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Geology and Technology of the California Oil Fields

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BY RALPH ARNOLD
AND
V. R. GARFIAS
Los Angeles, Cal.

Reprinted from *Bulletin* No. 87, March, 1914, American Institute of Mining Engineers

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Geology and Technology of the California Oil Fields

BY RALPH ARNOLD AND V. R. GARFIAS, LOS ANGELES, CAL.

(New York Meeting, February, 1914)

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INTRODUCTION

THE following paper has been prepared to meet a demand for a concise review of the California oil industry. It is based largely upon information secured during the course of the senior author's professional activities, and upon data obtained during the course of investigations for the U. S. Geological Survey and the U. S. Bureau of Mines. Considerable information has been obtained from other sources, and to those who by publication or otherwise have contributed, the writers extend their thanks.

General Statement

In 1912 the United States produced[1] 63.25 per cent. of the world's production of petroleum, Russia, its nearest competitor, yielding only about 19 per cent. The production in 1912 reached 222,113,218 barrels (or 29,615,096 metric tons), compared with 220,449,391 barrels in 1911. The average price per barrel in 1912 was nearly 74 c., as against nearly 61 c. in 1911. The total value, therefore, increased 22.20 per cent., or $163,802,334 above the value for the previous year. These figures of production include pipe-line runs, independent railroad shipments, oil piped direct to refineries, and the crude oil consumed as fuel in oil production. The production does not include oil in storage in the field which has not been sold.

California ranks first of all the States in the Union in the production and value of petroleum, the total output in 1912 being 86,450,767 barrels, or an increase of 6.55 per cent. over the production of the State in 1911. Consumption, however, increased 18.8 per cent. Stocks increased from 44,240,118 barrels at the end of 1911 to 47,552,392 barrels at the end of 1912, when consumption had nearly equaled production. The average price received was 45.4 c. per barrel in 1912, against 47.7 c. in 1911.

Oil stands first in value in the State's mineral products, the output in 1913 being valued at $43,500,000[2] as against $20,000,000 for gold, its nearest competitor. Eleven districts furnish the product, and these, in the order of their importance in 1912, are listed in the table on the opposite page.

With the exception of a negligible quantity of oil carrying some paraffine, all of the oil from the California fields has an asphalt base. About 40 per cent. is what is commonly known as heavy or fuel oil, while about 60 per cent. is passed through stills for topping or refining, the residuum being used as fuel. The bulk of the production is, therefore, used for fuel or road dressing, either in its crude state or as residuum. Most of it is utilized in the Pacific States and Canada, but some is exported to the adjacent States to the east, and to Hawaii, Japan, Alaska, Panama, and South America.

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[1] Figures taken from *Mineral Resources, U. S. Geological Survey.*

[2] Preliminary estimate of the State Mineralogist.

Production of Petroleum in California for 1912

In Barrels of 42 gal.

Valley Districts:		
Coalinga	19,911,820	
Lost Hills	1,367,359	
McKittrick	5,881,996	
Midway	23,928,368	
Sunset	6,509,093	
Kern River	12,558,439	
		70,157,075
Coast Districts:		
Santa Maria	5,909,300	
Summerland	65,376	
Santa Clara Valley	746,780	
Los Angeles	2,670,463	
Puente Hills	6,881,650	
Other fields	20,123	
		16,293,692
Total		86,450,767

The proved area of oil-producing territory in California is approximately 100,000 acres, and this practically represents the possible acreage, as it does not seem probable that any more large districts will be discovered. For that reason, further development doubtless will be carried on within the limits of the proved fields or along the line of minor extensions of the same. Assuming the possible productive area confined to the present districts, California is still destined, according to the most conservative estimates, to hold premier place among the oil-producing States of the Union for many years.

Location of Oil Districts

California is the southernmost State of the United States of America adjacent to the Pacific ocean. It includes an area of 158,360 square miles, comprised within an irregular strip about 200 miles wide, roughly paralleling the coast for 800 miles. The trend of the California coast line is governed by that of the western flanks of the Coast Ranges. These mountains have an average elevation of 2,500 ft. and extend from the northern boundary of the State in a southeasterly direction for 550 miles, changing at Point Conception to a more easterly trend, which is followed to the Mexican frontier, 250 miles southeast. This natural western boundary is duplicated along the eastern portion of the State by the Sierra Nevada, a range of lofty peaks rising, on an average, 10,000 ft. above sea level and culminating in Mount Whitney, the highest mountain in the United States, 14,500 ft. high. The Sierra roughly parallel the Coast Ranges throughout the central half of the State, the depression between these mountain masses forming the Sacramento and San Joaquin valleys, with a total length of 400 miles and an average width of 40 miles. The northern part of this depression is drained by the Sacramento river, the southern part by the San Joaquin, which joins the Sacramento and discharges through a narrow channel into San Francisco bay. North of the Sacramento valley and south of the San Joaquin, the Coast Ranges and Sierra Nevada mountain systems coalesce into extensive regions of irregular mountains and valleys.

Valley Districts.—All the commercially productive oil fields in California are located in the southern half of the State along the flanks of the Coast Ranges, as shown on the map, Fig. 1. The most important developed fields are situated along the southwestern rim of the San Joaquin valley and extend, with intervening unproductive areas, for about 100 miles. The San Joaquin valley districts include the Coalinga, Lost Hills, McKittrick, Midway, Sunset and Kern River. The first is in Fresno county, about 250 miles southeast of San Francisco, and the last five in Kern county, from 80 to 110 miles further southeast. The Sunset district extends around the angle at the southwest corner of the valley, and the Kern River district lies on the lowest foothills of the Sierra Nevada, near the southeastern corner of the San Joaquin valley.

The Valley districts produced in 1912 over 70,000,000 barrels of oil, or about 81 per cent. of the total output of the State. With the exception of the oil from Lost Hills, Belridge, and local areas in the other fields, which produce refining grades up to 40° Baumé gravity (0.8235 sp. gr.), the product of the Valley districts is a typical fuel oil, averaging about 16° Baumé (0.9589 sp. gr.).

Coast Districts.—The fields which yielded in 1912 the remaining 20 per cent. of the State's production are situated on the western flanks of the Coast Ranges in secondary ranges and valleys merging into the main system. These fields extend from Santa Barbara county on the north to Orange county on the south, throughout a distance of about 150 miles. The greatest portion of the yield of these fields is of lighter gravity than the product from the Valley fields, the oil being used largely for refining.

The Santa Maria district is located on the low rolling hills near the coast of Santa Barbara county, about 280 miles southeast of San Francisco and 200 miles northwest of Los Angeles. The Summerland district lies immediately on the coast, 120 miles northwest of Los Angeles, while the Santa Clara valley district includes the region from the Newhall field in Los Angeles county, 40 miles northwest of Los Angeles, to the Ojai Valley field in Ventura county, 50 miles further west. The topography of the Santa Clara valley district consists largely of hills and valleys, some of the oil fields being located in rugged and almost inaccessible places. The Los Angeles district lies on or along the edge of the great coastal plain in or adjacent to the city of Los Angeles. The Puente Hills, or Fullerton district, as it is sometimes called, lies on the south flank of the Puente hills from 12 to 30 miles southeast of Los Angeles.

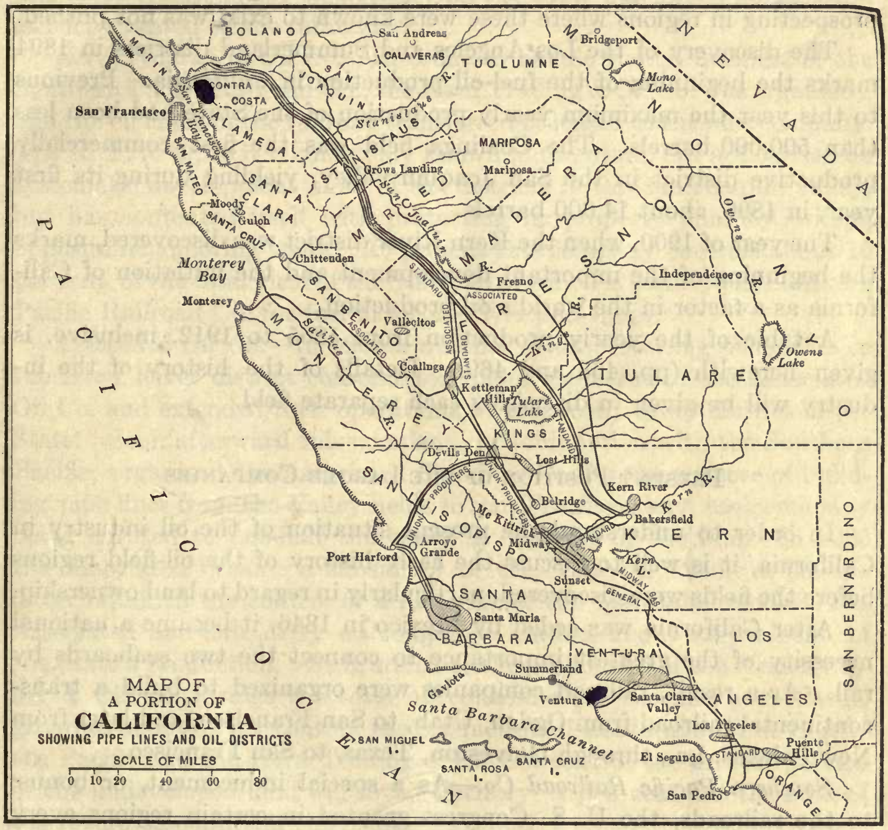

FIG. 1.—MAP OF A PORTION OF CALIFORNIA SHOWING PIPES LINES AND OIL DISTRICTS.

HISTORICAL

The oil industry in California owes its origin to asphaltum mining. The first definite effort to develop oil in California was made in the Ojai valley, Ventura county, in 1867, when a shallow well was drilled near one of the numerous brea or asphaltum deposits of this region which had been worked for some time previous. Owing to the lack of proper tools for operation, and insufficient knowledge concerning the handling of the heavy oil obtained, this well was not a success. Following the drilling of the Ojai valley well there was a lapse of several years and then came more determined development work in the region of Pico canyon and Newhall, in western Los Angeles county. Here a light oil suitable for refining was obtained, and a little later development work in Adams canyon, south of Santa Paula, Ventura county, and in the Puente hills, southeast of Los Angeles, was rewarded by the finding of refining oils. No use was known for the heavy oils at that time, and, as a consequence, prospecting in regions where these were known to exist was not pushed.

The discovery of the Los Angeles and Summerland districts in 1894 marks the beginning of the fuel-oil production in California. Previous to this year the maximum yearly production of the State had been less than 500,000 barrels. The Coalinga field was the first commercially productive district in the San Joaquin valley, yielding during its first year, in 1896, about 14,000 barrels.

The year of 1900, when the Kern River district was discovered, marks the beginning of the important development and the initiation of California as a factor in the world's oil production.

A table of the yearly production from 1865 to 1912, inclusive, is given herewith (pp. 468 and 469.) Details of the history of the industry will be given in discussing each separate field.

Present Position of the Larger Companies

In order to understand the present situation of the oil industry in California, it is well to discuss the early history of the oil-field regions before the fields were discovered, particularly in regard to land ownership.

After California was ceded by Mexico in 1846, it became a national necessity of the greatest importance to connect the two seaboards by rail. As a result, railroad companies were organized to build a transcontinental railroad from Ogden, Utah, to San Francisco, and later from New Orleans, La., through Galveston, Texas, to San Francisco.

Southern Pacific Railroad Co.—As a special inducement, or bonus, to the railroads, the U. S. Congress granted in certain regions every alternate square mile of government land within a zone along the railroad lines varying between 10 and 20 miles in width. It so happened that a large portion of the land in which the San Joaquin valley districts are now located came within the 20-nile zone allotted to the Southern Pacific railroad for building its line along the valley, and as a consequence every alternate section of land within this zone became the property of the railroad. (In this connection it should be remembered that these Valley fields yield at present about 80 per cent. of the State's production.) When some of these lands were granted to the railroad, the government reserved the mineral rights on same, but at the time neither the government nor the railroad officials knew of the existence of the oil deposits. Before the discovery of the Valley fields, the railroad company sold a small portion of this land and rented a larger amount. However, it still retained and at present owns practically every alternate section of land throughout the greater portion of the San Joaquin valley fields. The Coast fields being located in the fertile lands nearer the ocean were owned in large areas—Spanish grants—by the descendants of the Spanish settlers, and little, if any, of the oil territory on the coast was public domain and as such granted to the railroad.

Kern Trading & Oil Co.—In order to handle the oil business of the Southern Pacific Railroad Co., the Kern Trading & Oil Co. was organized, and the oil lands of the railroad transferred or leased to the new company. The K. T. & O., as it is commonly known in the State, has not carried on systematic development in all of the districts in the San Joaquin valley, but has contented itself with protecting its property lines by drilling opposite neighboring wells. At present this company controls about 10 per cent. of the total yield of the State, all of which is used by the Southern Pacific Railroad Co. for fuel in locomotives and shops.

Associated Oil Co.—In 1902 a number of oil-producing properties in the Kern River district consolidated under the name of the Associated Oil Co. and extended their operations to practically every district in the State. Soon afterward this company, in conjunction with the Southern Pacific, organized the Associated Pipe Line Co. for the purpose of building pipe lines from the Valley fields to San Francisco bay, each company being entitled to one-half the carrying capacity of the line. In 1905 the Associated became a subsidiary of the Southern Pacific when the latter obtained the control of a majority of the Associated stock. The Associated and subsidiary oil companies control about 22 per cent. of the State's production, which, added to the production of the Kern Trading & Oil Co., brings the total oil controlled by the Southern Pacific group to about 32 per cent. of the production of California. The Southern Pacific and the Kern Trading & Oil Co. control the greater portion of the undeveloped land in proved territory[3] which contains the bulk of the future oil supply of the State.

The Southern Pacific, through its subsidiary companies, controls pipe lines from the Valley fields to tidewater, with a combined daily capacity estimated at 58,000 barrels, and pipe lines from some of the Coast fields to the seaboard with an aggregate daily capacity of about 25,000 barrels. The Associated Oil Co. owns a fleet of tank steamers plying mainly along the Pacific Coast States and Canada.

Standard Oil Co.—Early in the oil history of California, the Standard Oil Co. obtained control of the Pacific Coast Oil Co. and became interested

[3] The United States government has instituted suits against the Southern Pacific railroad in an effort to recover a part of these lands.

in the transporting, marketing, and refining of oil. As the industry grew it built pipe lines to every important district in the State, also extensive refineries near San Francisco and Los Angeles. Lately this company has become an important factor in oil production, particularly in the Valley fields, and at present controls over 30 per cent. of the production of the State and the greater part of the refining industry. The Standard pipe line system from the Valley fields to San Francisco bay has an aggregate capacity of about 65,000 barrels per day, the coast system of pipe lines having a daily estimated capacity of 30,000 barrels. This company also owns an up-to-date fleet of tank steamers plying along the Pacific seaboard and to foreign ports.

Union-Agency Companies.—The Union Oil Co. was organized in 1890, and at present owns productive oil lands in nearly every district in the State; a fleet of tank steamers; refineries near San Francisco and at Port Harford; and pipe lines from the different districts to tidewater. It also owns a pipe line across the Isthmus of Panama, used to supply fuel to the different plants in the Canal zone.

About four years ago a number of independent producers in the Valley fields organized the Independent Producers Agency in order to market to better advantage their combined product, which at that time aggregated between 15,000 and 20,000 barrels of oil per day. It soon became apparent to the Agency members that in order to dispose of their oil to any but the California marketing companies owning pipe lines it would be necessary for the Agency to transport its oil to the coast. To this end the Agency enlisted the aid of the Union Oil Co., and as a result the Producers Transportation Co. was organized to build a system of pipe lines connecting the Valley districts to Port Harford. The Union Oil Co. acts as the marketing agent for the oil produced by the companies in the Agency. At present there are about 170 companies in the Agency, their combined production, and that of the Union Oil Co. which is handled in conjunction with the Agency's oil, totaling about 25 per cent. of the State's yield.

General Petroleum Co.—Two years ago the General Petroleum Co. was organized, acquiring a number of the small independent properties. Later, the General Pipe Line Co. was organized as an affiliate of the General Petroleum Co., and built a pipe line connecting the Midway district to Los Angeles. Last year the General Petroleum Co. came into prominence when it secured an option to buy the Union Oil and subsidiary companies. If this purchase is consummated, the General Petroleum, Union Oil, and Independent Producers group will become one of the most important in the State and will control about one-third of the total present yield.

Royal Dutch-Shell Co.—During the present year—1913—the Royal Dutch-Shell group acquired the California Oilfields, Ltd., one of the largest companies outside of those just mentioned, and one or two other properties in the Valley fields, and although it is estimated that the present combined production of these properties represents a small percentage of the total yield of the State, it is natural to suppose that such a strong organization as the Royal Dutch-Shell Co. will eventually assume a more important position in the California petroleum industry.

It is estimated that there were 290 oil-producing companies in the State during 1912, with a combined production of some 86,450,000 barrels for the year, and that about 87 per cent. of this was controlled by the three groups first mentioned through purchase from independent consumers, royalties from rented oil lands, and production from their own properties, the remaining 13 per cent. being marketed by small independent companies.

Market Conditions and Price of Oil

The Railroads and the Price of Oil.—The largest consumers of oil in the State are the railroads, it being estimated that in 1912 the Southern Pacific alone used 11,680,000 barrels, or 13.5 per cent. of the total production of the State, or about 16.4 per cent. of the production of the Valley fields, from which the fuel supply of the railroads is obtained almost entirely. It is thought that the Kern Trading & Oil Co. furnished the Southern Pacific railroad only a portion of the oil consumed, the remainder being obtained from other sources. The Atchison, Topeka & Santa Fé railroad also owns a large acreage of proved land in the Midway district and lesser holdings in the Kern River and Puente Hills districts, and produces much of its own oil, but still buys some. It is evident, therefore, that it is to the railroads' advantage to try to hold the price of fuel oil as low as possible. Again, there will be no immediate need to develop further the railroad oil lands if the independent producer, who must continue to operate his producing wells under the present unfavorable conditions, as a matter of self preservation, is compelled to sell his product at a price below what it costs the railroad companies to produce it, for under these circumstances the required amount is readily and cheaply obtained by the railroads while they save their own supply for future demands.

At present the Standard Oil Co. produces little heavy oil and does not buy any under 18° Baumé (0.9459 sp. gr.). It is not concerned, therefore, about the price at which the heavier grades are purchased by the railroads. True this company sells in the State and exports residuum from its refineries for fuel, but the profits derived from the sale of this heavy oil are believed to be small compared with those derived from the sale of its lighter refined products. For these and other reasons which have been made clear in the course of time, the Standard Oil Co. and the

Southern Pacific Co. and the latter's subsidiaries have worked in harmony as regards their influence toward keeping the price of crude oil in California as low as possible. This condition was brought about and made possible by the control of the oil-transportation facilities by the two companies, and has been sustained by the overproduction occasioned by the bringing in during the last three or four years of the large flowing wells in the Valley districts.

Position of the Small Producer.—Under these conditions an independent company in the Valley fields, producing the average quality of fuel oil, had to sell at the price offered by the Standard Oil or Southern Pacific Railroad companies, or, as an alternative, ship the product by rail to the coast and sell it in the open market. In most cases this last course did not materially improve conditions, as the railroad freight on oil from the Valley fields to San Francisco added to the cost of transporting the oil from the property to the railroad, and to the cost of production, left, as a rule, little or no margin of profit at the price paid for the oil at tidewater.

Effect of the Advent of an Independent Transportation Company.—In an effort to improve these conditions, the Independent Producers Agency was organized, and later, with the help of the Union Oil Co., the Producers Transportation Co. built pipe lines from the valley to the coast. The Producers Agency became a sort of clearing house for a large portion of the oil produced by independent companies, charging for its handling ½ c. per barrel. The Agency has no interest in the transportation company, the only tie being a contract which binds them for a term of ten years beginning with 1910. The Producers Transportation Co. charges the Agency's members from 17 to 22 c. per barrel for piping the oil from the fields to Port Harford, on the coast. The Union Oil Co. acts as the selling agent for the Agency, and is empowered to make contracts, subject to the Agency's approval, for the whole or any part of the combined production.

From the foregoing it will be noted that up to the present time the local marketing conditions of the San Joaquin valley oil produced by independent operators have only been slightly improved by the organization of the Producers Transportation Co.; in fact, with oil selling at San Francisco for 70 c. per barrel, there is practically no opportunity for the producer to market his oil there at a profit, as Port Harford is about 215 miles from San Francisco and the oil has to be transported in tank steamers. It is expected by many familiar with the oil situation that with the passing of the present period of overproduction the price of oil will be materially increased, as soon as the large companies are compelled to draw from their stock to fulfill their selling contracts. While the producer, up to the present time, has benefited only slightly by the organization of the Agency and the Producers Transportation Co., this latter company, on the other hand, has become a very lucrative enterprise. It is evident, therefore, that even under the present unfavorable conditions, the position of the independent producers would be improved had they been able at the outset to build their own pipe line and operate it to their mutual benefit.

Oil Reserve and Future Price of Oil.—The probable productive oil territory of California is to all intents and purposes outlined to-day, and the same statement holds good for all of the Pacific coast of the United States, for outside of California there is within the region mentioned, with the possible exception of Alaska, no commercial oil field, nor do the geologic conditions offer any hope of any important field ever being developed.

The proved area of California consists of approximately 100,000 acres, or 156 square miles, outside of which there is a relatively small amount of probable territory, and this latter area is becoming more and more restricted each year through the adverse results obtained in the drilling of test or "wild-cat" wells at the most favorable localities. This proved acreage contains an available reserve which the senior author has estimated at from four to eight billion barrels of oil, the variability in estimate being due to the uncertain effects which such factors as the ingress of water, etc., have on the quantity which can be recovered at a commercial profit. The oil production of California for the calendar year 1913 was about 97,000,000 barrels, which is the maximum for any one year up to date. At this rate of production, the California fields would last only 40 to 80 years, but it is quite obvious to any one who has studied the normal rate of decrease in the production of individual wells, even in a cursory manner, that it will take a most vigorous campaign of drilling to keep up the present rate, let alone increase it to any appreciable extent. Furthermore, within a short time the production will begin to decrease in spite of the most extensive drilling, as it has done in other States, so that it will require from 50 to 100 years in which to recover the available supply.

Roughly speaking, it has been found by experience that to simply maintain the production of any group of wells in California, it is necessary to drill one new well each year for every five producing during that year. In other words, the normal decrease is nearer 20 per cent. than 10 per cent. as was estimated when the field gas pressure was high.

Although the production in California has grown rapidly during the past few years, the consumption has nearly kept pace. At present the oil in storage in the State is about 50,000,000 barrels, or only about a six months' supply. For the first half of 1913 the surplus production over consumption averaged only 2,085 barrels per day; for October the average was about 18,000 barrels per day and practically all of this came from the flush yield of two or three big gushers which were recently brought in and the production from which is even now rapidly falling off. In estimating future production, the flush yield of gushers must be taken into account, but in this connection it should be borne in mind that these big wells are becoming less and less common and their period of abnormally large flow shorter and shorter as the fields become developed and the field gas pressure is consequently reduced.

As a concluding statement concerning production, it is the senior author's belief that the total yield of California for any one year will never go much, if any, over 100,000,000 barrels and that the time will come within the next year or two when the maximum production will be reached, after which, the curve of production will be a descending one. Such has been the history of all of the older fields in this country and such is the logical result to be expected in California. With the increasing uses and markets for oil resulting in a constantly increasing consumption, it is obvious that the price of oil will go up rapidly the minute the general public realizes that the reserves are being drawn upon to meet the demand.

The standard for fuel values is coal, and compared with coal on the Pacific coast, heat unit for heat unit, oil is worth 93 c. per barrel at the well. Considering the many acknowledged advantages which oil has over coal as a fuel, and the many uses for which oil is more valuable than as a fuel, it will be clear to the thoughtful man that the price of even fuel oil will eventually go much higher than the standard set by coal. True, certain of the larger companies in the California field are not talking in an optimistic vein regarding the immediate future price of oil, but their almost feverish activity to acquire additional acreage and production speaks louder than words as to their real beliefs in the matter.

Transportation

In order to understand the conditions affecting oil transportation from any district to the coast, it is necessary to keep in mind whether the district in question is located along the western (Coast districts) or eastern flanks (Valley districts) of the Coast ranges. Transportation from the Coast districts to tidewater is a comparatively simple and inexpensive operation, the distance that the oil has to be piped never being over 50 miles. Ideal conditions are attained in the Los Angeles field, where producing wells are located about 1 mile from the business center of the city of Los Angeles, which has an estimated population of 400,000. The Puente Hills district lies from 12 to 25 miles east of the city of Los Angeles and about 30 miles from Los Angeles harbor. Another district advantageously located is the Summerland, where the wells are located on wharves and drilled under the Pacific ocean. Nearly all the lines joining the Coast fields to Los Angeles or tidewater are laid over flat or low rolling ground, and their operation is further facilitated by the high gravity of the oil produced in most of the fields. In fact, nearly all the lines from the Santa Clara valley fields transporting light oils are operated without pumps, the oil gravitating for about 50 miles to Ventura, on the coast. The good quality of the oil and the low cost of transporting it to the market greatly benefit the independent producer in the Coast fields, as the large marketing companies are anxious to obtain all the light oil in these fields and the heavier grades can be readily disposed of at a good price to the small consumers in the cities along the coast. Unfortunately, the most productive fields (yielding 80 per cent. of the State's production) are separated from tidewater by the Coast ranges, and in order to transport the oil to the coast it is necessary to pipe it for 280 miles along the San Joaquin valley and out to San Francisco bay, or from 110 to 160 miles over the Coast ranges to Monterey bay, Port Harford, or Los Angeles. The cost of building and operating these pipe lines can be afforded only by organizations with large financial backing and which control enough production to keep the lines in continuous operation at their full working capacity. It is evident, therefore, that the cost of piping the bulk of the State's yield (which represents practically all the fuel oil produced) from the Valley districts to tidewater has a most vital effect on the oil industry of the State.

Pipe Lines from the Valley Districts to Tidewater

The pipe lines from the Valley districts to the sea coast are owned or controlled, either directly or through some subsidiary company, by the Standard Oil, Southern Pacific, Union Oil, and General Petroleum companies. The Valley system of the Standard consists of:

Standard Oil Co.

	Estimated Daily Capacity Barrels
Two 8-in. trunk lines 275 miles long from Kern River district to San Francisco bay	60,000
One 8-in. branch line 28 miles long from Coalinga to Mendota	28,000
Two 8-in. branch lines 36 miles long from Kern River to Midway	65,000
One 8-in. branch line 21 miles long from Lost Hills to Pond	20,000

The working capacity of the Standard Oil Co.'s Valley system connecting all the San Joaquin districts to Point Richmond in San Francisco bay is that of the two trunk lines, or about 60,000 barrels per day.

Southern Pacific Railroad

Associated Pipe Line Co.	Estimated Daily Capacity Barrels
One 8-in. trunk line 280 miles long from Kern River to San Francisco bay	13,000
One 8-in. trunk line 285 miles long from Sunset district to San Francisco bay	30,000
Associated Transportation Co.	
One 6-in. trunk line 110 miles long from Coalinga district to Monterey bay	15,000

The total daily capacity of pipe lines controlled by the Southern Pacific Railroad Co. from the Valley districts to San Francisco bay is 43,000 barrels, and from the Coalinga district to Monterey bay 15,000 barrels, making a grand total of 58,000 barrels as the carrying capacity of this company's lines from the Valley districts to tidewater.

Union Oil Co.

Producers Transportation Co.	Estimated Daily Capacity Barrels
Two 8-in. trunk lines 70 miles long from Junction to Port Harford	50,000
With 8-in. branch lines to Coalinga, Kern River, Sunset, Midway, and Lost Hills.	

The Union Oil Co., therefore, controls pipe-line transportation facilities from all the San Joaquin valley districts to Port Harford, having an aggregate daily capacity of about 50,000 barrels. It should be noted that Port Harford is situated 215 miles southeast of San Francisco, and 200 miles to the northwest of Los Angeles.

General Petroleum Co.

General Pipe Line Co.

This company has one 8-in. pipe line from the Midway district to Los Angeles harbor, a distance of 158 miles, the estimated daily capacity of which is about 30,000 barrels. A branch 8-in. line 35 miles long runs from Lebeck Station to Mojave, where the oil is topped before shipping by rail to the south and east of Mojave.

Summary

	Barrels
Total daily carrying capacity of Valley system of pipe lines	198,000
Daily production of Valley districts during 1912	194,500
Available daily pipe-line capacity in excess of production, assuming all lines working at their rated capacity	3,500

Pipe Lines from the Coast Districts to Tidewater

The Santa Maria and Santa Clara valley oil districts are connected by pipe lines to seaboard, while practically all the oil produced in the Los Angeles and Puente Hills districts is piped or hauled into or near Los Angeles, where it is used as fuel or by refineries.

Pipe Lines from Santa Maria District to Seaboard.

Standard Oil Co.

	Barrels
One 8-in. line 32 miles long from Orcutt to Port San Luis, estimated capacity	20,000

This line is only intermittently used, as the oil controlled by the Standard in the Santa Maria district is but a very small fraction of the capacity of the line.

Southern Pacific Railroad Co.

Associated Pipe Line Co.	Barrels
One 8-in. line 35 miles long from Santa Maria to Gaviota, estimated capacity	15,000
One 8-in. line 30 miles long from Orcutt to Port Harford	Idle

Half of this amount, or 7,500 barrels, belongs to the Associated Oil Co., the Union Oil Co. controlling the other half.

Union Oil Co.

This company, through its subsidiaries, controls:

	Barrels
One 8-in. line 50 miles long from Santa Maria to Port Harford	
One 6-in. line 30 miles long from Santa Maria to Port Harford, estimated capacity	40,000
One 2-in. line 30 miles long from Santa Maria to Port Harford for gasoline.	

This company makes use only of from 10,000 to 15,000 barrels per day, this being the oil controlled and produced in Santa Maria.

Other Companies

Pinal-Dome Oil Co.

One 4-in line from Santa Maria field to a topping plant at Betteravia for crude.

One 2-in. line from Santa Maria field to a topping plant at Betteravia for gasoline.

Summary

	Barrels
Total daily carrying capacity of Santa Maria system of pipe lines, assuming idle lines operating at full rate of capacity	90,000
Daily production of Santa Maria district during 1912	16,190

It will be seen that this district is provided with ample pipe-line transportation facilities to seaboard, being able to carry over five times the production of the field during 1912.

Pipe Lines from the Santa Clara Valley District to Seaboard

(Operating mostly by gravity)

Standard Oil Co.

	Barrels
One (2-in., 3-in.), 44 miles long from Newhall field through Santa Clara valley fields to Ventura, estimated daily capacity	1,400

Union Oil Co.

	Barrels
One 4-in. line 45 miles long from Torrey canyon to Ventura, estimated daily capacity	3,000

Summary

	Barrels
Total daily carrying capacity of Santa Clara valley system of pipe lines to Ventura	4,400
Daily production of Santa Clara valley fields for 1912 about	2,040

These fields are, therefore, supplied with pipe lines having an aggregate capacity of about twice their present production.

Pipe Lines from the Los Angeles and Puente Hills Districts to Los Angeles City and Harbor

Standard Oil Co.

This company owns one 8-in. line, 24 miles long, connecting the Puente Hills district to the refinery at El Segundo, near the coast, about 15 miles southwest from Los Angeles. This line has an estimated capacity of 9,000 barrels per day.

Southern Pacific Railroad Co.

Amalgamated Oil Co.

The Los Angeles fields are connected to a refinery near the city of Los Angeles by a pipe line having an estimated capacity of 9,000 barrels per day.

Union Oil Co

	Barrels
One 8-in. line 30 miles long from Puente Hills to Los Angeles harbor.	
One 6-in. line 25 miles long from Puente Hills to Los Angeles harbor, estimated daily capacity	45,000

Summary of Pipe-line Transportation in California Controlled by the Different Companies

Standard Oil Co.

			Barrels
Valley districts		60,000	
Coast districts:			
Santa Maria	20,000		
Santa Clara valley	1,400		
Puente hills	9,000	30,400	90,400

Southern Pacific Co.

Valley districts		58,000	
Coast districts:			
Santa Maria	22,500		
Los Angeles	9,000	31,500	89,500

Union Oil Co.

Valley districts		50,000	
Coast districts:			
Santa Maria	47,500		
Santa Clara valley	3,000		
Puente hills	45,000	95,500	145,500

General Petroleum Co.

Midway district			30,000
Total daily carrying capacity of all the pipe lines in the State			355,400

Railroad Transportation.—Although the bulk of the production of the State is transported through pipe lines, a considerable amount is shipped in tank cars, particularly from the Midway and Kern River districts, to points in the San Joaquin valley, the oil being used chiefly by the railroads. Tank-car transportation is also resorted to in hauling the heavy oil produced in certain areas of the Santa Maria district, and is used to a small extent for transporting minor amounts of oil from practically every field to the markets or refineries.

Nearly all the large marketing companies have their own cars, the Standard Oil Co., which operates in most every district in the United States, owning over 15,000 through its subsidiary, the Union Tank Line Co. The Southern Pacific railroad is equipped with about 5,800 cars; the Atchison, Topeka & Santa Fé railroad with about 4,800; and the San Pedro, Los Angeles & Salt Lake railroad with 260. The Associated Oil Co. has about 340; the Union Oil Co. about 180; the Western Pacific railroad 70; and other smaller concerns own a greater or lesser number according to their needs. The cars have a capacity of between 200 and 300 barrels, thus necessitating between 150 and 100 tank cars daily to transport as much oil as is carried by an 8-in. pipe line in that time.

Tank-Steamer Transportation.—The transportation of oil in tankers is conducted mainly from San Francisco and Port Harford along the Pacific coast from Chile to Alaska, and to the Hawaiian Islands, Japan, and other countries. The large shipments are made to the States of Oregon and Washington, to Canada, and to Hawaii. The tank steamers are owned by the Standard Oil, Union Oil, and Associated Oil companies, the capacity of the tankers varying between 10,000 and 65,000 barrels, the largest at present being the *Richmond* of the Standard and the *Pectan* of the Union, with an estimated capacity of 65,000 barrels each. The number of oil-carrying vessels and their estimated total capacity, controlled by the three companies at present, is as follows:

	Vessels	Capacity Barrels
Standard Oil Co[a]	33	1,360,000
Union Oil Co.	17	560,000
Associated Oil Co.	8	230,000
	58	2,150,000

[a] Includes steamers for the transportation of refined products.

Oil in Storage

The following table gives in a condensed form the oil reserves above ground during the last four years. It will be noted that the stocks have increased each year until at present it is estimated that there are over 48,000,000 barrels on hand. This accumulation has been mainly brought about by the "bringing in" of large flowing wells in the Valley fields at a time when the consumption was absorbing only the normal output. As a result, practically all the overproduction at that time had to go into storage.

Oil in Storage in California during last Four Years

	Barrels
1910	33,088,000
1911	44,240,000
1912	47,552,000
1913[a]	48,000,000

[a] Estimated.

Storage Capacity

In order to store the large overproduction of recent years it has become necessary to provide ample tankage in excess of that required under normal conditions. The storage usually employed is of five different types: (1) covered steel tanks; (2) covered reinforced-concrete tanks; (3) covered concrete-lined reservoirs; (4) covered clay reservoirs; (5) open earth reservoirs or sump holes.

The steel tanks in more common use for storing oil in large volumes are those having capacities of 55,000 and 37,000 barrels, with a preference for the larger size. Two 1,000,000-barrel reinforced-concrete tanks were built near the Pacific terminal of the Producers Transportation Co.'s pipe line, the walls being designed to carry all the pressure of the oil content. These tanks were not very economical or successful, one of them partly collapsing when oil was run into it. The most efficient receptacles for storing oil in large amounts are the concrete-lined reservoirs built partly into the ground. The Associated Oil Co. has followed this method of construction with great success. The capacity of these reservoirs varies between 500,000 and 750,000 barrels, the latter figure being found more economical. The Standard Oil Co. has used the covered earth or clay reservoir, varying in capacity from 500,000 to 750,000 barrels, for storing the heavy oil of the Kern River district. It is claimed that considerable oil is lost through seepage in these reservoirs, as there is no very good clay available near the fields to build the impervious inner surfaces. The open sump holes are used mainly as temporary storage, for the settling of the sand in the oil, and in case of the unexpected "bringing in" of a large gusher, as was the case with the Lake View gusher, when it is estimated that over 6,000,000 barrels of oil were stored in open earthen reservoirs at one time.

The storage capacity of the three largest companies in California is estimated to be as follows:

	Barrels
Standard Oil Co.	30,000,000
Associated Oil Co.	12,000,000
Union Oil Co.	6,000,000
	48,000,000

Refineries

Standard Oil Co.

Point Richmond Refinery.—This is the largest on the coast, has an estimated daily capacity of 60,000 barrels, and is located on San Francisco bay at the terminal of the Standard Oil Co.'s pipe-line system from the Valley fields. The oil is carried to complete fractionation, the residuum being sold locally or exported for fuel, or run down to asphalt.

El Segundo Refinery.—This refinery is situated on the coast near Los Angeles, and has been in operation but a short time. It handles oil from the Puente Hills and Los Angeles districts to complete fractionation, and has a daily capacity of about 15,000 barrels.

Associated Oil Co.

Avon Refinery.—This plant is located on San Francisco bay, Contra Costa county, and has an estimated daily capacity of 20,000 barrels. Here the oil from the Valley fields is refined to gasoline, No. 1 and No. 2 distillate, kerosene, and asphalt.

Gaviota Refinery.—Located at Gaviota, on the coast, about 40 miles from Santa Maria, for treating the oil from the Santa Maria district, the refined products—gasoline, No. 1 and No. 2 distillate, and kerosene—being sold in nearby towns. It is connected by an 8-in. pipe line with the district, and has a daily capacity of about 8,000 barrels. At present the residuum is used by the railroads as fuel.

Amalgamated Refinery.—This plant is located near the city of Los Angeles, for treating a part of the oil produced in the Salt Lake field and Puente Hills district. It has an estimated capacity of 5,000 barrels.

Union Oil Co.

Avila Refinery.—Located near Port Harford, the Pacific terminal of the Producers Transportation Co.'s pipe line. Here the oils from the Santa Maria district and a small part of the production from the Valley fields are topped. The residuum is shipped in tank steamers with the crude oil of the Independent Producers Agency. This refinery is connected with the Santa Maria district by a 6-in. and an 8-in. pipe line, and has an estimated daily capacity of 12,000 barrels.

Oleum Refinery.—This refinery is located on San Francisco bay, and has an estimated daily capacity of 18,000 barrels of crude oil. Here the oil, mainly from the Valley fields, is fractioned into gasoline, kerosene lubricants, distillate, and asphaltum.

Bakersfield Asphalt Refinery.—Located between Bakersfield and the Kern River district and having an estimated daily capacity of 67 tons of asphaltum.

Other Refineries

There are about 15 small, independent refineries and topping plants near Los Angeles, about 10 near San Francisco, and others throughout the oil fields of the State. Several asphalt and topping plants are located near Bakersfield, which utilize the heavy oil produced in the Kern River district. One or two topping plants are also located near Santa Maria.

Exports

The total amount of crude oil exported from Pacific ports during 1912 was about 2,300,000 barrels, or about 2.66 per cent. of the total production of the State during that year. The greatest amount, about 927,000 barrels, was exported to Canada; the Hawaiian Islands were second in importance, with about 875,000 barrels; while about 227,000 barrels were exported to Panama and utilized in the building of the canal. Crude oil was also exported to Alaska, Guatemala, Chile, and some other South American countries, the greater part of the oil being shipped from San Francisco. These figures do not take into account the oil that was shipped from San Francisco, Port Harford or Los Angeles to Puget sound and used in American territory, nor any other trade along the western coast of the United States. Practically all the oil shipped is produced in the Valley fields, being transported to San Francisco bay or to Port Harford. The oil shipped from Los Angeles, amounting to 189,000 barrels, was produced in the Coast fields, although at present some of the oil produced in the Valley fields, as well as a part of the residue from the El Segundo refinery of the Standard, is being piped by the General Pipe Line Co. to Los Angeles and thence exported. Of late, the Royal Dutch-Shell Co. has brought some tank steamers loaded with gasoline from the Orient and returned them with kerosene distilled from California oils. It is very likely that the activities of the Shell Co. will open new markets for the California products.

Exports of Oil and Oil Products from San Francisco and Port Harford during October, 1913

Crude	Gallons	
Hawaii	5,523,000	$94,400
England	330	10
	5,523,330	$94,410
Illuminating		
Costa Rica	1,400	$148
Guatemala	19,000	1,995
Honduras	1,300	140
Nicaragua	87,302	9,780
Panama	2,500	312
Salvador	7,751	903
Mexico	2,000	225
Chile	1,020	107
Colombia	450	72
Ecuador	2,000	250
Peru	3,500	400
China	2,297,684	103,396
Dutch East Indies	1,606,473	74,451
Hongkong	2,004,150	90,186
Japan	8,238,584	370,736
French Oceania	2,000	270
German Oceania	2,425	354
Hawaii	49,456	7,606
American Samoa	5,092	854
	14,334,087	$662,185

Lubricating

Canada	3,810	$1,131
Costa Rica	363	153
Guatemala	200	52
Nicaragua	70	29
Salvador	1,387	430
Mexico	867	160
China	6,506	748
British India	12,952	1,105
Dutch East Indies	12,500	1,063
Hongkong	3,000	240
Australia	35,833	5,726
French Oceania	392	181
German Oceania	48	27
Philippine Islands	440	100
Hawaii	16,240	5,357
American Samoa	300	120
	94,908	$16,622

Gasoline

Costa Rica	2,510	$495
Nicaragua	1,785	304
Salvador	2,283	504
French Oceania	11,020	2,132
Hawaii	139,953	19,679
	157,551	$23,114

Other Distillates

Costa Rica	5,550	$659
Australia	30,870	2,748
French Oceania	17,737	1,665
	54,157	$5,072

Fuel Oil

Canada	5,040,000	$90,000
Panama	3,780,000	67,500
Salvador	1,552	38
Chile	6,762,000	120,750
Australia	1,914	106
Hawaii	24,348	1,736
	15,609,814	$280,130

Residuum for Fuel

Canada	882,000	$18,270
Chile	8,199,996	123,869
Japan	1,763,226	31,481
French Oceania	10,920	306
Alaska	1,680,000	30,000
	12,536,142	$203,926
Grand Total, all oils	48,309,989	$1,285,459

The shipments of oil and oil products to all foreign countries and to Alaska, Hawaii and the American possessions, during October, 1913, from the customs district of San Francisco, which includes Port Harford, from which point some of the heavy shipments to Spanish-American ports are made, totaled 48,309,989 gal., with a value of $1,285,459. Some of the Spanish-American shipments have been transferred from Port Harford to Los Angeles since the completion of the General Pipe Line to that city.

Geologic Formations of the Oil Districts

Oil is found in commercial quantities at one place or another in California in every important geologic horizon from the Chico or upper Cretaceous to the Fernando or Pliocene, and even to the Quaternary if tar springs and asphaltum deposits are included. The principal formations involved in the geology of the oil fields in order of age, beginning with the oldest, are: Jurassic or pre-Jurassic crystalline rocks; the Franciscan, of probable late Jurassic age; the Knoxville-Chico rocks, of Cretaceous age; the Tejon, of Eocene age; the Sespe, probably of Oligocene age; the Vaqueros and Monterey, of lower Miocene age; the Fernando or equivalent, largely of upper Miocene and Pliocene age; and the Quaternary. The commercial quantities of oil are confined chiefly to the Miocene, although important deposits are found locally from the upper Cretaceous to the Pliocene. The geologic column of the southern California Coast Ranges is shown in the accompanying tabulation. A discussion of each of the principal divisions of this column follows.

Basement Crystalline Complex.—Under this head are grouped the granite, schistose, and strongly metamorphosed crystalline rocks which go to make up the core of many of the Coast Ranges. The granite, schist, and limestone included in this series in the Santa Cruz, Santa Lucia, and adjacent mountains, may possibly be older than the Jurassic. The granitic and crystalline rocks, also included in the same category, but occurring in the ranges farther south, are probably of Jurassic age.

Geologic Formations

Tentative correlation of oil-bearing formations of southern California with the standard geologic section.

Period	System	Series	Southern California Section	Estimated Thickness Feet
Cenozoic	Quaternary	Recent Pleistocene	Alluvium, San Pedro, Fernando (in part)	1,000
			Unconformity	
	Tertiary	Pliocene	Deadman Island, Fernando (in part)	1,000
			Unconformity	
		Upper Miocene	Etchegoin, Fernando (in part), Jacalitos (in part), McKittrick (in part)	7,000
			Unconformity	
			Santa Margarita, Jacalitos (in part), McKittrick (in part)	2,000
			Unconformity	
		Lower Miocene	Monterey (Puente, Modelo)	7,000
			Unconformity	
			Vaqueros (Puente in part)	3,000
			Unconformity	
		Oligocene	Sespe	4,300
			Unconformity	
		Eocene	Tejon (Topa Topa)	5,000
			Unconformity	
			Martinez	4,000
			Unconformity	
Mesozoic	Cretaceous	Upper Cretaceous	Chico	6,000
			Unconformity	
		Lower Cretaceous	Knoxville	7,000
			Unconformity	
	Jurassic?		Franciscan	12,000
			Unconformity	
Paleozoic		?	Granite	?
			Unconformity	
			Black schist, limestone	?
			Total	59,300

Franciscan or Jurassic Metamorphic Series.—The Franciscan formation usually consists of glaucophane and other schists, quartzite, more or less altered sandstone, and shale, the whole intruded by serpentine and igneous dikes and masses. It is one of the most widespread formations in the Coast Ranges, occurring from the region of Santa Barbara at least as far north as Humboldt county. With the exception of some unimportant traces of oil found in beds believed to be of Franciscan age in Humboldt county, the formation is not known to carry oil.

Knoxville-Chico Cretaceous Rocks.—The Knoxville-Chico series comprises the Cretaceous rocks of the southern Coast Ranges, and attains a thickness of at least 12,800 ft., and possibly much more, in the Coalinga district. The Cretaceous rocks cover large areas in the Coalinga, McKittrick-Sunset, and Santa Maria districts, and other extensive regions in the Coast Ranges, where they are usually characterized by rugged topography. The lower or Knoxville portion of the series generally consists of hard, dark-colored shale and alternating thin-bedded, hard sandstones and shale. The upper or Chico portion of the series is made up of coarse conglomerate at the base, coarse concretionary sandstone above this, and finally, in the Coalinga district in particular, a series of purple organic shales which yield oil. The nodular or concretionary facies is its most characteristic one. Greenish oil, averaging about 35° Baumé (0.8484 sp. gr.), and containing 3 to 4 per cent. of paraffine wax, is produced in commercial quantities from sandstone layers in the purple upper Chico shale in the Oil City field of the Coalinga district. With the exception of oil from one or two localities in Ventura county, this is the only petroleum in the State carrying appreciable amounts of paraffine. Traces of oil are found in the Cretaceous in Contra Costa county and one or two other localities in the State.

Tejon or Eocene Formation.—The Tejon or Eocene rocks, like the Cretaceous, are widespread over the southern Coast Ranges, and, like the Cretaceous, are relatively negligible as a factor in the production of oil in California. Although the Tejon or Eocene carries unmistakable evidences of petroleum at numerous localities throughout the Coast Ranges, and although many wells have been sunk to tap its oil content, there are at present but few commercially productive wells in California deriving their fluid from this formation. Oil in commercial quantities has been obtained from the Tejon or Eocene in the Coalinga, Midway (Carrizo Plains), Santa Clara Valley (Ventura county) districts, and in Vallecitos, San Benito county. The diatomaceous, or other organic shales of the Tejon, are probably the source of the oil contained in it, and in the case of the Coalinga district, the Tejon is the principal ultimate source of the great deposits of oil which are found there in the Vaqueros and other Miocene formations. Although the past development work has not yielded encouraging results, it is probable that the testing of anticlines or other advantageous structural positions in the Tejon will eventually result in successful wells from this formation.

Sespe or Oligocene Formation.—The formation in the geologic column of the southern Coast Ranges most nearly corresponding to the Oligocene in the world's geologic series, is one characterized by a peculiar reddish-brown and green sand, and called the Sespe, owing to its important development on Sespe creek in Ventura county. In the Summerland district, where it apparently has its maximum development, the formation reaches 4,300 ft. in thickness. It thins rapidly toward the west, and where last distinguished by its peculiar red and green colors in the western end of the Santa Ynez Range, is but a few hundred feet thick. The marine origin of the Sespe formation, unlike most all the other members of the West Coast Tertiary, has not been established; in fact, it is believed by most students of geology to be a non-marine formation. The Sespe contains, so far as is now known, no fossils by which its age can be conclusively determined, but its stratigraphic position relative to other highly fossiliferous strata locates it definitely in the geologic column. It carries commercial quantities of petroleum at one horizon or another in several localities in Ventura county, the most important of which, so far proved, are those of Sisar canyon and the Big and Little Sespe canyons, where it occurs near the base of the formation, and in the Bardsdale, Montebello, and Torrey Canyon fields, where it occurs near the top. The oil occurs in alternating hard sandstone and shales in all portions of the formation except the extreme top and bottom, where well-developed sands yield the fluid. The oil from the Sespe is usually of an excellent quality, ranging in gravity from 25° to 36° Baumé (0.9032 to 0.8434 sp. gr.). Much heavier oil occurs locally, however, as in certain wells in the Big Sespe canyon.

Vaqueros or Lower Miocene Formation.—The Vaqueros or Lower Miocene, unlike the Sespe, is of widespread distribution, occurring in the Coast Ranges practically from one end of the State to the other. From the region of San Francisco bay southward, to the southern end of San Joaquin valley and the western portion of the Santa Ynez Range, the Vaqueros is characterized largely by sandstones and conglomerates. South of these limits, however, it usually consists of dark-colored shales with alternating thin sands. The formation is most variable in thickness, changing from 200 or 300 ft. to 2,000 or 3,000 ft. in relatively short distances. In the Santa Cruz mountains the maximum thickness is about 3,000 ft., in the Coalinga region about 700 ft., in the Sunset-McKittrick from 60 to 1,000 ft., and in the region of Ventura county and southward, from 3,000 to possibly 5,000 ft. The Vaqueros is one of the most important oil-bearing formations of California, being the principal reservoir in the Coalinga district, and one of the most important sources in the Santa Maria, Puente Hills, and Santa Clara valley districts. In addition, it is possible that commercially important deposits of oil will be found in the Vaqueros in scantily tested portions of the Coalinga, Sunset-McKittrick, and Santa Clara valley districts. In the Coalinga district the petroliferous Vaqueros beds are well-defined sands from 30 to over 100 ft. in thickness near the bottom of the formation, yielding oil varying from 11° to 27° Baumé (0.9929 to 0.8917 sp. gr.); in the Santa Maria district important deposits of 24° to 26° Baumé (0.9091 to 0.8974 sp. gr.) oil occur in the alternating sand, limestone, and shale beds in the transition zone between the top of the Vaqueros and the bottom of the Monterey; while in the Santa Clara valley and Puente Hills districts the oil is of excellent quality, 25° to 35° Baumé (0.9032 to 0.8485 sp. gr.), and occurs in alternating thin-bedded shales and sands at various points throughout the formation. In the Eureka wells, Santa Clara valley district, the oil is believed to come from well-defined sand beds toward the base of the Vaqueros.

Monterey or Lower Miocene Formation.—The Monterey is considered by far the most important formation in the State as regards the ultimate source of the oil, and it is also one of the most important reservoirs of petroleum. Like the Vaqueros, with which it is usually associated and on which it usually rests conformably, it has a widespread distribution over the southern Coast Ranges. It is characterized above everything else by its diatomaceous composition. Diatoms are microscopic, aquatic plants, having the power of locomotion and consisting of a shell or test of silica and an interior of chlorophyl or green matter, the same as the cells of ordinary plants. It is largely the accumulation of innumerable millions of the minute shells of marine diatoms which form the shales of the Monterey. The oil derived from it is also believed to come from the hydrocarbon chlorophyl of the same organisms. With the exception of the diatoms which form such an important part of the Monterey, this formation is almost barren of fossils. The Monterey attains its maximum development in the Santa Maria and Sunset-McKittrick districts, two of the most important oil regions of the State. Here the Monterey shale, largely of diatomaceous origin, attains a thickness of over a mile. Similar conditions, though less pronounced as to thickness of strata, prevail over many other parts of the Coast Ranges. In general, the shale is soft above and harder, even flinty, toward the bottom of the formation, where thin, hard, impure limestone layers are often interbedded. It is in the lower part of the Monterey, in the alternating limestone, sandstone, and flinty shale layers, that the commercial deposits of oil in the main Santa Maria and Lompoc fields occur.

The Monterey formation, or its equivalent, carries commercially important deposits of oil in the main or Orcutt field and the Lompoc field in the Santa Maria district. The gravity of the oil in the former varies from 18° to 27° Baumé (0.9459 to 0.8917 sp. gr.); in the latter from 12° to 35° Baumé (0.9859 to 0.8485 sp. gr.). In these fields the oil occurs in the interbedded sands or in the interstices and crevices in the fractured flinty shale and hard limestone. In the Modelo Canyon region of the

Santa Clara Valley district the oil, which is of excellent quality, varying from 14° to 32° Baumé (0.9722 to 0.8642 sp. gr.), occurs in coarse sands interstratified with the Modelo (equals Monterey) shales. At other localities the oil occurs in crevices and joint planes throughout a considerable extent of the formation, though such deposits are almost always of little value commercially, owing to the uncertainty of striking impregnated zones, and the low available saturation of these zones when encountered. The Monterey or transition Monterey-Fernando yields important quantities of oil in the fields south of Sulphur mountain, Santa Clara Valley district, and in the Whittier, Brea Canyon, and Fullerton fields, Puente Hills district.

Fernando or Miocene-Pliocene Formation.—After the deposition of the Monterey formation in what is now the Coast Ranges of California, came a marked period of disturbance resulting in the elevation and erosion of the Monterey and older formations. This was followed by a general subsidence. The formations laid down following this post-Monterey subsidence are usually conformable with each other (including everything older than the later Quaternary beds) and for this reason they have been grouped together under the name Fernando in the Coast Counties districts. The Fernando and its equivalent post-Monterey formations contain the most important oil reservoirs in the State, this important fact being due in great measure to the unconformable position which they hold to the underlying Monterey shale which is the ultimate source of the oil over so much of the State. More strictly speaking, one should say that the basal portion of the Fernando is the important part, as the upper portion and its equivalents are not commercially oil-bearing so far as known. In general, the Fernando sediments consist of more or less incoherent conglomerates and sands, clayey shales, and soft clays. The Fernando and its equivalents are thick, aggregating from 3,000 to 10,000 ft. in each of the various sections. Among the fields which obtain their oil from the Fernando or its equivalents are the Kern River, Sunset, Midway, McKittrick, Belridge, and Lost Hills (all from the McKittrick formation); San Emidio, a prospective district 20 miles south of Bakersfield (oil sands in Santa Margarita (?) formation); Arroyo Grande and Cat Canyon fields in the Santa Maria district; the Summerland district (main productive area); the Elsmere Canyon field, the field south of Sulphur mountain, the field east of Santa Paula creek, all in the Santa Clara Valley district; the Salt Lake and Western fields, and certain portions of the central and eastern fields in the Los Angeles district; and the Whittier, La Habra, Coyote Hills, Brea Canyon, and portions of the Olinda (Fullerton) fields of the Puente Hills district. With the exception of certain localities in the Sunset, Midway, Belridge, Lost Hills, and some Santa Clara Valley fields, the oil produced by the Fernando is of the fuel type, varying from 11° to 19° Baumé (0.9929 to 0.9396 sp. gr.). The first four mentioned exceptions yield oil only up to 27° Baumé (0.8917 sp. gr.), while the light oils classified as from the Fernando in the fields south of Sulphur mountain and east of Santa Paula creek, Santa Clara Valley district, are from beds probably transitional Monterey-Fernando. Large deposits of asphaltum, the residuum from oil escaping into the Fernando from the Monterey formation, occur near Arroyo Grande, Sisquoc, Graciosa Ridge, and south of Guadalupe in the Santa Maria district.

San Pedro or Quaternary Formation.—Although not yielding fluid oil in commercial quantities, this, the latest of the California formations, is important from an oil standpoint, as it is the source of commercial deposits of asphalt, the residuum of the oil. The Quaternary deposits usually unconformably overlie the upturned edges of the older formations on the terraces or benches along the coast and important water channels. The deposits are almost always more or less incoherent, generally gravelly or sandy, and are seldom over 30 to 100 ft. thick. Deposits of Quaternary age in the Los Angeles basin and in parts of Ventura county are, however, at least 1,000 ft. thick. The formation is often rich in fossils, most of which are of species still living on the Pacific coast, although in general of a type found in the fauna of Lower California, thus indicating warmer water conditions for the California coast during the Quaternary. The asphaltum deposits and similar indications of petroleum are found, among others, at the following localities: Graciosa ridge and Purisima ridge, Santa Maria district; Santa Barbara and westward along the coast for 20 or 30 miles; Summerland and Carpenteria, Summerland district; Rincon creek and southward, Ventura county; and Newport, Orange county. In the McKittrick district; Sisar Canyon and Sulphur Mountain fields, Santa Clara Valley district; Salt Lake field, Los Angeles district; and Brea Canyon and Olinda fields, Puente Hills district, deposits of asphalt of Quaternary age are found associated with oil sands and oil seepages of the older oil-bearing formations. The deposit on the Rancho la Brea, in the Salt Lake field, near Los Angeles, is noted as containing one of the most important faunas of extinct Quaternary vertebrate animals in the world. This fauna includes mastodons, elephants, lions, saber-toothed tigers, sloths, camels, buffaloes, hyenas, foxes, wolves, bears, horses, and birds and insects, all of which were caught in this great oil or tar spring in past ages.

Relation of Geologic Structure to Oil Deposits

Commercial quantities of petroleum occur in practically every form of geologic structure known to the Coast Ranges at one place or another in the California oil fields. When it is remembered that the Coast Ranges of this State afford some most involved folds and faults, complicated by igneous intrusions, the significance of this statement is apparent.

Oil in Anticlines, Monoclines, and Fault Zones.—Among the types of accumulation are those found in both broadly or sharply folded anticlines (Figs. 11 and 13), lying in normal, asymmetric, and overturned positions; in low- and steep-dipping and shouldered or terraced monoclines; in fault zones; and finally, in blocks having little definite structure. The quantity and quality of the oil are usually affected by its relative position in these structures, although in some instances these characteristics remain practically uniform over adjacent structures.

In general, the San Joaquin Valley fields are developed on monoclines (Fig. 2), while anticlines and fault zones are more potent in the fields of the coast counties. In most localities the structure is well exposed at the surface, but in the Salt Lake field of the Los Angeles district, and in one or two other regions, the structure of the oil-bearing formation is entirely blanketed by the Quaternary deposits. It is common to find the structure reflected in the topography, the anticlinal axes, as a rule, following the crests of hills while the more profound valleys occupy the basins of synclines. In the case of asymmetric anticlines and synclines the most important deposits are ordinarily found on the lowest-dipping flank, as evidenced, among other occurrences, by the Coalinga anticline in the Eastside Coalinga field. An exception to the rule is found in the steep-dipping north flank of the Mount Solomon anticline of the Santa Maria field, which yielded more important wells than the lower-dipping south flank.

Oil in Synclines.—Where no water is present in the oil sands and where the axes of the anticlines are not fractured, there is more of a tendency for the oil to collect in synclines than in anticlines. Examples of commercial deposits in synclines are the very important deposits in the Midway Valley syncline, and the equally important ones occurring in the Coalinga syncline between the north end of the Westside field and the Eastside field at Coalinga. Far down on the plunge of both these synclines it is predicted that water will probably be found.

Reservoir for Oil.—Practically all of the wells in California secure their oil from porous marine sedimentary sandstones (Fig. 2). In rare instances, notably in the Santa Maria district, a portion of the oil probably comes from the cracks and interstices in fractured hard flinty shales, or from pores in the softer shales. The character of the sandstone reservoir has a most marked effect upon the accumulation, migration, retention, and quality of the oil; the coarser the sandstone or conglomerate the less will be its normal capacity and the easier the migration of the oil through it, and consequently the quicker will it be drained of its contents. Conversely, very fine sandstones and unfractured shale are slow but persistent producers. Again, other things being equal, the oil in fine sandstones is frequently of lighter quality than that found in adjacent coarser beds. Hard, coherent sandstones generally offer fewer difficulties in drilling and cause less trouble in the operation of wells than soft or incoherent sands, which often accompany the oil from the well and plug or "sand-up" the hole. On the other hand, where a well which taps a soft sand is enabled through excessive gas pressure to clean itself out during its initial or "flush" flow, the production usually stands up well owing to the favorable conditions produced at the bottom of the hole, where the "blow-out" sand leaves an ideal collecting reservoir for the oil. The famous Lake View gusher and most of the other large producers of the Midway, Sunset, and Coalinga districts might be cited as examples of this kind. A soft sand, however, is not prerequisite for great production, even when the oil occurs in sands, as is evidenced by certain of the large wells of the Eastside Coalinga field and several wells in the Olinda and Brea Canyon fields of the Puente Hills district. Obviously, the thickness of the oil sand or reservoir has an important influence not only on the daily production but on the life of any well. The thicker the sand, other things being equal, the longer the life of the well. This fact accounts for the great staying quality of parts of the Kern River, Coalinga, Santa Maria, Puente Hills, and Santa Clara valley districts. Thin sands, such as encountered in certain areas of the Midway and Sunset districts, though initially most prolific, fall off with alarming rapidity after the first few weeks or months of production.

Capping of the Reservoir.—In practically every field in California the cap-rock or formation immediately overlying the oil reservoir consists of a hard blue or brown shale or clay or hard shell. In rare instances, such as the McKittrick district, and in the Los Angeles field and elsewhere, beds brought into position by horizontal or oblique faulting have acted as efficient barriers to the escape of the oil. Again, in fields where the oil occurs in monoclines with the edges of the oil sands exposed, the hydrocarbons are imprisoned by the residual oil or asphaltum remaining in the oil sand near the surface after the escape of the more volatile constituents. Marked instances of this are to be found in the Whittier field, and in the southeastern end of the McKittrick field, where vertical oil-bearing beds carrying commercial quantities of oil at depths are sealed at the top by asphaltum. The same beds or barriers which prevent the escape of the oils and gases usually prevent the downward migration of water and the dissipation of the former by the latter.

Relation of Water to Oil.—The oil in the California fields, as in most others throughout the world, occurs in inclined or sloping beds of porous sand, and these oil sands are usually overlain and underlain by water sands, which are separated from the oil sands by impervious clay, shale, or other strata. In these two cases the oil is extraneous to the oil sands. These waters are called "top" and "bottom" waters, in accordance with their occurrence, respectively, above or below the oil sands. In a properly finished well the "top" water is cased off or cemented off before the well is drilled into the oil sand. The "bottom" water is never drilled into except by accident, in which event it is plugged off. With the "top" water shut off and the "bottom" water untouched, the oil is produced practically free from water. Water, being heavier than oil and often also under a greater hydrostatic pressure, will replace part or all of the oil at the point of ingress into the well if it is allowed to reach the oil sand. In this way it replaces the oil, in whole or in part, and thus lessens the amount of oil produced. Water also occurs indigenous to the oil sands in certain fields, but in this case it does not occupy the same part of the stratum as that occupied by the oil, but lies in the lower or "down-slope" portion of the sand, and the line marking the junction of the oil in the "up-slope" part of the bed and the water in the "down-slope" part determines the limits of the productive territory. The water under these conditions is called "edge" water. Upon exhaustion of the oil by flowing or pumping, the "edge" water, through hydrostatic pressure, usually "follows up" and replaces the oil. The appearance of the originally extraneous "top" water or "bottom" water in a well indicates a failure to properly exclude the water by the manipulation of casing, cement, or plugs. Such a condition usually can be remedied and the offending fluid kept out of the oil sand, although what has already come in may sometimes remain in the oil to a greater or lesser extent. The appearance of "edge" water in a well is another matter, for here the oil has been permanently replaced by the water, and so far as the affected sand is concerned, the well can be considered as no longer productive. "Edge" water sometimes appears in a well in some particular sand, while other producing sands are free from water. In this instance the "edge" water sand is abandoned and cased off, and the production continued from the other sands.

In connection with the probable effect of water on oil production, it should be borne in mind that the production of the Kern River field, one of the oldest in the State, is holding up remarkably well, although it is affected by a complication of "top," "bottom," and "edge" waters.

Probably 95 per cent. of the water troubles in the various fields of California is caused by "top" waters which were not shut out of the wells during the drilling process or have broken into the wells since they were finished owing to faulty manipulation or the corroding of the water string of casing. This being the case, many of these troubles are remediable. The question of handling the water is among the most important confronting the California operators to-day.

Origin of the Oil.—The oils of the California fields are believed to have been derived largely from the organic shales which are associated with the oil-bearing beds in all of the fields of the State. It is believed that the oil originated from the organic matter, both vegetable and animal, once contained in these beds. Probably the principal source of the oil has been the diatomaceous deposits, which make up a large percentage of the Tejon or Eocene formation in the Coalinga district, and the Monterey or lower Miocene formation throughout the balance of the districts. Other organisms that may also be the source of some of the oil are plants, foraminifera, bryozoa, and possibly mollusca and fish. A great deal of evidence can be advanced favoring the organic origin of the oil in California, and enough demonstrating the impossibility of its inorganic origin locally to practically prove the former theory by the process of elimination.

SAN JOAQUIN VALLEY DISTRICTS

Coalinga District

This district is the northernmost of the important fields of California, comprising a strip of land about 50 miles in length by 15 miles in width

Fig. 2.—Coalinga District.

Outcrop of the main oil sand of the Eastside field, showing the unconformity between the underlying steep-dipping shales and the overlying porous pebbly sand and conglomerate. This sand is very prolific a mile or so down the dip from the outcrop.

along the eastern base of the Coast Ranges. The region is about 55 miles in a straight line from the Pacific ocean, 170 miles southeast of San Francisco, and 200 miles northwest of Los Angeles. The area of the entire district includes about 750 square miles, but the proved oil-bearing territory only embraces about 35 square miles, or 22,400 acres. It is now the second district in importance in the United States, and the most regular and best understood as regards geologic formations of the principal districts of California. It is accessible by a branch line of the Southern Pacific railroad which connects with the main San Joaquin Valley lines of this road and with that of the Atchison, Topeka & Santa Fé railroad. The pipe lines of the Associated Transportation and Standard Oil companies connect the field with San Francisco. Another Associated line runs to Monterey, and the Producers Transportation Co.'s line connects

FIG. 3.—COALINGA DISTRICT.
Derrick Avenue in Westside field, which is seven miles long and flanked on both sides for the entire distance by producing wells.

the field with Port Harford. Coalinga, the principal source of supplies, is located in Pleasant valley, in the north end of the district, and has a population of about 4,500 people. The main part of the Coalinga district is separated into the Eastside, Westside, and Oil City fields. With the exception of a little oil from the Oil City and Eastside fields, which carries material percentages of paraffine, all of the oil in this district is of asphalt base. The wells in this district vary in depth from 300 to 4,700 ft., the daily production per well ranges from 4 to 3,000 barrels, and the product varies in gravity from 12.4° to 34.5° Baumé (0.9833 to 0.8519 sp. gr.).

Oil City Field.—This field lies on the crest of the Coalinga anticline at the north end of the district and obtains its product from sands in the upper Chico or Cretaceous formation. The wells vary in depth from 300 to 1,700 ft., penetrate from one to three oil sands with a total thickness of 30 to 95 ft., and yield from 4 to 250 barrels of oil each per day. The oil is greenish in color, 35.5° to 34.5° Baumé gravity (0.8570 to 0.8519 sp. gr.), is characterized by the presence within it of 3 to 4 per cent. of paraffine wax, and is well suited for refining. The first successful work in Coalinga took place in the Oil City field about 1890, shallow wells obtaining a flow of about 10 barrels for a few days from the Chico shale. Desultory prospecting was carried on for a number of years, and in 1895 two wells were drilled which yielded between 15 and 20 barrels of 34° Baumé (0.8536 sp. gr.) oil per day. The development of the Oil City field became more systematic, and during 1896 and 1897 its commercial productivity was completely proved.

Eastside Field.—The Eastside field lies on the crest and east flank of the Coalinga anticline and forms the northeastern portion of the Coalinga district. It obtains its product from sands of Vanqueros or lower Miocene age (Fig. 2). The wells range in depth from 700 to 4,700 ft., penetrate from two to six oil sands with a total thickness varying from 40 to 250 ft., and yield from 30 to 3,000 barrels of oil each daily. The oil varies from greenish to black in color, is of 17.6° to 30.7° Baumé gravity (0.9493 to 0.8718 sp. gr.), and is useful for refining or topping. The development of the Eastside field began in 1900 with the drilling operations of the Independence, Oil City Petroleum, Twenty-Eighth, Caribou, and other companies. The California Oilfields, Ltd., now owns most of the Eastside field.

Westside Field.—The Westside field lies on the western flank (Fig. 3) of the great Coalinga syncline in the western part of the Coalinga district, and obtains its product from the Vaqueros (lower Miocene), Santa Margarita (?), and Jacalitos (upper Miocene). The wells range in depth from 500 to 3,300 ft., penetrate from two to ten oil sands with a total thickness of 25 to 200 ft., and yield from 10 to 2,500 barrels of oil each daily. The oil is black in color, 12.4° to 20° Baumé gravity (0.9833 to 0.9341 sp. gr.), and is used principally for fuel. Oil of 22° to 28° Baumé gravity (0.9210 to 0.8860 sp. gr.), well suited for refining, is obtained in small quantities in the extreme southern end of this field. Successful development work was begun in the northern end of the Westside field in 1901, and by the fall of 1906 the present limits of the field had been practically ascertained.

Prospective Fields.—Test wells have been put down at many points in the Coalinga district, outside the proved area, some obtaining oil, but none being commercially successful. Among the prospective fields partly tested are the Kettleman Hills, Kreyenhagen Hills, and Jacalitos Canyon.

Geology

The formations involved in the geology of the Coalinga district, in the order of their age beginning with the oldest, are: the Knoxville-Chico (Cretaceous); the Tejon (Eocene); the Vaqueros (lower Miocene); and the Santa Margarita, Jacalitos, and Etchegoin (all upper Miocene).

The Knoxville-Chico rocks consist of 12,800 ft. or more of sandstone and shale and form the basement on which most of the oil-producing and oil-bearing beds lie. An oil-bearing sand zone, yielding commercial quantities of oil locally, occurs in the purple shale in the upper part of the Chico in the vicinity of Oil City.

The Tejon consists largely of diatomaceous shales and is believed to be the source of most of the oil in this district. It has a thickness of at least 1,850 ft. on the flanks of Joaquin ridge, and consists of a lower sandy and clayey member of 850 ft. and an upper organic shale member at least 1,000 ft. thick. So far only small quantities of oil have been found in this formation in the Coalinga district, this oil being reported rich in paraffine.

The Vaqueros rests in an unconformable position on the Tejon and underlying formations (Fig. 2), and varies in thickness from 100 ft. in the Westside field to about 700 ft. in the Eastside field. The Vaqueros is the productive formation for the Eastside field and the deeper wells in the Westside field.

The Santa Margarita formation consists of a series of sands and clays with an estimated thickness between 800 and 1,000 ft. in the region of the oil fields proper, and is characterized in the Eastside field by a persistent bed of fine sand and clay about 300 ft. thick, locally called, on account of its peculiar color, the "Big Blue," which forms an effective cap-rock over the Vaqueros oil zone.

The formations above the Santa Margarita, and named in order upward the Jacalitos, Etchegoin, and Tulare (Miocene-Pliocene), consist of clay, sand, and gravel, and are important as affording a covering for the oil-bearing beds below and as carrying water and tar sands in places. The Jacalitos and Etchegoin formations are of upper Miocene age and marine origin; the Tulare formation is of Pliocene age and fresh-water origin.

Structure

All of the formations mentioned are affected in the Coalinga district by the great eastward-dipping monocline which marks the transition between the Coast Ranges and the valley. Subsidiary folds are developed in this monocline, the most important one being the Coalinga anticline, on which the Oil City and Eastside fields are situated. The Westside field covers a strip of land about 1 mile wide and 8 to 9 miles long following the strike of the monocline. The northern parts of the Westside and Eastside fields are connected, being separated on the south by the intervening Coalinga syncline resulting from the folds just described. The structural conditions affecting the entire district are very uniform, which makes it easy to predict with some degree of accuracy the depth at which the different oil sands will be reached.

Development

The well development in the Coalinga district is summarized in the following table, which indicates the progress in the last four years:

Well Development in the Coalinga District from 1909 *to* 1913, *Inclusive*

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	644	6	88
1910	794	11	148
1911	956	30	192
1912	1042	56	142
1913	911[a]	....	....

[a] Estimated for November, 1913.

The wells range in depth from 300 ft. in the Oil City field to over 4,700 ft. on the crest of the plunging Coalinga anticline on the southern limit of the Eastside field. The number of oil sands varies from one to as many as ten, their combined estimated thickness being between 30 and 400 ft.

Production

The following table gives the yearly production of the Coalinga district from beginning to date:

Yearly Production of Coalinga District

Year	Production Barrels	Year	Production Barrels
1896	14,119	1905	10,967,015
1897	70,140	1906	7,991,039
1898	154,000	1907	8,871,723
1899	439,372	1908	10,386,168
1900	532,000	1909	14,795,459
1901	780,650	1910	18,387,750
1902	572,498	1911	18,483,751
1903	2,138,058	1912	19,911,820
1904	5,114,958		
			119,610,520

The following table gives in a condensed form the chemical and physical characteristics of the Coalinga oil.

Physical and Chemical Properties of Coalinga Oils, by Fields

	Color	Baumé at 60° F.	Sp. Gr. at 15° C.	Flash Point, Degrees F.	Calorific Value	Sulphur Per Cent.	Water Per Cent.
Oil City	Greenish	33.5° to 34.5°	0.8570 to 0.8519	Below 53	10,657 to 01,478	0.03 to 0.05	0.0
Eastside	Greenish to black	17.6° to 30.7°	0.9493 to 0.8718	Below 53 to 128	10,515 to 10,685	0.35 to 0.60	0.0 to 0.12
Westside, Sec. 6	Black	12.4° to 20°	0.9833 to 0.9341	92 to above 167	10,242 to 10,633	0.47 to 0.77	0.0 to 0.87
	Brownish to Greenish	22° to 28°	0.9210 to 0.8860	....	....	....	....
Jacalitos	Greenish	37°	0.8383	....	....	....	....
Kreyenhagen:							
(Vaqueros)	Black	18°	0.9459	....	....	....	....
(Tejon)	Greenish to Black	18° to 37°	0.9459 to 0.8383	....	....	....	....

Results of Fractional Distillation of Coalinga Oils, by Fields

	Naphtha (Below 150° C.) Per Cent.	Burning Oil (150° to 300° C.) Per Cent.	Lubricating Oil (300° to 400° C.) Per Cent.	Asphaltum (Above 400° C.) Per Cent.	Paraffine Wax Per Cent.	Residue Per Cent.	Loss Per Cent.
Oil City	26.32 to 29.84	57.72 to 60.30	2.30 to 4.39	1.89 to 8.12	3.54 to 4.47	1.20 to 1.60	1.32 to 3.18
Eastside	0.00 to 13.35	22.20 to 40.85	24.48 to 44.75	8.07 to 36.15	....	1.42 to 6.89	1.01 to 4.77
Westside	0.00 to 5.14	10.71 to 35.22	23.45 to 46.23	14.30 to 57.42	....	0.42 to 6.04	0.41 to 3.79

From the foregoing tables it will be noted that the oil from the Oil City wells is characterized by the presence of a small percentage of paraffine wax, something practically unheard of in the California fields except in isolated cases in Ventura county where traces of paraffine occur in certain wells. The Oil City oil is the highest grade oil occurring in commercial quantities in the Coalinga district, being excellent for refining purposes. The great bulk of oil from the Eastside field is also used for refining, or, more properly speaking, for topping, while the Westside oil is practically all of a fuel quality. The oil from wells in Section 6, west of Coalinga, is used for refining, but this excellent quality is very limited in amount.

Lost Hills District

The Lost Hills district is situated about 50 miles southeast of Coalinga in the San Joaquin valley in Kern county. It is the newest of the productive fields, the first well having been drilled in July, 1909. The developed territory extends from Sec. 13, T. 26 S., R. 20 E., to Sec. 9, T. 27 S., R. 19 E., along a narrow strip about 6 miles long and from 1,000 to 2,000 ft. wide. The district is reached from Wasco station on the Santa Fé railroad, and McKittrick on the Southern Pacific railroad, the base of supplies being the town of Wasco, which is connected with the field by good wagon roads. Branch pipe lines of the Producers Transportation, Associated Oil, and Standard Oil companies connect the district with tidewater at Port Harford and San Francisco.

The wells range in depth from 500 to over 2,000 ft. The oil is of asphalt base, with an average gravity of 28° Baumé (0.8861 sp. gr.), and is utilized largely for refining. The gravity of the oil in the north end of the field, where the product comes from the Jacalitos formation, is about 18° Baumé (0.9459 sp. gr.), while that of the oil from the south end, where the product comes from the Santa Margarita formation, averages between 30° and 40° Baumé (0.8750 and 0.8235 sp. gr.).

Geology

The formations involved in the geology of the Lost Hills district, in the order of their age beginning with the oldest, are: the marine Santa Margarita, 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 ft. thick, the entire series being 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 a reservoir 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 ft., the whole believed to be the equivalent of the Jacalitos and Etchegoin formations so well 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 vary between 75 and 100 ft. in thickness, generally in two different bodies.

The Tulare formation, of fresh-water origin, 300 to 500 ft. 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.

Structure

The dominant structural feature of the Lost Hills district is the well-defined 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 southeast direction, finally plunging under the valley filling with an axial dip of about 150 ft. to the mile. The folding, which has had a controlling influence on all of 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, the latter being retained within its sandy members. It will be noted that the gravity of the oil in the Santa Margarita averages about 35° Baumé (0.8485 sp. gr.), 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° Baumé (0.9459 sp. gr.).

Development

The wells in the Lost Hills district vary in depth between 600 and 2,000 ft., those obtaining their product from the basal portion of the Jacalitos having a depth of from 500 to 700 ft., while those in the southern part of the productive area and which obtain oil from the sandy members of the

Santa Margarita attain a depth of from 1,200 to 2,000 ft. and over. The yield of the wells producing the heavy oil is close to 100 barrels per day during their early life, while the wells yielding the light oil generally start producing by natural flow as high as a thousand barrels per day. This flush production, however, soon decreases and leaves the well with a daily production at present averaging about 74.8 barrels per day per well, less than that of the more constant wells of heavy oil. The following table indicates the development in this district for the last four years:

Well Development in the Lost Hills District from 1909 to 1912, *Inclusive*

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	1	.....	3
1910	2	.....	7
1911	20	6	24
1912	56	15	51
1913[a]	102	.....	...

[a] Estimated for November, 1913.

Production

The production of the district during 1912 was 1,367,359 barrels. Previous to this year the yield was included with that of the McKittrick district.

The following analysis gives the composition of typical oils of the Lost Hills District:

Composition of Oils of Lost Hills District

Specific gravity at 77° F.—0.9050, or 24.7° B. (23.6° B. at 60° F.)

		Per Cent.
Gasoline	(61° B.—0.7330 sp. gr.)	2.0
Engine distillate	(49.5° B.—0.7800 sp. gr.)	18.0
Stove distillate	(33.6° B.—0.8557 sp. gr.)	20.0
Fuel oil	(25.0° B.—0.9032 sp. gr.)	10.4
Residue	(13.4° B.—0.9765 sp. gr.)	49.6
		100.0

McKittrick, Midway, and Sunset Districts

The McKittrick, Midway, and Sunset districts are situated in the southwestern corner of the San Joaquin valley in western Kern county, and include, roughly, about 400 square miles. They are reached by the Sunset Western railroad, a branch line connecting with the main lines of the Southern Pacific and Atchison, Topeka & Santa Fé railroads at Bakersfield, 40 miles to the east. The towns of Maricopa, in the Sunset district, Taft and Fellows, in the Midway district, and McKittrick in the district of the same name, are the chief centers of distribution of supplies. The pipe lines of the Standard Oil, Associated Oil, General Petroleum, and Producers Transportation companies connect the districts to tidewater.

The topography of these districts is dominated by the Temblor Range, which rises to heights of from 3,000 to 4,000 ft. and bounds them on the west; the San Emidio Range, attaining altitudes of over 8,000 ft., bounds the Sunset district on the south, this district lying in the obtuse angle formed by the junction of the two ranges. In general, the districts may be described as occupying the transition zone of low rolling hills, which is developed between the more or less sharp and rugged topography of the major ranges, and the flats of the San Joaquin valley.

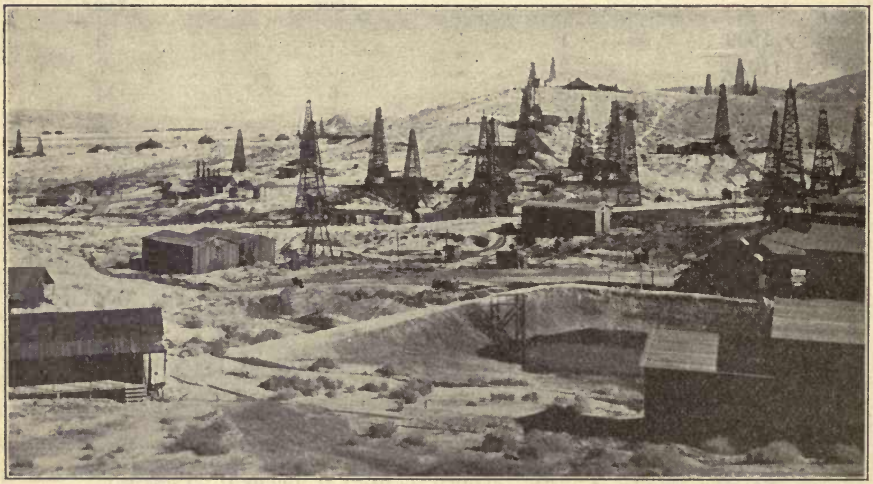

FIG. 4.—McKITTRICK FIELD.
View of north end of field. Note the earthen reservoirs for catching oil and settling the sand. Photograph for U. S. Geological Survey, by R. A.

In November, 1913, there were 311 producing wells in the McKittrick district (includes Belridge), ranging in depth from about 600 to 1,800 ft. The oil in this district is dark colored, varying in gravity from 12° to 20° Baumé (0.9859 to 0.9333 sp. gr.); the production from individual wells ranges from 2 to 1,000 barrels per day. The first recorded commercial production from this district was in 1898, when it is estimated that about 10,000 barrels were produced.

The wells in the Midway district vary in depth from 500 to over 4,000 ft., the product grading from a black oil of 11° Baumé (0.9929 sp. gr.) to a greenish-brown oil of 29° Baumé (0.8805 sp. gr.), and even oil of 36° Baumé gravity (0.8433 sp. gr.) has been reported from certain wells in the Elk and Buena Vista hills. The production of individual wells

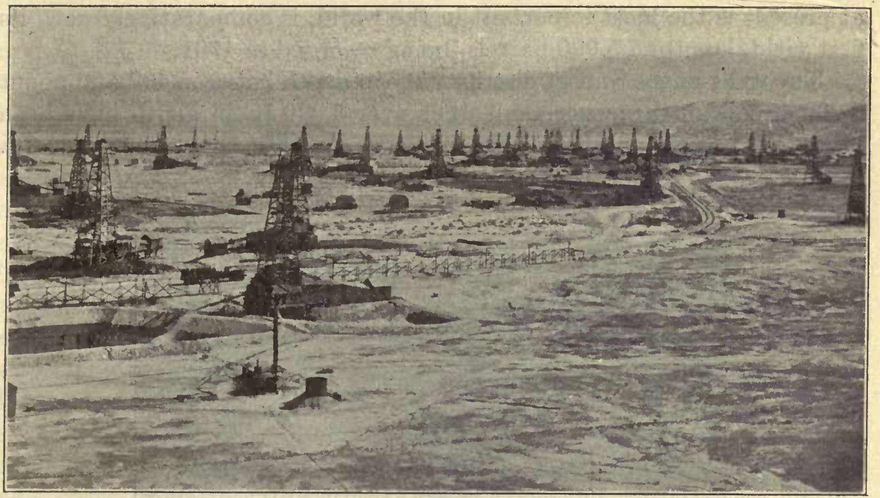

FIG. 5.—SUNSET FIELD.
Portion of the developed field. The San Emidio Range appears in the distance on the right. Photograph for U. S. Geological Survey, by R. A.

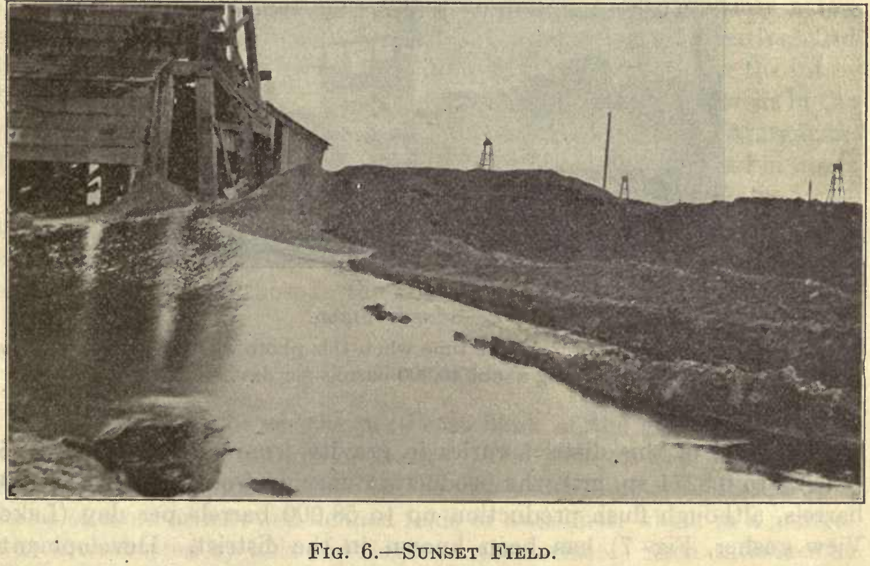

FIG. 6.—SUNSET FIELD.
Mound of sand and shale "pebbles" that have come with the heavy oil produced. This material greatly hinders the productivity of the wells.

varies from 10 to 2,500 barrels per day, although flush or initial productions have reached 20,000 barrels or more per day. This district, which at present is the most important in the world, is comparatively new, its first yield, less than 5,000 barrels, being recorded in 1901.

The wells in the Sunset district vary in depth between 400 and about 3,000 ft., although unsuccessful wells over 5,200 ft. in depth have been drilled in the region east of the Midway and Sunset producing areas.

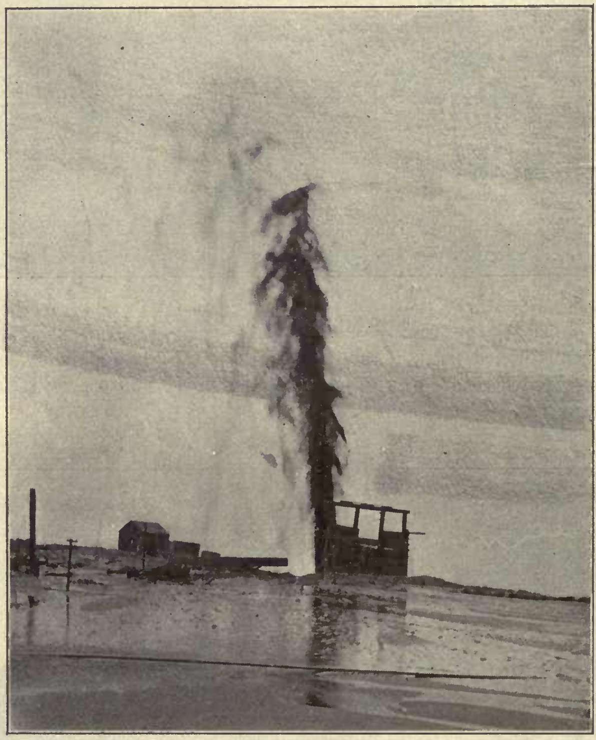

Fig. 7.—Sunset Field.
Lake View Gusher in action. At the time when this photo was taken the well was producing about 40,000 barrels per day.

The product of this district varies in gravity from 11° to 21° Baumé (0.9929 to 0.9271 sp. gr.), the production varying from 4 to 300 or 400 barrels, although flush production up to 58,000 barrels per day (Lake View gusher, Fig. 7) has been known in the district. Development work has been carried on in this district for many years, but not until 1900, when it produced somewhat over 12,000 barrels, were the returns commercially profitable.

Geology

The formations involved in the geology of the McKittrick, Midway, and Sunset districts include, in the order of their age beginning with the oldest, coarse, semi-concretionary sandstone 400 ft. or more in thickness, believed to be of Vaqueros or lower Miocene age; 3,000 to 5,000 ft. of siliceous and clayey shale containing numerous thin calcareous layers and concretions of Monterey or lower Miocene age; softer, lighter-colored diatomaceous shale locally silicified to chalcedony, in which are intercalated prominent lenses of coarse granitic sand and conglomerate (the latter containing some boulders up to 6 ft. in diameter), 1,000 to 1,500 ft. thick and believed to be of Santa Margarita or upper Miocene age; a series of 1,200 to 2,000 ft. of soft sands, clays, and conglomerates, probably divisible into more than one stratigraphic horizon called the McKittrick formation and of upper Miocene and possibly Pliocene age; and, finally, stream deposits, valley fillings and alluvium, of Quarternary age. The Monterey and Santa Margarita formations apparently lie in a conformable series, while the McKittrick (upper Miocene) overlies these unconformably, contains intraformational unconformities, and is, in turn, unconformably overlain by the Quarternary deposits.

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 sands and gravels of the unconformably overlying McKittrick formation. With possibly a few exceptions, the productive sands in all of the operating wells are included in the base of the McKittrick formation or in sands overlying the intraformational unconformity. The deeper sands in some of the wells in the northern part of the Midway district may occur in the Santa Margarita. It is also possible that commercial quantities of oil are contained in sands near the base of the Monterey or in certain structurally favorable localities, particularly in the Sunset district. The geological and structural conditions affecting the accumulation of oil in the Belridge field are somewhat similar to those in the Lost Hills district.

Structure

These districts lie on the northeast flank of the great geoanticline which dominates the Temblor Range. The beds on this flank do not form a simple slope into the San Joaquin valley, but are affected by a series of more or less well-defined folds or anticlines, which in a general way are reflected by hills and ridges on the surface. Such anticlines as the Twenty-five hill and those in the Buena Vista and Elk hills are characteristic of the folds in this region. In general, the dips of the beds on the flanks of these folds are relatively low (5° to 12°) as compared with those developed in the heart of the Temblor Range, which average over 45°. The largest producers are found on or near the axes of anticlines and subsidiary folds. More water troubles and usually smaller productions are encountered in the wells in synclines.

Broadly speaking, the productive McKittrick district lies on the flanks of three more or less local and highly complex folds subsidiary to the great northeast-dipping monocline. Thrust faulting and overturning have so complicated the folding as to often place the older beds above the younger.

The Midway district is developed on the monocline and on subsidiary folds. The district is divided locally into a number of areas named for topographic or structural features. The most important of these areas are the Buena Vista hills, Midway Flat (valley), Twenty-five hill, Elk hills, etc.

The Sunset district is located on the main monocline and on the Twenty-five and California Fortune anticlines and subsidiary flexures.

McKittrick District

Location

The McKittrick (Fig. 4) is the northernmost of the districts under discussion, and covers a narrow strip 7 or 8 miles along the foothills immediately west of the town of McKittrick. It includes the newly discovered extension known as the Belridge field, situated 11 miles northwest in an intermediate position between McKittrick and Lost Hills.

Development

The well development in this district is summarized in the following table, which indicates the progress in the last four years:

Well Development in the McKittrick District from 1909 *to* 1912, *Inclusive*

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	208	3	6
1910	231	2	15
1911	246	9	24
1912	297	20	16
1913	311[a]	....	....

[a] Estimated for November, 1913.

Production

The following table gives the yearly production of the McKittrick district from beginning to date:

Yearly Production of McKittrick District

Year	Production Barrels	Year	Production Barrels
1898	10,000	1906	531,185
1899	15,000	1907	1,944,671
1900	80,000	1908	2,517,951
1901	430,450	1909	5,077,362
1902	619,296	1910	5,604,653
1903	658,351	1911	5,149,226
1904	400,000	1912	5,881,996
1905	276,171		
			29,196,312

The oil from the wells of this district is black to brownish in color and varies in gravity from 12.5° to 24° Baumé (0.9845 to 0.9091 sp. gr.), the last being unusually light, and, so far as known, produced only by one well. At the north end of the district it ranges between 12.5° and 21° Baumé (0.9845 and 0.9271 sp. gr.), average 15° or 16° Baumé (0.9655 or 0.9589 sp. gr.); the variation in the central part of the district is between 12° and 24° Baumé (0.9859 and 0.9091 sp. gr.), average 15° to 17° Baumé (0.9655 to 0.9524 sp. gr.); the gravity of the oil in the southern end of the district is uniform and of about 18° Baumé (0.9459 sp. gr.), while the gravity of oil from wells in the valley and in the hills north of the McKittrick valley runs from 12° to 14° Baumé (0.9859 to 0.9722 sp. gr.), or possibly a little lighter. The following analysis gives the main physical and chemical characteristics of the average McKittrick product:

Physical and Chemical Properties of Oil from the McKittrick District[4]

Commercial Values	Average of 26 Samples	Composite Sample
Sp. gr. at 15° C	0.9566	0.9600
Degrees Baumé at 60° F	16.37	15.83
Heating value:		
Per gram, calories	10,282	10,186
Per pound, B.t.u	18,508	18,335
Per gallon, B.t.u	148,276	146,680
Weight per gallon, pounds	8.01	8.00
Flash point (open cup), °C	87	74
Burning point (open cup), °C	115	109
Viscosity at 20° C. (Engler scale)	200	160.7
Water, per cent	2.0	1.5
Sulphur, per cent	0.78	0.74
Naphtha (unrefined), per cent	.....	....

[4] Allen, Irving C., and Jacobs, W. A.: *Bulletin No.* 19, *U. S. Bureau of Mines* (1911).

Physical and Chemical Properties of Oil from the McKittrick District (Continued)

Commercial Values

	Average of 26 Samples	Composite Sample
Fuel oil, per cent	98.0	98.5
Gasoline (refined), per cent	.....	....
Lamp oil (refined), per cent	13.2	14.0
Lubricants (refined), per cent	41.0	36.5
Refining losses, per cent	6.6	6.1
Distilling losses, per cent	0.8	1.2
Asphaltum (commercial), per cent	36.4	40.7

Fractional Distillation

	Average of 26 Samples	Composite Sample
Pressure of mercury, millimeters	741	735
Water, per cent	2.0	1.5
Naphthas:		
Up to 150° C., per cent	.....	....
Unrefined, per cent	.....	....
Lamp oils:		
150° to 175° C., per cent	0.1	....
175° to 200° C., per cent	0.4	....
200° to 225° C., per cent	0.9	1.3
225° to 250° C., per cent	2.4	3.1
250° to 275° C., per cent	3.7	5.0
275° to 300° C., per cent	6.8	5.7
Unrefined, per cent	14.3	15.1
300° to 325° C., per cent	8.9	7.7
Pressure of mercury, millimeters	17	20
Lubricants:		
150° to 175° C., per cent	0.2	....
175° to 200° C., per cent	1.6	1.6
200° to 225° C., per cent	5.4	3.2
225° to 250° C., per cent	6.5	6.1
250° to 275° C., per cent	6.7	5.8
275° to 300° C., per cent	6.8	6.9
300° to 325° C., per cent	10.4	10.2
Unrefined, per cent	46.5	41.5
Residue (asphaltum), per cent	36.4	40.7
Distilling loss, per cent	0.8	1.2

Midway District

Location

The Midway district embraces the belt of territory about 15 miles long and 10 miles wide extending in a southeasterly direction from about 6 miles southeast of McKittrick to the north limit of the Sunset district, 15 miles southeast. It is separated from the McKittrick district by a strip of unproductive territory, and from the Sunset district by an arbitrary east-and-west line which marks the change from the Mount Diablo to the San Bernardino base and meridian.

Development

The well development in this district is summarized in the following table, which indicates the progress in the last four years:

Well Development in the Midway District from 1909 *to* 1912, *Inclusive*

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	208	....	25
1910	408	12	230
1911	692	46	333
1912	802	92	202
1913	917[a]	....	.....

[a] Estimated for November, 1913.

Production

The following table gives the yearly production of the Midway district from beginning to date:

Yearly Production in Barrels of Midway District

Year	Production Barrels	Year	Production Barrels
1901	4,235	1907	134,174
1902	3,048	1908	410,393
1903	5,000	1909	2,094,851
1904	8,045	1910	10,436,137
1905	11,033	1911	21,196,475
1906 (Included in Sunset)	....	1912	23,928,368
			58,213,759

The oil from the wells of this district varies from black to brown in color, and in gravity from about 11° to 12° Baumé (0.9929 to 0.9859 sp. gr.) to as high as 25° Baumé (0.9032 sp. gr.). The following analysis gives the main physical and chemical characteristics of the average Midway product:

Physical and Chemical Properties of Oil from the Midway District[5]

Commercial Values

	Average of 29 Samples	Composite Sample
Sp. gr. at 15° C	0.9570	0.9580
Degrees Baumé at 60° F	16.34	16.14
Heating value:		
Per gram, calories	10,341	10,314
Per pound, B.t.u	18,613	18,565
Per gallon, B.t.u	148,345	148,149
Weight per gallon, pounds	7.97	7.98
Flash point (open cup), °C	78	61
Burning point (open cup), °C	99	87
Viscosity at 20° C. (Engler scale)	518.1	137.9
Water, per cent	0.3	0.5
Sulphur, per cent	0.83	0.82
Naphtha (unrefined), per cent	0.1	......
Fuel oil, per cent	99.6	99.5
Gasoline (refined), per cent	0.1	......
Lamp oil (refined), per cent	14.4	15.3
Lubricants (refined), per cent	39.7	33.9
Refining losses, per cent	6.6	5.8
Distilling losses, per cent	0.7	0.7
Asphaltum (commercial), per cent	37.8	43.8
Fractional Distillation		
Pressure of mercury, millimeters	744	739
Water, per cent	0.3	0.5
Naphthas:		
Up to 150° C., per cent	......	......
Unrefined, per cent	......	......
Lamp oils:		
150° to 175° C., per cent	0.4	......
175° to 200° C., per cent	1.0	......
200° to 225° C., per cent	1.3	0.6
225° to 250° C., per cent	2.5	3.5
250° to 275° C., per cent	4.0	4.9
275° to 300° C., per cent	6.8	7.5
Unrefined, per cent	16.0	16.5
300° to 325° C., per cent	9.0	8.5
Pressure of mercury, millimeters	18	20
Lubricants:		
150° to 175° C., per cent	0.4	......
175° to 200° C., per cent	2.0	0.9
200° to 225° C., per cent	5.0	2.4
225° to 250° C., per cent	6.1	4.2
250° to 275° C., per cent	6.3	7.1
275° to 300° C., per cent	6.7	7.0
300° to 325° C., per cent	9.7	8.4
Unrefined, per cent	45.2	38.5
Residue (asphaltum), per cent	37.8	43.8
Distilling loss, per cent	0.7	0.7

[5] Allen, Irving C., and Jacobs, W. A., *Bulletin No.* 19, *U. S. Bureau of Mines* (1911).

Sunset District

Location

The Sunset district (Fig. 5) embraces the territory along the northeastern base of the Temblor Range, south of the line marking the change from the Mount Diablo to the San Bernardino base and meridian, and includes the southeastern part of T. 12 N., R. 24 W., the northeast part of T. 11 N., R. 24 W., the southwest part of T. 12 N., R. 23 W., and the western part of T. 11 N., R. 23 W.

Development

The well development in this district is summarized in the following table, which indicates the progress in the last four years:

Well Development in the Sunset District from 1909 *to* 1912, *Inclusive*

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	190	2	20
1910	248	4	67
1911	330	7	94
1912	380	32	82
1913	306[a]	....	....

[a] Estimated for November, 1913.

Production

The following table gives the yearly production of the Sunset district from beginning to date:

Yearly Production of Sunset District

Year	Production Barrels	Year	Production Barrels
1900	12,500	1907	567,175
1901	188,600	1908	1.556,263
1902	167,558	1909	1,712,771
1903	250,000	1910	7,157,030
1904	276,000	1911	6,350,298
1905	302,701	1912	6,509,093
1906	409,335		
			25,459,324

The hydrocarbon products of the Sunset district consist of heavy tar, oil varying in gravity from 11° to about 20° Baumé (0.9929 to 0.9333 sp. gr.), and gas. The tar occurs in springs along the outcrops of the oil sands in certain exposures of the upturned petroliferous siliceous shales in the southeastern part of the district. The oil is black, and the heavy qualities are very viscous. The heavier oil, averaging from 12° to 13° Baumé gravity (0.9859 to 0.9790 sp. gr.), occurs in the zone just under the tar sands in the shallower wells which are located at either end and along the southwestern edge of the district. The lighter oil, 13.5° to 20° Baumé gravity (0.9756 to 0.9333 sp. gr.), is produced by the deeper wells, especially those in the northern part of the district. The lightest oil occurs in the deeper wells at the northern end of the district. Much sand accompanies the oil (Fig. 6), sometimes as much as two-thirds of the gross yield of the well being sand. One well alone produced over 110,000 cu. ft. of sand in about four years and another has yielded almost as much in two years. The following analysis gives the main physical and chemical characteristics of the average Sunset product:

Physical and Chemical Properties of Oil from the Sunset District[6]

	Average of 25 Samples	Composite Sample
Commercial Values		
Sp. gr. at 15° C	0.9701	0.9705
Degrees Baumé at 60° F	14.37	14.26
Heating value:		
Per gram, calories	10,266	10,233
Per pound, B.t.u	18,478	18,419
Per gallon, B.t u	149,302	149,010
Weight per gallon, pounds	8.08	8.09
Flash point (open cup), °C	89	71
Burning point (open cup), °C	113	101
Viscosity at 20° C., (Engler scale)	527.2	604.2
Water, per cent	1.7	0.4
Sulphur, per cent	1.02	1.06
Naphtha (unrefined), per cent	0.3	......
Fuel oil, per cent	97.9	99.6
Gasoline (refined), per cent	0.3	......
Lamp oil (refined), per cent	8.3	10.7
Lubricants (refined), per cent	37.9	32.5
Refining losses, per cent	5.8	5.2
Distilling losses, per cent	0.7	0.9
Asphaltum (commercial), per cent	45.3	50.3
Fractional Distillation		
Pressure of mercury, millimeters	743	736
Water, per cent	1.7	0.4
Naphthas:		
Up to 150° C., per cent	0.3	....

[6] Allen, Irving C., and Jacobs, W. A., *Bulletin No.* 19, *U. S. Bureau of Mines* (1911).

Physical and Chemical Properties of Oil from the Sunset District (Continued)

Fractional Distillation

	Average of 25 Samples	Composite Sample
Unrefined, per cent	0.3	....
Lamp oils:		....
150° to 175° C., per cent	0.2	....
175° to 200° C., per cent	0.6	....
200° to 225° C., per cent	0.7	....
225° to 250° C., per cent	1.4	1.3
250° to 275° C., per cent	2.3	3.4
275° to 300° C., per cent	3.8	6.8
Unrefined, per cent	9.0	11.5
300° to 325° C., per cent	6.6	7.2
Pressure of mercury, millimeters	18	20
Lubricants:		
150° to 175° C., per cent	0.2	....
175° to 200° C., per cent	1.7	0.4
200° to 225° C., per cent	4.4	3.1
225° to 250° C., per cent	6.3	4.9
250° to 275° C., per cent	6.3	5.4
275° to 300° C., per cent	7.4	6.2
300° to 325° C., per cent	10.2	9.7
Unrefined, per cent	43.1	36.9
Residue (asphaltum), per cent	45.3	50.3
Distilling loss, per cent	0.6	0.9

Kern River District

The Kern River district (Fig. 8) lies on the low rolling hills at the foot of the Sierra Nevada which form the eastern rim of the San Joaquin valley. The relief in the immediate vicinity of the field is not sharp, although steep-sided gullies cut the hills in some places. The elevations range from 500 to 1,000 ft. above sea level, the field presenting an undulating appearance. The Kern river, one of the largest in the San Joaquin valley drainage basin, flows south and east of the productive field. A branch of the Southern Pacific railroad penetrates the district and connects with the main line at Oil Junction, about 4 miles to the southwest. The center of supplies is the city of Bakersfield, situated about 4½ miles southwest, with a population of about 12,700 inhabitants. The district is tapped by the pipe lines of the Standard Oil, Associated Pipe Line, and Producers Transportation companies, and most of the oil, although of low gravity, is satisfactorily pumped through pipe lines or shipped in tank cars.

This district is one of the oldest in the State, its discovery in 1899 marking the initiation of the State as a world factor in the production of fuel oil. During its first productive year the yield of the district amounted to nearly 900,000 barrels, and four years afterward its yearly production was over 18,000,000 barrels. Although no flowing wells were ever struck within its limits, this district is noted for the large amounts of oil that have been recovered from some of the properties. This is due, to a great extent, to the great thickness of the producing sands, which ranges from 200 to 500 ft. This district has produced to date the largest amount of oil of any in the State.

The proved territory has an area of about 15 square miles, having an irregular elliptical form with its longest axis extending in a northwest-

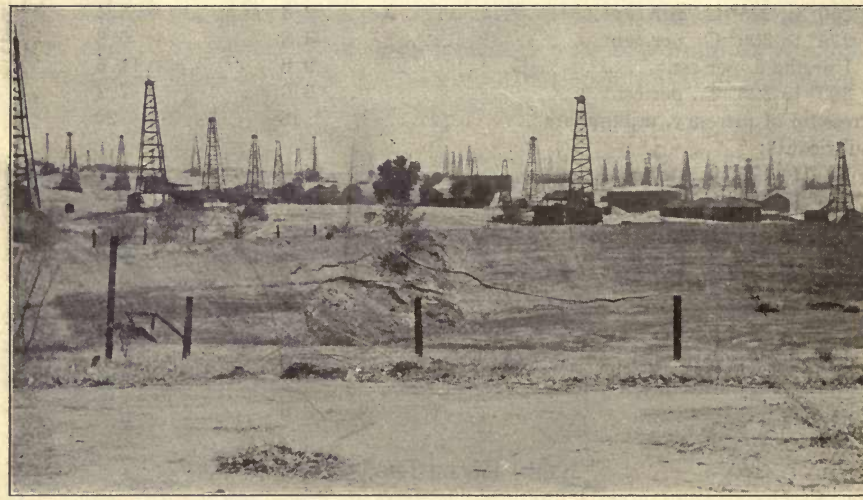

FIG. 8.—KERN RIVER FIELD.

Fully developed area. Wells in this field are placed from 200 to 300 feet apart. One of the large open reservoirs utilized for temporary storage of oil shown in foreground.

southeast direction. 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 located near the central portion. The depth to the productive oil horizons varies from 400 ft. on the northeast rim of the fold to 1,100 or 1,200 ft. on the south and west borders. The average depth of all the wells in the district will approximate 900 ft., and the gravity of the oil produced averages about 14° Baumé (0.9722 sp. gr.). It is used mainly for fuel and the manufacture of asphalt.

Geology

The formations involved in the geology of the Kern River district consist of a basement complex of granitic rocks overlain by a series of

Tertiary sedimentaries which well records show to attain a thickness of about 5,000 ft. in the region of the oil field proper. 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.

The Tertiary formations are classed into an upper and a lower division. The upper division is made up of coarse, unconsolidated sands and gravel and contains large quantities of boulders. These beds are supposed to correspond to portions of the Tulare, Etchegoin, and possibly Santa Margarita formations of the western side of the valley. The lower division, composed mostly of clays and soft diatomaceous shales grading up from a basal sandstone, represents the Monterey. The geologic studies so far made tend to show that the major features of Tertiary geologic history were alike on the two sides of the San Joaquin valley. The lower division is regarded as the source of the oil, and the upper as the main zone of its accumulation.

Structure

The structure of this district is that of a low monoclinal dome and presents a symmetrical arrangement as regards its productive territory. Minor folds occur throughout the productive portion of the monocline, and these control, to a certain degree, the extent of local accumulation in the district. The latter, as outlined by drilling, is an ellipse with the production and quality of the oil best immediately northeast of the center and gradually decreasing toward the perimeter.

Development

The following table gives in a condensed form the principal data regarding the operation in this district for the last four years:

Well Development in the Kern River District from 1909 *to* 1912, *Inclusive*

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	1393	22	25
1910	1591	8	22
1911	1787	34	153
1912	1813	68	94
1913	1699[a]	....	....

[a] Estimated for November, 1913.

The wells average in depth about 900 ft. and are drilled in about 30 days. The formations penetrated by the wells are sands and clays and contain water-bearing strata above and below the oil-producing zones.

Production

The following table gives the yearly production of this district from beginning to date:

Yearly Production of Kern River District

Year	Production Barrels	Year	Production Barrels
1900	800,000	1907	13,006,136
1901	3,870,170	1908	13,648,286
1902	8,915,801	1909	14,946,784
1903	17,164,549	1910	14,698,907
1904	18,924,000	1911	13,225,713
1905	13,898,062	1912	12,558,439
1906	13,580,334		
			159,237,181

The oil produced in this district is heavy, having an average gravity of 14° Baumé (0.9722 sp. gr.). It is used mainly for fuel, road dressing, and the manufacture of asphalt. The following analysis gives the main physical and chemical characteristics of the average Kern River product:

Physical and Chemical Properties of Oil from the Kern River District[7]

Commercial Values

	Average of 40 Samples	Composite Sample
Sp. gr. at 15° C	0.9645	0.9670
Degrees Baumé at 60° F	15.16	14.78
Heating value:		
Per gram, calories	10,307	10,312
Per pound, B.t.u.	18,553	18,562
Per gallon, B.t.u.	148,980	149,610
Weight per gallon, pounds	8.03	8.06
Flash point (open cup) °C	108	102
Burning point (open cup) °C	130	128
Viscosity at 20° C. (Engler scale)	915.6	690.0
Water, per cent	0.5	0.5
Sulphur, per cent	0.83	0.89
Naphtha (unrefined), per cent	......	......
Fuel oil, per cent	99.5	99.5
Gasoline (refined), per cent	......	......
Lamp oil (refined), per cent	6.6	3.0
Lubricants (refined), per cent	39.2	40.9
Refining losses, per cent	5.9	5.8
Distilling losses, per cent	0.5	0.5
Asphaltum (commercial), per cent	47.3	49.3

[7] Allen, Irving C., and Jacobs, W. A.: *Bulletin No.* 19, *U. S. Bureau of Mines* (1911).

Physical and Chemical Properties of Oil from the Kern River District (Continued)

Fractional Distillation

	Average of 40 Samples	Composite Sample
Pressure of mercury, millimeters	743	741
Water, per cent	0.5	0.5
Naphthas:		
Up to 150° C., per cent	......	......
Unrefined, per cent	......	......
Lamp oils:		
150° to 175° C., per cent	......	......
175° to 200° C., per cent	0.3	......
200° to 225° C., per cent	0.4	......
225° to 250° C., per cent	0.8	0.5
250° to 275° C., per cent	1.6	0.9
275° to 300° C., per cent	4.0	1.8
Unrefined, per cent	7.1	3.2
300° to 325° C., per cent	7.7	4.9
Pressure of mercury, millimeters	18	20
Lubricants:		
150° to 175° C., per cent	0.1	1.1
175° to 200° C., per cent	0.6	2.5
200° to 225° C., per cent	2.5	4.1
225° to 250° C., per cent	5.8	7.9
250° to 275° C., per cent	7.2	9.1
275° to 300° C., per cent	8.5	8.3
300° to 325° C., per cent	12.2	8.6
Unrefined, per cent	44.6	46.5
Residue (asphaltum), per cent	47.3	49.3
Distilling loss, per cent	0.5	0.5

COAST DISTRICTS

Santa Maria District

The Santa Maria district (Fig. 9) lies in northern Santa Barbara county, in the region of rolling hills between the Santa Ynez and San Rafael mountains. The district comprises three principal fields, the Santa Maria or Orcutt field, the Lompoc field, and the Cat Canyon field. Up to the present time the greater part of the development has taken place in the Orcutt field, as this was the first one discovered and exploited, the first successful well being finished in August, 1901. The wells in this field yield from 60 to 2,500 barrels of oil per day each, although initial yields of from 2,000 to 12,000 barrels have been recorded. The gravity of the oil varies from 18° to 31° Baumé (0.9459 to 0.8695 sp. gr.). The wells of the Lompoc field yield oil of 16° to 37° Baumé gravity (0.9589 to 0.8383 sp. gr.), varying in amount in the individual wells from 100 to

600 barrels per day. Successful wells were drilled in this field in 1904, and since that time the further development of this part of the district has been assured. In the Cat Canyon field the wells so far brought in have yielded from 150 to as high as 10,000 barrels per day. The quality of the oil in this field runs from 11° to 19° Baumé gravity (0.9929 to 0.9395 sp. gr.).

The center of supplies is the town of Santa Maria, which is connected with Guadalupe, a station on the Coast Line of the Southern Pacific railroad, by an electric railroad. The Pacific Coast railroad connects the different fields with Santa Maria, Port Harford, and San Luis Obispo, this latter city being on the Southern Pacific Coast Line. The greater quantity of the oil produced is piped to the refineries at Gaviota and

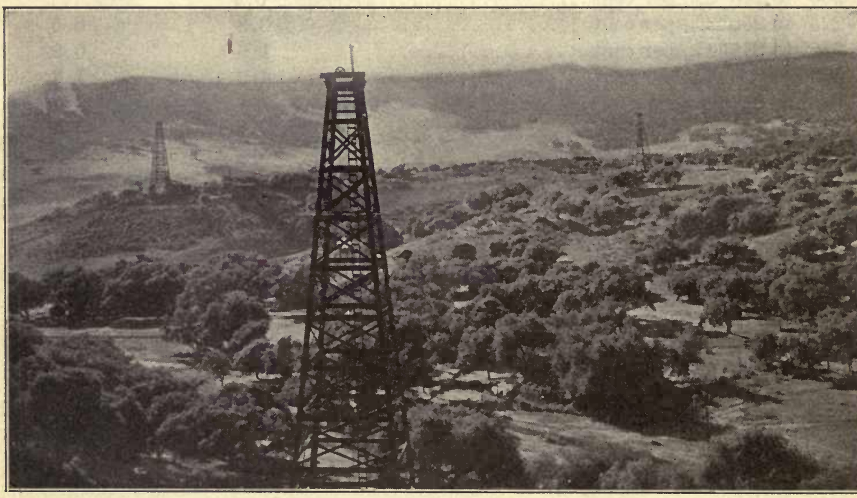

Fig. 9.—Santa Maria District.

View of portion of the Santa Maria or Orcutt field. Photograph for U. S. Geological Survey, by R. A.

Avila on the coast, the Associated Oil Co. owning the former, and the Union Oil Co. the latter plant. The Standard Oil Co., which controls a very small portion of the output, has a pipe line connecting the district with Port San Luis.

Geology

The formations involved in the geology of the productive region of this district include the Monterey (lower Miocene); Fernando (Miocene-Pliocene-Pleistocene); and Quaternary.

The Monterey formation is made up of a 5,000-ft. series of fine shales, largely of organic origin, which overlies conformably the older coarse and fine sedimentary deposits. These shales are especially important as the probable source of the oil in the district, and the present reservoir in some of the fields, and are characterized by their diatomaceous composition. Although there seems to be perfect conformity throughout the series, it may be divided on lithologic grounds into two parts, a lower one composed chiefly of hard, metamorphosed, in places flinty shales, and an upper one in which soft shale, resembling chalk and giving evidence to the naked eye of its organic origin, is predominant. The oil in the Orcutt and Lompoc fields is derived largely from the basal Monterey beds; the reservoir being interstices in the fractured flinty shales or in fine-grained true oil sands.

The Fernando formation consists throughout of a series of sandstone, conglomerate, and shale resting unconformably upon the Monterey. Unconformities also exist locally within the Fernando. It attains a thickness of at least 3,000 ft. The chief importance of the Fernando in connection with studies of this oil district is derived from the facts that it obscures the oil-bearing formation over a wide area; that it affords through its structure a clue to the structure of the underlying Monterey; and that it acts as a reservoir for the oil in the Cat Canyon field, and as a receptacle for escaping bituminous material in several localities within the district.

Structure

This district is a region of long sinuous folds, a peculiar type of structure characteristic of the Santa Maria region. It is near the axis of these folds that the productive wells are located. In the Santa Maria and Lompoc fields the evidence indicates that anticlinal structure is favorable, although probably not absolutely essential, to the accumulation of oil. Wide, low folds are characteristic of the structure in the Fernando within the Santa Maria basin region. The producing horizons in the Orcutt field are mostly zones of fractured shale or flint offering interspaces, although beds of sand in the Monterey also carry commercial quantities of oil locally. Some of the oil-producing zones are very thick, amounting to hundreds of feet. The oil occurs chiefly in the lower portion of the formation, where brittle, flinty shale is abundant; and it is noticeable wherever these hard, flinty layers appear at the surface that they are usually much more contorted and fractured than the associated softer shales. The wells of the Cat Canyon field probably obtain their product from the basal Fernando or upper Monterey beds along the flanks of low-dipping anticlines.

Development

The well development in this district is summarized in the following table, which indicates the progress in the last four years:

Well Development in the Santa Maria District from 1909 *to* 1912, *Inclusive*

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	220	4	30
1910	241	1	45
1911	255	5	19
1912	249	29	23
1913	240[a]	..	..

[a] Estimated for November, 1913.

The wells range in depth from 1,000 to 4,000 ft., the oil being obtained from coarse, hard shale at the base of the Monterey; that of the Cat Canyon from the sandy members near the upper part of the formation.

Production

The following table gives the yearly production of this district from beginning to date:

Yearly Production of Santa Maria District

Year	Production Barrels	Year	Production Barrels
1902	99,288	1908	7,758,579
1903	178,140	1909	7,565,000
1904	669,500	1910	6,947,000
1905	2,560,966	1911	6,630,000
1906	4,692,513	1912	5,909,300
1907	8,651,172		
			51,661,458

This district yields four distinct grades of petroleum in addition to the heavy oil which flows from springs or collects as asphalt deposits. These petroleums vary widely in their physical and chemical properties, and as a consequence are utilized in many different ways, the lighter oils usually for refining, the heavier for fuel, road dressing, etc. The oil as it comes from the wells contains varying quantities of gas, often amounting to a considerable percentage. Some of this gas is very rich in gasoline hydrocarbons, which are removed before utilizing for fuel. The greater portion of the oil is refined at Port Harford and Gaviota. The range in chemical constituents is shown in the following tables.

The oils of the Cat Canyon field range in gravity from 11° to 15.5° Baumé (0.9929 to 0.9622 sp. gr.). The viscosity is high; they are without doubt the most viscous oils produced in California. The yield of asphalt is very high, and the sulphur content of these oils exceeds that of most oils found in the State.

Constituents of Orcutt Field Oil

Sp. gr. (24.1° Baumé)	0.9084
Color	Greenish

		Per cent.
Gasoline	(61° B.–0.7330 sp. gr.)	5.0
Engine distillate	(52° B.–0.7692 sp. gr.)	17.0
Kerosene	(42° B.–0.8139 sp. gr.)	6.0
Stove oil	(33° B.–0.8588 sp. gr.)	23.3
Fuel distillate	(29.2° B.–0.8794 sp. gr.)	16.3
Reduced stock	(15.5° B.–0.9622 sp. gr.)	12.7
Asphalt	(grade "D")	19.7
		100.0

Constituents of Cat Canyon Field Oil

Sp. gr. (14.4° Baumé)	0.9695
Color	Brownish-black

		Per cent.
Gasoline	(61° B.–0.7330 sp. gr.)	None
Engine distillate	(52° B.–0.7692 sp. gr.)	None
Kerosene	(42° B.–0.8139 sp. gr.)	8.0
Stove oil	(33° B.–0.8588 sp. gr.)	24.0
Fuel distillate	(29.5° B.–0.8778 sp. gr.)	18.3
Reduced stock	(15.9° B.–0.9596 sp. gr.)	16.9
Asphalt	(grade "D")	32.8
		100.0

Summerland District

General Statement

The Summerland district owes its importance largely to the fact that its oil is obtained from wells which penetrate sands lying below the Pacific ocean (Fig. 10), and one of the most novel and interesting sights along the coast of California is that of the wharves carrying the derricks which mark the location of these unique wells. The important operations in this district began in 1891, and a maximum of 412 wells have been drilled to date. The district is reached by the Coast Line of the Southern Pacific railroad, and by vessels which touch at the port of Santa Barbara. The town of Summerland, at which is situated the only productive oil field so far developed in the district, lies nearly 6 miles east of Santa Barbara, where practically all the oil is sold being transported in tank wagons and cars.

The wells range in depth from 100 to more than 600 ft., their initial production being as high as 100 barrels per day; the average during the most productive years was probably not over 5 barrels per day each. The maximum yield of the district was in 1899, when about 208,000 barrels were produced. The oil is dark brown or black in color and ranges in gravity from 9° to 18° Baumé (1.0071 to 0.9459 sp. gr.), the average being about 14° Baumé (0.9722 sp. gr.), and is used principally for the manufacture of asphalt, for fuel, or for road dressing.

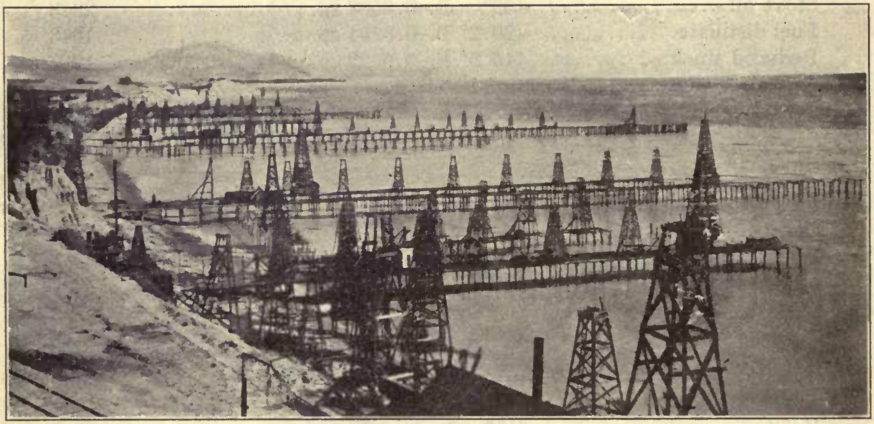

FIG. 10.—SUMMERLAND DISTRICT.
The ocean bluffs in front of Summerland, with wharves and wells. Photograph for U. S. Geological Survey, by G. H. Eldridge.

Geology

The formations involved in the geology of this district include 9,000 ft. of conglomerate, sandstone, and shale of the Tejon or Topatopa (Eocene), and possibly Martinez (lower Eocene); 4,300 ft. of conglomerate, sandstone, and shale of the Sespe, grading conformably into 2,400 ft. of sandstone and shale of the Vaqueros (lower Miocene); 1,900 ft. of shale and volcanic ash of the Monterey (lower Miocene); 1,000 ft. of conglomerate, sandstone, and clay shale of the Fernando (upper Miocene-Pliocene); and 50 ft. of gravel, sand, and clay of the Pleistocene; in all, 18,650 ft. of sediments of Tertiary age. The formations more directly connected with the oil production and accumulation are the Monterey and Fernando.

The Monterey shale, as in many other parts of the Coast Ranges, is here distinguished by its diatomaceous character, and is believed to be the ultimate source of the oil. It has a thickness of at least 1,900 ft. in the Summerland region. Volcanic ash occurs in the Monterey in two zones of 125 ft. and 75 ft. in thickness respectively.

The Fernando in the region east of Santa Barbara consists of clay and clayey shale, sandstone, and conglomerate. The last two contain oil toward the base of the formation in the Summerland field, and south of the latter, but only in commercial quantities in the developed area. Sandstone and conglomerate with some interbedded clays make up the upper portion of the Fernando, the coarse sediments being composed largely of water-worn Eocene sandstone with scattered pebbles of quartzite and other hard rocks.

Structure

Two local flexures affecting the oil-bearing Fernando formation have been recognized near this district. One of these is a well-developed anticline striking west-northwestward from Loon point, the axis being nearly coincident with the edge of the bluff for more than half a mile northwest of the point. Another flexure, which appears to be a sharp and possibly locally overturned and faulted anticline, striking north of west, occurs in the Fernando beds near the edge of the bluff opposite the Becker and North Star wharves.

The wells of this district for the most part penetrate the beds of the Fernando formation. Those on the terrace in the town, particularly north of the railroad, are drilled in the basal beds of the Fernando; some reach the Monterey shale. The oil is obtained from sands alternating with clay beds in the Fernando formation (upper Miocene or lower Pliocene) which dip 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 ft. thick, is penetrated by the terrace wells, but in the wharf wells, two, and in some wells, three oil sands occur.

Development

The following table gives, in a condensed form, the principal data regarding the operation in the district for the last four years:

Well Development in the Summerland District from 1909 *to* 1912, *Inclusive*

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	124	3	..
1910	120	4	..
1911	161	1	42
1912	152	9	..
1913[a]	122	..	..

[a] Estimated for November, 1913.

Production

The following table gives the yearly production of the Summerland district from beginning to date:

Yearly Production of Summerland District

Year	Production Barrels	Year	Production Barrels
1894	1,500	1904	119,506
1895	16,904	1905	123,871
1896	39,792	1906	81,848
1897	130,136	1907	56,905
1898	132,217	1908	58,103
1899	208,370	1909	71,189
1900	153,750	1910	71,511
1901	135,900	1911	63,238
1902	143,552	1912	65,376
1903	127,926		
			1,801,594

Water, sludge, and gas accompany the oil in most of the wells of the area. The production ranges from an initial yield of oil containing practically no water to an emulsion containing 98 to 99 per cent. of water.

The color of the oil from the Fernando or main oil zone in this district ranges from the black of the heaviest oil through dark brown to olive brown for the lighter grades. The gravity of the oil ranges from 9° to 18° Baumé (1.0071 to 0.9459 sp. gr.), the average being between 14° and 15° Baumé (0.9722 and 0.9655 sp. gr.). This is classed as among the heaviest oils produced in the State. The viscosity of the average oil in this district is as high as any found in California, being 65 at 15° C. (59° F.) and 3.20 to 3.90 at 85° C. (185° F.) where the viscosity of water equals 1.00. The most prominent chemical characteristics of the Summerland oil are its high percentage of asphaltum, and the absence from it of any gasoline. The range in chemical constituents is shown in the following table:

Constituents of Summerland Oils

Sp. gr. (12.7° to 14° Baumé)			0.9815	0.9722
Color			Black	Black
				Per cent.
Gasoline		Below 150° C.	0[8]	0
Engine distillate	(48° B.–0.7865 sp. gr.)			0.1[9]
Kerosene	(41° B.–0.8187 sp. gr.)	150 to 250° C.	8.67	3.0
Stove oil	(33° B.–0.8588 sp. gr.)			4.0
Gas oil	(28° B.–0.8860 sp. gr.)	250° to 350° C.	22.80	16.3
Fuel oil	(25° B.–0.9032 sp. gr.)			19.1
Lubricants	(21.5° B.–0.9241 sp. gr.)	350° C.	36.67	20.4
Asphalt	(grade "D")		30.	37.1
			98.14	100.0

[8] O'Neill, Edmond: *Journal of the American Chemical Society*, vol. xxv, pp. 707 to 709 (1903). (Percentage figures after taking out water.)

[9] Prutzman, P. W.: *Bulletin No. 32, California State Mining Bureau*, p. 194 (1904).

Some analyses show a sulphur content of from $\frac{1}{10}$ to as much as 1 per cent. This is a typical fuel oil, high in asphalt.

Santa Clara Valley District

The Santa Clara valley district is the oldest oil-producing territory in the State, the first oil being obtained about 48 years ago from tunnels driven near Ventura and on the southern flanks of Sulphur mountain.

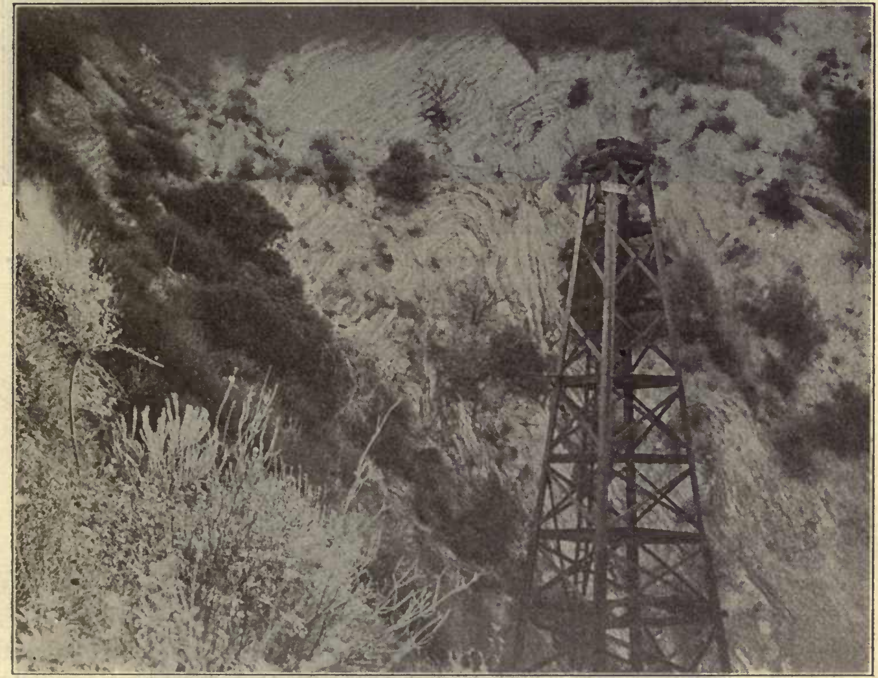

Fig. 11.—Santa Clara Valley District.
Axis of main anticline in Tar Creek shales, east side of canyon at Pico Canyon wells. Photograph for U. S. Geological Survey, by R. A.

The first productive well in California was drilled near Ventura in 1867. The district includes the region on either side of the Santa Clara valley from Newhall field in Los Angeles county, 40 miles northwest of the city of Los Angeles, to the Ojai valley field in Ventura county, about 50 miles further west. The Santa Clara valley district produced practically all the oil in the State up to 1880, when the Puente Hills district was discovered. The bulk of the production is of refining grade, its high quality being mainly responsible for the commercial importance of the district. The production of the district in 1912 was 746,780 barrels, most of it being

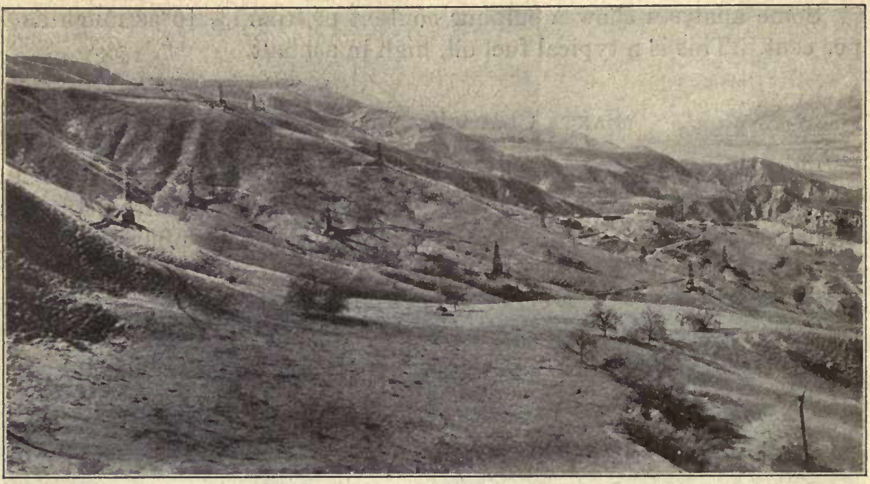

FIG. 12.—SANTA CLARA VALLEY DISTRICT.
View northwest from Oak Ridge, showing Torrey Canyon wells. Photograph for U. S. Geological Survey, by G. H. Eldridge.

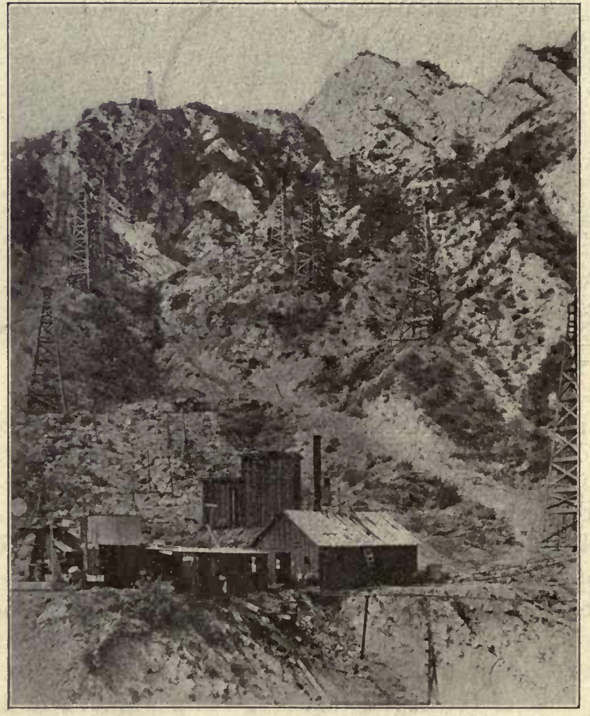

FIG. 13.—SANTA CLARA VALLEY DISTRICT.
Oil wells along the axis of anticline in Modelo Canyon. Photograph for U. S. Geological Survey, by G. H. Eldridge.

transported to seaboard through pipe lines, the oil gravitating from some of the fields to Ventura for a distance of about 50 miles.

This district comprises a number of isolated small fields which derive their production under most peculiar conditions. Some are located in almost inaccessible places, the productive territory being sometimes confined to a very narrow strip along the crest of a sharp fold. The depths of the wells vary from 200 to 3,700 ft., a large number being less than 1,000 ft. It is estimated that the average depth of the wells throughout the district is somewhat less than for any other district in the State. These fields may be grouped according to their position relative to the Santa Clara valley, as follows:

Fields North of Santa Clara River

Ojai Valley and Sisar Creek
Southern flanks of Sulphur mountain (Aliso-Wheeler, Adams, Salt Marsh)
Sespe fields
Hopper Canyon
Modelo, (Fig. 13)

Fields South of Santa Clara River

Bardsdale
Montebello
Torrey Canyon (Fig. 12)
Eureka Canyon
Pico Canyon }
Wiley Canyon } (Fig. 11) Newhall field.
Elsmere Canyon }
Simi Valley

The heaviest oil, ranging from 11° to 16° Baumé gravity (0.9929 to 0.9589 sp. gr.), is found in the Ojai Valley, Hopper Canyon, and Elsmere Canyon fields. Practically all of the other fields yield refining oil ranging from 23° to 38° Baumé gravity (0.9150 to 0.8333 sp. gr.). The wells vary in capacity from an initial flow of 500 to 600 barrels per day, to wells which can be profitably operated for a yield of two barrels per day or even less. It is estimated that the average daily production per well for the entire district in November, 1913, was 6.4 barrels.

The oil is derived from various geologic formations under several conditions of structure. The most important oil-producing horizons are the Sespe, Vaqueros, and Modelo (Monterey), and the commonest structural position of accumulation is in anticlines.

The country is accessible through one of the branches of the Southern Pacific railroad, which extends from Saugus on the main Valley line to Montalvo on the main Coast line from 30 to 90 miles northeast of Los Angeles. Roads extend into the various fields from Santa Paula, Fillmore, Piru, and Newhall, the centers of supply for the region. The Santa Clara valley offers an excellent way for pipe lines through which the oil gravitates from the various fields to Ventura, whence a considerable part of the product is shipped by boat. The Union and Standard Oil companies own pipe lines down the Santa Clara valley, while several local companies own short lines connecting their properties with the main lines or loading racks on the railroad.

Although practically all the fields have been operated for many years, the territory is by no means all prospected, and additions to the productive areas are being made from time to time.

Geology

The formations involved in the geology of the district include a basement complex of granitic and gneissic rocks, on which the following sedimentaries have been laid down in ascending order: the Tejon (Topatopa); Sespe; Vaqueros; Monterey (Modelo); and Fernando. Oil is found in all of these sedimentaries at one point or another throughout the district.

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 from 3,000 to possibly 9,000 ft. 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.

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 ft. of alternating hard sand and shale layers. It has yielded oil from 11° to 37° Baumé gravity (0.9929 to 0.8383 sp. gr.), and is the most important producer of oil in this district.

The Sespe formation is conformably overlain by the Vaqueros or lower Miocene, which consists of from 800 to 3,000 ft. of dark-colored organic shale and minor amounts of sandstone. At most localities in this region the sandstone members of the formation carry petroleum, so that the formation, when available to the drill, offers inducements for exploitation, especially when 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:

	Thickness Feet
1. Lower sandstone	300 to 1,500
2. Lower shale	400 to 1,600
3. Upper sandstone	100 to 900
4. Upper shale	200 or more

The lower sandstone yields a high-grade oil in the Modelo Canyon wells, while at other points throughout the series there is evidence of petroleum. The lower shale is an important member, well exposed along Pole and other canyons, where it lies in sharp contrast to the creamy upper Modelo sandstone above it.

The Fernando formation, from 5,000 to 8,000 ft. thick, extending from the upper Miocene to the Quarternary, lies in an unconformable position with relation to the older beds, and is locally largely made up of the water-worn fragments of the latter. It is commonly incoherent, although hard layers of conglomerate or sandstone are sometimes met with. 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.

Structure

The general structure in this district is dominated by an overturned anticline making up the mountain range north of and paralleling the productive oil fields. The local structure affecting the accumulation of oil in any particular region is very complicated, sharp folds (Figs. 11 and 13), faults, cross-folding and overturning 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, such being the case in the Montebello and Bardsdale fields with apparently unproductive local areas between them. 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 same, even in near-by properties, is, at times, almost impossible. This irregularity accounts also to some degree for the diversity of product obtained, the oil ranging in gravity from 10° to 35° Baumé (1.0 to 0.8485 sp. gr.) and even higher.

Development

The following tables give, in a condensed form, important data regarding the principal fields or groups of wells in this district, and the development which has taken place during the last four years.

It is estimated that the average depth of the producing wells is somewhat less than 1,000 ft. and that about five-sixths of the wells produce oil over 18° Baumé gravity (0.9459 sp. gr.).

	North of Santa Clara River	Began Producing
Ojai Valley	12° to 18° B., 0.9929 to 0.9459 sp. gr.	1885
Sisar Creek	21° to 27° B., 0.9271 to 0.8917 sp. gr.	1885
Southern flanks of Sulphur Mountain	20° to 32° B., 0.9333 to 0.8641 sp. gr.	Tunnels in 1861 Wells in 1875
Sespe fields	12° to 34° B., 0.9790 to 0.8536 sp. gr.	1885
Hopper Canyon	14° to 15° B., 0.9722 to 0.9655 sp. gr.	1887
Modelo	26° to 28° B., 0.8974 to 0.8860 sp. gr.	1898
	South of Santa Clara River	
Bardsdale	27° to 29° B., 0.8917 to 0.8805 sp. gr.	1896
Montebello	33° to 35° B., 0.8588 to 0.8484 sp. gr.	1911
Torrey Canyon	24° to 30° B., 0.9090 to 0.8750 sp. gr.	1896
Eureka Canyon	26° 0.8974 sp. gr.	1893
Tapo Canyon	21° 0.9271 sp. gr.	1882
Pico Canyon	38° 0.8333 sp. gr.	1875
Wiley Canyon	30° 0.8750 sp. gr.	1900
Elsmere Canyon	14° 0.9722 sp. gr.	1889
Simi Valley	36° 0.8433 sp. gr.	1912

Well Development in the Santa Clara Valley District from 1909 to 1912, Inclusive

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	335	9	18
1910	341	1	32
1911	333	9	19
1912	347	11	55
1913[a]	406	....	....

[a] Estimated for November, 1913.

Production

The following table gives the estimated production of this district from beginning to date. The figures from 1870 to 1882 represent the total production of the State, and those from 1883 to 1898 include the production of the Puente Hills district, the only other producing region in the State at that time.

Yearly Production of Santa Clara Valley District

Year	Production Barrels	Year	Production Barrels
1870	3,600	1891	323,600
1871	5,200	1892	385,049
1872	6,500	1893	470,179
1873	7,200	1894	524,469
1874	7,700	1895	461,883
1875	8,400	1896	298,866
1876	9,600	1897	631,135
1877	13,000	1898	792,990
1878	15,227	1899	729,718
1879	19,858	1900	734,684
1880	40,552	1901	563,127
1881	99,862	1902	584,764
1882	128,636	1903	448,295
1883	142,857	1904	617,770
1884	262,000	1905	437,970
1885	325,000	1906	390,101
1886	377,145	1907	447.223
1887	678,572	1908	469,942
1888	690,333	1909	370,000
1889	303,220	1910	597,000
1890	307,360	1911	620,228
		1912	746,780
			15.097,595

The range in chemical constituents is shown in the following tables:

Constituents of Santa Clara Valley District Oils[10]

Ojai Valley Field

Sp. gr. (11.8° to 18.8° Baume')		0.9873	0.9409
Color		Black	Black
		Per Cent.	Per Cent.
Engine distillate	(52° B.–0.7692 sp. gr.)	0	11
Kerosene	(42° B.–0.8139 sp. gr.)	0	7
Heavy distillate		58	59
Asphalt	(grade "D")	42	23
		100	100

[10] Prutzman, Paul W.: Petroleum in Southern California, *Bulletin No.* 63, *California State Mining Bureau*, (1913).

Sespe Field

Sp. gr. (13° to 33.7° Baume')		0.9790	0.8555
Color		Black	Brownish
		Per Cent.	Per Cent.
Gasoline	(61° B.–0.7330 sp. gr.)	0	20
Engine distillate	(52° B.–0.7692 sp. gr.)	0	10
Kerosene	(42° B.–0.8139 sp. gr.)	0	11
Heavy distillate		100	44
Asphalt	(grade "D")	0	15
		100	100

Torrey Canyon Field

Sp. gr. (23.9° to 29.9° Baume')		0.9097	0.8756
Color		Black	Black
		Per Cent.	Per Cent.
Gasoline	(61° B.–0.7330 sp. gr.)	1	17
Engine distillate	(52° B.–0.7692 sp. gr.)	6	0
Kerosene	(42° B.–0.8139 sp. gr.)	20	15
Heavy distillate		53	66
Asphalt	(grade "D")	20	17
		100	100

Bardsdale Field

Sp. gr. (19.8° to 27.6° Baumé)		0.9346	0.8883
Color		Black	Black
			Per Cent.
Gasoline	(61° B., 0.7330 sp. gr.)		18
Engine distillate	(52° B., 0.7692 sp. gr.)		0
Kerosene	(42° B., 0.8139 sp. gr.)		17
Heavy distillate			33
Asphalt	(grade "D")		29
			97

Sisar Creek Valley

Sp. gr. (21.6°B. to 27.3° Baume)		0.9234	0.8900
Color		Brown-black	Brown-black
		Per Cent.	Per Cent.
Gasoline	(61° B., 0.7330 sp. gr.)	0	11
Engine distillate	(52° B., 0.7692 sp. gr.)	10	13
Kerosene	(42° B., 0.8139 sp. gr.)	11	13
Heavy distillate		66	50
Asphalt	(grade "D")	13	13
		100	100

Los Angeles District

The Los Angeles district includes the City field (Fig. 14), lying in the city of Los Angeles, and the Salt Lake field, immediately west of the city limits about 4½ miles from its business center. The district lies from 15 to 20 miles from the coast. The Salt Lake field is connected with Los Angeles by a pipe line; the oil from the City field is delivered in tank wagons. The product is sold in Los Angeles and neighboring towns both in a crude and a refined state.

The City field was discovered in 1892 when a 155-ft. shaft was sunk near a small deposit of brea on Colton street. The first successful well was drilled the latter part of 1892 on Second street, and by the end of 1895 there were more than 300 wells. This field covers a narrow belt about 5½ miles long running through the northern part of the city; the total area is about 2 square miles. The wells vary in depth from 500 to 1,200 ft., the oil produced being between 12° and 19° Baumé gravity (0.9859 and 0.9396 sp. gr.). The limits of the field are well defined; the wells have always been small producers, necessitating pumping, and owing to the great number of wells drilled within such a small area the field has

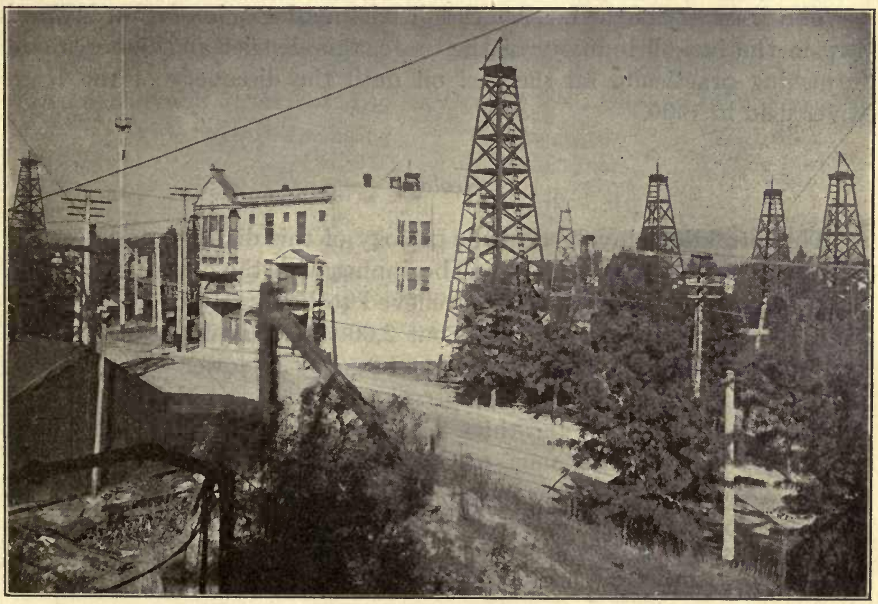

Fig. 14.—Los Angeles District.
Part of City field and City of Los Angeles.

been drained at a rapid rate and the water allowed to enter the oil sands in many areas. In November, 1913, there were about 420 wells producing an average of about 2.4 barrels per day per well.

The first well in the Salt Lake field was drilled in 1901 by the Salt Lake Oil Co., and since 1902 this field has become the most important in the Los Angeles district. The wells are deeper than in the City field, varying between 1,200 and 3,000 ft., the average gravity of the oil being between 16° and 18° Baumé (0.9589 and 0.9459 sp. gr.). Considerable gas under strong pressure accompanies the oil, which causes the wells to gush during their early life. This gas is used as fuel in the operation of the properties of the field. The limits of this field are ascertained in several directions. It is estimated that there were 290 wells in this field during November, 1913, producing an average of about 23 barrels per day per well.

The discovery of the Los Angeles district marks an important forward step in the fuel-oil industry of the State, this district and Summerland furnishing practically all the fuel oil until the discovery of the Kern River field in 1900.

Geology

The formations involved in the geology of this district consist of the following, in the order of their age beginning with the oldest: more than 2,000 ft. of indurated sandstone, believed to be largely of Vaqueros or lower Miocene age, overlain by about 2,000 ft. 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 ft. or more of soft, thin- and thick-bedded sandstone, 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 ft. of the Monterey and the basal beds of the Fernando.

Structure

The most prominent structural feature in the district is the great flexure in the Vaqueros and Monterey sandstone and shale 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 might almost be regarded as 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 base of the Fernando formations, on the southern 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 assumed a direction closely approximating east-and-west. The oil appears to have accumulated in the 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 developed on the flanks of the fold along the southern limb of which the other Los Angeles fields are located.

Development

The well development in the Los Angeles district is summarized in the following table, which indicates the progress in the last four years:

Well Development in the Los Angeles District from 1909 *to* 1912, *Inclusive*

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	697	15	8
1910	703	32	21
1911	701	27	25
1912	699	24	22
1913	710[a]	....	....

[a] Estimated for November, 1913.

The wells in the City field range in depth from 500 to 1,200 ft.; those in the Salt Lake field from 1,200 to over 4,000 ft.

Production

The following table gives the yearly production of this district from beginning to date:

Yearly Production of Los Angeles District

Year	Production Barrels	Year	Production Barrels
1894	180,000	1904	1,190,000
1895	729,695	1905	2,672,349
1896	900,000	1906	2,586,779
1897	1,072,000	1907	3,659,088
1898	1,168,000	1908	3,779,311
1899	1,032,036	1909	3,766,415
1900	1,500,000	1910	3,409,000
1901	2,060,000	1911	2,970,000
1902	1,835,000	1912	2,670,463
1903	1,680,000		
			38,860,136

The oils of the City field are uniform in quality, although they vary considerably in gravity. They contain considerable sulphur, and owing to the entire absence of light products are of little value for refining, being used almost entirely for fuel. The oils produced in the Salt Lake field show a marked similarity in general properties, being characterized by a high percentage of sulphur. The heavy oils are highly viscous, and the yield of asphalt is considerable. The following analyses give the composition of typical oils of the Los Angeles district:

Composition of City Field Oil[11]

Sp. gr. (16.5° Baumé)	0.9557
Viscosity at 185° F.	2.83 Redwood
Sulphur	0.85 per cent. by weight
Thermal value	18,787 B.t.u.
Color	Brownish black

		Per Cent.
Gasoline	(61° B.–0.7330 sp. gr.)	None
Engine distillate	(52° B.–0.7692 sp. gr.)	None
Kerosene	(42° B.–0.8139 sp. gr.)	None
Stove oil	(33° B.–0.8588 sp. gr.)	7.0
Middlings and lubricants	(25° B.–0.9032 sp. gr.)	69.0
Asphalt	(grade "D")	21.8
Loss and water		2.2
		100.0

Composition of Salt Lake Field Oil[11]

Sp. gr. (17.6° Baumé)	0.9485
Viscosity at 60° F.	78.63 Redwood
Viscosity at 185° F.	2.83 Redwood
Flash point	Below 60° F., Abel-Pensky test
Color	Black

		Per Cent.
Gasoline	(61° B.–0.7330 sp. gr.)	4.0
Engine distillate	(52° B.–0.7692 sp. gr.)	6.8
Kerosene	(42° B.–0.8139 sp. gr.)	6.5
Stove oil	(33° B.–0.8588 sp. gr.)	4.0
Middlings and lubricants	(264° B.–0.8951 sp. gr.)	51.4
Asphalt	(grade "D")	26.8
Loss		0.5
		100.0

Puente Hills District

The Puente Hills district is developed along the southern face of the Puente hills, beginning at a point about 12 miles slightly south of east of the city of Los Angeles and extending in a general east-southeasterly

[11] Prutzman, Paul W.: Petroleum in Southern California, *Bulletin No.* 63, *California State Mining Bureau* (1913).

direction for 22 miles to Santa Ana river. The hills cover an area, roughly, of about 140 square miles; their western and northern parts lie in Los Angeles county, the southeastern part being divided between San Bernardino county on the north and Orange county on the south. This district is situated but 35 miles from Port Los Angeles, the principal deep-water harbor of southern California, and was the second district discovered in California, the first producing well being finished in 1880. Until 1893 the Puente Hills and Santa Clara valley districts yielded practically

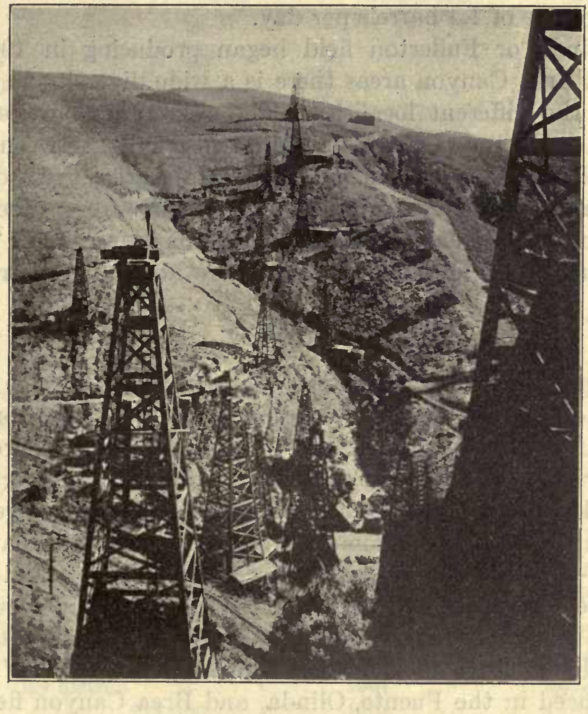

Fig. 15.—Puente Hills District.
Whittier oil field, showing development along property lines. Photograph for U. S. Geological Survey, by R. A.

all the oil produced in California. This district comprises the Whittier, Coyote, Puente, and Olinda (Fullerton) fields.

The wells in the Whittier field (Fig. 15) are small producers and range in depth from 600 to 3,500 ft., the average depth being close to 1,650 ft. The oil produced varies between 15° and 24° Baumé gravity (0.9655 and 0.9091 sp. gr.).

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 ft., the maximum about 4,500 ft., the oil being between 20° and 33°

Baumé gravity (0.9333 and 0.8589 sp. gr.). The average daily production per well in the Whittier and Coyote fields is at present about 22.8 barrels; that of the Coyote field alone probably several times 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 the years of 1886 and 1887 are still pumping. The average depth of the wells in this field is somewhat over 1,300 ft.; the average producing life has been about 16 years; the gravity of the oil varies between 21° and 32° Baumé (0.9271 and 0.8642 sp. gr.). At present individual wells yield an average of 1.4 barrels per 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 ft. in depth and produce oil ranging in gravity between 15° and 34° Baumé (0.9655 and 0.8536 sp.gr.). 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 now about 71.5 barrels.

Geology

The formations involved in the geology of the district include the Puente (Vaqueros and Monterey) formation, largely sandstone and shale of lower Miocene age, and believed to be the ultimate source of the oil in the district; post-Monterey diabase, probably contemporaneous with similar rocks found elsewhere throughout the Coast Ranges; 4,000 ft. of clay, sandstone, and conglomerate of the Fernando formation, largely Pliocene in age; and superficial Pleistocene deposits of sand and gravel. The Puente formation has been divided on lithologic grounds into a lower shale 2,000 ft. thick; a lower sandstone 300 to 1,000 ft. thick; and an upper shale 300 to 400 ft. thick. The lighter grades of oil, such as those produced in the Puente, Olinda, and Brea Canyon fields, are believed to come from the Puente formation, while the heavier grades are derived largely from the coarser sediments of the Fernando.

Structure

The structure of the Puente Hills is that of an anticline, contracted in the western part, expanded in the eastern. The main axis of the flexure is not everywhere easy of recognition, owing to the prominence of nearly parallel secondary folds that exist throughout the length and breadth of the hills. The general and local structure is affected in places by faults of varying intensity. The Coyote hills follow the axis of a well-defined anticline, paralleling the general east-west trend of the Puente hills.

Development

The well development of this district is summarized in the following table, which shows the progress in the last four years:

Well Development in the Puente Hills District from 1909 *to* 1912, *Inclusive*

	Producing Dec. 31	Abandoned During Year	Completed During Year
1909	422	7	14
1910	431	4	53
1911	454	57	43
1912	470	46	32
1913	499[a]	..	..

[a] Estimated for November, 1913.

Production

The following table gives the yearly production of the district from beginning to date:

Yearly Production of Puente Hills District

Year	Production Barrels	Year	Production Barrels
1882–1898	Included with Production under Santa Clara Valley district	1905	2,126,772
		1906	2,804,000
		1907	2,333,000
1899	217,599	1908	4,181,000
1900	511,550	1909	3,963,000
1901	753,198	1910	5,641,165
1902	1,043,463	1911	6,425,000
1903	1,732,153	1912	6,881,650
1904	2,329,655		
			40,943,205

The oil produced varies greatly in composition, the greater portion being of light grade and utilized by refineries near Los Angeles. The following analyses give the physical and chemical characteristics of typical oils of this district, and serve to emphasize the wide range in variation of the different constituents:

Constituents of Puente Hills District Oils.[12]

Whittier Field

Color	Brown-black	Green-black
Gravity (14.2° to 23.1° Baumé)	0.9709	0.9144
Sulphur, per cent	0.9	0.7
	Per Cent.	Per Cent.
Gasoline (61° B., 0.7330 sp. gr.)	0	8.0
Engine distillate (52° B., 0.7692 sp. gr.)	0	5.0
Kerosene (42° B., 0.8139 sp. gr.)	0	8.0
Heavy distillate (28° B., 0.8861 sp. gr.)	73.0	65.0
Asphalt (grade "D")	27.0	14.0
	100.0	100.0

Coyote Field

Color	Brown-black	Brownish
Gravity (21° to 30.7° Baumé)	0.9271	0.8712
Sulphur	......	......
	Per Cent.	Per Cent.
Gasoline (61° B., 0.7330 sp. gr.)	......	9.0
Engine distillate (52° B., 0.7692 sp. gr.)	......	5.0
Kerosene (42° B., 0.8139 sp. gr.)	......	17.0
Heavy distillate (28° B., 0.8861 sp. gr.)	......	43.0
Asphalt (grade "D")	......	26.0
		100.0

Puente Field

Color	......	Brown-black
Gravity (21.5° to 32.5° Baumé)	0.9241	0.8616
Sulphur per cent	......	0.4
	Per Cent.	Per Cent.
Gasoline (61° B., 0.7330 sp. gr.)	0	15.0
Engine distillate (52° B., 0.7692 sp. gr.)	0	13.0
Kerosene (42° B., 0.8139 sp. gr.)	19.0	13.0
Heavy distillate (28° B., 0.8861 sp. gr.)	62.0	46.0
Asphalt (grade "D")	19.0	13.0
	100.0	100.0

[12] Prutzman, Paul W.: Petroleum in Southern California, *Bulletin No.* 63, *California State Mining Bureau*, (1913).

Fullerton Field

Color		Black-green	Black
Gravity (15° to 34.5° Baumé)		0.9655	0.8511
Sulphur, per cent		1.2	0.4
		Per Cent.	Per Cent.
Gasoline	(61° B., 0.7330 sp. gr.)	0	25.0
Engine distillate	(52° B., 0.7692 sp. gr.)	0	0
Kerosene	(42° B., 0.8139 sp. gr.)	4.0	27.0
Heavy distillate	(28° B., 0.8861 sp. gr.)	67.0	34.0
Asphalt	(grade "D")	29.0	14.0
		100.0	100.0

Drilling Methods

The drilling methods most commonly employed in California are the standard, rotary, and circulating systems.

With the standard rig the hole is made by the percussion effect of a heavy steel bar suspended from a manila rope or wire line, the motion being imparted by an oscillating beam connected with a steam engine or electric motor. A characteristic of this method is that it necessitates the periodical suspension of drilling in order to remove the accumulated débris, an operation which is greatly facilitated by the water which is let into the well from the strata penetrated or poured into the casing by the drillers.

In the rotary method the hole is made as a result of the abrasive action of a bit or shoe screwed to the end of a revolving column of casing, the débris being removed or washed to the surface and the entire operation greatly facilitated by the action of a stream of water forced through the drill pipe to the space between it and the wall of the hole or to the space between casings. It is therefore apparent that by the use of the rotary method, in certain cases, considerable time is saved over the standard owing to the automatic removal of the drillings.

The circulating system, which has been successfully used, particularly in the Coalinga field, includes the string of tools of the standard and the circulating water arrangement of the rotary. The circulator contains some of the advantages as well as disadvantages of the standard and rotary systems, and in certain territory its use has been found very satisfactory.

As the formations encountered in the different fields vary as to character and thickness, the general use of a single method is out of the question; in fact, two and even the three systems are employed in some fields. In general, it may be said that the standard is used successfully in territory where considerable quantities of hard "shells" are encountered, or where conditions are not well known, as in the case of "wild-cat" territory, or in undeveloped properties in productive fields. The standard is also used for finishing some rotary wells, it being considered that there is less chance with the standard tools of missing an oil-bearing bed, by going through it without identification. This system is the one in most general use in California, and has been employed exclusively in the Kern River district, and to a greater or less extent throughout all the fields in the State.

The rotary system is more adapted for drilling through unconsolidated sandstones, clays, and shales, such as are encountered in certain parts of the Sunset-Midway and Coalinga districts. Its use is very efficient in territory where oil or gas is encountered under great pressure, it being a great deal easier to control these large flows by means of the rotary than by the standard or circulating systems. The rotary is most useful where it is possible to land the water string near the oil sand, thus causing a great saving in pipe, as often the well can be finished with two strings instead of four or five, as in the case of standard tools. Some operators claim that by the use of improved drilling bits the field of usefulness of the rotary can be extended to territory where the harder rocks are common.

In certain of the oil districts it has been found economical to drill the unconsolidated sands and clays near the surface with the rotary and finish the well with the standard, a combination rig being employed. The field of usefulness of the circulating system is a matter for careful experimenting, and undoubtedly in many cases this method can replace advantageously either or both the standard and the rotary.

Steam engines generally are used in drilling, although in comparatively shallow wells drilled with the standard rig electric motors have been successfully employed of late. Portable rigs of the standard type are being economically used in some shallow areas in the Lost Hills and Santa Clara valley districts.

Derricks.—In order to place and remove the casing in the well a wooden frame, or derrick, is built over the hole. The derricks vary in height between 87 and 130 ft., the smaller size being used when comparatively shallow wells are drilled by the standard method, the larger size being employed when drilling holes which are expected to attain great depths.

Drilling Lines and Cables.—When drilling by the rotary or circulating systems, the tools are suspended from the walking beam by either a manila cable or a steel wire line. It is customary to employ the cable for the first 1,000 ft. of hole, after which, owing to the buoyancy of the thick cable in the mud-laden water, the cable is replaced by a wire line. The former is from $1\frac{5}{8}$ to $2\frac{1}{2}$ in. in diameter, the lines varying between $\frac{5}{8}$ and $1\frac{1}{4}$ in.

Casing.—In drilling, it is the aim to finish the well with as few strings of casings as possible. Usually the hole is first lined for a few hundred feet with a 16-in. stove-pipe or screw casing, which is employed mainly to hold back the loose surface formation. The hole proper starts with casing having an inside diameter of 12½ in. and continues with 10-, 8¼-, and 6⅝-in. casings, the sizes being reduced with a view to finishing the well with a 6⅝-in. or larger casing. As water-bearing strata generally occur above, between, or below the oil horizon, and it is of the utmost importance that the water be excluded, it is necessary (even where it is possible to reach the oil sands with the first casing) to utilize one or more strings for shutting off the water before reaching the oil-producing zone. In order properly to exclude the water the cementing process is generally employed. By this method cement is forced between the casing and the wall of the hole. The casings vary in weight from 20 to 70 lb. per foot and are of the screw-joint type in 20-ft. lengths. These are perforated either before being put into the hole or after installation, to admit the inflow of oil and exclude the accompanying sand.

Cost of Drilling

Owing to the lack of uniformity in the system followed by operators in segregating cost data it is difficult to obtain reliable information regarding the cost of drilling in the different districts. Even when comparing drilling costs on neighboring properties it is necessary to ascertain what items of expense have been included. The following figures represent a rough estimated average of drilling cost in California, the actual cost for individual wells of the depths noted varying at times from 50 per cent. over to 50 per cent. below the average figure given.

Estimated Average Cost of Oil-Well Drilling in California

Depth Feet	Cost
1,000	$10,000.00
1,500	17,000.00
2,000	25,000.00
2,500	35,000.00
3,000	50,000.00
3,500	70,000.00
4,000	100,000.00

In properties where many wells are drilled, these figures can be reduced materially. For instance, the average cost of drilling wells about 1,000 ft. deep in some properties in the Kern River field varies from $5,000 to $6,000; the average cost of a great number of wells about 1,800 ft. deep in the Coalinga and Midway districts being about $22,000, and that of several wells about 3,100 ft. deep in the Coalinga district about $44,000.

Recovery of Oil

With the exception of the cases where it reaches the surface by natural flow, the oil in California is pumped by means of a steel-barreled special oil-well pump, screwed at the end of a column of tubing 2 to 3 in. in diameter. These pumps are operated with metal rods, the motion being imparted by means of steam engines, gas engines, pumping powers, or electric motors. The average speed is 20 strokes per minute, the length of the stroke being about 23 in. The estimated maximum capacity, when no gas accompanies the oil, is close to 400 barrels per day. As considerable sand generally accompanies the oil in practically all the fields, a great deal of trouble is occasioned by the wearing of the pump barrels and valves by the sand, and this precludes the use of any but the smooth, tight-fitting steel pumping barrel. In cases where the amount of water in the oil renders the capacity of these pumps insufficient to recover an economical volume of oil the use of the air-lift has been found economical. This method is employed in the Kern River district, and to a lesser degree in other districts. The use of compressed air is also beneficial in special cases, where, owing to peculiar local conditions, the other methods are found uneconomical, as is the case in certain property in the Salt Lake field; where compressed air is used in place of steam to operate steam engines.

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Table Showing Yearly Production of the Cali-
(Data largely from U. S.

Year	Santa Maria	Summer land	Santa Clara	Los Angeles	Puente	Coalinga	McKittrick
1865	...	...	First tunnel on Sulphur Mt.			...	...
1867	...	...	First oil well near Ventura.			...	...
1870	...	...	3,600	...	...	...	...
1871	...	...	5,200	...		...	...
1872	...	...	6,500	...		...	...
1873	...	...	7,200	...		...	...
1874	...	...	7,700	...	First well included under Sta. Clara.	...	...
1875	...	...	8,400	...		...	...
1876	...	...	9,600	...		...	...
1877	...	...	13,000	...		...	...
1878	...	...	15,227	...		...	...
1879	...	...	19,858	...		...	...
1880	...	...	40,552	...		...	...
1881	...	...	99,862	...		...	...
1882	...	...	128,636	...	...	...	...
1883	...	...	142,857	...	...	...	...
1884	...	...	262,000	...	...	...	...
1885	...	...	325,000	...	...	...	...
1886	...	...	377,145	...	...	...	...
1887	Only 3 companies in State, operating at Ventura, Pico & Puente.		678,572	...	...	...	...
1888	...	...	690,333	...	...	...	...
1889	...	...	303,220	...	...	...	...
1890	...	First well	307,360	...	...	First well	...
1891	...	...	323,600	...	...	...	...
1892	...	...	385,049	...	...	...	First well
1893	...	...	470,179	...	...	...	...
1894	...	1,500	524,469	180,000	...	...	...
1895	...	16,904	461,883	729,695	...	...	...
1896	...	39,792	298,866	900,000	...	14,119	...
1897	...	130,136	631,135	1,072,000	...	70,140	...
1898	...	132,217	792,990	1,168,000	...	154,000	10,000
1899	...	208,370	729,718	1,032,036	217,599	439,372	15,000
1900	...	153,750	734,684	1,500,000	511,550	532,000	80,000
1901	First well	135,900	563,127	2,060,000	753,198	780,650	430,450
1902	99,288	143,552	584,764	1,835,000	1,043,463	572,498	619,296
1903	178,140	127,926	448,295	1,680,000	1,732,153	2,138,058	658,351
1904	669,500	119,506	617,770	1,190,000	2,329,655	5,114,958	400,000
1905	2,560,966	123,871	437,970	2,672,349	2,126,772	10,967,015	276,171
1906	4,692,513	81,848	390,101	2,586,779	2,804,000	7,991,039	531,185
1907	8,651,172	56,905	447,223	3,659,088	2,333,000	8,871,723	1,944,671
1908	7,758,579	58,103	469,942	3,779,311	4,181,000	10,386,168	2,517,951
1909	7,565,000	71,189	370,000	3,766,415	3,963,000	14,795,459	5,077,362
1910	6,947,000	71,511	597,000	3,409,000	5,641,165	18,387,750	5,604,653
1911	6,630,000	63,238	620,228	2,970,000	6,425,000	18,483,751	5,149,226
1912	5,909,300	65,376	746,780	2,670,463	6,881,650	19,911,820	5,881,996

fornia Oil Fields. In Barrels (42 *Gallons*)
Geological Survey.)

Midway	Sunset	Kern River	Lost Hills	Other Fields	Total Production	Total Value	Avg. Price Per Bbl.	Year
....	....	....	....	....	....	....	....	1865
....	....	....	....	....	....	....	....	1867
....	....	....	....	....	3,600	$5,125	$1.420	1870
....	....	....	....	....	5,200	7,370	1.420	1871
....	....	....	....	....	6,500	9,876	1.520	1872
....	....	....	....	....	7,200	10,920	1.515	1873
....	....	....	....	....	7,700	11,540	1.500	1874
....	....	....	....	....	8,400	12,090	1.440	1875
....	....	....	....	....	9,600	15,410	1.605	1876
....	....	....	....	....	13,000	18,140	1.395	1877
....	....	....	....	....	15,227	22,780	1.500	1878
....	....	....	....	....	19,858	29,672	1.495	1879
....	....	....	....	....	40,552	68,450	1.690	1880
....	....	....	....	....	99,862	130,678	1.307	1881
....	....	....	....	....	128,636	172,730	1.340	1882
....	....	....	....	....	142,857	207,540	1.450	1883
....	....	....	....	....	262,000	428,600	1.630	1884
....	....	....	....	....	325,000	613,920	1.885	1885
....	....	....	....	....	377,145	642,785	1.705	1886
....	....	....	....	....	678,572	1,357,144	2.000	1887
....	....	....	....	....	690,333	1,380,666	1.990	1888
....	....	....	....	....	303,220	368,048	1.214	1889
....	....	....	....	....	307,360	384,200	1.250	1890
....	First well	....	....	....	323,600	401,264	1.240	1891
....	....	....	....	....	385,049	561,333	1.455	1892
....	....	....	....	....	470,179	608,692	1.294	1893
....	....	....	....	....	705,969	825,983	1.170	1894
....	....	....	....	....	1,208,482	966,785	0.800	1895
....	....	....	....	....	1,252,777	1,180,793	0.944	1896
....	....	....	....	....	1,903,411	1,713,102	0.900	1897
....	....	....	....	....	2,257,207	2,144,346	0.950	1898
....	....	First well	....	....	2,642,095	2,615,674	0.990	1899
First well	12,500	800,000	....	....	4,324,484	4,108,259	0.950	1900
4,235	188,600	3,870,170	....	....	8,786,330	4,973,062	0.566	1901
3,048	167,558	8,915,801	....	....	13,984,268	4,873,617	0.348	1902
5,000	250,000	17,164,549	....	....	24,382,472	7,399,349	0.303	1903
8,045	276,000	18,924,000	....	....	29,649,434	8,265,434	0.279	1904
11,033	302,701	13,898,062	....	50,563	33,427,273	8,201,846	0.245	1905
....	409,335	13,580,334	....	31,464	33,098,598	9,553,430	0.289	1906
134,174	567,175	13,006,136	....	77,108	39,748,375	14,699,956	0.370	1907
410,393	1,556,263	13,648,286	....	88,741	44,854,737	23,433,502	0.522	1908
2,094,851	1,712,771	14,946,784	....	70,179	54,433,010	30,756,713	0.564	1909
10,436,137	7,157,030	14,698,907	First well	60,405	73,010,560	35,749,473	0.490	1910
21,196,475	6,350,298	13,225,713	....	20,462	81,134,391	38,719,080	0.477	1911
23,928,368	6,509,093	12,558,439	1,367,359	20,123	86,450,767	39,213,588	0.454	1912

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