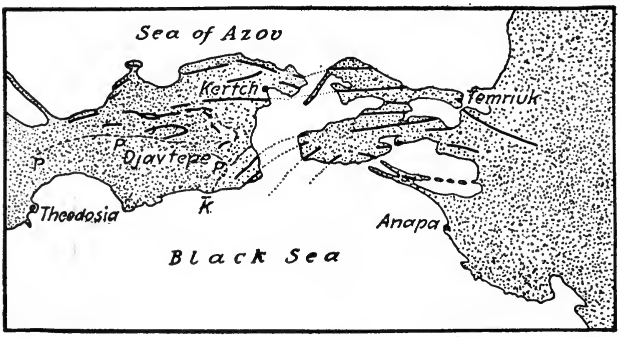

Fig. 232.—Map of the Strait of Kertch, Russia. The heavy lines indicate late Tertiary anticlines. (*After Andrussov. Redrawn from a sketch in Suess Das Antlitz der Erde, vol. 3, part 2, p. 12. The original is not accessible to me. W.H.E.*)

Cheleken Island.—Cheleken Island, in the Caspian Sea, contains middle Tertiary strata and later beds correlated with the Baku and Apsheron formations of the Baku region. These beds crop out on an anticline which is extensively faulted. The island

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[1] May, H.: Discussion of a Paper by Thompson. Inst. Min. and Met. *Trans.*, vol. 20, p. 248, 1911.

itself is a structural dome. Hot salt springs abound, and deposits of ozokerite are found in faults. Wells on this island have been highly productive. Thompson[1] states as probable the hypothesis that the highly faulted uplift of this field is related to igneous bodies concealed below the surface. Holland[2] dissents from Thompson's view. He states that the intense faulting present in the central portion or axial region is not apparent in the peripheral areas, which are occupied by the later beds. This difference may be due to the faulting having taken place prior to the deposition of the later beds, but as there is no pronounced unconformity between the two series, it appears probable that faulting was originally limited to the central part of the dome. The oil is in part of paraffin base and has sealed the faults by forming ozokerite in them.[3]

Transcaspian Province.—The Mainland east of the Caspian Sea also yields oil. Napthnia Gora, or Naptha Hill, is about 100 miles inland of Krassnovodsk and 16 miles southwest of the Tageer wells. The hill, which is about 3 miles long by about a mile and a half wide, appears to be due to a short anticlinal fold. Petroleum mixed with sand and ozokerite escapes at the surface. Mud volcanoes throw out mud, water, petroleum, and ozokerite. It is said that fragments and even layers 3 inches thick of ozokerite have been found in the mud and sand hills surrounding these volcanoes. Abandoned wells on the northwestern slope show where petroleum was collected in ancient times. Trial borings for petroleum have been made by the Government, and these, at a shallow depth, are reported[4] to have given a daily output of 500 to 700 poods.

Tiflis.—In the Tiflis Government petroleum occurs in the middle Jurassic series a few versts southwest of Tsona, on the Kutais border. South of the Kur, about 16 or 20 miles below Gori, the Sarmatian limestones, in a vertical position, contain traces of petroleum, which is also reported to occur on the eastern shore of Lake Toporovan, southwest Tiflis, possibly impregnating some absorbent igneous rock. East of Tiflis the Tertiary belt assumes

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[1] Thompson, A. B.: The Relationship of Structure and Petrology to the Occurrence of Petroleum. Inst. Min. and Met. *Trans.*, vol. 20, p. 230, 1911.

[2] Holland, Thomas: Discussion of Paper by Thompson. *Op. cit.*, p. 266.

[3] I have no data concerning the geology of the Emba field north of the Caspian and the Derbeill field north of Baku.—W.H.E.

[4] Redwood, Boverton: A Treatise on Petroleum, vol. 1, pp. 14-15, 1913.

a more regular course and is practically continuous, extending over 100 miles southeastward. Petroleum is produced in this belt from both Oligocene and Miocene beds.[1]

Ferghana.—The Ferghana district, about 400 miles east of Bokhara, Turkestan, produces about 240,000 barrels of oil a year. Although the area covered by the oil formation is very large, the results of drilling are said to be discouraging.[2]

Northern Russia.—In northern Russia about 400 miles east-southeast of Archangel, a Government boring 40 feet deep penetrated blue marl, and petroleum flowed in a continuous stream to a height 14 inches above the casing of the well.[3] A second well was bored with similar result. Later explorations were unsuccessful. The oil contains 41 per cent of kerosene and is superior to the Baku oil.

MESOPOTAMIA

The oil fields of Mesopotamia[4] are between the plateau of Iran and the Mesopotamian depression, north of latitude 30 N., in the valleys of the lower Euphrates and Tigris rivers. They lie within the Turkish vilayets of Mosul, Bagdad, and Busra. The oil-bearing beds extend in a general belt striking northwest parallel to a line of Tertiary folds rising on its eastern border.

The oil generally occurs in Miocene rocks, which consist of bright-colored sandstones, marls, and limestones permeated with salt. As a rule the petroleum and bitumen are found in soft whitish limestones. Sulphurous springs, some of them hot, saline springs, oil seeps, gas seeps, and asphaltic deposits are numerous. These bituminous materials have been utilized for centuries, but there is no considerable oil industry in Turkey.

The Chiarsukh springs occur at the foot of the Koh-i-Ahengeran, along an anticlinal fold which fringes the Chiarsukh River. Oil, accompanied by brine and ozokerite, flows from sandstone strata underlying marls. A small native industry is established.[5]

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[1] Redwood, Boverton: *Op. cit.*, p. 152.

[2] Golubiatuikoff, D. W.: A Report to the Russian Geological Committee, reviewed by *Oil and Gas Jour.*, vol. 16, No. 1, p. 36, 1917.

[3] Redwood, Boverton: *Op. cit.*, p. 15.

[4] Dominion, Leon: Fuel in Turkey. Am. Inst. Min. Eng. *Trans.*, vol. 56, pp. 237-256, 1916.

[5] Dominion, Leon: *Loc. cit.*

PERSIA

Petroleum seeps and asphalt are found at many places in Persia. These have been known since ancient times. Development on the modern scale began in 1903, and a few years later at Maidan-i-Naphtun, near Shustar, a well 1,100 feet deep came in and oil spouted 70 feet high, carrying away the derrick. Since then oil concessions covering most of Persia have been granted, and the Anglo-Persian Oil Co. has developed an extensive field which is supplied with pipe lines and a refinery. In 1919 it was said[1] that wells already drilled are capable of producing 5,000,000 tons annually. Many of the wells are gushers and yield heavily by flowing.

The Persian fields are closely related geologically to the Baku field of Russia. The northern field borders the Caspian Sea and lies southwest of Baku. The western field extends from Kermanshah southeastward to the head of the Persian Gulf and thence continues southeastward on the border of the gulf to the Arabian Sea. The southern field lies north of the Arabian Sea along the coast. These fields are shown in Fig. 233. The following section after Pilgrim is quoted by Hunter:

Geologic Section of West Persian Oil Fields

Recent and sub-recent	Shelly conglomerates and dead coral reef of littoral; red sand hills of coast of Oman, alluvium of Mesopotamia, etc.
Pleistocene	Foraminiferal oolite.
Pliocene	Bakhtiari series, grits and conglomerates.
Miocene	Fars series, marls, clays, and sandstones with limestones and interbedded strata of rock gypsum.
Miocene	Urumieh series, limestones.
Oligocene	Nummulitic limestone of Khamir.
Eocene	Nummulitic limestone of Persia, Muscat, and Bahrain series.
Upper Cretaceous	Hormuz series, lavas, tuffs, etc.

In the field near Shustar the Fars series crops out. At White Oil Springs seeps yield about 20 gallons a day of oil resembling

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[1] Hunter, C. M.: The Oil Fields of Persia. *Mining and Metallurgy*, No. 158, sec. 11, pp. 1-8, February, 1920.

kerosene. There are two strong folds in this region, both lying southwest of the Iranian Mountain chain. These are the Maidan-i-Naphtun fold and the Ahwaz fold, 36 miles southwest of it. The oil in the Maidan-i-Naphtun fold is found in the Fars formation

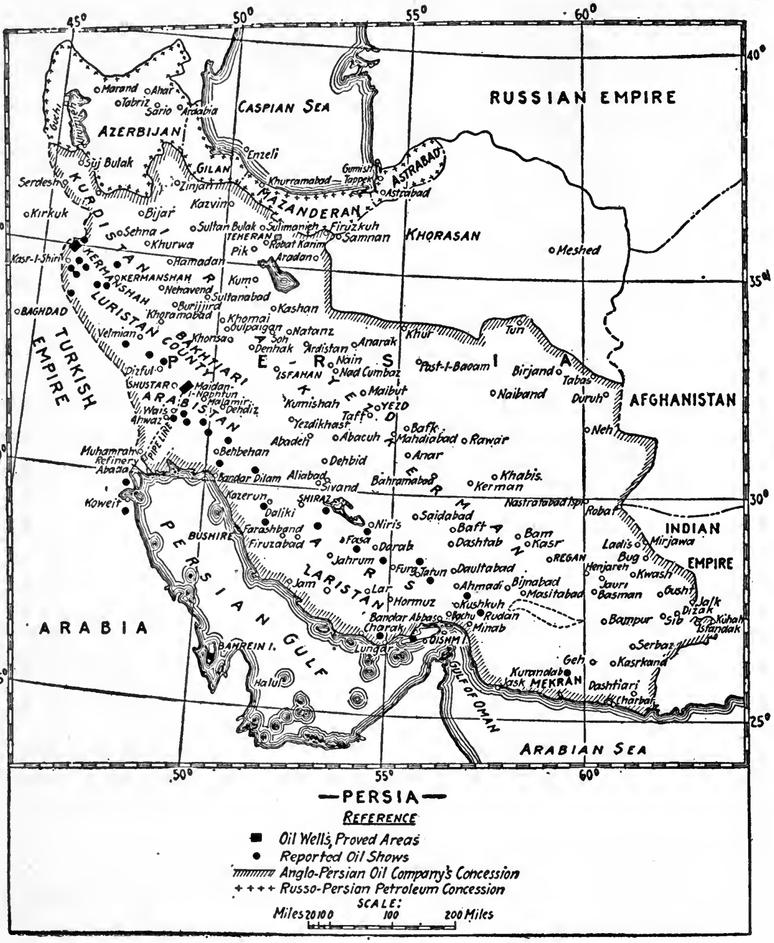

FIG. 233.—Sketch map showing oil fields of Persia. (*After Hunter.*)

of the Miocene. Oil has been flowing from the reservoir unde strong pressure for 10 years. The principal productive bed is 1,200 to 1,300 feet deep in the main fields. The Ahwaz anticline is 100 miles long and strikes west-northwest through Ahwaz. Oil has been found in this region in the detrital limestones forming the base of the Fars series. This anticline is the farthest outlying fold of the Iranian Mountain chain and is asymmetric, having a steep vertical or inverted dip on the southwestern face and a gentle slope on the northeastern face. In the neighborhood of Ahwaz the crest of the anticline is in the form of elongated domes, and denudation has shown that the lowest 200 to 300 feet of exposed beds belong to the middle group of the Fars series. The wells yield considerable gas. Although there are no seeps above this fold, the bed that yields the seeps at White Oil Springs, according to Hunter, is supposed to be present at no great depth.

PROPERTIES OF PERSIAN OILS[a]

Location	Specific Gravity	Flash Point of Crude (°F.)	Fractions			Sulphur	Odor	Color
			Benzine (Per cent)	Kerosene (Per cent)	Lubricating Oils, (Per cent)			
Shustar District..	0.927	......	.....	27.0	45	....	....	Dark green.
White Oil Springs (Ahwaz)......	0.773	......	.....	.....	.....	Present.	Inoffensive.	Light straw.
Tchiah Sourlch (Near Kasr-i-Shirin).	0.815	Low.	9.4	57.6	.....	0.4 per cent present.	Inoffensive.	Brown, strongly fluorescent.
Daliki..........	1.016	170	.....	.....	.....	Present.	Strongly of sulfuretted hydrogen.	Dark brown.
Qishm..........	0.837	190	.....	.....	.....	....	Pleasant.	Brownish red.

[a] HUNTER, C. M.: *Op. cit.*, p. 7.

EGYPT

The oil fields in Egypt (Figs. 234, 235) lie along the west coast of the Gulf of Suez,[1] in an area of Cretaceous and Tertiary strata. The oil is found in Miocene rocks[2] and also in the Mesozoic.

[1] HUME, W. F.: Some Notes on the Post-Eocene and Post-Miocene Movements in the Oil-Field Region of Egypt. *Geol. Mag.*, decade 6, vol. 4, pp. 5-9, 1917.

[2] The Oil Fields of Egypt; Abstract from Report on the Oil-Fields Region of Egypt, by W. F. HUME, Director Geol. Survey of Egypt, with a geological map (1:150,000) from surveys by JOHN BALL, 23 plates and 9 text figures, Cairo, Government *Press*, vol. 54, pp. 315-320, 1917.

As stated by Hume, a basal conglomerate is overlain by a dark fossiliferous limestone (lower middle Miocene), which in turn is overlain by *Globigerina* marls. These beds are succeeded by

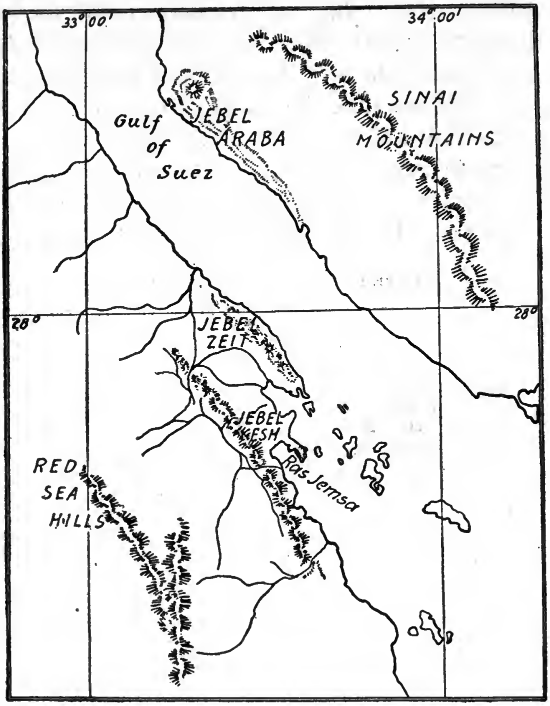

Fig. 234.—Sketch map of region of Egyptian oil fields. (*After Hume.*)

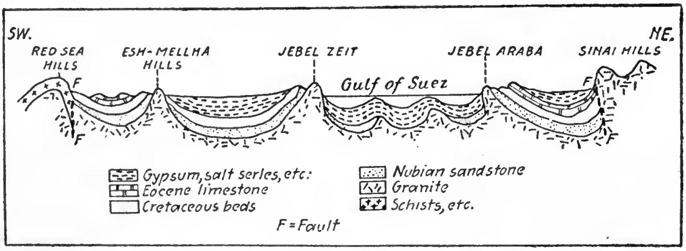

Fig. 235.—Generalized section across region of Egyptian oil fields. (*After Hume.*)

deposits of clay, gypsum, salt, and dolomitic limestones. Their total thickness is from 3,000 to 6,000 feet. Pliocene and Pleistocene strata overlie the Miocene beds.

The country has undergone two major orogenic movements, which are expressed in its present structure. During Cretaceous time, in a great depression, limestones, clays, and sandstones were laid down on an old foundation of granites and metamorphic rocks. Emergence and erosion followed. This was succeeded during the Eocene epoch by the deposition of nummulitic and other strata.

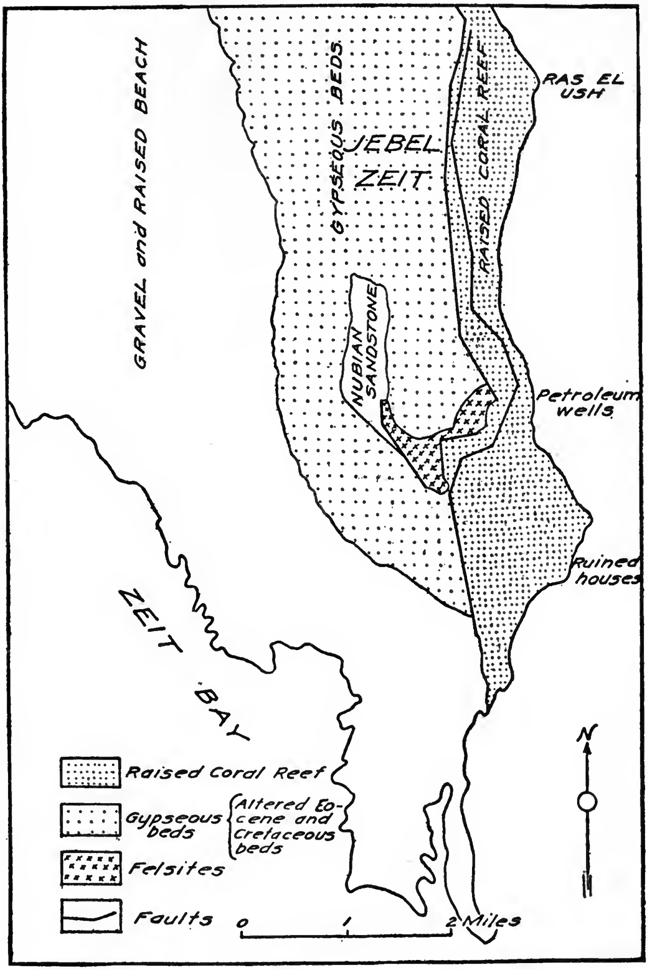

FIG. 236.—Sketch map of Jebel Zeit oil field, Egypt. (*After Hume.*) The Nubian sandstone is Cretaceous. The coral reef is Pleistocene.

At the end of Eocene time the great Egyptian syncline was formed; east of it there is probably a corresponding anticline. A number of parallel axes were developed during the folding—one running through the Red Sea Hills, another through the Sinai Hills of Arabia. The block between these two folds was faulted down, and during middle Miocene time beds of *Globigerina* oozes were laid down in this trough. Upon these beds a series at least 3,000 feet thick, consisting of limestone, gypsum, and salt, was deposited. At the end of Miocene time the region again became subject to compression, which resulted in the formation of many asymmetric folds which strike northwest, and whose more steeply inclined sides lie toward the Gulf of Suez. The ancient petroleum field of Jebel Zeit is shown in Fig. 236.

At Jemsa and Zeit a light oil was found in Miocene strata below gypsum. The wells at Jemsa went to salt water soon after they were drilled.

At Hurgada (Rorquada), west of Gifatin Island, a heavy oil is found near the top of the Nubian (Cretaceous) sandstone. The structure is domatic.

CHAPTER XXVI

BURMA AND OCEANICA

BURMA

Seeps of oil are found at many places in Burma, as is indicated by Fig. 237. The chief developments are located along the Irrawaddy River, where the oil is found in folded and faulted Tertiary strata. The principal fields are the Yenangyaung and Yenangyat-

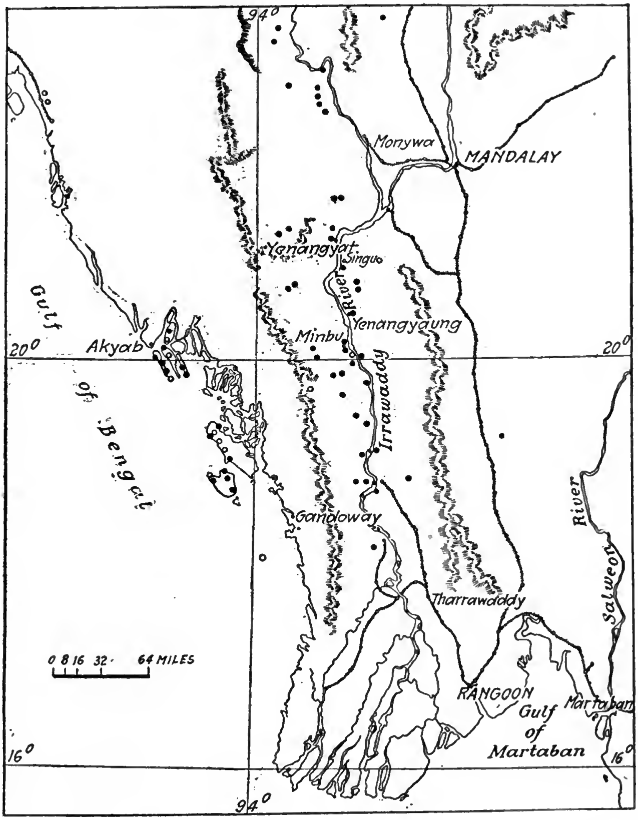

Fig. 237.—Sketch map showing location of oil and gas occurrences in Burma. (*After Pascoe.*)

Singu fields. Burma furnishes by far the greater part of the oil produced in India, as is shown in the following table.

PETROLEUM PRODUCED IN BURMA AND IN INDIA, 1913-1917

Year	Burma (Imperial Gallons)	Total, India			
		Quantity		Value	
		Imperial Gallons	Barrels (42 United States Gallons)	Rupees[a]	Dollars
1913	272,865,397	277,555,225	7,930,149	15,518,790	5,035,803
1914	254,652,963	259,342,710	7,409,792	14,378,475	4,664,857
1915	282,291,932	287,993,576	8,202,674	18,852,045	6,116,232
1916	291,769,083	297,189,787	8,491,137	16,791,075	5,447,584
1917	272,795,191	282,759,523	8,078,843	16,394,460	5,318,909

[a] The value of the rupee is taken as 32.44⅓ cents; 15 rupees = £1.

Yenangyaung.—The Yenangyaung oil field[1] is on an elongated dome whose crest lies 2 miles east of the Irrawady River, at Yenangyaung, in the Magwe district. Oil seeps have long been known in this district, and in the period before modern machinery was introduced the Burmese recovered small quantities by sinking shallow shafts.

The country is a rolling plateau about 600 feet above the sea and is dissected by steep ravines. An elliptical area of Pegu beds about 6 miles long and 1 mile wide is surrounded by Irrawaddian sandstone (Fig. 38, p. 132). The Pegu series (Miocene) consists principally of sand and clay, with some calcareous sandstones. Current bedding indicates deposition in shallow water. Marine and non-marine fossils, gypsum, calcite, and carbonized wood are found in the Pegu.

The Irrawaddian series (Pliocene), which locally is unconformable upon the Pegu, consists of cross-bedded loose, friable sands. Near the base of the series is the Red bed, a persistent member,

[1] PASCOE, E. H.: The Oil Fields of Burma. India Geol. Survey *Mem.*, vol. 40, part 1, pp. 55-100, 1912.

5 or 6 feet thick, which contains vertebrate remains and is used as a horizon marker. Pleistocene and Recent sands and clays locally cover the Irrawaddian.

The principal structural feature of the field (Fig. 238) is an elongated dome with an undulating crest studded by small dip faults. Both the Pegu and Irrawaddian formations are cut by dikes of mud that probably represent the conduits of old mud volcanoes which have been eroded.

Most of the producing wells are scattered over an elliptical area of between 1¼ and 1½ square miles within the larger elliptical area of the dome. The larger part of the petroleum has come from an area of less than a square mile. The oil sands of the Pegu have been called the 400-foot, 700-foot, and 1,000-foot sands, but in certain areas within the district there are small sand pockets of extremely irregular distribution.

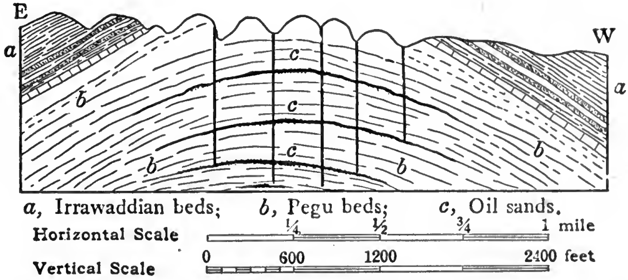

FIG. 238.—Section through Yenangyaung oil field, Burma. (*After Thompson.*)

Some of the wells in the Yenangyaung field, when first brought in, spout a very gassy oil. One well yielded gas at first, followed by oil.

The Beme area of this district at the surface is much cut by mud dikes. In one well mud rose 300 feet in the casing.

The oil and gas tend to rise to the higher structural positions, but there is, according to Pascoe, no clear segregation of gas above the oil.

Yenangyat-Singu.[1]—The Yenangyat Hills, a long range, form the right bank of the Irrawaddy River in the Pakokku district. On the south they are cut through obliquely by the river, and their

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[1] PASCOE, E. H.: The Oil Fields of Burma. India Geol. Survey *Mem.*, vol. 40, part 1, pp. 101-123, 1912.

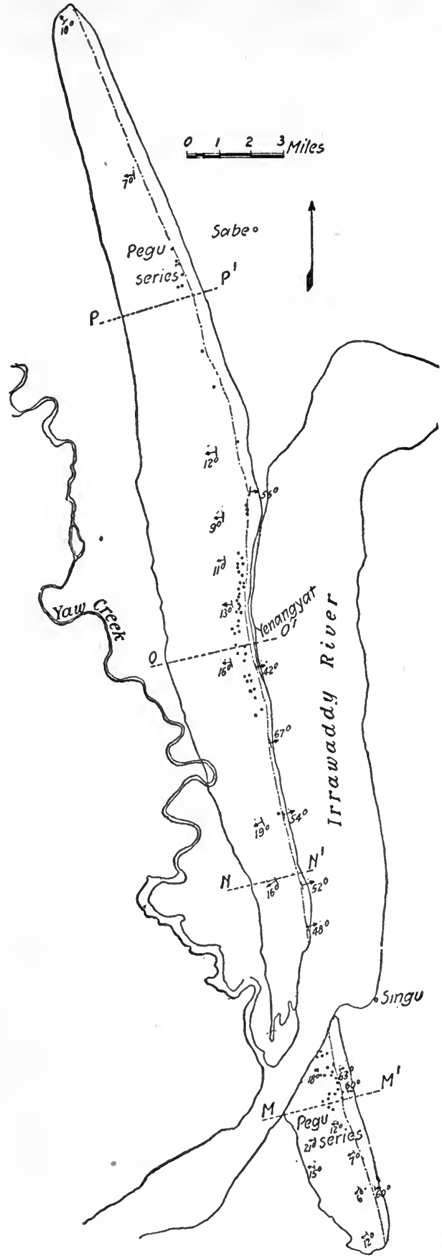

FIG. 239.—Sketch map of Yenangyat-Singu oil field, Burma. (*Based on map by Grimes, Cotter and Rama Rau.*) Sections on lines *PP'*, *OO'*, etc., are shown in Fig. 240.

southern continuations known as the Singu Hills, sink gradually southward into the plateau. The hills consist of a long inlier of Pegu beds cropping out from beneath Irrawaddian sandstone, as at Yenangyaung. The structure is that of a single asymmetric anticlinal fold (Figs. 239, 240), which rises at three places, producing three local domes or crest maxima, each of which forms a separate oil field. The axis is not the same as that of Yenangyaung but lies on a line about 8 miles east of it.

As in the Yenangyaung district the Red bed where present provides a horizon marker. The outcrop of the Pegu, which is the oil-bearing series, is 39 miles long and 1½ to 3½ miles wide. On account of the steep eastward and lower westward dip the "crest locus," according to Pascoe, bends strongly to the west. Oil seeps are numerous.

The most valuable part of this anticline is the Singu area. An oil sand is exposed on the north side of Moksoma Kon, south side of Singu area, but very little oil has been obtained there (1912). A well in this vicinity had an initial yield of about 80 barrels a day from a depth of 2,015 feet. This sand is identical with the sand at 1,400 to 1,450 feet near the crest of the fold, and the position of the oil-pool boundary has been placed a little to the west of this well. According to Pascoe, this sand will probably not yield oil enough to pay where the depth is greater than 2,100 feet. No wells have been drilled east of the crest of the anticline, but one or two situated practically on the superficial crest have struck small supplies.

On the local domes along the anticline oil and gas are reached at depths of about 1,400 to 2,000 feet, the gas rising higher on the structure. There are ten or more sands, which split or join others, making correlation difficult. The principal part of the production, according to Pascoe, is obtained above 2,000 feet. Much of the oil is emulsified with water.

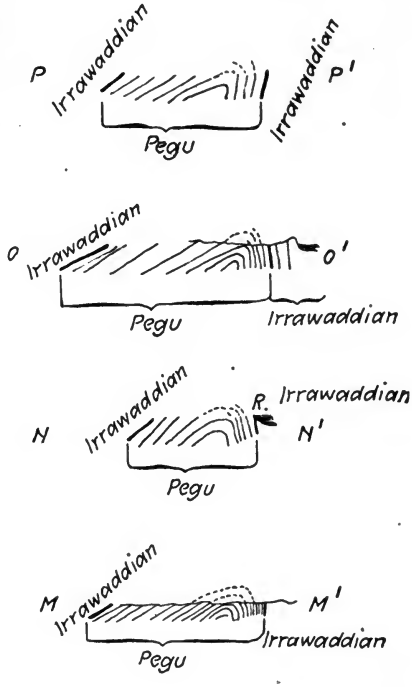

Fig. 240.—Sections through Yenangyat oil field, Burma, along lines shown on Fig. 239.

SUMATRA

In Sumatra a large production of petroleum is obtained from Miocene and Pliocene sandstones interbedded with shales and clays.[1] One of the principal Sumatra fields has been developed on

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[1] Tobler, A.: Tijdschrift van het Koninklijk Nederlandsch Aardrijkskundig Genootschap, 2d ser., vol. 23, No. 2, p. 199, 1906.

Pratt, W. E.: Occurrence of Petroleum in the Philippines. *Econ. Geology,* vol. 11, p. 265, 1916.

acute anticlines. Extensive fields exist on the northeast coast, in a belt about 10 miles wide, extending from Edi, in Atjeh, some 70 miles southeastward. The rock strata in the principal Sumatra fields consist of coarse-grained loose sandstones and marly shales and clays of Miocene and Pliocene age. These beds are thrown into folds, and the oil deposits are concentrated in anticlines. The oil has an unusually high proportion of the more volatile hydrocarbons, evolving inflammable gas in the cold. Oil is reported in the kingdom of Siak, and an oil spring was noticed in the Eocene conglomerates 3 or 4 miles west of Kottabaru. In Palembang there is an extensive oil field in rocks of upper Tertiary age, from the northern margin of the province, 100 miles west of the capital, to the vicinity of Lahat, 80 miles to the south, and eastward to the Ogan River.[1]

In 1917, at Pangalan, it is said a well yielding 1,200 tons of light-gravity oil daily was brought in. This well is said to be drilled on a large anticlinal fold.

In southern Sumatra[2] petroleum is found only in the Tertiary formations, except near Bajur, where in the crater of the Ringgit volcano, according to Tobler, oil rises from schists. The richest oil wells have been struck at different horizons in the lower Pliocene, which is 4,900 feet thick and which consists in this region of blue clays passing locally into sandy shales and argillaceous fine-grained sandstones. Calcareous septaria, which are absent in the upper Pliocene, are characteristic of the lower division, which is also extremely rich in fossil Mollusca. Three groups of brown coal seams are characteristic of the middle Pliocene division, 2,000 feet thick, which consists of blue and brown clays, shales, and, at the top, fine-grained, soft shaly pale-blue and white sandstones. Some of the lignitic seams are 40 to 50 feet thick, and some contain slabs of silicified coal 4 to 12 inches thick. Tobler found plant remains in the middle Pliocene, but practically no marine fossils. Petroleum occurs in this division also in workable quantities and appears to be more especially concentrated at the base of each of

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[1] Redwood, Boverton: A Treatise on Petroleum, vol. 1, p. 161, 1913.
Thompson, A. B.: Oil-Field Development, p. 208, 1916.

[2] Tobler, A.: Einige Notizen zur Geologie von Südsumatra. Naturforsch. Gesell. Basel *Verh.*, vol. 20, pp. 272-292, 1904. Reviewed in Inst. Min. Eng. *Trans.*, vol. 27, pp. 701-702, London, 1905. The original paper is not accessible to me.—W. H. E.

the brown-coal groups. The topmost coal group is immediately overlain by the vast mass of the tuffaceous sediments of the upper Pliocene, 3,300 to 5,000 feet thick.

Petroleum Produced in Dutch East Indies, 1908-1917, in Metric Tons
(After Northrop)

Year	Borneo	Java	Sumatra	Total	
				Metric Tons	Barrels
1908.......	511,049	137,013	738,588	1,386,650	10,283,357
1909.......	411,506	140,351	922,894	1,474,751	11,041,852
1910.......	633,472	142,503	719,740	1,495,715	11,030,620
1911.......	814,707	172,438	683,523	1,670,668	12,172,949
1912.......	671,662	184,989	621,481	1,478,132	10,845,624
1913.......	797,059	207,135	529,947	[a]1,534,223	11,172,294
1914.......	[c]931,903	226,590	475,423	[b]1,634,403	11,834,492
1915.......	[d]960,896	256,838	491,611	[e]1,710,445	12,386,800
1916.......	[f]1,047,462	243,442	526,080	[g]1,820,247	13,174,399
1917.......	[h]946,737	246,126	583,384	[i]1,778,495	12,928,955

[a] Includes 82 metric tons produced in Ceram.
[b] Includes 487 metric tons produced in Ceram.
[c] Includes 65,185 metric tons produced in British Borneo.
[d] Includes 67,000 metric tons produced in British Borneo.
[e] Includes 1,100 metric tons produced in Ceram.
[f] Includes 90,067 metric tons produced in British Borneo.
[g] Includes 3,263 metric tons produced in Ceram.
[h] Includes 77,614 metric tons produced in British Borneo
[i] Includes 2,248 metric tons produced in Ceram.

1 gallon Borneo crude=7.5322 pounds.
1 gallon Java crude=7.1924 pounds.
1 gallon Sumatra crude=6 7754 pounds.

JAVA

The principal oil field of Java[1] extends from Samarang through Rembang and Surabaya to Madoera Island and the smaller islands east of it. Oil is found 10 kilometers south of Surabaya, in the Lidah and other pools. In the residency of Rembang are the Tinawun and Panolan pools. The most productive horizon is

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[1] Verbeek, R. D. M., and Fennema, R.: Geologische Overzichtskaart von Java en Madoera, Geologische Beschrijving von Java en Madoera (no date on map).

near the contact between the middle and upper Miocene. The depth of the wells ranges from 500 to 800 feet. The average production is not large but is sustained. The crude oil has a density ranging from 23° to 40° Baumé, and contains considerable asphalt and a large proportion of paraffin.

The anticlinal structure of Madoera Island, shown by Fig. 241, is typical. The rocks are Tertiary clays, sands, and marls.

BORNEO

The island of Borneo is complicated geologically and is not fully explored. The backbone of the island is an area of crystalline schists with which are associated sandstones and limestones. Jurassic fossils have been found in some of the sedimentary rocks. These rocks are much disturbed and folded. On them are deposited Cretaceous and Tertiary sediments, the latter predominating. Eruptive rocks are associated with the Tertiary sediments.

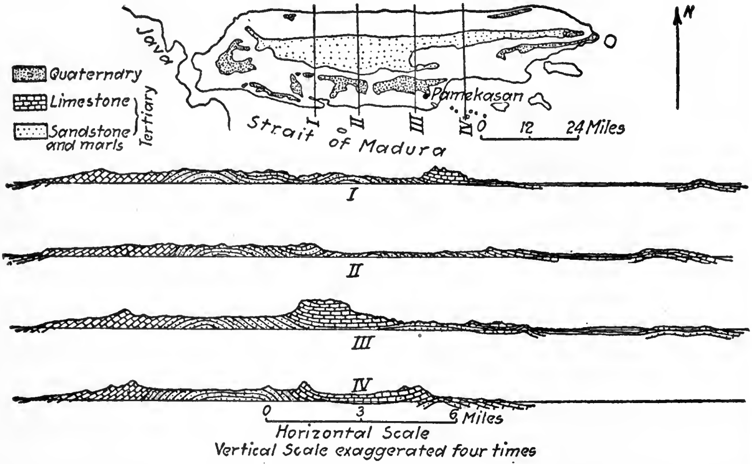

Fig. 241.—Geologic map and cross sections of Madura Island, east of Java. (*After Verbeck and Fennema.*)

Petroleum is found in the Tertiary sedimentary rocks. Three fields are known. One of them is at Kutei and Balik Papan in southeast Borneo, where a company associated with the Dutch Shell Company operates wells and refines the oil. A heavy oil is found near the surface in wells 600 or 700 feet deep. Lighter oils are found at depths about 1,200 below the surface. In northeast Borneo, on Tarakan Island, and on the mainland opposite, productive fields are developed. In Sarawak also fields have been developed yielding heavy oil like that of Baku, Russia.

Very little is available to me regarding the relation of the oil pools to the geological structure. Stigand[1] states that the favorable structural feature in eastern Borneo is a long anticline with an undulating crest.

PHILIPPINE ISLANDS

The Philippine Islands form an archipelago in the Malay group, lying between Borneo and Formosa, both of which produce oil. Seeps and residues of petroleum and inflammable gas are found at many places in the Philippines, although there are no producing oil wells. In the Philippine sedimentary column no rocks older than the Tertiary have been identified with certainty. The Oligocene, which carries the oldest fossils determined in the islands, rests unconformably upon a complex of metamorphic and igneous rocks. The Tertiary rocks include limestones, shales, muds, sandstones, and tuffs. The Tertiary section[2] is given below.

Divisions of the Philippine Tertiary (After Douvillé)

Philippine Islands		Borneo	
Upper limestone with small *Lepidocyclinas*.	*Lepidocyclina* cf. *L.* Verbeeki, *Miogypsina*.	Burdigalien.	
Sandstone and shale.	*Cycloclypeus communis*, *Orbitolites*, *Alveolinella*, *Miogypsina*.	Aquitanien.	Miocene.
Middle limestone with large *Lepidocyclinas*.	*Lepidocyclina insulaenatatalis*, *L. formosa*, *L. richthofeni*.		
Lower limestone with *Nummulites*. Coal measures.	*Nummulites niasi*, *Amphistegina* cf. *A. niasi*, *Lepidocyclina*.	Stampien.	Upper Oligocene.

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[1] Stigand, I. A.: Inst. Min. and Met. *Trans.*, vol. 20, p. 264, London, 1911.

[2] Douvillé, H.: Sur le Tertiaire des Philippines. Soc. Géol. France *Bull.*, 4th ser., vol. 9, p. 338, 1909.

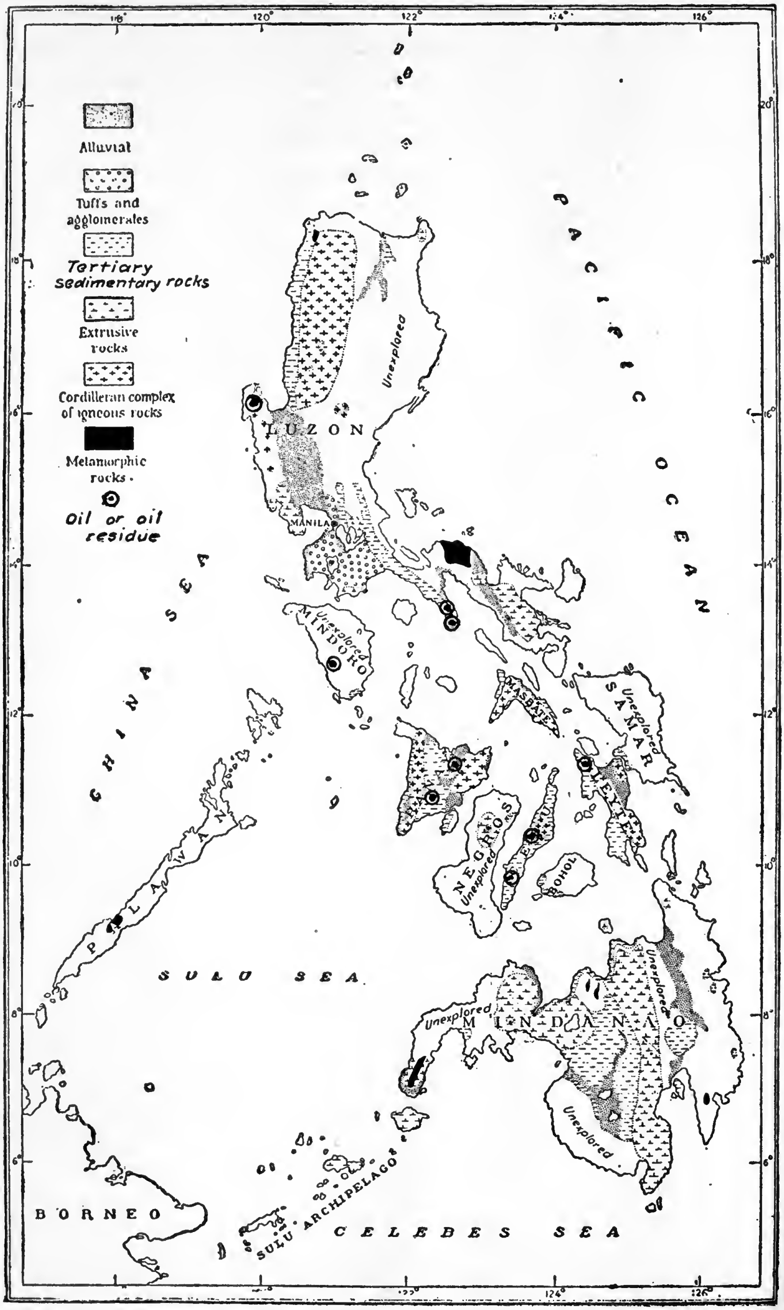

FIG. 242.—Geologic map of the Philippine Islands. (*After Smith, with additions by W. H. E.*)

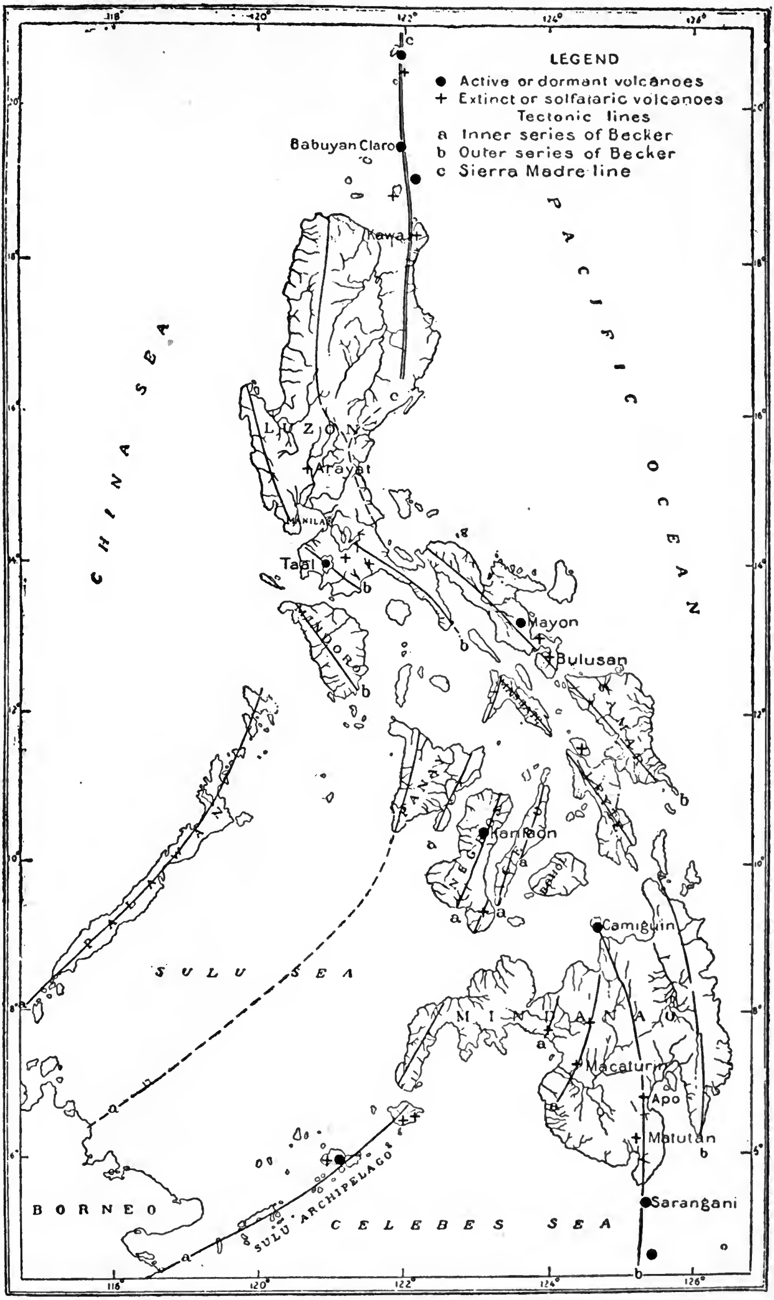

Fig. 243—Map showing tectonic lines and volcanic centers of Philippine Islands. (*After Smith.*)

The petroleum-bearing beds are generally folded so that they dip at high angles. The shale series is closely folded, but the overlying rocks usually dip more gently, though in the same direction. The difference in dip is evidence of unconformity between the shale series and the overlying rocks. The folds into which the beds are thrown are characterized by sharp broken anticlines and by broader, less acute synclines.[1]

Fig. 242 is a geologic map, after Smith,[2] on which are plotted localities where oil residues occur, taken from a map by Pratt. Fig. 243 shows the principal tectonic lines.

At Villaba, near the northwest end of Leyte, petroleum residues are found in considerable amounts. The largest deposit is in a mass of porous limestone and sandstone having an outcrop 200 feet long and 30 feet high. The rock is impregnated for at least 30 feet from the exposed face. Solid residues of black petroliferous material fill fissures several feet wide. Oil seeps are numerous, yielding brown petroleum having a gravity of 28° to 30° Baumé. The rocks are of upper Tertiary age, and the field lies near one of the principal tectonic lines. The beds are thrown into folds and are faulted, and the principal seeps lie along an escarpment that is probably a fault line.

In the southern part of the peninsular portion of Tayabas, which juts off the southern coast of Luzon, in line with the axis of the eastern cordillera, there are four small petroleum seeps and half a dozen other places where traces of petroleum and inflammable gas are found. These showings are distributed over an area 25 miles long by 12 miles wide. The rocks are Tertiary and have the structure of an anticlinorium that includes steeply dipping asymmetric anticlines. Erosion has taken place more rapidly along the broken crests of the sharp anticlines, and valleys mark the anticlinal axes. The result is that, although the peninsula has a general anticlinal structure, the highest elevations and the bulk of the land mass are within the synclines. Traces of petroleum are found wherever the massive shale beds of the upper part of the shale series are exposed, and the principal seeps of petroleum occur where erosion has uncovered these beds on the crests of sharp

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[1] Pratt, W. E.: Occurrence of Petroleum in the Philippines. *Econ. Geology*, vol. 11, pp. 246-265, 1916.

[2] Smith, W. D.: The Philippine Islands, included in a separate of the Handbuch der Regionalen Geologie, p. 4, Heidelberg, 1912.

folds. The shale from which the petroleum escapes emits an odor of light oil. It contains numerous small calcareous shells of *Globigerina,* some of which are greasy. Gas usually accompanies the petroleum, bubbling up through the water, and a spring of salt water occurs near the southernmost seep on the eastern anticline, at an elevation of several hundred feet. At the central seep two wells, 117 and 300 feet in depth, have been drilled on an anticline. The shallower well, which is only 3 inches in diameter and was drilled by hand, encountered small quantities of petroleum and inflammable gas. Possibly a barrel of oil a day could be obtained from this hole. The other well obtained a temporarily strong flow of inflammable gas.[1]

In Pangasinan, west-central Luzon, a well drilled by the Bureau of Public Works encountered salt water and a little petroleum in organic clay or mud at a depth of 1,200 feet. The outcropping rocks are limestones, calcareous sandstones, and marls of upper Tertiary age. Structurally the area is a gentle monocline, dipping west.

In Panay a well was drilled for artesian water at the town of Janiuay, 2 miles east of the southern gas seep, and at a depth of 1,800 feet this well encountered salt water, charged with gas. Both gas and water have flowed by heads through a period of two years, the well having been abandoned, and tiny films of oil appear on the surface of the water. The well is in an alluvium-filled structural valley.[2]

Petroleum is found in shale near the towns of Toledo and Alegria, 35 miles apart, on the western coast of Cebu. The wells at Toledo and the adjacent seep are upon the outcrop of sandy bedded shales which dip northwest at angles of 45° or more and form a monocline flanking the cordillera of Cebu. The petroleum at Alegria comes from steeply dipping beds of sandy blue shale in the crest of a sharp anticline that parallels the adjacent coast. Two miles to the south of the seep, and along the line of the anticlinal axis, there is a spring of hot water.[3]

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[1] PRATT, W. E.: *Op. cit.,* p. 253.

[2] PRATT, W. E : *Op. cit.,* p. 256.

[3] PRATT, W. E.: *Op. cit.,* pp. 256-257.

JAPAN AND FORMOSA

The chief oil districts in Japan[1] are in the provinces of Echigo, Shinano, Akita, Totomi, and Hokkaido, and one is in Formosa. In each of these districts there are one or more oil fields. The oil in Japan is associated everywhere with Tertiary sedimentary rocks and is found in anticlinal folds.

The early methods of getting the oil were simple. Where seeps occurred, as at Kurokawe, in the Niitsu field in Echigo, trenches or shallow wells were dug and allowed to fill with oil. The Nippon Petroleum Co. in the fall of 1890 set up a drill over an old dug well. A well 1,000 feet deep was completed in April, 1892, and began with a production of 45 barrels a day of oil of 42° Baumé. Other productive wells were drilled in succession to a depth of 1,500 feet. The first gusher was struck at Amaze, in the Nishiyama field, Echigo district.

PETROLEUM PRODUCED IN JAPAN AND FORMOSA, 1913-1917, IN KOKU[a]
(From the Department of Agriculture and Commerce, Tokyo)

Field	1913	1914	1915	1916	1917
Akita	76,830	625,719	989,223	879,188	874,484
Hokkaido	4,218	6,270	8,846	6,627	5,763
Niigata[b]	1,610,117	1,761,792	1,728,687	1,733,934	1,655,250
Shizuoka	1,983	2,055	1,720	1,646	1,551
Yamagata	336	....	....	....	....
Others	98	....	....	....	....
	1,693,582	2,395,836	2,728,476	2,621,395	2,537,048
Formosa	15,933	14,708	16,651	16,966	12,340
Grand total	1,709,515	2,410,544	2,745,127	2,638,361	2,549,388

[a] 1 koku=39.7 English gallons=47.46 United States gallons=1.136 United States barrels.
[b] Includes the oil from Nishiyama.

The Echigo and Akita districts produce 90 per cent of the oil of Japan. The Tertiary petroliferous beds, according to Iki,[2] con-

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[1] CLEMENTS, J. M.: Petroleum in Japan. *Econ. Geology*, vol. 13, pp. 512-523, 1918.

[2] IKI, T.: Preliminary Note on the Geology of Echigo Oil Field. Geol. Soc. Japan, *Mem.*, No. 2, pp. 29-57, Tokyo, 1910.

Petroleum Produced in Japan and Formosa, 1908-1917

Year	Japan		Formosa		Total	
	Koku	Barrels	Koku	Barrels	Koku	Barrels
1908........	1,815,001	2,061,841	7,310	8,304	1,822,311	2,070,145
1909........	1,657,036	1,882,393	5,664	7,170	1,662,700	1,889,563
1910........	1,520,458	1,727,240	3,208	4,062	1,523,664	1,730,882
1911........	1,529,593	1,737,618	1,442	1,638	1,531,035	1,739,256
1912........	1,458,290	1,656,617	3,040	3,454	1,461,330	1,660,071
1913........	1,693,582	1,923,909	15,933	18,100	1,709,515	1,942,009
1914........	2,395,836	2,721,670	14,708	16,708	2,410,544	2,738,378
1915........	2,728,476	3,099,549	16,651	18,915	2,745,127	3,118,464
1916........	2,621,395	2,977,905	16,966	19,273	2,638,361	2,997,178
1917........	2,537,048	2,884,624	12,340	14,030	2,549,388	2,898,654

sist of sandstones and volcanic tuffs interbedded with shales. The oil-bearing areas are broken into a series of small mountain ridges, of which the highest rises to an altitude of 2,300 feet, although the general height is much lower. The ridges normally correspond to anticlines and strike northeast; the valleys occupy synclines. Broadly the oil fields correspond with these anticlines. In the Echigo and Akita districts oil occurs at three horizons. The beds at the upper horizon consist of shale, sandstone, and conglomerate, and those at the middle one of shale with thin beds of sandstone. The lower oil zone is subdivided into two parts—an upper one of sandstone and shale and a lower one of shale, sandstone, and tuff. The most productive oil strata are in the middle and lower zones. The sandstone and tuff are the chief oil carriers, though some oil is obtained in places from the shale. Volcanic rocks, tuffs, and dikes are found with the Tertiary oil strata, some contemporaneous with and others intrusive in the sediments. Where the oil strata are cut by an intrusion the oil is reported to be of low specific gravity, much of it averaging even less than 10° Baumé. As a rule the heavy oils, according to Clements, occur at the highest horizon.

The Nishiyama field[1] is the most productive one in the Echigo district. The axis of the Nishiyama anticline strikes N. 45° E., and along the axis the northwest side of the anticline is dropped down by faulting. The shallow wells are along the southeast side

[1] Production included above in Niigata, 9.

of the anticline. Those so far developed range in depth from 1,490 to 1,790 feet. The deeper wells are on the northwest side of the anticline. Their average depth is 2,980 feet, but one reached a depth of 4,613 feet.

The only field in which gas is produced in notable quantity is the Nishiyama field, in the Echigo district. One company produces from this field 4,000,000 cubic feet of gas a day.

Oil seeps are numerous in the Washinoki region, Hokkaido. A section made by B. S. Lyman in 1875 is shown as Fig. 244.

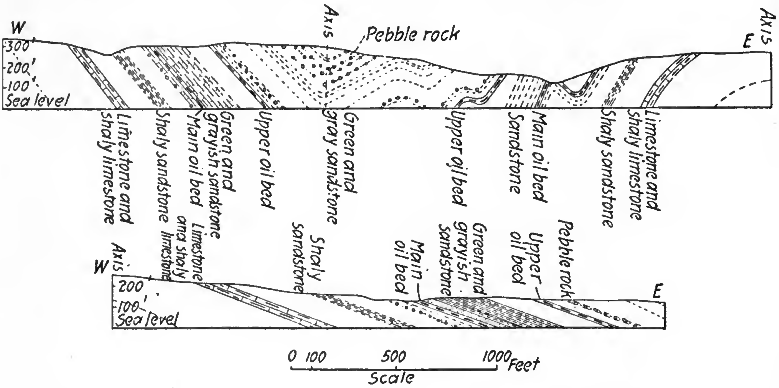

FIG. 244.—Geologic section of Washinoki oil region, Hokkaido, Japan. (*After Lyman.*)

Formosa (Taiwan), immediately north of the Philippine Islands and geologically similar to them, produces a little petroleum from Miocene shales and sandstones.[1]

CHINA

Oil is found in Szuchuan where[2] there are in the neighborhood of Fu-chuan wells from 1,000 to 3,500 feet deep, in which petroleum occurs with gas and brine. The gas is used in evaporating the brine and the petroleum is burned in lamps without refining.

NEW ZEALAND

Petroleum[1] is found near New Plymouth, Paritutu, Taranaki, North Island, New Zealand, on the north slope of Mount Egmont.

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[1] PRATT, W. E.: Occurrence of Petroleum in the Philippines. *Econ. Geology,* vol. 11, p. 265, 1916.

[2] COLDRE, LOUIS: Les Salines et les Puits de Feu de la province du Se-Tchoan, *Annales des Mines,* Ser. 8, vol. xix, p. 441 (1891).

The production is small. Oil seeps are found along the coast near the breakwater at New Plymouth, where on calm days the sea locally is often covered with an oil film. Gas seeps are numerous, and a mud volcano is reported to have erupted violently in 1859. Oil is found in the Onairo series (Miocene), which consists of sandstones, conglomerates, clays, and limestones, with some coal seams. It is overlain unconformably by the Pouakai series, but it seems probable that no great lapse of time separates the two series and that in some places they are conformable. If inclined the Pouakai beds should form a key to the inclination of the Onairo series. The Pouakai beds, however, are, according to Clark, nearly everywhere horizontal. In the more eastern portion of the subdivision there is evidence that the Onairo rocks form the western end of an eastward-pitching anticlinorium, whose axis runs in an east-southeast direction through the southern portion of the Waitara district.[2]

Salt water is associated with the oil. It is more concentrated than sea water and consists principally of sodium chloride and is nearly free from sulphate. It carries 20 parts in a million of sodium iodide. The gases contain methane, ethane, and olefins, and some are nearly half carbon dioxide and nitrogen.

AUSTRALIA

At Roma,[3] Queensland, Australia, about 275 miles west of Brisbane, inflammable gas was discovered in 1904 in a deep boring sunk for water. The gas-bearing strata are probably the Walloon series, of Jura-Trias (?) age. They consist of sandstones, dark shales, and thin seams of coal, and both vertical and lateral changes are closely spaced. The gas-bearing stratum is said to be a gray shale.

The structure is monoclinal, and the dip is about 150 or 200 feet to the mile. The beds are but little disturbed. The gas is said to be mainly methane, but contains no gasoline. The pressure is low. No salt water is reported.

There are no surface indications of gas or oil. The gas belt is 1,500 feet below the lowest of the coal seams and about 3,700 feet

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[1] CLARK, E. DE C.: The Geology of the New Plymouth Subdivision, Taranaki Division. New Zealand Geol. Survey *Bull.* 14, new ser., pp. 1-47, 1912.

[2] *Idem*, p. 38.

[3] CAMERON, W. E.: Report on the Significance of a Flow of Gas in the Roma No. 2 Bore. Queensland Geol. Survey *Pub.* 247, 1915.

below the surface. In the first well drilled the gas was allowed to escape for four years; it was then shut off and gaged and found to flow at the rate of about 70,000 feet a day. The flow decreased rapidly afterward. In 1907 a second deep well was sunk about 250 feet south of the first gas well. It struck a heavy flow of gas that lighted from the boilers and burned 46 days.

CHAPTER XXVII

CARIBBEAN ISLANDS

CUBA

Asphalt, pitch, and oil seeps have been known in Cuba[1] for many years, but little petroleum has been recovered.

The rocks of Cuba may be divided into five series, as follows:

5. Quaternary and Recent deposits, including coral limestones, terrace gravels, soils, and sands.

4. Tertiary rocks, igneous, in part.

3. Upper Cretaceous marls, shales, sandstones, conglomerates and some limestone.

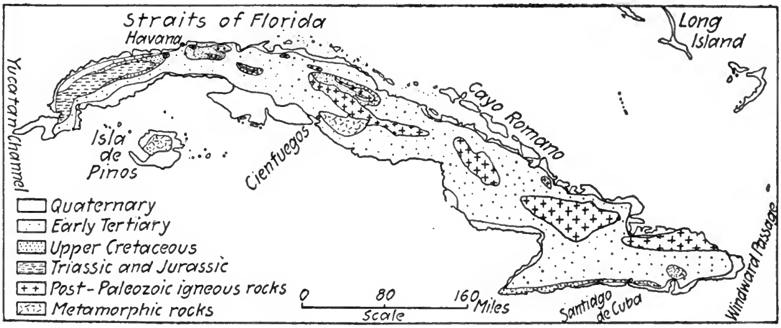

FIG. 245.—Geological sketch map of Cuba.

2. Triassic and Jurassic limestones and associated rocks.

1. The basement complex, consisting of granites, schists, slates, and limestones. Of unknown age, most of them probably Paleozoic or older. Includes probably also some serpentines of Cre-

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[1] DeGolyer, E.: The Geology of Cuban Petroleum Deposits. Am. Assoc. Petroleum Geologists *Bull.*, vol. 2, pp. 133-167, 1917.

Vaughan, T. W.: Bitumen in Cuba. *Eng. and Min. Jour.*, vol. 73, p. 344, 1902.

Hayes, C. W., Vaughan, T. W., and Spencer, A. C.: Report on a Geological Reconnaissance of Cuba, made under the direction of Gen. Leonard Wood, Military Governor, 123 pp., 17 figures and maps, Washington, 1901. Chapter on asphalt and petroleum same as Vaughan's work cited above.

Peckham, H. E.: Bituminous Deposits of Cuba. *Am. Jour. Sci.*, 4th ser., vol. 12, pp. 33-41, 1901.

taceous age. Serpentine is said to crop out in every province in Cuba.

The basement rocks and the Triassic rocks are in general intensely folded and are overlain by the Cretaceous and later rocks, which as a rule have comparatively low dips. The Cretaceous and older rocks are intruded by igneous rocks. The Quaternary and Recent deposits are laid down upon the older rocks and are now forming near the sea shore.

The structure in general is anticlinal, the older rocks forming the central axis and younger rocks cropping out on either side. The folding was probably accomplished in the Tertiary or in a later period. Subordinate folds occur away from the central axis.

Asphalt, oil seeps, and gas seeps have been reported from every province in Cuba and extend over a distance of 475 miles. They are most common on the north coast, in a zone some 20 miles wide between Esperanza and the eastern boundary of Santa Clara province. The scattered wells that have been drilled here have not yielded commercial supplies, though several of them have encountered oil or gas. Most of the occurrences are in fractured serpentines. De Golyer[1] believes that the oil was derived from the Jurassic limestones or other sedimentary rocks, that the igneous rocks from which the serpentines are derived were intruded, for the most part, into the Cretaceous rocks that overlie the Jurassic, and that the asphalt deposits and oil seeps found in the serpentine and other igneous rocks are the result of oil seeping from the underlying sedimentary rocks or from patches of the sedimentary rocks which have been caught up in the serpentine. It is believed by some, however, that the Cretaceous beds are unconformable with some of the serpentine bodies and that the oil has accumulated near the unconformity.

The oil recovered is of a remarkably high grade, ranging from 55° to 70° Baumé. One well, which belongs to the Cuban-American Sugar Co., is at Motembo, in the Province of Santa Clara. It is about 1,900 feet deep, and yields 10 gallons of 70° Baumé oil daily. Other wells from 300 to 700 feet deep have been drilled in the same region. The most that has so far been taken from a single well (Cardenas) does not exceed 100,000 gallons.

Several wells have been sunk both east and west of Cardenas, attaining depths of 1,000 to 2,385 feet, the latter the maximum

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[1] *Op. cit.*, p. 165.

depth for the island. They have all started in limestone and finished in serpentine.[1] Commercial production was not obtained in any of the wells.

HAITI AND SANTO DOMINGO

On the island of Haiti indications of oil have been noted 3 miles north of Azua and on the coast near San Cristobal, 10 or 15 miles west of Santo Domingo. The oil is said to be derived from Cre-

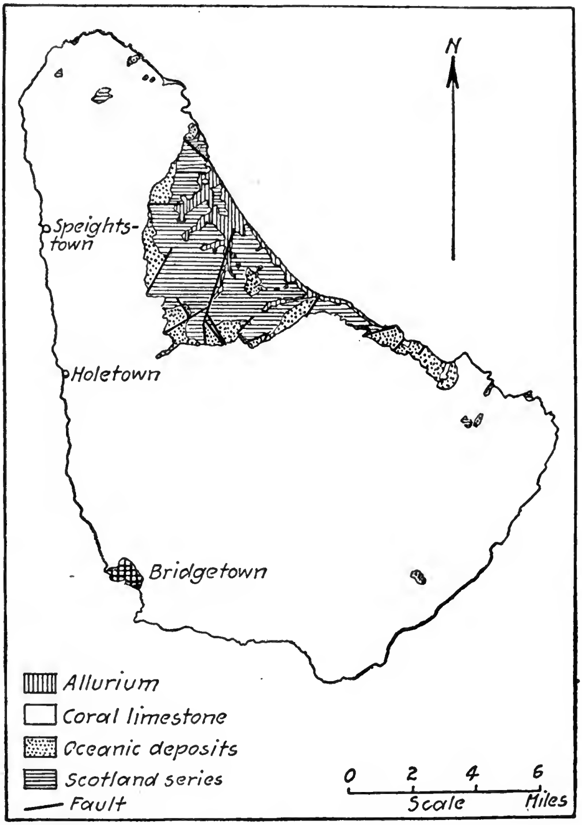

Fig. 246.—Geologic map of Barbados Island. (*After Harrison and Jukes-Browne.*)

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[1] Arnold, Ralph: Conservation of the Oil and Gas Resources of the Americas. *Econ. Geology*, vol. 11, pp. 301-302, 1916.

taceous beds.[1] A well at Azua is reported to have flowed commercial quantities of 20° Baumé high-sulphur oil.

BARBADOS

Oil is found on the east side of Barbados Island,[2] in Miocene[3] sandstones and shales known as the Scotland series (Fig. 246). Manjak, a tar formed by the drying of oil, has been exploited. The production of oil is small and has been obtained from shallow wells. There is a well 1½ miles north of St. Andrew, and another one about 3 miles southwest. South of that point is Tarry Gully, which derives its name from earth saturated with petroleum.

The rocks in the Scotland district, which includes the parishes of St. Joseph and St. Andrew, consist of thick-bedded sandstones, coarse grits, bituminous sandstones and shales, and dark-gray and mottled clays. The strata are much disturbed and are broken by many faults. In many places the oil is found in pools on the fields, and in a little valley about 1,000 yards east of the Lloyd wells, at St. Andrew, the oil trickles out along the foot of a hill. In this district there is also the "boiling spring," where in a pool of water inflammable gas bubbles. The Lloyd wells formerly numbered 21, but in 1895 there were only 5. These wells were dug 5 feet in diameter and from 80 to 140 feet deep, and were lined with pine wood. All yielded oil, and 1 or 2 barrels could be obtained daily from each well.

TRINIDAD

Trinidad[4] is an island in the Caribbean Sea off the coast of Venezuela. Trinidad is famous for its asphalt lake, which has been well known for centuries and from which asphalt has been recovered extensively and exported. Lately it has produced considerable oil, mostly of low grade. The oil ranges in density from 14° to 25° Baumé and is essentially a fuel oil. Recently some higher-grade oils have been discovered. These yield gasoline and kerosene and are refined in distilleries on the island.

[1] ARNOLD, RALPH: *Op. cit.*, p. 302.

[2] REDWOOD, BOVERTON: A Treatise on Petroleum, vol. 1, p. 192, 1913.

[3] RALPH ARNOLD states that the Scotland series is Oligocene. *Econ. Geol*, vol. 00.

[4] WALL, G. P., and SAWKINS, J. G.: Report on the Geology of Trinidad· West Indian Survey, part 1, pp. 1-211, 1860.

The northern part of Trinidad (Fig. 247) is made up of metamorphic rocks. The central and southern parts consist of Cretaceous, Tertiary, and Quaternary sediments. The Tertiary and older rocks are thrown into folds, some of which are asymmetric and overturned. Exudations of oil and asphalt,[1] oil seeps, gas seeps, and mud volcanoes are present on a grand scale, many of them on crests of anticlines. Cunningham-Craig[2] says that it is possible to walk for miles in the forests without ever being out of sight of asphalt, and in certain localities near Oropuche and on Mont L'Enfer more asphalt than soil is to be seen.

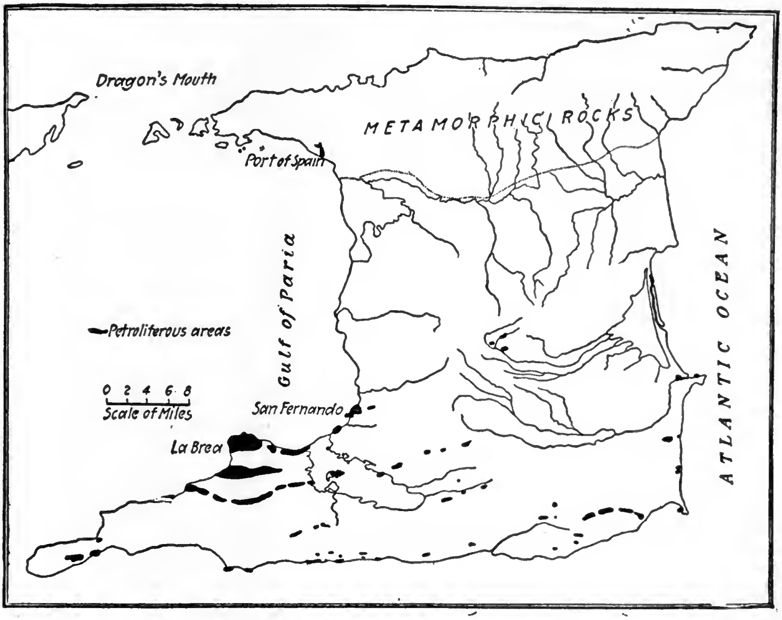

FIG. 247.—Sketch map of Trinidad showing petroliferous areas. (*Based on on map by Wall and Sawkins. Petroliferous areas from map by Redwood.*)

Fig. 247 is a map of Trinidad showing the position of the metamorphic belt in the northern area as outlined by Wall and Sawkins. Oil is present in the Tertiary formations, which are sediments

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[1] CUNNINGHAM-CRAIG, E. H.: Oil Finding, pp. 6, 44, 74, 75, 102, London, 1914.

RICHARDSON, CLIFFORD: The Modern Asphalt Pavement, New York, 1905.

CROSBY, W. O.: Native Bitumens and the Pitch Lake of Trinidad. *Am. Naturalist*, vol. 13, p. 240, 1879.

[2] CUNNINGHAM-CRAIG, E. H.: *Op. cit.*, p. 102.

formed under fluviatile, deltaic, and estuarian conditions. According to Cunningham-Craig the Tertiary rocks include littoral sandstones and marine silts, thin calcareous bands and ironstones, lignite seams, and oyster beds, showing rapidly alternating marine and terrestrial conditions.

The oil is in the sands that lie between the clays and is concentrated in anticlines. The wells are from 700 to 2,000 feet deep, and according to Thompson[1] many of them have produced from 37,000 to 375,000 barrels within one to three years. Oil fields located near La Brea produce a heavy oil from Miocene sand. In the Tabaquite field near the center of the island a very light oil of pariffin base is produced from Cretaceous sandstone. The structure is anticlinal.

The Pitch Lake of La Brea, a village on a small peninsula southwest of San Fernando, is about 137 acres in extent and of great depth. It has produced over 2,000,000 tons within 40 years. It is one of the largest deposits of solid or semisolid bitumen known. The pitch at the surface has the consistency of coal, so that teams may be driven on it. It is chopped with axes and loaded into carts. About 140,000 tons was produced in 1909. As the pitch is removed the lake tends to maintain a level surface although the level of the lake is sinking. There was also a constant flowage of pitch to the sea in a stream 15 to 18 feet deep. Pitch not only forms the seashore for the greater part of a distance of 4 miles, but in front of the village it appears from beneath the sea as a solid barrier reef which lies some 100 yards from the shore and is a source of danger to boatmen when the water is rough. According to Crosby[2] the peninsula of La Brea owes its existence to the protection afforded to the land by the asphalt, which is more resistant to waves than the unconsolidated clays and sands that form the coast to the east and south. The village of La Brea rests on the pitch, and the inhabitants complain that their houses are thrown out of level by the rising or sinking of the tarry formation. Inflammable gas with sulphureted hydrogen and salty sulphurous water issue near the center of the lake.[3]

The material as mined consists of about one-third bitumen, one-

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[1] Thompson, A. B.: Oil-Field Development, p. 40, 1916.

[2] Crosby, W. O.: Native Bitumen and the Pitch Lake of Trinidad. *Am. Naturalist*, vol. 13, p. 240, 1879.

[3] Thompson, A. B.: Oil-Field Development, p. 188, London, 1916.

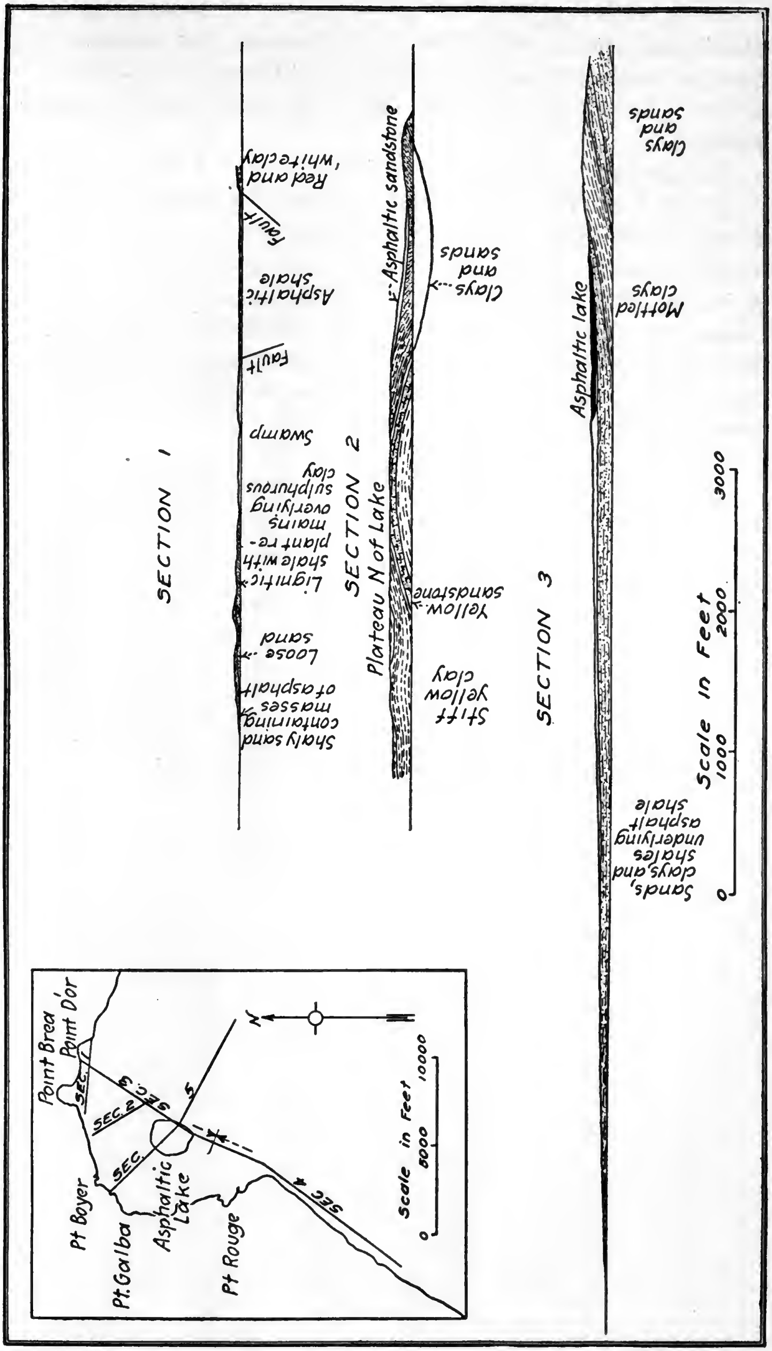

Fig. 248.—Plan and sections of Trinidad asphaltic lake region. (*After Wall and Sawkins.*) For sections 4 and 5, see Fig. 249.

third sand, and one-third water. On heating, the bitumen liquefies, the sand sinks and is separated, and the water is driven off as steam. According to Crosby the pitch is rich also in vegetable remains.

The geology of the region containing Pitch Lake is shown by Figs. 248 and 249. The strata are thrown into gentle folds. As shown by these sections, the lake is situated in an open syncline. Cunningham-Craig,[1] however, who studied the region at a later date than Wall and Sawkins, in tracing the genesis of the lake, states that it has been formed by the denudation of the soft clay that caps a petroliferous sand, in an area where it had been thrown upward by folding. The removal of the clay permitted the oil to escape and form the lake.

Petroleum Produced in Trinidad, 1908-1917

	Barrels		Barrels
1908	169	1913	503,616
1909	57,143	1914	643,533
1910	142,857	1915	[a]750,000
1911	285,307	1916	928,581
1912	436,805	1917	1,599,455

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[1] Cunningham-Craig, E. H.: Oil Finding, pp. 90-100, 1914.

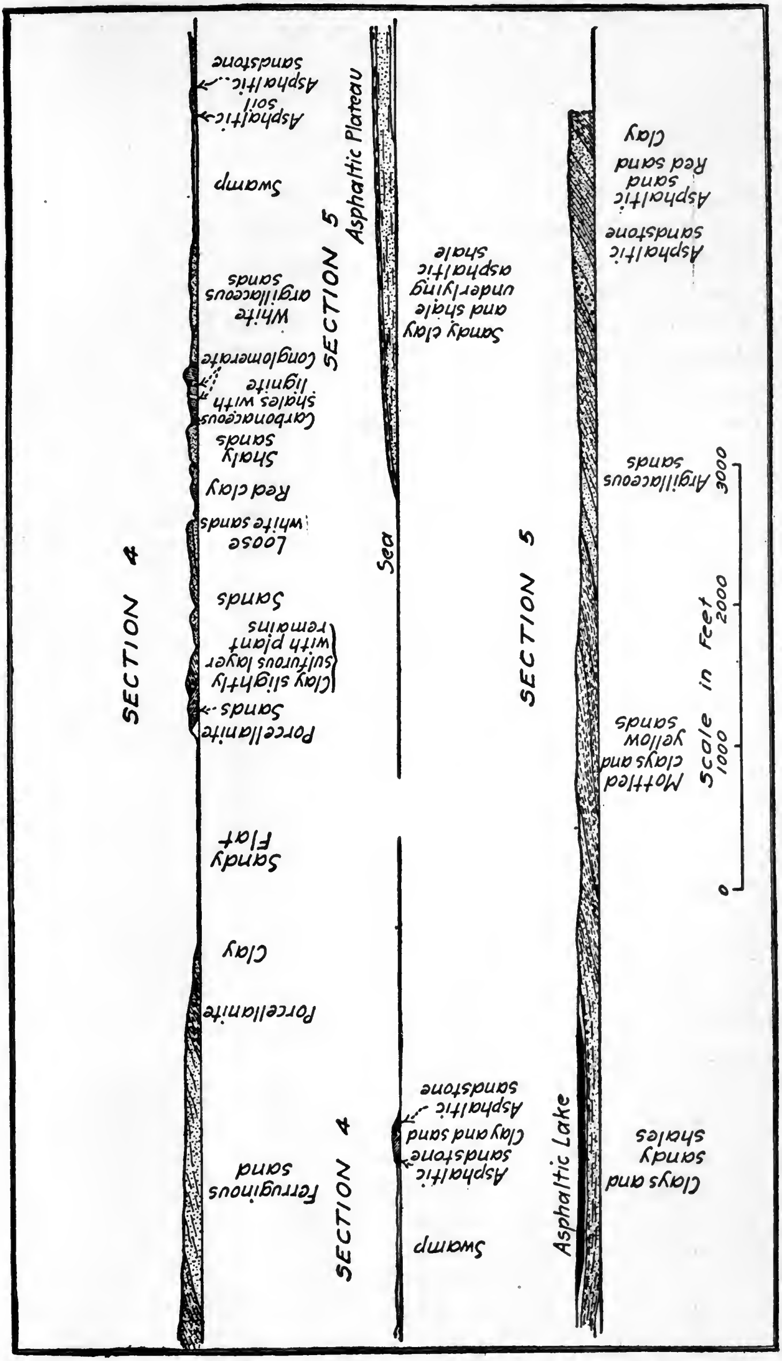

FIG. 249.—Sections of asphaltic lake region, Trinidad. (*After Wall and Sawkins.*) For position of sections, see Fig. 248.

CHAPTER XXVIII

SOUTH AMERICA

VENEZUELA

In Venezuela deposits of bitumen are found at many places. The best known is the Bermudez asphalt lake, so called from the name of the State in which it is located. This lake is near the coast of the Gulf of Paria, a short distance from Pedernales, in the eastern part of Venezuela (Fig. 250) not far from the Pitch Lake of Trinidad. The deposit is about 2,500 feet long in a northeasterly direction and from 300 to 600 feet wide. It has yielded large amounts of commercial asphalt, which is purer than Trinidad asphalt and is said to contain only 2.14 per cent of earthy and vegetable matter. The deposit is, however, not as deep as that of Trinidad. Oil springs and mud volcanoes occur also in this region.

Oil seeps and asphalt are found at many places in the vicinity of Lake Maracaibo. Clapp[1] lists the occurrences in this region as follows:

1. In the district of Mara, near the River Liman asphalt lake, where oozings of petroleum cover considerable areas.
2. At Bella Vista, near the city of Maracaibo.
3. In the district of Sucre, on the eastern shore of Lake Maracaibo, where signs of petroleum have been found associated with asphalt deposits.
4. On the Sardinate River, extending into Colombia, where petroleum is developed on a small scale and sold locally.
5. In the district of Colon, in the State of Zulia, south of Lake Maracaibo. This is the largest and most accessible field in Venezuela at present developed.
6. In the Perija field, 50 miles west of Lake Maracaibo.

West of Maracaibo Lake the rocks dip eastward, away from the Perija Mountains. Oil is believed to have accumulated on local subordinate folds in Cretaceous rocks.

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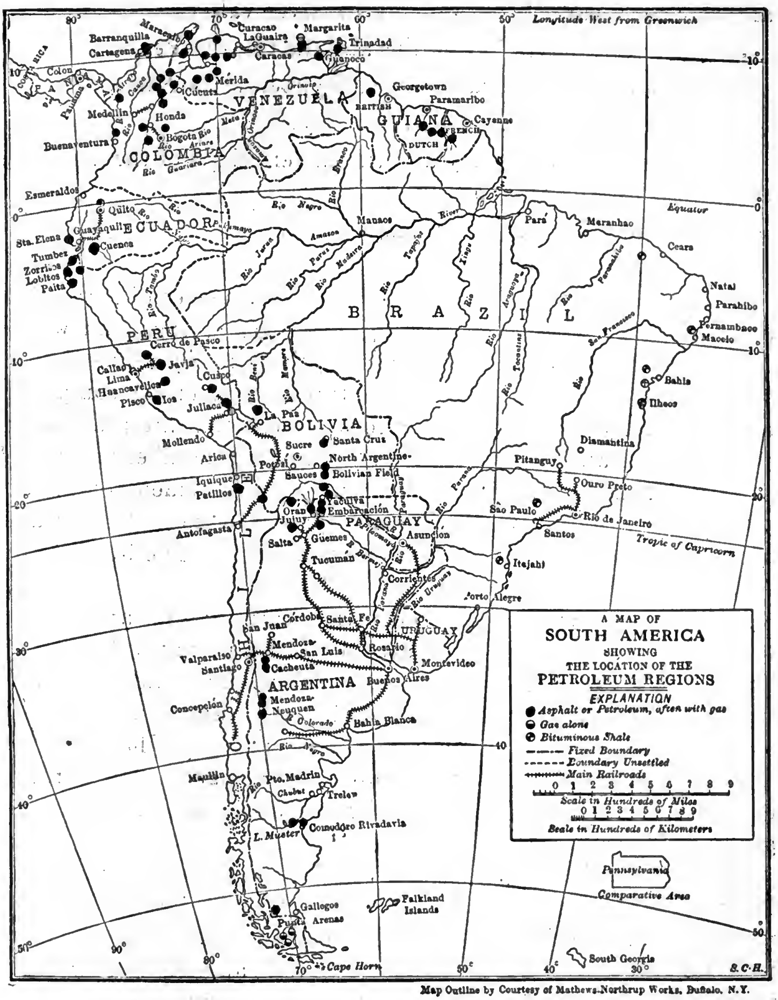
[1] Clapp, F. G.: Petroleum Resources of South America. Am. Inst. Min. Eng. *Bull.* 130, pp. 1,764-1,765, 1917.

COLOMBIA

Colombia.—Colombia[1] may be divided into seven provinces, which are more or less geographic units. Each province, according to White, has distinctive petroliferous evidence, structural



Map Outline by Courtesy of Mathews-Northrup Works, Buffalo, N.Y.

FIG. 250.—Index map of South America, showing regions containing petroleum, asphalt, gas and oil shale. (*Based on map by Clapp and Herold.*)

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[1] WHITE, K. D.: Oil Development in Colombia, South America Southwestern Assoc. Pet. Geologists *Bull.*, vol. 1, pp. 157-159, 1917.

deformation, and stratigraphic section. The seven provinces are as follows:

1. The Caribbean region, extending from the Gulf of Darien to the mouth of the Magdalena River, including the Sinu River valley and the lower part of the Magdalena River valley.
2. The Santa Marta Mountains and the Goajira Peninsula.
3. The lower Magdalena River valley, below the falls at Honda.
4. The upper Magdalena River valley.
5. The Meta River valley and the eastern slope of the Andes in the Orinoco River drainage basin.
6. The Lake Maracaibo drainage basin.
7. The Pacific coast region.

In the northern or Caribbean region the evidences of petroleum are mud volcanoes, some covering acres, gas springs, salt-water springs, and seeps of petroleum ranging from heavy asphaltic oils with a gravity as low as 10° Baumé through amber oils composed almost entirely of the lubricants to white oils that are practically pure kerosene and gasoline. The seeps are in general either in the shattered zones of faults of considerable displacement or in the crushed cores of closely folded asymmetric anticlines. The surface rocks are either Miocene or Pliocene sediments. The Miocene of the coast has a thickness of at least 8,000 feet.

According to Arnold,[1] the rocks that carry the oil are mostly coal-bearing also and are of early Tertiary, probably Oligocene age. The great bulk of the sediments are dark-colored shales, with sandstone members; the oil occurs in the sandstones.

The Caribbean district includes several promising fields. The Turbaco field lies 12 to 15 miles south of Cartagena. Its surface evidence of oil consists largely of mud volcanoes. A medium-grade oil is produced.

The Tubara field is 20 miles east of Cartagena. As many as 100 mud volcanoes are said to occur in an area of 3 acres in the vicinity of the wells. A Canadian company has drilled three wells ranging in depth from 700 to 3,018 feet, at least one of which yielded 7 or 8 barrels daily of oil having an asphalt base and a gravity of 22° to 26° Baumé. The oil is associated with considerable gas.

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[1] Arnold, Ralph: Conservation of the Oil and Gas Resources of the Americas. Second Pan American Sci. Cong. *Proc.*, vol. 3, pp. 225-227, 1917.

The lower part of the valley of Magdalena River, extending from 200 to 500 miles from the coast, is bounded by the Eastern and Central Andean ranges and in places is 100 miles wide. This area is now being actively explored. The petroleum in the seeps ranges from liquid asphaltum to amber oils. Gas springs and sulphur-water springs occur. There are also veins of gilsonite and grahamite, and asphaltum-impregnated sandstones. Most of the oil seeps consist of thick black asphaltic oil having a gravity of about 12° to 14° Baumé. The larger number of seeps come from black carbonaceous limestones and shales of Cretaceous age, though asphaltic sandstones, gilsonite and grahamite veins, and oil seeps occur in younger beds.

The structure is of the block-fault mountain type. This major structure has been complicated by intense folding, parallel to the Andean ranges and less intense transverse or cross folding. The lands that may be studied where the petroleum-bearing beds may be reached by the drill are, according to White, confined to a narrow belt at the foot of the two mountain ranges.

The upper part of the Magdalena Valley is much narrower than the lower part and can be studied across its entire width, though the older strata are masked in places by a covering of late Tertiary pyroclastic rocks. The evidence of petroleum consists of seeps of thick black asphaltic oils having a gravity of 14° Baumé and amber oils of 18° Baumé. The seeps are in general found along the lines of faulting, where the black carbonaceous limestones and shales of Cretaceous age have been brought to or very close to the surface. Seeps occur also in rocks of later age, especially the Tertiary tuffs.

In the Lake Maracaibo drainage basin, in the Department of Santander, numerous seeps of high-grade oil, as stated by White, are located on the crest of an asymmetric anticline.

The Magdalena and Santander districts together cover a belt approximately 200 miles long and 50 miles wide, or 10,000 square miles, where oil seeps are numerous. At Pamplona, near the Venezuelan frontier, a small refinery is operated. The oil in this district occurs in the Cretaceous limestones and sandstones and in the coal-bearing lower Tertiary (probably Oligocene) beds, where sandstones are the reservoirs. Well-defined anticlines, in places overturned, and possibly fault zones in the Cretaceous rocks are said to afford favorable structure for accumulation. According to Aughinbaugh,[1] foreign editor of the New York *Commercial*, a field in Colombia near the Venezuela line has been developed which promises to become very large. The Caribbean Petroleum Co., he says, has brought in 17 wells, some of them gushers. In this region, at a depth of about 1,000 feet, a gusher yielding 12,000 barrels a day was brought in.

In the Tolima district are grouped the occurrences in the upper Magdalena basin, in the departments of Cundinamarca and Tolima, and on the edge of the San Martin and Casanare plains. The oil-bearing rocks are probably of Cretaceous or Tertiary age and form a continuation of those in the Santander belt, to the north.

The Pacific district includes a belt 60 or 70 miles long extending up the Pacific coast north of Buenaventura to Baudo River and reaching inland to Atrato River at Quibdo and as far south as Cali, on the Cauca River. On Baudo River oil is associated with the "coal series" and probably occurs in a southwestward extension of the Caribbean coastal belt.

AREAS INCLUDED IN THE PROSPECTIVE OIL DISTRICTS OF COLOMBIA, IN SQUARE MILES[a]

District	Area	Possible Oil Territory	Proved Oil Territory
Caribbean	15,000	300	1
Pacific	1,800	18	..
Magdalena-Santander	10,000	200	1
Tolima	7,500	100	..
	34,300	618	2

[a] ARNOLD, RALPH: Conservation of Oil and Gas Resources of the Americas. Second Pan American Sci. Cong. *Proc.*, vol. 3, p. 225, 1917.

PERU

Peru[2] is one of the leading oil-producing countries in South America. Oil is found in the northwestern part of the Republic (Fig. 251), on the coast near the Ecuador boundary, and in the Lake Titicaca region. The coastal belt extends southward along

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[1] AUGHINBAUGH, W. E.: Supplement to New York *Commercial*, not dated.

[2] MARSTERS, V. F.: Informe Preliminar sobre la zona Petrolífera del norte del Perú. Cuerp. ing. Minas del Perú *Bol.* 50, pp. 1-150, 1907.

the Pacific Ocean from the Ecuador frontier for 180 miles, to and beyond Paita, and is bounded on the east by spurs of the Andes. It is about 30 miles wide and occupies the region near Tumbez and the northern part of the province of Piura. Asphaltites and asphaltic clays are common in Peru. The petroliferous rocks are porous sandstones of Eocene age. Fossils in the petroliferous series closely resemble those of the California Eocene. The sequence of formations from east to west, as described by Deustua,[1] is as follows:

Commencing in the mountain region of La Brea, there are: (1) A series of crystalline rocks, dioritic in the main, which may be regarded as the basal formation of the chain; (2) a mass of sediments composed almost entirely of shales metamorphosed into slates, and greatly folded and faulted; these constitute the western flanks of La Brea; (3) a series of thick beds of sandstones, which are highly indurated and unconformable to (2) and which also form a part of the flanks of La Brea; (4) a series of alternating beds of sandstones and clays or shales, unconformable to (3) and extending from the base of La Brea Mountain to the sea-shore; the lower beds of this series inclose the oil-bearing strata; (5) a series of horizontal deposits, unconformable to (4), forming the plateau of the "tablazo" and composed of clays of different colors, alternating with a few beds of loose and little-hardened sandstones; both rocks are capped by thick beds of conglomerates. There are several conglomerates in division 4, at least some of which mark unconformities. The angular difference, however, between the beds above and below the unconformities is slight as compared with the regional dips.

The metamorphism of the shales (division 2) is due to the intrusive rock (1), and these rocks form the principal base of the northern oil-bearing region, and the eastern limit of the oldest sediments. The rocks of division 3 are later than the metamorphosed shales, but older than those of division 4, which form a series of anticlinal and synclinal flexures, terminating in a wide anticline along the coast line. The upper sandstones are gray and coarse grained, and are intercalated with red and yellow clays rich in fossils; the lower oil-bearing sandstones are dark and coarse grained, and are

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[1] Duestua, R. A.: La Industria del Petróleo en el Perú durante 1915, 2d ed., Lima, 1916, quoted from Clapp, F. G., Am. Inst. Min. Eng. *Bull.* 130, p. 1,751, 1917. The original is not accessible to me.—W. H. E.

intercalated with thick clayey beds which are greenish, nonfossiliferous, and more compact than the upper argillaceous beds.

The plateau deposits show three well-marked fossiliferous beds. The conglomeratic cap is formed of pebbles, breccia remains, and coral reefs, strongly cemented. Fossils are found on the surface, the species of which are identical with those now living in the sea, near the shore. It is obvious that the beds were laid down in shallow water.

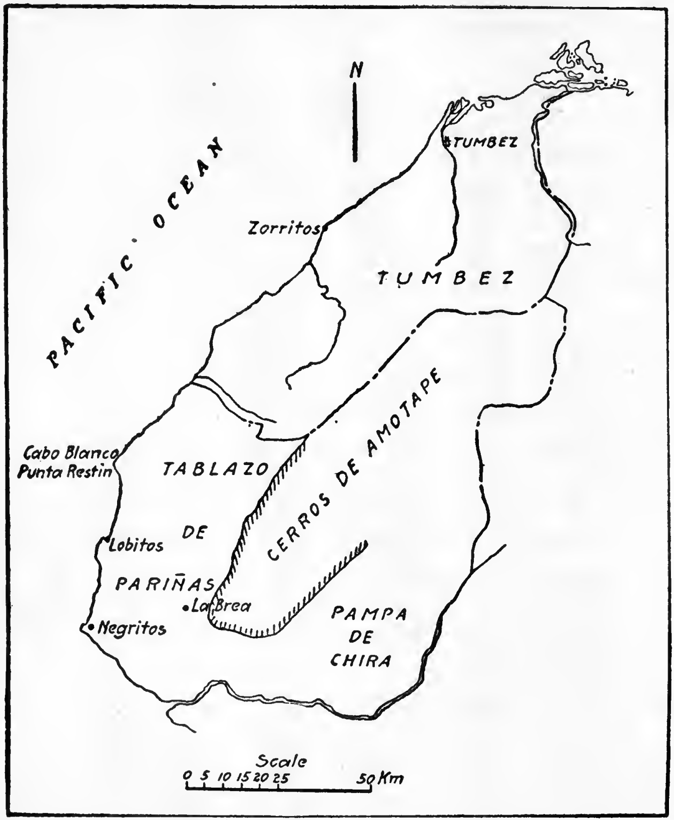

FIG. 251.—Sketch map showing location of oil fields in northern Peru. (*Based on map by Marsters.*)

The regional dip of the country is westward, away from the mountains, but in the oil fields the beds dip east (Fig. 252). The principal fields are associated with anticlines. No large gushers have yet been brought in, but some of the wells yield over 100 barrels a day. The initial production is not very long-lived, and after a few weeks or months it settles down to 4 to 10 barrels a day, which appears to be maintained for several years. The depth of the wells ranges from 700 to 3,000 feet, the average being probably about 1,500 feet.

The Zorritos field (Fig. 253) is the northernmost of the Peruvian fields and lies a few miles south of Tumbez, on a narrow, sharp fold that runs parallel with the coast. The producing territory extends along the coast for about 4 miles, most of the producing wells being drilled at the water's edge. The oil is of asphalt base and ranges from about 37° to 43° Baumé. The wells are from 600 to 850 feet deep and yield an average of 6 barrels a day. The fold is faulted longitudinally. The highest part of it is dry. This may be due to low water head in the sands, so that the oil has not been forced to the crest of the anticline, or it may be due to an overthrust fault on the south end.

There are at Zorritos three principal sands, one at a depth of 800 feet, one at 1,200 feet, and one at 1,700 feet. The upper two sands have been practically exhausted, and the present output is obtained from

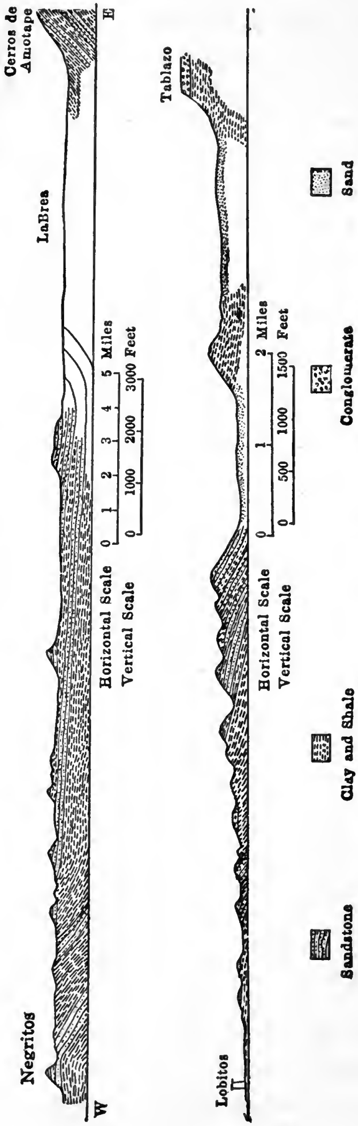

FIG. 252.—Sections of Peruvian oil fields, looking north. (*After Marsters.*)

the deep one. The sands are thick, soft, and shaly. The production averages about 8 barrels a day per well. No big wells have been drilled. Owing to the very soft and shaly nature of the sands shooting is out of the question.

Producing wells recently sunk at Punta Restin and Cabo Blanco are on a narrow compressed and longitudinally faulted anticline running close to the beach. Much of the west flank of the anticline is in the sea and has not been drilled, owing, it is said, to refusal of the Government to permit drilling in the sea.

La Brea is a seep lying inland close to the base of the Amotape Mountains. The oil is derived from the basal conglomerate and coarse sandstone series. It has accumulated in a small dome on a very extensive anticline, which is at this point capped by several hundred feet of soft shale. Nearly everywhere else this anticline is deeply eroded, exposing the sands. The dome is faulted and the seep is due to leakage along fault planes.

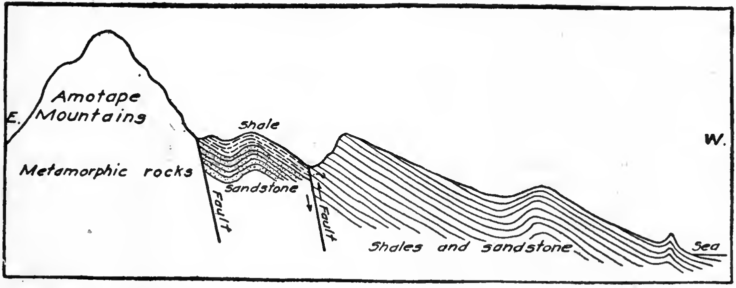

Fig. 253.—Generalized ideal geological section showing structure Mancora Valley, between Zorritos and Lobitos, Peru (looking south.)

The Lobitos field lies about 110 kilometers south of Zorritos, and comprises a proved area of 25 square miles. In character of the oil and productivity of the wells this field is similar to Zorritos.

The Negritos field is the southernmost one developed of the coastal areas. It is 40 miles north of Paita and includes about 150 square miles of proved territory comprised in the hacienda La Mina Brea and Pariñas. The oil is brown and ranges in gravity from 35° to 38° Baumé. The wells range in depth from 500 to 3,000 feet and in individual production from over 800 barrels daily to an average settled production of 4 to 7 barrels. An asphalt seep, La Brea, is found 11 miles east of the field. The rocks in the Negritos field dip in general away from the mountains. Locally there are reversals of dip, and the field is probably on the eastern flank of a great anticline (Fig. 254). The dip of the sandstone and clay at the south end of the region is southeast; farther northward the dip becomes east; and north of Negritos it is northeast. Possibly the field is a dome with the west side below the sea. The eastern flanks of the fold present a number of secondary folds and local faults, which alter somewhat the distribution of the oil zones. The bore holes made along the flanks have yielded the best results. Along the anticlinal axis or ridge itself the results have been poor, and far to the east of the flanks there is danger of encountering the corresponding syncline, where the probability of obtaining oil is remote.

From a depth of 45 to 1,000 feet as many as seven oil-bearing formations have been encountered, but as a rule these are of little value, the most productive beds being those found below depths of 1,500 feet.

The eastward dip is the reverse of the regional dip of the country. The most reasonable supposition is that the normal regional westward dip is resumed west of the Negritos and Lobitos fields, beneath the sea floor. The monocline is then merely the eastern (reverse dip) side of a huge anticline. However, some of the oil is produced from relatively shallow wells out on the flank of the fold. As the dip at Negritos and Lobitos averages about 20°, it follows that some of the producing beds crop out on the surface within the limits of the field and that the oil must be accumulated in lenticular sands (Fig. 254). The oil at Negritos has probably accumulated both in anticlines and in sealed beds.

The Titicaca field lies high in the Andes, 8 miles from Lake Titicaca, near the Bolivian frontier. Exudations of oil are numerous, and according to Duestua[1] oil issues in boiling springs. The rocks are limestones, clays, and sandstones. An anticline is said to extend N. 40° W. through the field, and the formations on its flanks are much disturbed by faulting and folding.

Ten wells had been drilled up to 1908, with varying results. Although the initial production in some wells has been as high as 900 barrels daily, the output falls rapidly. The oil is unlike that of the northern fields of Peru, as it contains about 5 per cent of paraffin wax and 40 to 50 per cent of kerosene.

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[1] Duestua, R. A.: La Industria del Petróleo en el Perú durante 1915, Lima, 1916.

PETROLEUM PRODUCED IN PERU, 1907-1917, IN BARRELS OF 42 GALLONS

Year	Lobitos	Negritos	Zorritos	Lake Titicaca (Huancane)	Lagunitos	Total	
						Barrels	Metric Tons[a]
1907	[b]279,000	396,750	65,476	15,000	....	756,226	100,830
1908	319,898	543,750	71,429	[b]76,103	....	1,011,180	134,824
1909	429,195	740,070	70,750	[b]76,103	....	1,316,118	175,482
1910	400,080	773,025	107,000	[b]50,000	....	1,330,105	177,347
1911	391,290	882,698	64,286	[b]30,000	....	1,368,274	182,436
1912	587,048	1,071,000	78,095	[b]15,000	....	1,751,143	233,486
1913	557,355	1,136,490	83,343	[b]10,000	346,073	2,133,261	284,434
1914	504,743	1,032,210	88,136	[b]10,000	282,713	1,917,802	255,707
1915	664,972	1,355,925	72,736	b1,000	392,618	2,487,251	331,633
1916	654,060	[c]1,822,733	73,852	....	([d])	2,550,645	340,086
1917	686,595	[c]1,771,560	75,262	....	([d])	2,533,417	337,789

[a] One metric ton=7.5 barrels.
[b] Estimated.
[c] Includes Lagunitos.
[d] Included in Negritos.

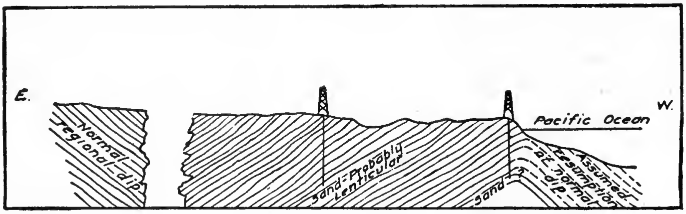

FIG. 254.—Generalized geological section, showing structure of Negritos oil field, Peru (looking south.) The western part of section is hypothetical.

ECUADOR

The eastern range of the Andes in Ecuador[1] consists of rocks of Archean age; the coastal regions consist of Tertiary deposits; and the intermediate region, which includes the western range of the Andes and the inter-Andean region, is made up mainly of Cretaceous sedimentary and eruptive rocks. Only the western two of these three belts has oil possibilities.

In the Santa Elena field,[2] 64 miles west of Guayaquil, oil seeps

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[1] WOLF, W. A.: Sketch of the Geology of Ecuador. *Min. and Sci. Press,* vol. 105, pp. 110-111, 1912.

[2] ARNOLD, RALPH: Conservation of the Oil and Gas Resources of the Americas. *Econ. Geology,* vol. 11, p. 309, 1916.

and desiccated petroleum residues have long been known. This district is a continuation of the Peruvian coast fields. The oil is derived from sandstones and shales of Eocene age. Forty dug wells at Santa Paula yield small quantities of heavy oil, which is taken to the coast on donkeys. A number of dug wells were formerly operated at Achagian. The oil ranges in gravity between 12° and 22° Baumé. Oil springs are reported on the east side of the Andes, 130 miles north of east of Guayaquil, and at points in the coastal plain north of Guayaquil, particularly at Atacames.

The topography of the Santa Elena field is hilly, with many valleys and ravines, portions of which grade into a plain bordering the Pacific Ocean and Bay of Santa Elena. The climate of the Santa Elena fields is described as healthy. The whole of the peninsula between the Pacific Ocean and the Bay of Santa Elena is considered as more or less petroliferous. Stephan[1] states that the large supply of oil at present obtained at Aguiquimi and at Santa Elena Paula clearly points out the existence of a rich oil zone at a deeper horizon at these points. Petroleum is found at many places near the promontory of Santa Elena. According to unpublished reports by Charles Maddock, seeps of oil are found in many places over an area of 600 square miles. To judge from the depths at which it is found in the adjacent field of Peru it is believed that oil will be reached here at about 1,000 feet.

ARGENTINA AND BOLIVIA

There are three oil-bearing districts in Argentina[2]—the Comodoro Rivadavia district, on the Atlantic coast of Patagonia, and the Salta-Jujuy and Mendoza-Neuquen districts, in the Andean region.

In the Rivadavia district oil was discovered in 1907, when a boring was being sunk for water. The oil-yielding formation is a Cretaceous coarse, pebbly sandstone, which lies on schist and granite and is unconformably overlain by Eocene and later Tertiary tuffaceous and fossiliferous beds. The origin of the oil is obscure. The beds dip southeast at a low angle, not exceeding 12

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[1] Stephan, M. J.: Unpublished Report, quoted by Clapp, F. G., Petroleum Resources of South America. Am. Inst. Min. Eng. *Bull.* 130, pp. 1,776-1,777, 1917.

[2] Arnold, Ralph: Conservation of the Oil and Gas Resources of the Americas. Second Pan American Sci. Cong. *Proc.*, vol. 3, pp. 207-237, 1917; *Econ. Geology*, vol. 11, pp. 203-222, 299-326, 1917.

feet to the mile, and are said to occupy a broad syncline with minor warpings. The oil occurs in flat domes at a depth of 1,800 to 1,900 feet, and Herold[1] states that the structural conditions are shown on the surface and that conditions favor an extension of the producing area. The oil is of asphaltic base and ranges in gravity from 18° to 24° Baumé. The wells are rather small producers, so far averaging less than 100 barrels daily. The oil produced in Argentina comes entirely from the Comodoro Rivadavia field and is consumed in the country, principally for fuel.

PETROLEUM PRODUCED IN ARGENTINA, 1908-1917

Year	Metric Tons	United States Barrels	Year	Metric Tons	United States Barrels
1908..........	1,680	11,472	1913..........	19,050	130,618
1909..........	2,700	18,431	1914..........	40,530	275,500
1910..........	3,050	20,753	1915..........	75,900	516,120
1911..........	1,920	13,119	1916..........	116,000	796,920
1912..........	6,850	47,007	1917..........	166,871	1,144,737

The oil field of northern Argentina and Bolivia[2] extends in a narrow belt from the north-central part of the Province of Salta, Argentina, northward into the central part of Bolivia. This belt passes through the border town of Yacuiva and extends from 18° to 23° south latitude.

The oil region lies between a mountainous country to the west and extensive plains to the east. A series of mountain ranges, with parallel northerly trend, stretch westward with increasing altitude toward the great Andes Range. Between these ranges are long, narrow valleys at altitudes of 10,000 to 12,500 feet above the sea.

The mountainous relief has been produced by the same dynamic forces which caused the uplifting of the main Andes Range. The easternmost range, known as the Sierra de Aguaragüe, with its

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[1] HEROLD, S. C.: Petroleum in the Argentine Republic. *Mining and Metallurgy*, sec. 12, No. 158, pp. 1–5, 1920.

[2] HEROLD, STANLEY C.: The Economic and Geologic Conditions Pertaining to the Occurrence of Oil in the North Argentine-Bolivian Field of South America. Amer. Inst. Min. Eng. *Bull.*, pp. 1,503-1,522, 1918.

northern extension in the Sierras de Santa Cruz, constitutes the frontal range, extending from north to south approximately 300 miles, with altitudes between 1,000 and 3,000 feet above the level of the adjoining plains.

Seeps of oil and asphalt deposits have been known to exist in this part of the continent for many years. Several springs are very persistent in their flow, though each produces only 2 or 3 quarts a day. Among the best known, according to Herold, are the following, named in geographic order from south to north:

Creek	Department
Galarza	Oran (Argentina)
Iquira	Oran (Argentina)
Agua Salada (Ipaquazu)	Tarija (Bolivia)
Los Monos (Villamontes)	Tarija (Bolivia)
Caigua (Villamontes)	Tarija (Bolivia)
Peima	Tarija (Bolivia)
Oquita	Sucre (Bolivia)
Mandiyuti	Sucre (Bolivia)
Espejos (Santa Cruz)	Santa Cruz (Bolivia)

Most of the oils are of paraffin base, though some of the heavy oils contain some asphalt. Usually a small amount of sulphur is present.

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