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GEOLOGY AND OIL RESOURCES

OF A PART OF

LOS ANGELES AND VENTURA COUNTIES CALIFORNIA

BY

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GEOLOGY AND OIL RESOURCES OF A PART OF LOS ANGELES AND VENTURA COUNTIES, CALIFORNIA.

By William S. W. Kew.

INTRODUCTION.

The first petroleum used by white men in California came from the region now known as the Ventura-Newhall oil district, where the padres of the early missions gathered tar from natural seepages. The pioneer attempt at refining was made by Andreas Pico, who in 1856, with a copper still, obtained a small amount of illuminating oil from seepage oil in Pico Canyon near Newhall, Los Angeles County. Refining on a commercial scale was begun by George S. Gilbert in 1861, and later several companies were formed to treat petroleum. The years between 1860 and 1870 were marked by the first oil boom, and southern California was advertised as having rivers of oil which only required pipe lines to carry it to the ports on the seacoast. On the strength of these claims many spurious companies were formed. Some drilling was done, but it was not until later that any producing wells were obtained. In 1875 the California Star Oil Co., of Los Angeles, acquired its first producing well in Pico Canyon. A great many wells were drilled in Los Angeles and Ventura counties between 1880 and 1900, after which the oil excitement died down. Within the last few years, however, owing to the rise in the price of crude oil, the less productive fields have attracted the attention of the California oil companies. This has resulted in a renewal of activity in the Los Angeles and Ventura County fields, which has brought about the development of some new territory. This latest work has been done according to modern geologic principles, in marked contrast to the haphazard location of wells in the early days. The growth of the oil industry in the Ventura County-Newhall district is shown by the annual production,[1] which increased from 12,000 barrels in 1877 to 2,122,449 barrels in 1920. The total production to 1919 was 23,433,712 barrels.

The first geologic report on this area was the work of W. L. Watts,[2] of the California State Mining Bureau. In 1901–2 George

[1] Standard Oil Bull., vol. 8, No. 10, p. 10, February, 1921.

[2] California State Min. Bur. Bull. 11, 1897; Bull. 19, 1900.

H. Eldridge,[3] of the United States Geological Survey, made a survey of Santa Clara River valley in Los Angeles and Ventura counties, and later a detailed map of this region was published. Since Mr. Eldridge's report was completed the knowledge of California geology has greatly advanced and the oil industry in this region has increased to a marked degree. It was therefore thought advisable to remap at least a part of this area, and in 1917 the writer was assigned to the task of making a geologic survey of the Camulos quadrangle, having as a primary object the investigation of its oil resources. This quadrangle lies between latitude 34° and 34° 30′ and longitude 118° 30′ and 119°, bordering the coast west of Los Angeles and extending northward so that it includes a large part of the Santa Clara Valley, as shown in the index map (fig. 1). As the work progressed, it was seen that the Santa Monica Mountains were not important as a possible oil producing territory, and for that reason they were not surveyed. On the other hand, the work was extended to certain oil-bearing or potentially oil-bearing districts outside of the Camulos quadrangle that were found to be closely allied both structurally and lithologically to the main area. These districts include South Mountain and the Camarillo Hills, lying to the west, in the Santa Paula and Hueneme quadrangles, and the whole of the Fernando quadrangle to the east.

ACKNOWLEDGMENTS.

During the greater part of the field season of 1917 the careful, accurate, and efficient work of Carroll M. Wagner was a material aid to the completion of this report. John P. Buwalda assisted during the first month and contributed many excellent observations. Walter A. English accompanied the writer during the time spent in this region in 1918, and a large part of the work accomplished then was due to his efforts. Chester Stock and the writer, in November, 1919, made further investigations in the upper Santa Clara Valley region, and the determination of the age of the Mint Canyon formation is the result of Dr. Stock's study of the vertebrate fauna. R. N. Nelson has contributed some details of the Eocene stratigraphy of the Simi Hills. The investigations of the geology and oil resources of the Los Angeles-Ventura region have been under the general supervision of David White and K. C. Heald, of the United States Geological Survey, whose advice and suggestions have greatly aided the work.

The writer is under obligations to John C. Merriam for the privilege of using the paleontologic collections at the University of Cali-

[3] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles districts, southern California; U. S. Geol. Survey Bull. 309, 1907.

fornia, and to Bruce L. Clark for assistance and advice on the determination of the fossils collected during the field work.

For much valuable information in regard to the development of the several fields the writer is indebted to the operating oil companies and to the California State Mining Bureau. Without exception, any information desired was freely given. Numerous residents of the country have contributed to the completeness of the report and extended many courtesies to the field party during the course of the work. Among those who have helped make this report possible are G. C. Gester and S. H. Gester, of the Standard Oil Co. of California; F. C. van Deinse, F. S. Hudson, and W. E. Coan, of the Ventura Consolidated Oil Fields; B. L. Cunningham and T. D. Boyce, of the Pan American Petroleum Co.; A. Hirschi, of the Santa Susana Syndicate; Wallace Gordon, of the Union Oil Co. of California; F. L. Wright, of the Calumet Oil Co.; Frank Leslie, superintendent for several companies in Sespe Canyon; Irving V. Augur, H. R. Johnson, Robert Moran, Joseph Dabney, William Hope Henderson, George J. Henley, A. C. Swall, and J. W. Mitchell.

GEOGRAPHY AND ACCESSIBILITY.

The area discussed in this report lies in the southernmost part of the California Coast Ranges, directly east of the San Gabriel Mountains and north of the Santa Monica Mountains. (See fig. 1.) The area mapped includes nearly all of the Camulos quadrangle, South Mountain, and the hills north of Camarillo on the west, and the Fernando quadrange on the east. The Fernando quadrangle was mapped in order to include any possible oil-producing territory in the Santa Clara and Fernando valleys and to show the relations of the sedimentary rocks to the basement complex that forms the San Gabriel Mountains.

Los Angeles is but a few miles southeast of this region, any part of which is easily accessible from that city. In fact, San Fernando Valley is within the city limits, which reach westward to Calabasas and northward nearly to Fernando Pass. Both main lines of the Southern Pacific Railroad to San Francisco traverse this region; the Coast Line crosses by the way of Santa Susana Pass and Simi Valley, and the Valley Line runs north over Fernando Pass and thence eastward to the Mohave Desert by way of Santa Clara River (Soledad Canyon). A subsidiary line of the Southern Pacific passes down the Santa Clara Valley, leaving the main line at Saugus and connecting with the Coast Line at Montalvo, a few miles west of the area shown on the map. Electric lines extend from Los Angeles into San Fernando Valley as far as the towns of Fernando and Owensmouth. Though there are no railroads in the southern part of the area, automobile stages run over the State highway from Los Angeles to Ventura through Calabasas and Conejo Valley.

With the exception of the higher mountainous areas, the country is easily accessible by roads, the main arteries being paved. The

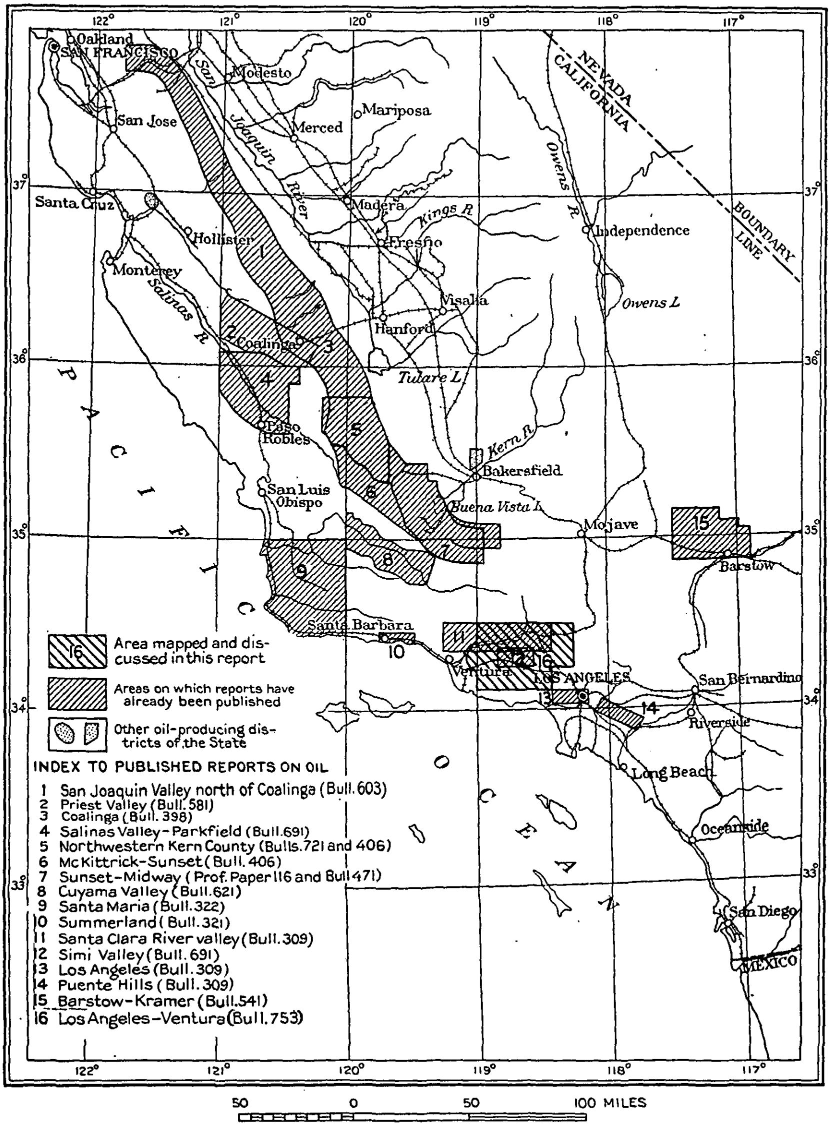

FIGURE 1.—Index map of a part of California, showing oil fields discussed in reports published by the United States Geological Survey.

most difficult part to reach is that lying north of Santa Clara Valley, where there are but few roads and these follow the larger streams and are often poor and sometimes impassable. The more mountainous and rugged parts of Pine Mountain and the Topatopa Mountains, just north of the area mapped, form what is considered one of the roughest and most inaccessible regions in California.

The area is fairly well populated. The main industry is farming and cattle raising, though the oil business in large part supports the towns of Fillmore, Santa Paula, and Newhall. Most of the residents live in the valleys and along the main highways. San Fernando Valley is now almost entirely under cultivation, being irrigated with water from the Los Angeles aqueduct. Santa Clara Valley, being narrow, has a comparatively small amount of tillable land, so that there stock raising is the main occupation. Simi and Las Posas valleys, however, are broad and floored with fertile soil, and in those areas citrus fruit and walnut orchards are rapidly increasing. Where the land is not planted to fruit trees, the principal product is beans, which are grown both by dry farming and under irrigation.

Of the towns within the area mapped, Santa Paula is probably the largest, with a population in 1920 of 3,967. Fernando, Fillmore, Owensmouth, Moorpark, and Camarillo are others that serve as centers of trade. The city of Ventura is on the coast about 10 miles west of the area, and Oxnard is about 5 miles to the southwest.

CLIMATE AND VEGETATION.

This region is of the typically semiarid type, the mean annual average rainfall at Newhall being 17.05 inches, at Ventura 16.02 inches, and at West Saticoy 14.75 inches. Practically all the rain falls during the months from November to March, inclusive, though a shower may come in summer, with light rains in the early fall and late spring. With the exception of Santa Clara River and a few of its larger tributaries, the streams are intermittent. Even the streams that have comparatively large drainage areas dwindle during the dry season to very small size, but in the winter after a hard rain they turn into veritable torrents which often cause considerable damage. Snow falls occasionally in the higher parts of the mountains and is common in the still higher San Gabriel Range and the high mountains of the Coast Range, to the north. The water in the streams that originate in the harder and older rocks, such as the bedrock complex or the Cretaceous rocks, is usually very good, but that in the streams that rise in or come into contact with the Miocene or Pliocene strata is likely to be alkaline, especially in the Calabasas region.

The temperature in this region is considerably higher than that along the California coast. According to United States Weather Bureau records the mean annual temperature at Newhall is 61.5° F., whereas that at Ventura, on the coast, is 58.2°. The hottest month at Newhall is August, with a mean of 77.3°. During the summer the thermometer often runs above 100°. However, the heat is somewhat tempered by low humidity and by cool west winds that blow during the late forenoon and afternoon, and the nights are nearly always cool. Fogs occur almost every morning near the coast and extend into the interior as far as the San Gabriel Mountains, though their frequency becomes less in proportion to the distance from the ocean.

The vegetation depends largely on the kind of soil prevailing, though almost invariably the north sides of the hills possess the more luxuriant growth, being less exposed to the direct rays of the sun. Oak Ridge and parts of the Santa Susana Mountains offer a very good example of the variety of vegetation due to differing types of underlying rock. Grass or a light growth of sage is found on the shaly soils. Chaparral grows thickly on the coarse-grained sandstone and is in places so dense that it is almost impossible to penetrate, making geologic work very difficult. Trees are present over most of the region, though they are less numerous toward the coast. Sycamore and cottonwood are common along the streams, and a few pines are found at the east end of the Santa Susana Mountains and on the San Gabriel Mountains. Black walnut trees, which are abundant in places, appear to be limited to the soil derived from Modelo or Pico shales.

STRATIGRAPHY.

GENERAL CHARACTER AND CORRELATION.

The rocks of the Los Angeles-Ventura region fall into three classes—a metamorphic and granitic complex, which is commonly referred to as the " basement complex," a series of sedimentary rocks, and a series of igneous extrusive and intrusive rocks. In this report the many different kinds of rocks that compose the basement complex have not been separated, as their separation is not important in relation to the occurrence of petroleum in this region. The metamorphic rocks are all of pre-Jurassic age and have been intruded by granite that is probably of the same age as that of the Sierra Nevada, which is considered to be late Jurassic or early Cretaceous. The sedimentary rocks, which in this region form the greater percentage, range in age from Upper Cretaceous to Recent and comprise the Chico formation (Upper Cretaceous), Martinez formation (lower Eocene), Meganos formation (middle Eocene), Tejon formation (upper Eocene), Sespe formation (Oligocene?), Vaqueros formation (lower Miocene), Topanga formation (middle Miocene), Mint Canyon formation (upper Miocene), Modelo formation (upper Miocene), Pico formation (lower Pliocene), Saugus formation (upper Pliocene and Pleistocene), and river terraces and valley alluvium (Pleistocene and Recent). In lithology they show a great diversity in types of sandstone, shale, and conglomerate, which in this region act both as the source of the oil and as reservoirs for its accumula-

Geologic age	Eldridge and Arnold, 1907 U. S. G. S. Bulletin 309: Santa Clara district	Eldridge and Arnold, 1907 U. S. G. S. Bulletin 309: Puente Hills	Eldridge and Arnold, 1907 U. S. G. S. Bulletin 309: Los Angeles district	Arnold and Anderson 1907 U. S. G. S. Bulletin 317: Santa Maria district	Arnold, 1907 U. S. G. S. Bulletin 321: Summerland district	Arnold and Anderson 1907 U. S. G. S. Bulletin 322: Santa Maria district	Kew, 1919 U. S. G. S. Bulletin 691: Simi Valley	Kew, 1923 This report: Parts of Los Angeles and Ventura counties
Quaternary	Alluvium Pleistocene deposits	Pleistocene	Quaternary 1'-600'	Alluvium Terrace deposits	Alluvium Pleistocene deposits	Alluvium Terrace deposits	Alluvium Terrace gravels	Alluvium Terrace deposits, 250' ±
Pliocene	Miocene, Pliocene, and Pleistocene: Fernando formation 5,000'-6,000' (conglomerates, sandstones, and arenaceous clays)	Fernando formation 1,500'-2,000' (conglomerates, sandstones, and clay)	Fernando formation 2,000' ±: Sandstone, conglomerate, and shale, 1,000'; Shale 500'; Sandstone and sandy shale, 500'	Fernando formation, 3,000'	Fernando formation 1,000' ±: Sandstone, conglomerate, and clay; Sandstones and conglomerates with sandy clay, shale, and bluish and grayish clay; Clayey shale 400'	Fernando formation, 3,000'+	Absent Fernando formation, 1,000' ± [Absent]	Fernando group: Saugus formation (upper Pliocene and Pleistocene) 2,000 ±; Pico formation (lower Pliocene), 4,000' ±
UNCONFORMITY								
Miocene	Miocene: Modelo formation 1,700'-6,000': Shale 200'-1,500'; Sandstone No. 2 900; Shale 400'-1,600'; Sandstone No. 1 200'-2,000' Vaqueros formation 2,000'-3,000': Shale and limestone 500'-600'; Brown and gray shale, 700'; Gray shale 500'; Purple, rusty, and gray shale, 500' [Absent(?) May be represented in basal part of Modelo formation]	Puente formation 2,600'-3,400': Intrusive diabase; Upper shale 300'-400'; Sandstone 300'-1,000'; Lower shale 2,000'	Puente formation: Intrusive diabase and basalt; Upper Puente shale (shale with 50' sandstone bed) 2,000'; Sandstone 2,000'	Monterey shale 5,200': Soft shale 2,600'; Hard shale 2,600' Vaqueros formation, 5,000'	Monterey shale 1,900'+ Vaqueros formation, 2,400' ±	Intrusive diabase Monterey shale 5,400'+ Vaqueros, Sespe, and Tejon formations undifferentiated 5,000'+	Modelo formation 8,700' (redefined): Upper shale of Eldridge absent; Intrusive basic rocks; Sandstone No. 1 3,000' ±; Shale 1,700' ±; Sandstone No. 2 2,500' ±; Shale, "erroneously called Vaqueros by Eldridge in Bulletin 309" 1,500' ± Vaqueros sandstone 100'-1,800' ±; [Absent in places] ?	Intrusive basic rocks Modelo formation (upper Miocene), 9,000' ± Mint Canyon formation (upper Miocene) 4,000' ± Topanga formation (middle Miocene), 6,000' ± ? ? ? Vaqueros formation, with true Vaqueros fossils (lower Miocene), 100'-1,800' ±
Oligocene(?)	Eocene, Oligocene, or Miocene: Sespe formation, 3,500'+: Sandstones and shales, 400'-500'; Heavy sandstones and conglomerates 2,500'; White sandstone and green and pink shale, 400'-500'	[Absent ?]	[Absent]	Sespe sandstone	Sespe formation: Shale, 2,400'; Sandstone, 1,900'		Sespe formation 4,000' ±	Sespe formation (Oligocene?) 3,500'-4,000' ±
Eocene	Eocene: Topatopa formation 5,500'+: Shales and sandstones, 3,500'; Quartzites and sandstones, 2,000'	[Absent]	[Absent]	Eocene(?)	Topatopa formation, 9,000' ±		Absent Tejon formation ? ? Martinez formation	Tejon formation (upper Eocene) 2,000' ± Meganos formation (middle Eocene) 2,000'-3,000' ± ? ? ? Martinez formation (lower Eocene) 1,500'-3,500' ±
UNCONFORMITY								
Cretaceous	[Absent]	[Absent]	[Absent]	[Absent(?)] Knoxville formation	[Absent(?)]	[Absent(?)] Basic intrusives Knoxville formation	Chico formation [Absent]	Chico formation (Upper Cretaceous) 5,500' ± Absent
UNCONFORMITY								
Jurassic(?)	[Absent]	[Absent]	[Absent]	Franciscan formation	Franciscan formation(?)	Franciscan formation	[Absent]	Absent
Jurassic(?)	Granitic basement		Granite	[Absent]	[Absent]	[Absent]	[Absent]	Granitic rocks (Jurassic?)
Pre-Jurassic			Black schist					Metamorphic rocks (pre-Jurassic)

CORRELATION TABLE SHOWING RELATIONS OF THE CLASSIFICATION USED IN THIS REPORT TO THE CLASSIFICATION USED IN PREVIOUS REPORTS ON THE SAME GENERAL REGION OF SOUTHERN CALIFORNIA.

tion. The igneous rocks are practically all of Miocene age and associated with the Vaqueros and Modelo strata; in one area they are associated with the Saugus formation. As they do not contain oil in this region, they have not been differentiated. They comprise mainly andesite, dacite, basalt, andesite breccia, and associated mud flows.

The relation of the map units of this report to the map units of previous reports on this same general region of southern California are shown in the accompanying correlation table (Pl. III). The section in this area is given in greater detail in the table on pages 8 and 9.

Formations exposed in a part of Los Angeles and Ventura counties, Calif.

System.	Series.	Generalized section.	Camulos quadrangle.	Upper Santa Clara valley.	Thickness (feet).	Character.
Quaternary.	Recent.	Alluvium.	Alluvium.	Alluvium.		Sand, gravel, and silt in valley bottoms and along streams.
	Pleistocene.	Terrace deposits.	Terrace deposits.	Terrace deposits.	250±	Gravel and sand, partly consolidated, forming terraces, now dissected.
Tertiary.	Pliocene.	Fernando group: Saugus formation.	Fernando group: Saugus formation.	Fernando group: Saugus formation.	2,000±	Conglomerate and sandstone, with some shale; mainly of terrestrial origin, but with marine strata in western part.
		Fernando group: Pico formation (restricted).	Fernando group: Pico formation (restricted).	Fernando group: Pico formation (restricted).	4,000±	Fine-grained gray sandstone, interbedded with coarse sandstone and conglomerate. Marine in origin. Along south side of Fernando Valley and westward to Las Virgenes Canyon the formation consists of laminated gray sandy shale and fine-grained sandstone with zones or lenses of white diatomaceous soft shale; upper strata largely medium-grained soft sandstone with some conglomerate.
	Miocene.	Modelo formation.	Modelo formation.	Modelo (?) formation.	9,000±	Primarily clay, diatomaceous shale, and fine-grained laminated sandstone and cherty beds; contains two or three large lenses of coarse brown and tan sandstone varying in thickness up to 4,000 feet; marine.
		Mint Canyon formation.		Mint Canyon formation.	4,000±	Nonmarine conglomerate, sandstone, and clay, predominantly red in lower part, light gray in upper part; vertebrate fossils indicate an upper Miocene age.
		Topanga formation.	Topanga formation.		6,000±	Mainly brown, tan, and gray coarse sandstone and conglomerate with prominent zone of medium-grained greenish-brown fossiliferous sandstone containing fauna probably equivalent in age to "Temblor formation" in San Joaquin Valley (*Turritella ocoyana* fauna). Intruded by basic volcanic rock.
		Vaqueros formation.	Vaqueros formation.		100–1,800±	On Little Sespe Creek and Oak Ridge, mainly gray to buff sandy shale with limy beds and concretions. In Simi Valley, brown conglomerate, coarse and fine sandstone. Marine.

	Oligocene (?).	Sespe formation.	Sespe formation.	Sespe (?) formation.	3,500–4,000±	Nonmarine red, brown, and yellow conglomerate and sandstone with interbedded shale.
	Eocene.	Tejon formation.	Tejon formation.		2,000±	In Simi Valley, brown medium to coarse sandstone with interbedded conglomerate. At Sespe Creek, hard greenish-brown sandstone and shale; at top, 500 feet of light-gray sandstone with some shale. Marine.
		Meganos formation.	Meganos formation.		2,000–3,500±	Brown to rusty-colored conglomerate, brown and gray sandstone, and gray shale with calcareous concretions. Marine.
		Martinez formation.	Martinez formation.		1,500–3,500±	Massive basal conglomerate overlain by brown and gray shale and sandstone. Marine.
Cretaceous.	Upper Cretaceous.	Chico formation.	Chico formation.		5,000±	Massive brown sandstone with thin beds of greenish-brown and gray shale. 500 feet of calcareous sandstone and shale below massive sandstone contains Upper Cretaceous fossils.
Jurassic (?).	(?)	Intrusive granite.	Intrusive granite.	Intrusive granite.		
Pre-Jurassic.		Metamorphic rocks.	Metamorphic rocks.	Metamorphic rocks.		Micaceous schist and quartzite intruded by granite.

GRANITIC AND METAMORPHIC ROCKS.

GENERAL FEATURES AND DISTRIBUTION.

The granitic and metamorphic rocks of this district have not been differentiated, because differentiation is not essential in order to determine their relation to petroleum. In general the basement complex, as it is usually termed, is made up of various types of granitic and metamorphic rocks, the latter consisting of schist, quartzite, slate, and limestone, into which is intruded granite of various kinds. These rocks appear in three places within the area mapped. North of the Santa Clara Valley the complex forms the Sierra Pelona, in the northern part of the Fernando quadrangle. Here the rocks consist mainly of dark bluish-gray micaceous schist veined with white quartz, though granite occurs immediately to the north. The planes of schistosity dip to the south. A small part of the complex of the San Gabriel Mountains east of Fernando Pass is shown on the map. In the vicinity of Placerita Canyon the rocks are mainly schist intruded by granite, probably a granodiorite or diorite. Some quartzite and limestone are present which show distinct bedding planes. The other area of metamorphic and granitic rocks is in the Santa Monica Mountains, a small part of which is included in the southeast corner of the area mapped. The rocks exposed here may be grouped into two main classes—a phyllite or black slaty rock that weathers into angular fragments, and a granitic rock in which quartz and feldspar are the principal constituents with hornblende and mica in lesser amounts. The granitic rock weathers a rusty-yellow to brown color, lighter than the phyllite, which is a dark coffee-brown.

No definite age has been assigned to the basement complex other than that the metamorphic rocks are pre-Jurassic, as the granite which intrudes them is thought to have been injected at the same time as the granite of the Sierra Nevada, which is late Jurassic or early Cretaceous.

RELATION TO PETROLEUM.

The rocks of the basement complex are of no especial importance in relation to petroleum, for the granite can not be considered a source of the oil, and the metamorphic rocks have been too greatly crushed and altered to have retained any oil which they may have once possessed. Where these rocks have been brecciated, as along a fault, they are capable of holding in the cracks thus formed a moderate amount of oil that may have migrated from adjacent petroliferous strata. Minor quantities of light oil occur in such rocks at the old Placerita Canyon wells. (See p. 156.) The production of these wells, however, was extremely small, and the deposits of this nature are at present of no economic importance.

CRETACEOUS SYSTEM.

CHICO FORMATION (UPPER CRETACEOUS).

GENERAL FEATURES.

The Cretaceous strata exposed within the area mapped all belong to the Chico formation, of Upper Cretaceous age, and consist of two members—a shale and an overlying massive sandstone. The shaly member occupies only a small area between Bell and Dayton canyons, its slight extent being due to faulting. The sandstone member forms the greater part of the Simi Hills, which separate San Fernando Valley from Simi Valley. Its outcrop has a general curving outline and structurally forms a broad syncline, plunging steeply to the west, the axis of which lies immediately north of Santa Susana Pass. The massive sandstone strata offer a very picturesque sight to the traveler passing over the mountains either by railway or by highway, as they rise abruptly from San Fernando Valley into massive, rugged brown layers, piled high one above another in a jagged, sawtooth ridge.

In many respects the Cretaceous of the Simi Hills resembles the Panoche formation[4] of the region north of the Coalinga. Although some differences in lithology are noticeable in the two places, these are probably due to a difference in composition of the rocks from which the Cretaceous strata were derived. The Moreno formation, composed largely of diatomaceous and foraminiferal shale, lies above the Panoche formation in the Coalinga district but is apparently absent from the Simi Hills, as no shale of this type occurs here.

LITHOLOGY.

The lower part of the Cretaceous consists of about 500 feet of shale, sandy shale, and calcareous sandstone. The shale is thin-bedded and dark gray, and contains numerous hard calcareous concretions of a lighter color. On weathering, it gives rise to a light-gray clay soil, that is easily eroded, forming low areas or swales that are in contrast to the prominent ridges formed by the weathering of the sandstone. Below the shale is about 250 feet of brown fine-grained calcareous sandstone, a considerable part of which is laminated, so that weathering leaves the surface strewn with thin slabs of this material. Fossil shells occur abundantly in this zone, and some of the first Cretaceous collections in California were obtained by Dr. Stephen Bowers in this vicinity. The base of the shale member is not here exposed, and as the Chico formation is

[4] Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Calif.: U. S. Geol. Survey Bull. 603, pp. 39–46, 1915.

overlain unconformably by the Topanga formation (middle Miocene), the total thickness of the Cretaceous can not be measured.

A series of heavy-bedded sandstones, which measure about 5,500 feet in thickness, overlie the shale member. These sandstones are interbedded with grayish micaceous shale, mainly in thin beds, though one bed noticed was at least 100 feet thick. This bed occurs near the top of the Simi Hills, in the vicinity of Santa Susana Pass. As this shale is easily eroded, it has formed a benchlike break in the profile of the east side of the hills. Shale forms but a minor part of the upper member of the Cretaceous, as the sandstone is the predominant type of rock. The uniformity of this sandstone is one of its most remarkable characteristics. Its color is prevailingly light brown or buff. In texture it is fairly well cemented and medium to coarse-grained, the largest grains being the size of a pea. Some thin beds consist almost entirely of the large grains, though these beds are usually lenticular. The sandstone is quartzose but contains considerable feldspathic material and some biotite. This stone was formerly quarried near Chatsworth for use in building the breakwater at Los Angeles Harbor. The sandstone beds give the hills an extremely rugged appearance on their eastern and southern fronts. Comparatively little soil has accumulated on the surface, except in the shale areas, so that the growth of brush is not as heavy as in some other places. Although the generalized profile of the Simi Hills on the east and south sides is not exceptionally steep, the massive sandstone beds have weathered into a series of steps that make this slope very difficult to climb.

EVIDENCE OF AGE.

The age of the massive sandstone strata that make up the greater part of the Simi Hills had for a long time been in doubt until Waring [5] in 1917 described these beds and correlated them with the Chico formation (Upper Cretaceous). Although these massive sandstones are unfossiliferous, they lie unconformably below beds of unquestionable Martinez (lower Eocene) age. Waring also listed an invertebrate fauna from shaly and calcareous beds occurring on the southeast flank of the Simi Hills. These localities, which were visited by the writer, have yielded a fauna that indicates Chico age. A fault separates the fossiliferous strata from the main area of massive sandstone, but at several places in this vicinity they underlie the sandstone.

Waring lists the following species collected from two localities on the southeast side of the Simi Hills:

[5] Waring, C. A., Stratigraphic and faunal relations of the Martinez to the Chico and Tejon of southern California: California Acad. Sci. Proc., 4th ser., vol. 7, pp. 41–124, 1917.

Locality 1. On hill on south side of Dayton Canyon, at county line near south line of sec. 4, T. 1 N., R. 17 W. Dayton Canyon is also known as Bower's Canyon and Beekeeper's Canyon.

Locality 2. In Bell Canyon immediately west of junction with canyon heading north toward Dayton Canyon.

Ophiuroidea:
- Amphiura lymani Waring (2).

Echinoidea:
- Scutella? sp. (2).

Pelecypoda:
- Acila truncata Gabb (2).
- Crassatellites tuscanus Gabb (2).
- Cucullaea youngi Waring (2).
- Dosinia milthoidea Waring (2).
- Glycimeris veatchii Gabb (1, 2).
- Isocardia chicoensis Waring (2).
- Lysis suciensis Whiteaves (2).
- Macrocallista cordata Waring (2).
- Nemodon breweriana (Gabb) (2).
- Pecten cowperi Waring (2).
- Trigonia evansana Meek (2).

Gastropoda:
- Anchura? sp. (1).
- Amauropsis oviformis Gabb (2).
- Cancellaria crassa Waring (2).
- Cinulia obliqua Gabb (2).
- Gyrodes canadensis Whiteaves (1).
- Gyrodes compressus Waring (1).
- Perissolax brevirostris Gabb (1).
- Rostellites gabbi White (1).
- Solariaxis templetoni Waring (2).
- Turris plicata Waring (2).
- Turritella chicoensis Gabb (2).

Cephalopoda:
- Baculites chicoensis Trask (1).
- Hauericeras transitionale Waring (2).

RELATION TO PETROLEUM.

The organic shale that occurs in the Moreno formation in the Cretaceous of the Coalinga district is absent in the area discussed in this report. The Cretaceous of the Simi Hills, consisting largely of coarse massive sandstone, includes but a small percentage of shale, and this does not contain sufficient organic material to be a source of petroleum. Although the massive sandstone is porous and might provide good reservoirs for holding oil, no rocks are present, either within the Cretaceous or adjacent to it, in which oil might have originated or from which oil might have migrated. Therefore, the Cretaceous in this region can not be included among the rocks from which there is any possibility of obtaining indigenous oil.

TERTIARY SYSTEM.

EOCENE SERIES.

GENERAL CHARACTER.

The Eocene series is represented in two areas within the region covered by this report, namely, the Simi Valley and an area west of Sespe Creek. In Simi Valley the Eocene comprises three formations—the Martinez (lower Eocene), Meganos (middle Eocene), and Tejon (upper Eocene)—which consist of conglomerate, sandstone, and shale, all of marine orgin and very fossiliferous. The Meganos formation is oil-bearing. In the Sespe Creek area the Martinez is absent and the Meganos is not known to be present, though its apparent absence may be due to lack of evidence. The Tejon is composed of sandstone and shale, which may be separated into more or less definite zones. The upper part of the Tejon is petroliferous.

Generalized section of Eocene formations on north side of Simi Hills directly south of town of Simi.

Tejon formation, 1,200 feet:
- Brown and gray to yellowish micaceous sandstone, medium grained and somewhat muddy.
- Yellow and gray fine sandstone and sandy shale.
- Massive medium-grained brown sandstone, forming conspicuous outcrops; some conglomerate.

Unconformity.

Meganos formation, 1,000 feet:
- Soft gray sandstone and shale.
- Conglomerate and hard sandstone.
- Gray fine sandstone and shale containing a few beds of hard sandstone.
- Brown conglomerate and sandstone.

Martinez formation, 3,500 feet:
- Fine gray sandstone and shale, in places weathering nearly white.
- Conglomerate and sandstone.
- Light-gray fine-grained soft thin-bedded sandstone with a few calcareous nodules containing a few fossils.
- Massive greenish-brown fine to coarse grained sandstone, with calcareous beds containing an abundance of fossils.
- Shale and fine-grained sandstone.
- Hard fossilferous sandstone, which forms prominent strike ridges.
- Dark-gray shale.
- Massive basal conglomerate composed of well-rounded boulders.

MARTINEZ FORMATION (LOWER EOCENE).

GENERAL FEATURES AND DISTRIBUTION.

The Martinez formation in the area mapped consists of 1,500 to 3,000 feet of marine sediments and presents the best exposures of this formation to be found in California. Besides having simple structure it contains an abundance of fossils, which are in a better state of preservation than those found elsewhere. This fauna, together with that from the overlying Eocene formations, has been described by Waring.[6] In lithologic character the formation consists in general of a heavy basal conglomerate, from 25 to 1,000 feet or more in thickness, above which are fine-grained brownish sandstone and shale. A prominent bed of very fossiliferous brown sandstone, which lies about 450 feet above the conglomerate, is one of the most persistent strata. This is followed by bluish-green or gray shale that contains calcareous concretions and varies considerably in thickness. The upper part of the Martinez on the north side of the Simi Hills is formed of a series of massive coarse dark-brown sandstone with a few interbedded thin layers of conglomerate. Toward the east the massive sandstone is absent, its place being taken by fine-grained sandstone and shale.

RELATIONS TO ADJOINING FORMATIONS.

The Martinez formation is exposed in this area as a single continuous strip that lies along the south and east sides of Simi Valley and extends eastward at its northern extremity into Devil Creek, a stream draining into San Fernando Valley. At the head of Simi Valley the exposure of the beds is interrupted by a covering of Quaternary alluvial deposits. To the north the strata are cut off by an east-west fault, but on their southwest end the Eocene, together with the Sespe, is overlapped unconformably by the Topanga and Modelo formations. A repetition of the Martinez beds along the top of the Simi Hills has been caused by faulting.

The Martinez is unconformable with the underlying Cretaceous. Although a marked structural break is not everywhere shown, evidence of a slight difference in dip and strike appears on the south side of Simi Valley. Furthermore, there is a marked change in lithology at the contact. Above the unfossiliferous massive brown sandstone of the Cretaceous, a heavy, coarse conglomerate, in places over 1,000 feet thick, forms the base of the Martinez. In a tributary of Las Llajas Canyon a rounded boulder containing a specimen of *Turritella chicoensis* Gabb, a characteristic Cretaceous species, was

[6] Waring, C. A., Stratigraphic and faunal relations of the Martinez to the Chico and Tejon of southern California: California Acad. Sci. Proc., 4th ser., vol. 7, pp. 41–124, pls. 7–16, 1917.

found in a large mass of Martinez conglomerate. Although this rock was not in place it probably came from the base of the Martinez strata a few hundred feet distant. Unlike the Chico strata, which are all unfossiliferous except the beds below the massive sandstone member, the Martinez is fossiliferous throughout, and the fauna is very distinct.

The Martinez and the Meganos, so far as could be ascertained, are conformable, so that the line of division is more or less arbitrary and is based entirely upon the characteristic fauna contained in the respective beds. Lithologically the formations grade from one to the other. In a few places there is a conglomerate at this horizon which may indicate the dividing line. The faunas in the two formations are distinct, and some of the commonest forms are characteristic species. North of Simi Valley, however, no fossils occur in the Martinez, though they are abundant in the overlying Meganos formation. Here the division is made between the dark bluish-gray shale containing calcareous concretions, which belongs in the Martinez, and the lighter-colored sandy shale that contains the typical Meganos fauna. In general, the dividing line is put at the lowest point at which Meganos fossils occur.

LOCAL DETAILS.

AREA SOUTH OF SIMI VALLEY.

The westernmost point on the south side of Simi Valley, at which the Martinez formation is exposed, is at the divide crossed by the road from Conejo Valley to Simi. The formation is thinnest here and gradually thickens toward the east. Through faulting the section is repeated in the Simi Hills. The fault, which trends in a westerly direction, cuts the formations obliquely in such a way that a block of the Martinez has been let down so as to produce a repetition of the strata.

The Martinez is about 1,500 feet thick at its west end but thickens eastward until north of Burro Flats, the section aggregates 3,000 feet or more. Practically all the beds present at the west end are traceable eastward, over the top of the Simi Hills to Burro Flats, where they are cut off by a cross fault. In the Simi Hills the thickness of the Martinez measures slightly less than 4,000 feet. None of the Meganos formation is included in this measurement, for a typical Martinez fauna occurs near the top of the exposed section. There is a possibility that the Meganos lies unconformably on the Martinez and that a part of the Martinez may have been eroded toward the west before the younger formation was deposited. The soft shaly character of the upper Martinez does not permit the tracing of individual strata for any great distance, and as the contact between the two formations is indefinite no evidence of an unconformity was seen other than the thinning of the Martinez formation.

A section across the Martinez at its western exposure is as follows:

Section of Martinez formation south of west end of Simi Valley, about two-thirds of a mile east of road from Simi Valley to Conejo Valley.

	Feet.
Massive gray and greenish-brown sandstone	90
Gray sandstone and shale bands	21
Fine gravel and conglomerate	210
Massive brown sandstone with cavernous weathering; fossiliferous in part	180
Fine shaly sandstone containing fossiliferous calcareous concretions	5
Very dark brown coarse sandstone which weathers readily	95
Gray shaly sandstone with fossiliferous calcareous concretions and massive greenish-brown, medium-grained, hard sandstone containing limy fossiliferous concretions	30
Brown and gray sandy shale containing a few gray concretions	285
Fine to coarse conglomeratic sandstone	15
Brown sandstone with gray concretions; hard fossiliferous bed	105
Hard brown fine-grained sandstone	50
Brown fine sandstone, not as hard as overlying bed	100
Tan to brown conglomerate, moderately well cemented, but weathering easily; boulders large and well rounded	25
	1, 487

In the Simi Hills the Martinez rests upon the Chico without any apparent difference in dip and strike. The base of the section shows the usual massive brown conglomerate composed of well-rounded and polished quartzitic and granitic boulders, the average diameter of which is about 6 inches. The thickness of this conglomerate has increased from about 25 feet in the east end of the area to 800 feet in the Simi Hills. Included within it are numerous sandstone lenses, which make up probably 50 per cent of the entire conglomerate bed. Above this is about 800 feet of brown sandstone interbedded with calcareous strata containing numerous fossils. These fossil beds are particularly abundant along the crest of the ridge. Underlying the shallow depression extending along the top of the Simi Hills west of Burro Flats is a series of soft sandy shales which are easily weathered. Shale and shaly sandstone interbedded with layers of hard brown sandstone compose the remainder of this section.

The strip of Martinez northeast of the fault and extending to the floor of Simi Valley is similar to the section on the south side, though the basal conglomerate is thicker, averaging here about 1,000 feet. In place of the massive sandstone immediately above the conglomerate, gray shale and shaly sandstone are interbedded with massive hard sandstone, many beds of which are fossiliferous. These beds are coarser in their upper part, where about 600 feet of dark-brown sandstone carrying calcareous bands and nodules constitutes the prevailing type. Above this sandstone there is a narrow belt of shale which contains a typical Martinez fauna. It includes numerous specimens of *Turritella pachecoensis* Stanton and *Cucullaea mathewsoni* Gabb. The lower part of this shale is the highest zone stratigraphically in which Martinez fossils occur, for Meganos fossils are found in the sandstone immediately overlying the shale. No visible unconformity between this shale and the overlying sandstone could be discovered, and as there is 50 feet more of similar shale above the beds where the Martinez fossils are found the contact can not be definitely placed. In this report the line between the two formations is drawn between this shale and the overlying sandstone.

AREA NORTH OF SIMI VALLEY.

In general the section north of Simi Valley is similar to that south of the valley, but it differs in containing few fossils. The basal conglomerate is still prominent, though it has thinned to about 525 feet. Above it are about 700 feet of alternating brown calcareous sandstone and dark bluish-gray shale. The remainder of the Martinez is a dark bluish-gray shale containing calcareous concretions, within which are scattered remains of Foraminifera. Near the edge of the valley the shale incloses some large lenses of hard nodular calcareous sandstone, showing that the section has a tendency to become more sandy toward the south. Owing to the lack of fossils in the Martinez other than the Foraminifera and to the fact that the Meganos section here appears to be perfectly conformable above it, no exact division can be made between the two formations. The line separating them has been placed between the dark bluish-gray shale and a gray sandy shale, the lowest beds in which a Meganos fauna is present. This line probably corresponds to that taken for the division of the beds south of the valley.

To the north the Martinez beds curve around the nose of a plunging anticline in the Cretaceous sandstone. An east-west fault on the north limb of the anticline has cut out all of the Martinez except the basal conglomerate and a thin band of massive brown sandstone that lies against the lower Meganos strata. All the beds along this fault stand approximately vertical.

EVIDENCE OF AGE.

The Martinez formation is easily recognized in this region, for the reason that its fossils are both distinctive and abundant. In fauna, as well as in its stratigraphic position, it is similar to the type section of the Martinez in Contra Costa County, which was described by Merriam[7] and later by Dickerson.[8] The commonest and most characteristic forms occurring in the Simi Hills region are *Cucullaea mathewsonii* Gabb, *Glycimeris veatchii* var. *major* (Stanton), *Turritella martinezensis* Dickerson, and *Turritella pachecoensis* Stanton. In the following list of species Nos. 3501 to 3507 are from the paleontologic collections of the University of California; the others are from the United States National Museum.

Fossils from the Martinez formation in the Los Angeles-Ventura region.

	3501	3502	3503	3504	3505	3507	8105	8106	8107	8109	8111	8112	8113	8115	8118	8120
Anthozoa:																
Flabellum remondianum Gabb									×							
Echinoidea:																
Schizaster sp.?									×							
Pelecypoda:																
Acila sp.?	×															
Cardium near C. cooperi Gabb				×					×					×		
Cardium breweri Gabb															×	
Corbula cf. C. parilis Gabb						×										
Grassitellites n. sp			×			×		×								
Cucullaea mathewsonii Gabb.	×		×		×	×	×		×	×						×
Cucullaea n. sp.?									×			×				
Cuspidaria cf. C. hannibali Dickerson								×								
Cylichna sp						×										
Glycimeris veatchii var. major (Stanton)			×	×		×	×		×	×			×			×
Glycimeris sp.?													×			
Macrocallista stantoni Waring		×	×			×	×		×	×						
Macrocallista n. sp. *a*			×		×	×			×							×
Macrocallista n. sp. *b*						×		×		×						
Miltha parsonsi Waring								×								
Tellina undulifera Gabb	×				×											×
Tellina sp																×
Venericardia planicosta venturaensis Waring							×									
Gastropoda:																
Actaeon n. sp				×												
Amauropsis martinezensis Dickerson						×	×	×		×						×
Amauropsis n. sp				×		×										×
Brachyspingus sinuatus Gabb						×		×		×						
Cypraea n. sp		×														
Fasciolaria mucronata (Gabb)	×					×				×						
Lunatia hornii Gabb				×	×	×										
Lyria hannibali Waring						×			×							
Perissolax tricarinata Gabb						×										
Retipirula crassitesta (Gabb)						×		×		×						
Surcula sp.?									×							
Trachytriton titan Waring						×										
Turritella martinezensis Gabb						×			×					×	×	
Turritella pachecoensis Stanton	×	×	×		×	×	×	×	×	×	×	×	×			
Turritella simiensis Waring	×						×		×							×
Scaphapoda:																
Dentalium cooperi Gabb		×				×		×								
Cephalopodia:																
Aturia sp.?		×														

3501. On west side of canyon southeast of Runkle's place, 300 yards south of old barn. one-quarter mile south of north line of Calabasas quadrangle and 1.15 miles east of west line.
3502. 50 yards south of locality 3501.
3503. On west side of canyon southeast of Runkle's place. in small draw running westward from a point nearly half a mile south of old barn, 0.9 mile east of west line of Calabasas quadrangle and 0.7 mile south of north line.

[7] Merriam, J. C., The geological relations of the Martinez group of California at the typical locality: Jour. Geology, vol. 5, pp. 767–775, 1897.

[8] Dickerson, R. E., Fauna of the Martinez Eocene of California: California Univ. Dept. Geology Bull., vol. 8, pp. 61–180, 1914.

3504. Near head of west branch of east branch of canyon running southeast from Runkle's place, immediately south of fault line, 0.85 mile east of west line of Calabasas quadrangle and 1.65 miles south of north line.
3505. On ridge between forks of east branch of canyon running southeast from Runkle's place, 0.15 mile east of locality 3504.
3507. Near east end of long strike ridge half a mile southwest of E. Maier's ranch, on top of ridge, 1.95 miles east of west line of Calabasas quadrangle and 0.2 mile south of north line.
8105. On ridge south of town of Simi on top of southward-trending spur, S. 70° E. of 1,289-foot bench mark. Second fossil beds above base of Martinez.
8106. On long ridge southeast of Runkle's house, about halfway from Simi Valley to top of Simi Hills, at sadlle in long curving ridge at junction of spur which extends to branch in roads in canyon below, 1⅝ miles S. 55° E. of northwest corner of Calabasas quadrangle.
8107. On point of ridge trending west about halfway down from Simi Hills to Simi Valley, in northwest corner of Calabasas quadrangle, 1$\frac{1}{10}$ miles south of north line of quadrangle and three-fifths mile east of west line. Near top of Martinez formation.
8109. South of Simi Valley, near top of eastern extremity of long east-west ridge that turns south to Burro Flats, 0.4 mile south of north line of Calabasas quadrangle and 1.7 miles east of west line. Same zone as 8106.
8111. On ridge extending north from Simi Hills, 0.1 mile due north of 1926-foot hill.
8112. Top of Simi Hills, 0.8 mile west of 2,150-foot hill and 0.3 mile east of west edge of Calabasas quadrangle.
8113. On top of spur extending south from west end of Simi Hills 0.55 mile S. 45° E. of 1,289-foot bench mark.
8115. West side of head of Bell Canyon near top of Simi Hills, 0.2 mile S. 75° E. of 2,159-foot hill.
8118. Top of northward-trending ridge from Simi Hills, close to west side of Calabasas quadrangle and 1.45 miles south of north line.
8120. On spur extending north from west end of Simi Hills, south of west end of Simi Valley, 1.3 miles S. 80° E. of 1,289-foot bench mark.

RELATION TO PETROLEUM.

The shales of the Martinez formation, which contain a considerable percentage of organic matter, though not typical diatomaceous and foraminiferal shales, are thought to be, at least in part, the source of the oil that occurs in the Meganos formation on the north side of Simi Valley. These strata form the upper part of the Martinez in the vicinity of Las Llajas Canyon and appear to grade up into the shaly thin-bedded sandstone of the lower part of the Meganos formation. Although these Martinez shales show only slight traces of petroleum, this does not necessarily invalidate the hypothesis that they are a source for oil, because the Miocene diatomaceous shales that are thought to be the source of the oil in many California fields usually do not present any evidence of oil in the shales themselves, though the oil has probably migrated upward from them. (See pp. 108–110.)

MEGANOS FORMATION (MIDDLE EOCENE).

GENERAL FEATURES.

The Meganos formation in the Simi Valley region is exposed in three areas, which are evidently closely associated, as they are separated only by coverings of younger formations. The strata making up this formation, which are entirely of marine origin, consist of arenaceous shale, sandstone, and conglomerate aggregating from 2,000 to 3,500 feet in thickness. A characteristic feature of all the beds is their lenticular habit, which is strongly brought out not only by their surface distribution but also by a study of the well logs. Lithologic types of strata in the Meganos vary both in stratigraphic sequence and along the strike, a fact which indicates not only that the conditions of deposition changed from time to time while the Meganos was being laid down, but also that the conditions at any one time differed at different places along the strand line. The predominant rocks are bluish-gray and olive-colored shale and muddy, shaly sandstone that grades into coarser sandstone. These rocks weather to a brownish hue. A few lenticular beds of conglomerate are present. In the area at the foot of the Santa Susana Mountains the beds are composed mainly of soft fine bluish and brownish sandstones, which become coarse and massive toward the west. The area on the north side of the Simi Valley is made up almost entirely of soft muddy shale and fine gray sandstone interbedded with hard calcareous brown sandstone that is usually fossiliferous. South of the valley the same types of sandstone and shales are present but are interbedded with massive greenish-brown sandstone that forms a considerable percentage of the lower part of the formation. Fossils are very abundant in the Meganos and occur usually in concretions and sandstone beds. The massive brown sandstone is unfossiliferous.

When the first field work in this region was done by the writer, the Meganos was considered to be a part of the Tejon. The Meganos formation has, however, recently been described from its occurrence in various parts of California [9] and has been found to have a distinct faunal and structural unity. Nearly all the strata in Simi Valley that had been designated Tejon in a preliminary report [10] have now been correlated with the Meganos formation. Whether the Meganos is present in the area north of the Santa Clara Valley is not known, and in that area no separation has been attempted.

No unconformity with the underlying Martinez formation has been recognized in the Simi region, though at Mount Diablo [11] and in the Coalinga region,[12] where these formations are well developed, a break exists. Between the Meganos and the Tejon a well-defined unconformity is present in the Simi region, as in other areas in California. The Meganos formation is especially important in the discussion of this region, as it is intimately associated with the occurrence of oil. The oil that is found in porous beds in the upper part

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[9] Clark, B. L., Meganos group, a newly recognized division in the Eocene of California: Geol. Soc. America Bull., vol. 29, pp. 281–296, 1918; The stratigraphic and faunal relationships of the Meganos group, middle Eocene of California: Jour. Geology, vol. 29, pp. 125–165, 1921.

[10] Kew, W. S. W., Structure and oil resources of the Simi Valley, southern California: U. S. Geol. Survey Bull. 691, pp. 328–329, 1919.

[11] Dickerson, R. E., The stratigraphic and faunal relations of the Martinez formation to the Chico and Tejon, north of Mount Diablo: California Univ. Dept. Geology Bull., vol. 6, pp. 171–177, 1911. The lower part of what Dickerson called Tejon is now known to be Meganos.

[12] Dumble, E. T., Notes on Tertiary deposits near Coalinga oil field, and their stratigraphic relations with the Upper Cretaceous: Jour. Geology, vol. 20, pp. 28–37, 1912.

of the Meganos formation in the Simi Valley region is thought to originate in the formation itself. In the Oak Ridge and South Mountain districts, where the oil occurs in beds of Sespe age, the oil is also considered to be derived from Eocene beds (probably Meganos and Martinez) lying below.

DISTRIBUTION AND LITHOLOGY.

AREA SOUTH OF SIMI VALLEY.

The Meganos strata on the south side of Simi Valley comprise a varied assortment of rocks, all of which appear to be of marine origin. They consist mainly of shale, sandy shale, both coarse and fine grained sandstone, and conglomerate. The beds are lenticular, and this feature is well exemplified in the conglomerate, no lenses of which can be traced for any great distance. As a whole the Meganos is made up in large part of soft rocks, which occupy the lower foothills. Hard beds of sandstone and conglomerate form prominent points on ridges, though no large physiographic forms have been determined by them.

The base of the Meganos has been more or less arbitrarily determined, as no unconformity was apparent and there is no especial change in lithology. The separation is based mainly upon the faunas contained in the rocks, and for that reason some difference of opinion may prevail as to the exact horizon for the line of division.

At the east end of this area, south of the town of Santa Susana, the section is well exposed. Here the lower part consists of alternating beds of shale, sandstone, and conglomerate, above which is several hundred feet of massive coarse brown sandstone containing lenses of conglomerate. The upper part exposed is a gray or slightly olive-colored shale with beds of light-tan sandstone. A conglomerate bed, in which are numerous Meganos fossils, is present at the base of this shale.

The uppermost beds that contain Martinez fossils consist of dark, reddish-brown massive reef-like sandstone. These beds are overlain by grayish mudstone and sandy shale with a number of fine sandstone strata containing hard brown concretions that carry fossils. These fossils are not definitely of the Martinez type, so that this shale may represent a transition stage between the two formations. Fossils found in the upper part of this shaly series near the old well drilled for oil on the slope of the Simi Hills are of Meganos age. Above this shale there is a conglomerate bed 30 to 75 feet thick, formed of well-rounded boulders derived from hard crystalline rocks. These boulders range from 2 to 6 inches in diameter. The conglomerate is in turn overlain by yellow to olive-gray clayey shale and mudstone, which in some places contain fossiliferous concretions. Farther west and directly south of the town of Simi the beds become more sandy. Practically no shale is present in the lower part, which consists of massive brown sandstone and conglomerate with thin beds of finer-grained rock, some of which is hard and calcareous. Fossils appear to be rather scarce. The upper part is a soft muddy fine gray sandstone. This upper member is partly overlapped in the west end of the Meganos exposure by the Tejon formation.

AREA NORTH OF SIMI VALLEY.

North of Simi Valley, as in the area south of the valley, the lowest definitely known Meganos beds are shale showing no marked lithologic change from the underlying Martinez. The lowest strata in which a fauna of Meganos age is found consist of about 300 feet of rather uniform soft light-gray shale and sandy mudstone in which are calcareous concretions. Above these beds is 240 feet of dark-brown conglomerate similar to the basal conglomerate of the Martinez, except that the boulders are larger, many of them a foot or more in diameter. These boulders are well rounded and usually polished, and practically all are derived from quartzite. Some brown coarse sandstone occurs at the base of this conglomerate, and lenses of the same rock are interbedded with the conglomerate, composing about half of the section. Fossils typical of the Meganos occur in this conglomerate. It is followed by shales and shaly sandstone which are lithologically similar to those below the conglomerate, though possibly coarser. The brown hard sandstone becomes more prevalent toward the top, where a few beds of conglomerate are also present. The whole series is abundantly fossiliferous.

AREA AT HEAD OF LAS LLAJAS CREEK.

Rocks belonging to the Meganos and possibly in part to the Tejon are exposed along the axis of a plunging anticline in the southern foothills of the Santa Susana Mountains. The greatest width of the exposure is about 1 mile, in Las Llajas Canyon. From Aliso Creek the Meganos extends in a northwesterly direction nearly to Dry Canyon, which is an easterly tributary of Tapo Canyon, a distance of about 3 miles. As nearly as can be estimated about 2,500 feet of beds are exposed here. They consist mainly of very sandy medium to fine grained brown, gray, and bluish sandstones, which are massive or irregularly bedded. They are not well consolidated except for the darker-brown fossiliferous zones, which have been hardened by calcareous matter. The uppermost known Meganos beds consist of a soft, fine, even-grained blue and brownish sandstone, though the commonest type is a fine blue sandstone that weathers brown.

Fossiliferous calcareous concretions are common in all the beds. The bedding is well shown in Aliso Canyon, but in Las Llajas Canyon slumping has caused more or less diversity in the attitude of the strata. As a whole, the Meganos exposed in this area is remarkably homogeneous, and the lack of distinctive beds is noticeable. Several oil seeps occur in the soft sandstone in Las Llajas Canyon, which is stratigraphically about 1,700 feet above the lowest beds of the Meganos exposed to the east in Aliso Canyon. Toward the west end of the exposure the beds are more massive, and the uppermost strata in this vicinity may belong to the Tejon formation. Where the Eocene beds are closely associated with the Saugus (upper Pliocene and Pleistocene) beds their separation on a lithologic basis is difficult to make, but the two sets of strata contain abundant fossils that are very unlike.

Section of Meganos formation near mouth of Las Llajas Creek.

	Feet.
Fine-grained olive-gray shale and sand shale, or mudstone, interbedded with hard brown calcareous sandstone; all fossiliferous	1, 700
Conglomerate in which oil seeps occur	50
Fine-grained light-brown to gray sandstone and shaly sandstone in which are thin beds of sandstone; fossiliferous	1, 100
Coarse brown conglomerate of quartzite boulders with lenses of fossilferous coarse brown sandstone	240
Soft gray sandy shale with calcareous concretions; grades up from bluish-gray Martinez shale; fossiliferous	275
	3, 365

EVIDENCE OF AGE.

Fossils are abundant at numerous horizons within the Meganos formation. The species listed below, kindly determined by Dr. Bruce L. Clark, of the University of California, occur in the Meganos formation in Simi Valley. Comparatively few species from the Meganos have yet been described, but comparison with those of the Tejon formation above and the Martinez below shows that very few species are found to range outside of their respective divisions. According to Clark,[13] " Sixty-five species have been recognized in this fauna [at Mount Diablo]. Of these, four, possibly six, are found in the Tejon beds immediately above; two or three more are found in the Tejon of other sections." Practically all the species found in the beds of Simi Valley also occur in the Meganos of the type section at Mount Diablo, Contra Costa County. This, together with their

[13] Clark, B. L., Meganos group, a newly recognized division in the Eocene of California: Geol. Soc. America Bull., vol. 29, p. 290, 1918; The stratigraphic and faunal relationships of the Meganos group, middle Eocene of California: Jour. Geology, vol. 29, pp. 125–165, 1921.

analogous stratigraphic sequence, is enough proof to assign the Simi Valley beds to the Meganos.

Meganos fauna from the Simi Valley district, southern California.

[Locality numbers from U. S. National Museum.]

	8116	8117	8119	8121	8122	8123	8124	8125	Mount Diablo.
Pelecypoda:									
Cardium marysvillensis Dickerson	X	X							X
Cardium cf. C .marysvillensis Dickerson							X		
Corbula dilatata Waring				X				X	X
Isocardium tejonensis Waring				X				X	X
Meretrix sp		X							
Meretrix n. sp. *a*	X								
Meretrix sp			X						
Modiolus cf. M. ornatus				X					X
Periploma n. sp	X								
Glycimeris cf. G. cor (Gabb)	X								
Venericardia n. sp. *a* (large)				X					X
Venericardia n. sp. *b* (small)								X	X
Venericardia n. sp. *c*					X				
Gastropoda:									
Amauropsis alveata (Conrad)		X							X
Cancellaria n. sp				X					
Conus n. sp				X					
Cylichna n. sp	X								X
Galeodea n. sp				X					X
Natica hannibali Dickerson		X		X					X
Rimella n. sp	X	X		X				X	X
Scaphander n. sp	X								
Surcula (Surculites) n. sp							X		X
Turritella andersoni Dickerson		X			X			X	X
Turritella n. sp. near T. buwaldana Dickerson (straight sides)				X	X			X	X
Turritella n. sp. *a*								X	
Turritella n. sp. *b* (noded, with shape of T. uvasana)						X		X	X
Turris (Pleurotoma) monolifera (Cooper)								X	X
Turris (Pleurotoma) n. sp. *a*								X	
Murex n. sp								X	
Zenophora sp		X							

8116. About 3 miles S. 30° E. of Simi and a quarter of a mile west of old drill hole on north slope of Simi Hills.
8117. About 3 miles S. 35° E. of Simi, near old drill hole on north slope of Simi Hills, along road cut north of well and ridge south of well.
8121. About three quarters of a mile west of Aliso Canyon, in NE. ¼ SE. ¼ sec. 26, T. 3 N., R. 17 W., just east of Simi grant line.
8122. Near mouth of Las Llajas Canyon, half a mile N. 32° E. of 1,464-foot hill.
8123. On ridge about a quarter of a mile north-northeast of mouth of Las Llajas Canyon.
8124. On south bank of Simi Creek, 200 yards east of road crossing, 2 miles S. 30° W. of Santa Susana.
8125. Three miles S. 35° E. of Simi and a quarter of a mile west of old drill hole on north slope of Simi Hills.

RELATION TO PETROLEUM.

The upper part of the Meganos formation in the anticlines on the north side of the Simi Valley contains the most productive oil measures. These are medium-grained lenticular sands, interbedded with clay shale of a more or less sandy nature. The origin of the oil in these beds is not definitely proved, but there is a suggestion that it may have been derived in part from the underlying Martinez formation, whose shale contains considerable organic matter. No evidence is available, however, to show that the oil actually traveled from the Martinez shales into the upper part of the Meganos or the Tejon formation. The beds of shale in the Meganos on the north side of the valley constitute a large part of the formation, but these beds are of a sandy nature, and although they contain some plant remains the organic matter does not appear to be sufficient to serve as the entire source for the oil.

TEJON FORMATION (UPPER EOCENE).

GENERAL FEATURES.

The Tejon formation is found in this region in two distinct areas, widely separated geographically by Santa Clara River and Oak Ridge and structurally by the San Cayetano fault. The larger area lies west of Sespe Creek, in the northwest corner of the Camulos quadrangle. (See Pl. IV, *A*). The other is in Simi Valley, where the Tejon overlies the Meganos formation unconformably. A marked difference in lithology is apparent in the beds of the two areas. North of Santa Clara River five lithologic divisions can be made in what are known to be Tejon strata. They are as follows:

Tejon formation:
- White sandstone, locally known as "Coldwater sandstone."
- Sandstone.
- Shale.
- Sandstone.
- Shale.

The two shales and two lower sandstones are considerably alike. The shales are dark greenish gray to nearly black, somewhat arenaceous, and thin bedded. The sandstones are light brown, grayish brown, and grayish green, medium grained, and quartzitic. Both shale and sandstone are greatly indurated. Fossils are rare but where present indicate Tejon age. The "Coldwater sandstone" consists of white quartzitic sandstone interbedded with green and red clay. It lies apparently unconformably below the Sespe formation, but is conformable with the underlying beds, and though it contains no distinctive fossils it probably should be included within the Tejon.

The Tejon strata in Simi Valley comprise a few hundred feet of sandstone and conglomerate with thin layers of shale or sandy shale, all dark brown or greenish brown. A fauna of Tejon age has been collected from the lower beds.

DISTRIBUTION AND LITHOLOGY.

AREA NORTH OF SANTA CLARA RIVER.

The largest body of rocks assigned to the Tejon in this region lies on the west side of Sespe Creek south of Pine Canyon and forms the greater part of San Cayetano Mountain. (See Pl. IV, *A*.) It is the east end of a much larger body of Eocene strata that extends for 145 miles westward into the Santa Ynez Mountains of Santa Barbara County. In this vicinity the Tejon is exposed below the Sespe formation in two other small areas—one on Coldwater Creek along the axis of an anticline and another on Sespe Creek at the north edge of the area mapped. The Sespe Creek exposure is a tongue of the uppermost beds extending southward from the Topatopa Mountain area of Eocene rocks. On San Cayetano Mountain the rocks are cut off by the thrust fault, which limits their southern extent so that, in the area mapped only a very small part of the lower shale is exposed, and in like manner the other divisions are eliminated as Sespe Creek is approached. The lower shale consists of thin-bedded dark-brown to nearly black shale and sandy shale, which are greatly indurated. Where this division is exposed in the Camulos quadrangle the thickness of the shale could not be determined, because of faulting and folding.

Farther west, in the Santa Paula quadrangle, its thickness has been estimated at 3,000 to 3,500 feet.[14] Above this shale there is a thinner series composed of a light-brown to buff quartzitic sandstone that is somewhat coarser than the upper sandstone. The upper shale member is very dark gray, almost black, and it differs from the overlying sandstone only in being thin bedded and slightly darker, so that the two can not be sharply separated. This sandstone is about 1,500 feet thick on San Cayetano Mountain. It consists of grayish-green to rusty-colored shaly sandstone, which weathers into flags. The sand contains a considerable amount of mica and carbonaceous material. Thin layers of greenish-brown shale and arenaceous shale are interbedded with the sandstone. Rather poorly preserved specimens of *Turritella uvasana* and *Ostrea* cf. *O. idreaensis* found in the shaly sandstone indicate a Tejon age for these beds.

The uppermost sandstone, locally known as the "Coldwater sandstone," was described by Watts.[15] It is prominently exposed along an anticline in Coldwater Canyon. (See Pl. IV, *A*.) It also occurs in Sespe Canyon at Tar Creek, where Sespe Creek has cut through the overlying red beds and exposed it.

Resting on the middle sandstone of the Tejon it also extends as a narrow strip up Pine Canyon from Sespe Creek westward beyond the limits of the Camulos quadrangle into the Santa Paula Creek country. In fact, it is continuous from Pine Canyon to the area at Tar Creek on the north, being traceable around the west end of the syncline under the red beds that form the "plateau" north of Coldwater Canyon. It consists of 350 to 700 feet of sandstone, shaly sandstone, and shale, together with a few gravelly beds. The coarse sandstone is usually hard and quartzose and weathers fairly rapidly, though it is softer than the overlying red beds of the Sespe. In color the sandstone is pearly white or slightly yellowish, becoming reddish and greenish toward the top. Most of the beds average from

[14] Arnold, Ralph, and Pemberton, J. R., unpublished manuscript.

[15] Watts, W. L., Oil and gas yielding formations of the central valley of California: California State Min. Bur. Bull. 11, 1896; Bull. 19, 1900.

5 to 10 feet in thickness. They are separated by layers of greenish-gray and purple shale, which become more numerous in the upper part of the member. This sandstone forms a distinct though thin lithologic unit between the Tejon formation and the Sespe red beds. It is not confined to the Sespe Creek district but may be traced many miles westward. No fossils other than a few oysters have been found in it. This sandstone is now considered to be of upper Eocene age and should be grouped with the Tejon formation. This assignment rests upon the fact that the sandstone grades upward from the underlying sandstone of the Tejon formation but underlies the Sespe red beds with an unconformity. This unconformity, plainly seen in Sespe Canyon, consists of an irregular contact, together with a slight truncation of the strata. Eldridge [16] described this sandstone series as the lower zone of the Sespe formation but considered it to be of upper Eocene age.

AREA IN SIMI VALLEY.

In the Simi Valley region the Tejon formation has been certainly identified only on the south side of the valley, where it crops out south of the town of Simi. It is overlapped by the Miocene near the west end of the Simi Hills. North of the valley no Tejon strata have been mapped, though it is possible that the lower 400 feet included in the Sespe formation may be equivalent in part to the Tejon on the south side. At the west end of the exposure on the south side of Simi Valley, where the section is thickest, the Tejon consists of about 2,000 feet of sediments, which are probably of marine origin. The base of the formation here is made up of 30 feet of conglomerate, which thins out within a short distance to the east. This conglomerate is composed of rather large well-rounded boulders and is of a dark-brown color. It is followed by about 700 feet of massive cross-bedded coarse sandstone, which is gravelly in places. Above this there is a brown concretionary sandstone, which, in turn is overlain by about 1,150 feet of soft, fine gray sandstone and shaly sandstone. The uppermost member of the Tejon is a dark-yellow to brown fine-grained, rather thin bedded quartzose and micaceous sandstone, which contains casts of a few indeterminate fossils.

The Tejon rests upon the Meganos with a marked unconformity. Although no difference in dip is apparent, a discrepancy in strike is noticeable at the west end of the exposure. Here, directly south of Simi, the Tejon strata partly overlap the shale and sandstone of the Meganos. Typical Tejon fossils (see p. 29) have been found in the lower part of the Tejon brown sandstone. No direct evidence of unconformity with the Sespe above has been observed, and

[16] Eldridge, G. H., U. S. Geol. Survey Bull. 309, p. 8, 1907.

the strata south of Simi appear to grade up into the sandstone and conglomerate of the Sespe. However, the Tejon exposure narrows as it approaches the valley bottom, and this possibly indicates an unconformity with the overlying formation.

EVIDENCE OF AGE.

In comparison with the fossils in the other Eocene formations those in the Tejon are few and poorly preserved. Nevertheless, enough have been obtained to show that the Tejon here may be correlated with that of the type section in Canada de las Uvas (Grapevine Canyon), Kern County. The following species from the south side of Simi Valley have been collected and determined by Dr. Bruce L. Clark, of the University of California:

University of California locality 3311, on point of ridge at edge of Simi Valley, 1 mile north and 0.08 mile west of southeast corner of Piru quadrangle:

- Gastropoda:
  - Amauropsis alveatus (Conrad).
  - Crepidula pileum Gabb.
  - Ficopsis remondi Gabb.
  - Loxotrema turrita Gabb.
  - Natica hornii (Gabb).
  - Pseudoperissolax blakei (Conrad).
  - Surcula io (Gabb).
  - Turcicula n. sp.
  - Turritella uvasana Conrad.
  - Whitneya ficus Gabb.
- Pelecypoda:
  - Cardium cf. C. breweri Gabb.
  - Cardium remondianum Gabb.
  - Corbicula sp.
  - Glycimeris cf. G. sagittata (Gabb).
  - Marcia? n. sp.
  - Spisula sp.
  - Tellina sp.
  - Tivela sp.

In Pine Canyon the writer collected *Turritella uvasana* Conrad in beds near the top of the Tejon. These beds may be traced westward into the Santa Paula quadrangle, where a much more complete fauna of Tejon age is known to occur.[17]

RELATION TO PETROLEUM.

In the Sespe Creek area the Tejon formation is probably the source for the oil occuring in the Tejon itself and the overlying strata. Under ordinary conditions in California oil fields the petroleum has not accumulated in the same rocks in which it has originated, but has migrated to some associated or overlying porous sandstone which acts as a reservoir. The Tejon rocks in this region are composed partly

[17] Arnold, Ralph, and Pemberton, J. R., unpublished manuscript.

of shale and partly of sandstone, all of which are well indurated, the sandstone in places resembling quartzite. Below the white sandstone at the top of the Tejon occur shaly beds that may be composed in part of organic material, such as diatoms and foraminifers, in sufficient quantity to have formed the oil. No beds of an organic nature are present in the white sandstone member or the Sespe formation.

In the Simi Valley area no part of the Tejon formation was found to be petroliferous, nor did any of the strata appear to be of the type that would be considered a source for oil.

OLIGOCENE (?) SERIES.

SESPE FORMATION.

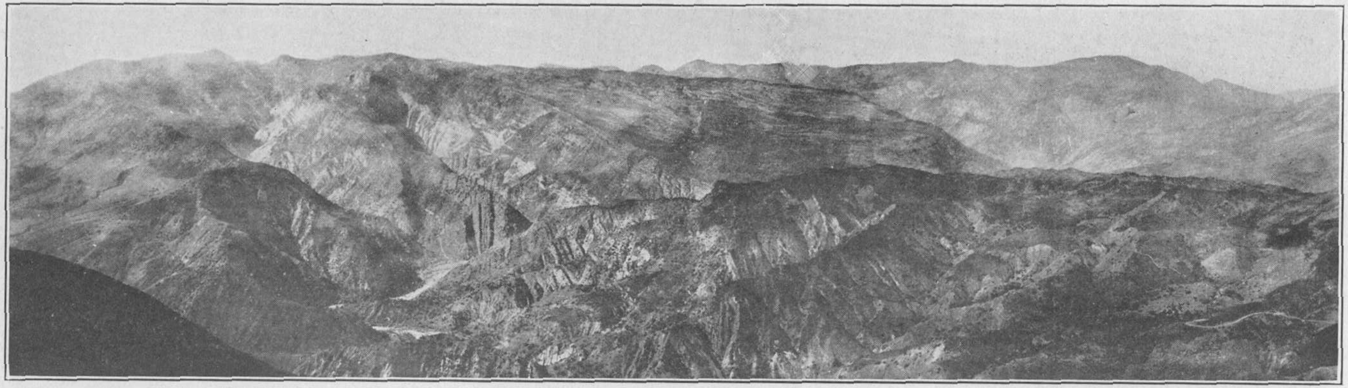
GENERAL FEATURES.

The Sespe formation within the area mapped exhibits two slightly different types of lithology, one of which is exemplified at the type locality on Sespe Creek (Pl. IV, *A*) and the other at the exposure of the formation to the south. At Sespe Creek the formation consists of about 3,500 feet of sandstone, shale, and conglomerate, usually well indurated and giving rise to a very rough and picturesque topography. Nearly all the beds are colored a deep red-brown, and hence they have by some been called Sespe "brownstone." The greater part of the formation consists of sandstone interlayered with red or purplish shale. In other areas where the Sespe occurs the formation consists mainly of brown to yellow massive sandstone and conglomerate, usually with a zone near the middle composed of soft sandstone and shaly beds. These beds are for the most part variegated with gray, green, blue, purple, and red. Thin beds of limestone occur rarely. A common and characteristic feature is the presence of brown concretions composed of impure aragonite having a radial structure.

The origin of these beds is more or less doubtful, but the greater proportion of evidence indicates that they were deposited under subaerial conditions. Within the area mapped no fossils have been found in them. The coarser deposits resemble those which have accumulated in alluvial fans, being ill sorted. Though the boulders are well rounded, the sand grains are somewhat angular. The clays seem to have been laid down in playas, with the finer sands interbedded. As these beds have a wide distribution over southern California there must have been a number of large valleys in which the climatic and depositional conditions were remarkably uniform.

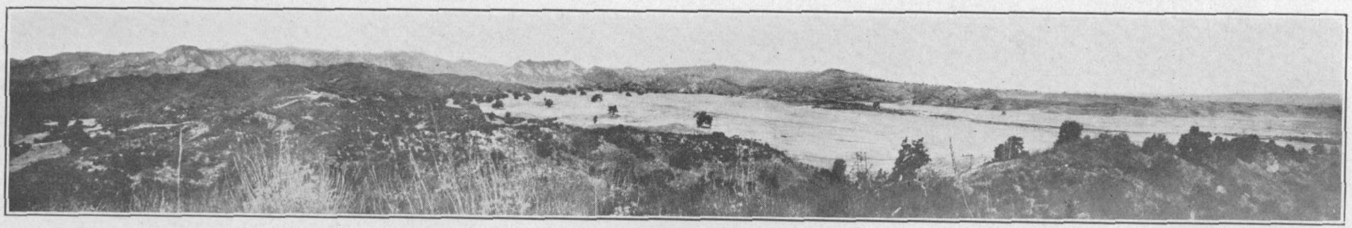
DISTRIBUTION.

The Sespe is one of the most widespread formations occurring in the region covered by this report. The type section of the Sespe occupies an irregular-shaped area west of Little Sespe Creek, in



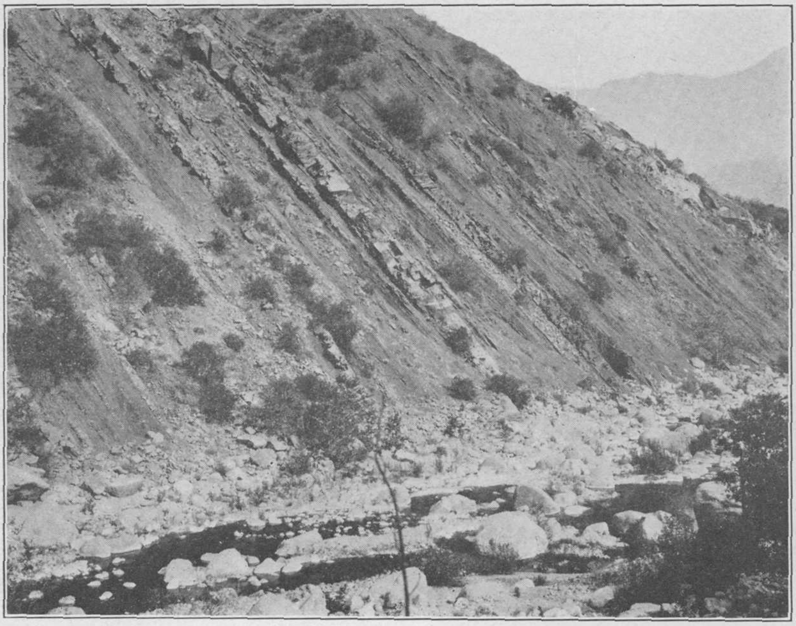
A. SESPE CANYON REGION, VENTURA COUNTY.

View from Oat Mountain, looking northwest across the "Plateau." San Cayetano Mountain on extreme left. Light-colored strata, upper division of Tejon formation (upper Eocene), locally called "Coldwater sandstone," shown forming central part of the Coldwater anticline; strata lying above, Sespe formation (Oligocene?); Pine Canyon syncline to left; San Cayetano Mountain composed of sandstone and shale of Tejon formation. Photograph by George H. Eldridge.



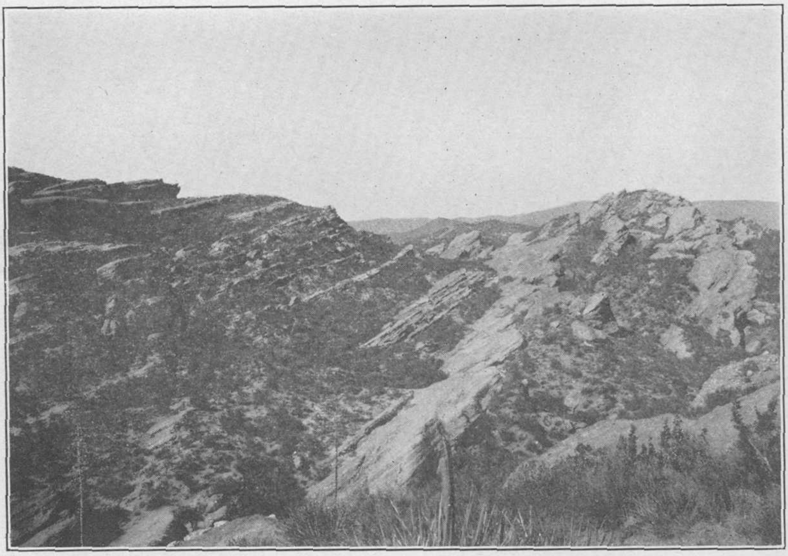
B. SANTA SUSANA MOUNTAINS AND TERRACES OF SANTA CLARA VALLEY, LOS ANGELES COUNTY.

North flank of Santa Susana Mountains, looking west from a point about 2 miles west of Newhall. Modelo formation forms higher parts of the mountains and the Pico and Saugus formations the foothills. Santa Clara Valley on right. Light-colored area in middle foreground is grain field, which roughly outlines the part covered by alluvium.



A. OUTCROP OF SESPE (?) FORMATION IN ESCONDIDO CANYON, LOS ANGELES COUNTY.

Massive conglomerate, sandstone, and shale of this series forms picturesque outcrops north of Soledad Canyon.



B. OUTCROP OF RED SHALE AND SANDSTONE OF SESPE FORMATION (OLIGOCENE?) IN SESPE CANYON BELOW MOUTH OF PINE CANYON, VENTURA COUNTY.

the northwest corner of the Camulos quadrangle. It extends beyond the area mapped for a relatively short distance both to the north and west, lying in a broad syncline above the Eocene rocks. Along Santa Clara River it crops out in lens-shaped patches along the Oak Ridge anticline from South Mountain to Torrey Canyon. Strata of similar lithologic character are exposed in Texas Canyon, in the Fernando quadrangle, and have been correlated tentatively with the Sespe formation. Sespe strata also occur in Simi Valley, where they occupy a synclinal trough. These beds extend westward from Las Llajas Canyon, rapidly widening to the west end of Simi Valley where they are covered by younger sedimentary and volcanic rocks. A narrow outcrop of the Sespe continues along the top of the ridge south of Las Posas Valley. The only other area mapped is in the Santa Monica Mountains west of Garapito Creek. This area lies southwest of Topanga Canyon, where it forms a large part of Calabasas Peak.

LITHOLOGY.

TYPE SECTION ON SESPE CREEK.

The type section of the Sespe formation, on Sespe Creek, is within the Camulos quadrangle. These beds were first described by Watts[18] in 1897, as follows:

> The Sespe brownstone formation consists of sandstone, shales, and conglomerate, all being more or less brown in color * * *. Although this stone is generally known as the Sespe brownstone, and much of it is of a dark-brown color, more correctly speaking it varies from reddish brown to brownish or bluish black.

The exposure of Sespe thus described occupies a comparatively large area in the country drained by Sespe Creek. At the type section the Sespe consists of about 3,500 feet of strata, of which 2,500 feet is exposed in the steep walls of Sespe Canyon. (See Pl. IV, *A*.) Its most striking and characteristic feature is its dark reddish-brown color. The strata consist mainly of a massive medium-grained sandstone. Some parts are rather shaly, and conglomerate occurs at intervals through it. A bed of conglomerate about 100 feet thick is usually present at the base. The sandstone is well bedded, commonly in thin beds, and grades into laminated purplish shale interbedded with thin layers of hard red sandstone. (See Pl. V, *B*.) Some of the thick beds of brownstone that are devoid of pebbles make very good building material. The formation as a whole is perhaps more shaly in its lower part, though it is hard to separate any distinct zones of shale and sandstone. The "plateau," or high, gently eastward

[18] Watts, W. L., Oil and gas yielding formations of Los Angeles, Ventura, and Santa Barbara counties: California State Min. Bur. Bull. 11, pp. 25–26, 1897.

sloping land west of Sespe Creek, is formed of massive red beds of low dip which have weathered out into huge blocks that cover the surface. Streams have cut down into these rocks, forming narrow vertical walled canyons perhaps 50 or 60 feet deep. This series of beds were called by Eldridge[19] the "red beds" and described as composing the middle and major part of the Sespe formation.

SOUTH OF SANTA CLARA VALLEY.

South of Santa Clara Valley the upper part of the Sespe is well exposed in four oval areas along the north slope of Oak Ridge and South Mountain. Good sections are seen in Shiells and Grimes canyons of Oak Ridge (see Pl. XIV, *A*, p. 164) and in Willard and Morgan canyons of South Mountain, where the oil fields of this district are located. At no place is there a complete section, but from wells it is evident that the formation is more than 5,000 feet thick. The formation in these areas consists of brown and buff to yellowish sandstone, conglomeratic sandstone, and conglomerate, interbedded with which are variegated sand and clay. Many of the beds are lenticular, and even very prominent strata are traceable only for short distances. At the top of the section there is a massive greenish-brown medium-grained sandstone about 50 feet thick, which appears to grade upward into the brownish-gray sandstone of the Vaqueros. In the Bardsdale field two massive beds of brown conglomeratic sandstone about 150 feet thick are exposed as lenses in the variegated sand and marl. These beds are harder than the surrounding strata, so that they weather into prominent ridges. They are separated by zones composed mainly of colored sand and clay interbedded with brown sandstone and conglomerate. A section of the exposed part of the Sespe formation immediately east of Grimes Canyon is as follows:

Exposed section of Sespe formation east of Grimes Canyon.

	Feet.
Light-gray fine and medium grained sandstone composed largely of pink and gray feldspar and weathered mica; very little quartz	25
Fine bluish-gray micaceous sand, gradational from beds below	10
Red sandy clay and blue sand	75
Fine-grained yellow sandstone with grayish clayey beds; some harder light-gray beds	50
Alternating brick-red clayey beds, bluish-gray fine sandy clay, and light-gray fine sandstone	200
	360

[19] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California: U. S. Geol. Survey Bull. 309, pp. 8–9, 1907.

West of Shiells Canyon the sandstone is composed largely of somewhat angular quartz, feldspar, and biotite grains. The coarser material is derived from granitic rocks, though pieces of acidic volcanic rock are not uncommon. Near the top of the section two limestone beds 1½ to 4 feet thick occur in the greenish-gray clay. This is the only occurrence of limestone in the Sespe formation in this region.

At Wiley and Torrey canyons, where the Sespe is exposed in the central parts of the small domelike uplifts along the Oak Ridge anticline, the beds are of the same general character.

The strata at South Mountain comprise typical red beds and grayish-white to light-greenish and bluish-gray sandstone and sandy clay, with minor amounts of yellow sand and one or two thin beds of conglomerate. Aragonitic concretions of a peculiar brownish-gray color are of common occurrence in the Sespe here. The sandstone and conglomeratic beds are considerably harder than the clay, so that they give rise to a much bolder topography. The colored sand and clay, being very poorly consolidated, have slumped down the hillside, making it necessary to take all structural measurements with care.

The Sespe may generally be divided into three lithologic divisions in the region south of Santa Clara Valley. According to F. S. Hudson, geologist for the Ventura Consolidated Oil Fields, a nearly complete section of the Sespe formation, measured on the surface and from a study of well records, is as follows:

Section of Sespe formation on north side of South Mountain.

	Feet.
Upper division: Gray and greenish-gray soft sandstone, with layers of red shale	650
Middle division:	
Mainly massive, yellow-weathering arkose sandstone, commonly conglomeratic, with boulders as much as 8 inches in diameter	150–275
Intermediate red beds; alternating layers of red sandy shale and gray sandstone with thin beds of greenish-gray shale	250–350
Massive yellow conglomeratic sandstone with a few thin partings of red shale	100–220
Oil measures; alternating layers of red clay shale and sandy shale, blue-gray clay, and gray sandstone; exposed only at South Mountain	200–400
Sandstone, similar to sandstone above	80–250
Lower division: Alternating layers of red sandy shale, red clayey sand, blue-gray shale, and gray sandstone; logged in wells as "brown shales" but always have a distinct maroon color; lower oil measures	4,000+
	5,500–6,315+

SIMI VALLEY.

In Simi Valley the Sespe lies apparently unconformably above the Tejon formation. On the north side of the valley east of Tapo Canyon there is some doubt as to the age of the lower 400 feet of beds which have been mapped as Sespe. Owing to the softness of the underlying Meganos formation the exact attitude of these beds is hard to determine. A study of the contact suggests some truncation of the lower beds, but as these beds are much softer than the Sespe beds their aspect may be due to crushing. The change in lithology is sharp, the rock above the contact being a massive brown to buff medium to coarse grained conglomeratic sandstone. This rock is quartzose, and the material of which it consists is not well sorted, as the sand grains are mixed with finer material. There are a few interbedded bands of gray clay. At the mouth of Tapo Creek a massive medium-grained yellow sandstone is present between the Meganos shales and the typical Sespe clays, but no unconformity exists between this yellow sandstone and the typical Sespe sands and clays above. At one place on the ridge about a quarter of a mile east of the mouth of Tapo Creek fragments of fossils were found which indicate a marine origin for these beds. As marine fossils are extremely rare in the Sespe, and none have been found in any exposures within the area mapped, it may be that these beds are not Sespe and should be correlated with the Tejon. In stratigraphic sequence these beds correspond in part to the 1,500 feet of the Tejon on the south side of the valley, but they are much thinner.

The typical Sespe beds in this region are well exposed, in a continuous section from their base to the overlying Vaqueros formation. The thickness of this series of beds is about 5,000 feet west of Tapo Canyon, where one of the best sections is found. (See Pl. XIV, *B*.) The Sespe may be divided roughly into three members—a lower sandstone and conglomerate with some colored clay; a middle sandstone with a large percentage of colored sand and clay containing oil measures; and an upper sandstone and conglomerate containing oil measures.

In the region of Tapo Canyon the lower beds consist of about 2,200 feet of medium-grained quartzose dark-brown to buff sandstone with lenticular beds of conglomerate. A few beds of gray, blue, or purple clay are present.

The sandstone and conglomeratic sandstone are massive and show few bedding planes. Though the sandstone contains little cementing material it is more resistant than the interbedded clay. This causes it to stand up in ridges and weather into badlands. Some of the more prominent ridges may be traced for several miles.

The middle member contains the largest proportion of colored clay and sand, and as these beds are softer than the coarser-grained strata they form an area of low ridges and small flat-bottomed valleys, though of the badland type. The greatest thickness of this member in Tapo Canyon is about 1,200 feet. The individual beds, which range in thickness from 5 to 25 feet, have a great variety of colors, including white, purple, gray, red, blue, green, and yellow. Interbedded with the clay are yellow sandstone and some conglomerate strata, which are usually softer than strata of the same type in the lower member. A typical section east of Tapo Canyon is as follows:

Section of upper part of Sespe formation on divide east of Tapo Canyon.

Modelo formation:	
White tuffaceous beds.	
Soft yellowish sandstone (Modelo formation?).	
Unconformity (upper Sespe absent).	
Sespe formation:	Feet.
Colored clay and sand	15
Light-gray medium to coarse soft sandstone	75
Colored clay	90
Soft yellowish and gray sandstone with some conglomerate	97
Light-gray sandstone with some shale	115
Yellow sandstone and colored shale, about equally divided	385
Light-yellowish and gray sandstone and conglomerate	3
Sandstone and purple shale	410
	1,190

In Brea Canyon, near the middle of this member, oil seeps occur in a zone that extends southwestward to Arroyo Simi. A large seep and brea deposit lies on the west side of Brea Canyon near the center of sec. 32, T. 3 N., R. 18 W.

The best section of the upper member is in Brea Canyon north of the Scarab wells of the Pan American Petroleum Co., where the Sespe is thickest. The beds of the upper member aggregate about 2,800 feet but diminish to only 350 feet just west of Tapo Creek. This member consists almost entirely of brown to buff sandstone and conglomerate in about equal amounts. Very few clay beds are present. It is in the lower part of these beds that the wells of the Scarab lease have been drilled. Northeast of Moorpark the coarse beds of the Sespe appear to grade up into the Vaqueros formation.

SANTA MONICA MOUNTAINS.

The Sespe formation occupies an elliptical area on the south side of the Santa Monica Mountains near the head of Topanga Canyon, where it is exposed along the axis of a large anticline. The Sespe in the Santa Monica Mountains is not shown on the map, as the formation here was not studied in sufficient detail. The strata as a rule rest upon the granitic and metamorphic rocks forming the core of the Santa Monica Mountains and are overlain, apparently conformably, by the Vaqueros formation. In these mountains the Sespe-Vaqueros section is probably unconformably overlain by the Topanga formation. The beds of the Sespe are similar in lithology to those in other places, consisting of massive light rusty-yellow and red sandstone and conglomerate, which form steep bluffs and precipitous canyons. Numerous softer beds of loose sand and clay of red and green color are interbedded. The conglomerate contains well-rounded boulders derived mainly from a quartzitic schist, with some of granite and volcanic rocks. The matrix is a sandstone, either red or green, which contains a considerable percentage of ferromagnesian minerals.

CORRELATION AND EVIDENCE OF AGE.

As the areas of the Sespe formation here described are separate and show somewhat different lithographic characteristics from those of the type section, evidence for their correlation will be given. This evidence is mainly stratigraphic and lithologic, as no fossils have been found in the beds.

In this report the Sespe is limited to the beds which Watts[20] originally described as the Sespe brownstone formation. Later Eldridge[21] enlarged the limits of the Sespe so that it included as his "lower zone" the underlying white sandstone. This was called by Watts[22] the "formation underlying Sespe brownstone." The typical Sespe, which Eldridge called the "red beds" (middle zone), is the same as the Sespe brownstone formation of Watts. Eldridge[23] included as the "upper zone" "about 500 feet of ferruginous greenish-gray calcareous sandstone" which Watts[24] called the "drab sandstone" and regarded as transition beds between the Miocene and Eocene formations. Watts[25] later called these Eocene, together with the brownstone, but made a distinction between the two. These upper beds are now known from their contained fauna to be equivalent to the Vaqueros formation, and they will be further described under that name.

As far as known definite evidence that will settle the question of the age of the Sespe formation in this region has not yet been found. For

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[20] Watts, W. L., Oil and gas yielding formations of California: California State Min. Bur. Bull. 11, pp. 25–26, 1897.

[21] Eldridge, G. H., U. S. Geol. Survey Bull. 309, pp. 7–12, 1907.

[22] Watts, W. L., Oil and gas yielding formations of California: California State Min. Bur. Bull. 19, p. 94, 1900.

[23] Op. cit., p. 10.

[24] Op. cit. (Bull. 11), p. 25.

[25] Op. cit. (Bull. 19), p. 94.

a long time it was considered to be Eocene, but is now thought to be Oligocene or possibly lowermost Miocene. Although no fossils were found in Sespe beds either at the type locality or in other areas of the Sespe within the region covered by this report, both marine invertebrate and mammalian remains are known to occur in beds of probable Sespe age in other places. In the Ojai Valley region the writer once found specimens of *Turritella* which resembled very closely the lower Miocene form *Turritella inezìana*. A *Hypertragulus*, a deerlike camel,[26] together with other species, has been found in beds at Tecoya Creek, in the south end of San Joaquin Valley. These beds lie above the Tejon and grade up into the Vaqueros (lower Miocene), and in lithology and stratigraphic position they are similar to the typical Sespe. The *Hypertragulus* is apparently identical with a form from the John Day formation of Oregon. From this mammalian fauna Stock considers these beds to be uppermost Oligocene or possibly lower Miocene. In 1924, according to Stock,[26a] F. S. Hudson found in the Sespe formation at South Mountain vertebrate fossils among which was a species of *Hypertragulus*.

As before stated, the beds on the south side of the Santa Clara Valley here called Sespe are not connected with the Sespe of the type locality. The correlation of the two is based on their general lithologic similarity and the fact that at both places the beds appear to grade up into the lower Miocene. The fauna of the overlying beds, which is of Vaqueros age, is the same on both sides of the valley. In the southwest end of Simi Valley, however, the Sespe is overlain with marked unconformity by beds containing a Miocene fauna. The Sespe is aparently conformable below Vaqueros beds on the north side of Simi Valley and also in the area in the Santa Monica Mountains.

RELATION TO PETROLEUM.

Both in Santa Clara Valley and in Simi Valley the Sespe formation serves as a reservoir in which petroleum has accumulated. The greater part of the oil that is obtained in the fields along the Oak Ridge anticline comes from certain sands in the lower and middle parts of the Sespe. Oil is also obtained in smaller amounts from the Sespe on Sespe Creek and north of Simi Valley. It has been rather difficult to explain the occurrence of oil sands near the middle of the Sespe formation, which are 1,000 feet or more stratigraphically above the most probable source, the Eocene shales. The lithology of the formation, which consists largely of lenticular sandstone and conglomerate interbedded with comparatively thin beds

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[26] Stock, Chester, An early Tertiary vertebrate fauna from the southern coast ranges of California: California Univ. Dept. Geology Bull., vol. 12, pp. 167-276, 1920.

[26a] Personal communication.

of argillaceous shale that are not of an organic nature, gives no suggestion of a source within itself, and the occurrence of the oil, locally confined to the highest parts of anticlines, does not bear out a hypothesis that the oil is indigenous. On the contrary, it appears that the oil must have migrated upward, either through fissures along the folds or by passing from one lenticular sand to another. From the facts that minor faulting is common in the South Mountain fields and that the oil itself resembles the Eocene oil of Simi Valley much more closely than any California oil of Miocene age, it is thought that the oil reached its present position in the Sespe formation by upward migration from the Eocene shales. This same method of migration occurred in the Simi field, where at least a part of the oil has come up from organic shales below the petroliferous upper Eocene sands.

SESPE (?) FORMATION IN FERNANDO QUADRANGLE.

GENERAL FEATURES AND DISTRIBUTION.

In 1902 Hershey[27] described as the "Escondido series" a succession of beds near the head of Escondido Canyon and directly east of the Tick Canyon borax mine in the Fernando quadrangle. Closely resembling these beds, but in no way connected with them, is another series of beds exposed in Texas Canyon and in the east branch of Deadman Canyon, which are faulted between two areas of granitic and metamorphic rocks. The lithology of both areas shows a striking resemblance to that of the type section of the Sespe formation in Sespe Canyon, north of Fillmore. On the other hand, as the beds are unfossiliferous and have not yet been traced into any formation of known geologic age, they can be only tentatively correlated with the Sespe formation.

In general these beds are composed of detritus which probably accumulated under subaerial arid or semiarid conditions. In detail the section consists of coarse sandstone and alluvial-fan conglomerate derived from granitic and metamorphic rock, angular boulders of which are as much as 5 feet in diameter. Some of the conglomerate beds are composed entirely of coarse talus in which the boulders, very slightly weathered, are so numerous that the material gives the impression of granite in place. Some of the beds are red; others dull pink and gray. Not more than 2 miles northeast of Deadman Canyon these beds are probably several thousand feet thick, but exact measurement is impossible, owing to the faults on both sides. Both at the head of Texas Canyon, in the Elizabeth Lake quadrangle, and east of Tick Canyon, especially in Agua Dulce and Escondido

[27] Hershey, O. H., Some Tertiary formations of southern California: Am. Geologist, vol. 29, pp. 349–372, 1902.

canyons (see Pl. V, *A*) these beds are prominently developed as boldly outcropping, hard conglomerate, interbedded with thin layers of shale. These beds in some places are dark red and in others dark buff to yellow. Lavas are interbedded in the lower part of the sespe (?) in the eastern areas, where they form a considerable part of the section.

The best section, exposed in Agua Dulce and Escondido canyons, shows about 400 feet of gray to reddish conglomerate and shaly sandstone at the base, resting upon granite. It is in the gray calcareous beds that the borax deposits occur which form a workable deposit at the Sterling borax mine in Tick Canyon, now owned by the Pacific Borax Co. These lower beds are overlain by a series of andesite flows, which are nearly everywhere vesicular and contain amygdules of chalcedony. The bulk of the Sespe (?) lies above the volcanic rocks and is chiefly a conglomerate. The boulders composing it show little erosion and thus suggest that the material has not been transported far from its source. The boulders are mainly granodiorite gneiss, diorite, and the peculiar white alaskite (?) rock that occurs on the north side of the San Gabriel Mountains. A few beds near the top of the section contain fragments of quartz diorite, a type of rock occurring near Sierra Pelona Valley. At the junction of Agua Dulce and Escondido canyons beds of sandstone and shale enter the section. They are of a dark maroon and yellow color, with here and there a yellowish tinge. These "red beds" are intercalated with fan conglomerate and angular-grained yellow, brown, and red grits. The thickness of the strata exposed in the Sespe(?) section in this region is estimated at 8,400 feet, divided as follows: Basal sandstone and fan conglomerate, 400 feet; andesite flows (maximum), 3,700 feet; fan conglomerate, sandstone, and shale, 4,300 feet.

EVIDENCE OF AGE.

The exact age of the beds here tentatively designated Sespe (?) formation is not known, as no fossils have been obtained from them and their stratigraphic relations are not definite. They are known to lie unconformably below the Mint Canyon formation (upper Miocene), the only formation with which they are in normal contact within the area under discussion. Should these beds be traceable westward it may be found that they are in whole or in part equivalent to the Sespe formation at Sespe Canyon.

RELATION TO PETROLEUM.

No oil is likely to be found in these beds, because they contain, so far as known, no petroliferous strata from which oil may have originated. Moreover, no formation occurs below them from which petroleum may have migrated.

MIOCENE SERIES.

GENERAL FEATURES.

The marine Miocene series, which in this report has been divided into the Vaqueros formation, Topanga formation, and Modelo formation, is one of the most widespread series of rocks in California, occurring at many localities from San Francisco Bay to San Diego County. It is economically important in that the rocks are in many places in the State closely associated with the occurrence of petroleum. In the present report the names which Eldridge[28] gave to this series of strata have been retained, but the units to which these names are applied have been readjusted, in general accordance with the classification adopted by the writer[29] in his preliminary report on Simi Valley. Further work since the publication of that report, however, has made necessary other subdivisions, namely, the Topanga and Mint Canyon formations. The Vaqueros is here limited to those rocks (composed of sandstone, shale, and in places conglomerate) with which is associated a lower Miocene fauna characteristic of Vaqueros strata at the type locality on Vaqueros Creek, Monterey County. These rocks lie below the strata here named Topanga formation, probably unconformably, but everywhere conformably above the Sespe formation (Oligocene?).

Although in Santa Clara Valley the Vaqueros from all appearances is conformable with the overlying strata, in Simi Valley it is everywhere unconformably overlain by the Modelo, the Topanga being nowhere present in the same section with the Vaqueros. The Modelo formation is essentially shale, both of the clay and siliceous varieties. As redefined by the writer in 1919, the Modelo at the type locality, north of Santa Clara Valley, includes the shale called Vaqueros formation by Eldridge, which lies directly above the true fossiliferous Vaqueros strata, which were included by Eldridge in his Sespe formation. Within the Modelo are huge lenses of coarse tan to buff sandstone which attain a maximum thickness of 4,000 feet. Three such lenses are present north of Santa Clara River and two in the Santa Susana Mountains. Although in previous reports these lenses have been mapped separately, they are here simply mapped as sandstone lenses within the shale, for the reason that correlation between the different areas is impossible, and the division between the shale and sandstone in many places is only approximate. In the writer's report on Simi Valley the Modelo and Vaqueros formations were classified as composing the Monterey group. The Topanga and Modelo formations as developed in the area under discussion are probably correlatives of the Salinas

[28] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California: U. S. Geol. Survey Bull. 309, pp. 12–22, 1907.

[29] Kew, W. S. W., Structure and oil resources of the Simi Valley, southern California: U. S. Geol. Survey Bull. 691, pp. 330–333, 1919.

("Monterey") shale and part of the deposits mapped by English[30] as Vaqueros sandstone in the Salinas Valley region, and with the undifferentiated Vaqueros and Maricopa shale of northwestern Kern County.[31]

The nonmarine Miocene Mint Canyon formation, which is well exposed in Mint Canyon, lies unconformably below beds that are thought to be equivalent in part to the Modelo formation. A vertebrate fauna from these land-laid deposits indicates that they are of upper Miocene age.

VAQUEROS FORMATION (LOWER MIOCENE).

GENERAL FEATURES.

Although not occurring in large areas, the Vaqueros crops out in many places in the northwestern part of the region mapped north of the Simi Hills and in Santa Clara Valley. Along Santa Clara River (see Pl. XIV, *A*) it consists usually of about 400 feet of gray to brown sandstone, which is in part shaly and contains a characteristic lower Miocene fauna. The Vaqueros here appears to be conformable with both the Sespe below and the Modelo above. Outside of the western Santa Clara River area the Vaqueros is unconformable with the Modelo. To the south the rock is coarser grained, and the sections are considerably thicker. In Simi Valley 1,800 feet of conglomerate, sandstone, and shale are exposed. The strata are mainly a brown coarse quartzitic sandstone containing very little shale. Conglomerate is rather common in the Simi region. Fossils, though present, are, as a rule, not well preserved.

DISTRIBUTION AND LITHOLOGY.

LITTLE SESPE CANYON.

The Vaqueros occupies a relatively narrow belt extending northward from a point about 2 miles north of Fillmore along Sespe Creek and the upper part of Bear and Elm creeks to the edge of the area mapped. The beds here grade up without a break from the Sespe red beds below. Similarly no discontinuity is present between the Vaqueros and the overlying shale of the Modelo. The Vaqueros is therefore limited in this region to those beds of a sandy nature, more shaly in their upper part, which contain a fauna of lower Miocene age that can be correlated with the fauna occurring in the Vaqueros at the type locality, on Vaqueros Creek, on the west side of the Salinas Valley in Monterey County. These beds are the

[30] English, W. A., Geology and oil prospects of the Salinas Valley-Parkfield area, Calif.: U. S. Geol. Survey Bull. 691, pp. 228–229, 1918.

[31] English, W. A., Geology and petroleum resources of northwestern Kern County, Calif.: U. S. Geol. Survey Bull. 721, 1921.

"shales, purplish, rusty, and gray in color, purplish prevailing, perhaps 500 feet," of the lower part of the Vaqueros as described by Eldridge[32] and apparently erroneously indicated on his map as the "upper zone" of the Sespe formation. The beds on Little Sespe Creek as mapped consist of about 500 feet of drab or greenish-gray calcareous sandstone and gray shale. In color there appears to be a uniform gradation from the reddish-brown and purplish beds of the typical Sespe through intermediate mottled reddish and greenish beds to gray-green fine-grained sandstone and shale. These are well bedded, but the strata are considerably fractured. Above the fossiliferous sandstone the beds grade into soft, fine dark-gray sandstone and muddy sandstone and shale that assume a brownish color on weathering. Gray limestone concretions, many of them containing fossils, occur in zones in these beds. The Vaqueros beds in turn pass into blue-black unfossiliferous shale, which has been grouped with the Modelo. A section of the Vaqueros taken along Little Sespe Creek just east of Fourfork Creek is as follows:

Section of Vaqueros formation on Little Sespe Creek near Fourfork Creek.

	Feet.
Thin-bedded fine blue-gray sandstone, oil stained, with interbedded clay and diatomaceous shale	150
Dark bluish-gray shale with limy beds and concretions	50
Massive fine-grained muddy sandstone	50
Fine-grained brownish-tan sandstone with limestone beds containing fossils	50
Hard brown sandstone containing *Scutella fairbanksi*	2
Fine brown sandstone	12
Gray-brown fine sandstone with fossils, including *Pecten sespeensis*, *Turritella ineziana* var. *sespeensis*, *Balanus*, and *Ostrea*	15
Greenish-brown shale with limy layers containing oysters and barnacles; some fine muddy sandstone	50
Thin-bedded gray and tan fine sandstone	30
Brown medium-grained sandstone with *Scutella fairbanksi*	10
Thin-bedded sandstone, becoming massive toward top	25
Medium-grained greenish-gray sandstone	3
Thin-bedded fine sandstone and green and brown shale	20
Medium-grained dark-gray and tan sandstone with a slight greenish color	7
Shale	5
Hard, coarse light gray-green sandstone, no fossils	4
Purple shale	2
Hard, coarse light gray-green sandstone, made up mainly of quartz, feldspar, and ferromagnesian minerals; contains numerous bones resembling those of *Desmostylus*	25
Thin-bedded green sandstone, mottled with purple, and purple shale; transition beds between Sespe and Vaqueros	25
	525

[32] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California: U. S. Geol. Survey Bull. 309, p. 12, 1907.

SOUTH SIDE OF SANTA CLARA VALLEY.

The Vaqueros on the south side of Santa Clara River crops out around the oval areas of Sespe rocks on the north side of South Mountain and Oak Ridge. The area on South Mountain extends from a point about 2 miles southwest of Santa Paula nearly to Sulphur Canyon. In this vicinity the Vaqueros is covered by the Modelo shales and is next exposed a mile east of this canyon, whence it extends to a point a short distance beyond Torrey Canyon. East of Guiberson Canyon the Vaqueros comprises the greater part of the outcropping strata, arching over the top of the Oak Ridge anticline and reaching down the north side along the edge of the valley bottom past Shields Canyon. (See Pl. XIV, *A*, p. 164.)

The Vaqueros here is similar to that on the opposite side of the river on Little Sespe Creek, except that it is slightly thinner. At no place do the strata aggregate much over 400 feet. West of Grimes Canyon it is about 200 feet thick, and in places on top of South Mountain it is partly or altogether cut out by an intrusion of igneous rock. The dividing line between the Sespe and Vaqueros formations has been taken at the top of the gray and purple sand and marl of the Sespe. The upper limit of the Vaqueros is somewhat indefinite, as sandy beds at the top grade into the Modelo, so that their separation has been more or less arbitrary, the more sandy strata being included with the lower formation.

The lithology on South Mountain and Oak Ridge varies but little. The Vaqueros of South Mountain consists primarily of a light-brown to tan medium-grained fairly well cemented sandstone which toward the top becomes finer, softer, fluffy in appearance, and easily weathered. Fossil shells are present in the harder, more calcareous sandstone beds. As the underlying Sespe formation has a decided tendency to slump, large blocks of the Vaqueros are often found far down the slope of the mountain. For this reason considerable care is necessary in mapping it.

Similar lithologic characteristics are shown by the Vaqueros in Oak Ridge, though in some places a limestone bed about 2 feet thick makes its appearance; also the beds as a whole may be softer and more shaly at one place than another. In the vicinity of Shiells Canyon the Vaqueros is somewhat thicker, aggregating nearly 400 feet of strata. The lower 250 feet is composed of shaly quartzose sandstone, fairly hard and poorly bedded. It has splintery fracture, thus resembling some phases of the Modelo, though it is more sandy. Interbedded with the sandstone are layers of fine-grained light-brown somewhat concretionary sandstone. Fossils occur through both sandstones in calcareous nodules. Above is 125 feet of fine-grained brown sandstone of varying hardness. This appears to grade into the typical shales of the Modelo, the unconformity, if one exists, not having been recognized. The upper sandstone is in places stained a dark brown or gray by petroleum. At Torrey and Chaffee canyons the beds show the same lithology. Fossils are abundant and distinguish the Vaqueros here from the Modelo sandstones, with which it might be confused where the two are faulted against each other. The Modelo contains no fossils except foraminifers and diatoms, so far as known, and its sandstones as a rule are coarser, harder, and of a lighter color.

A typical section of the Vaqueros across the south limb of the Oak Ridge anticline along a sharp hogback ridge half a mile east of Grimes Canyon is as follows:

Section of Vaqueros formation half a mile east of Grimes Canyon.

	Feet.
Light-yellow and light-gray fine sandstone, not shaly	100
Light pearl-gray fine-grained shaly sandstone and sandy shale. Thin darker beds common, and a few fossiliferous concretions and lenses. In places this member has a light-yellowish or tan tinge and contains brown sandstone at the base. These are the most conspicuous beds of the Vaqueros formation	100–125
Light-gray fine-grained shaly sandstone carrying a "reef bed" or "shell" made up largely of *Turritella ineziana* and several unrecognizable species of small pelecypods. In the sandstone *Ostrea eldridgi* is abundant	50
Bluish tough clastic shaly sandstone	10
Bluish-gray fine sandstone carrying light-gray calcareous lentils which contain *Scutella fairbanksi*, *Phacoides richthofeni*, and *Spisula* sp	25
Brown or dark-yellow medium and fine-grained micaceous and feldspathic sandstone, carrying hard light-gray nonfossiliferous lentils and concretions	50
	335–360

NORTH OF SIMI VALLEY.

North of Simi Valley the Vaqueros has been recognized in an area that extends from Tapo Canyon westward along the south side of the ridge south of Happy Camp Canyon. At the west end of this ridge it is covered by Pleistocene terrace gravels. This section differs from that on Oak Ridge in being unconformable with the Modelo formation above, the Topanga formation being absent. The Vaqueros and Sespe strata show no difference in attitude, so far as could be ascertained. A marked overlapping of the Vaqueros beds by the Modelo occurs from west to east, as strata having a thickness of 1,800 feet, about 5 miles west of Tapo Canyon, are entirely absent at this canyon. The mapping brings out this relation very clearly. It is due to an unconformity with the Modelo, which is further strengthened by the fact that the strike of the Vaqueros beds is at considerable variance with that of the Modelo.

The Vaqueros in its thickest section north of Alamos Canyon and the wells of the Pan-American Petroleum Co. on the Scarab lease, includes at the base conglomerate and brown sandstone that grade up from the Sespe, which here in its upper part is composed largely of conglomerate. The line between the two formations is rather indefinite. Above the brown sandstone there is a bluish-gray and rusty-colored coarse micaceous sandstone, which is in places hardened by calcification. This member becomes finer and more uniformly grained from the base up until at the top it is very fine grained and light colored. In more detail, the upper part of this member consists of a medium but even-grained light-colored sandstone, which has yielded a few poor casts of fossils that indicate a Vaqueros age. Above this is a rusty-yellow sandstone from which the characteristic Vaqueros fossils: *Pecten lompocensis* Arnold, *Turritella* cf. *T. ineziana* Conrad, and *Scutella fairbanksi* Arnold were obtained. A hard yellowish shaly sandstone carrying fragments of bone with a few indeterminate shells overlies the fossiliferous sandstone. This is followed by a bluish and yellowish sandy shale, which in turn is overlain by massive tan sandstone containing numerous specimens of a large oyster, *Ostrea vaquerosensis* Loel. At the top of the Vaqueros is a coarse white pebbly "reef bed" which is unfossiliferous. The chalky shales of the Modelo lie directly on this bed. Between the "reef bed" and the massive tan sandstone there is an igneous rock 150 to 200 feet thick, which is present only in the western part of the Vaqueros outcrop. It is probably a flow, as the rock is vesicular and scoriaceous toward the top. The sandstone beds below show baking in several places.

SANTA MONICA MOUNTAINS.

Unfossiliferous beds that are equivalent to the Vaqueros formation occupy a small area at the east edge of the Calabasas quadrangle directly south of the Encino grant. These strata, which are tilted to 45° N., lie unconformably below Modelo shales, which dip about 20° N. The beds consist mainly of dark reddish-brown conglomerate and sandstone, which in large part have originated from a fine-grained basaltic rock. These beds, resting upon the metamorphic rocks, can be traced southwestward toward Topanga Canyon, where the section grades up into the Topanga formation. Some of the rocks within the Topanga Canyon drainage area resemble parts of the Sespe formation, containing some reddish and green sandstone and clay.

CORRELATION AND EVIDENCE OF AGE.

In every locality where the Vaqueros is present it rests conformably upon the Sespe formation. In the Sespe and Oak Ridge areas it appears to grade up into the Modelo formation, but in parts of Simi Valley, where the Topanga formation is absent, a marked unconformity exists between the Vaqueros and the Modelo. North of Saugus the Vaqueros is absent, the Modelo (?) formation resting unconformably upon the Mint Canyon formation (upper Miocene).

The fauna of the Vaqueros is distinctive and characterized by several species of mollusks, of which the commonest is *Turritella ineziana* Conrad. The following species were collected by the writer from the Vaqueros beds in this region:

Fossils from the Vaqueros formation of the Los Angeles-Ventura region.

[Locality numbers from U. S. National Museum.]

	Sespe Creek 8130	Oak Ridge.					
		8128	8129	8132	8133	8137	8138
Rapana, n. sp. ? Lool MS.			+			+	
Turritella ineziana Conrad.			×		×		
Turritella ineziana var. sespeensis Arnold	×	×	?	×		×	×
Turritella n. sp.						×	
Arca n. sp.		×					
Cardium n. sp.			×				
Ostrea sp.					×		
Pecten lompocensis Arnold					×		
Pecten magnolia Conrad.				×			
Pecten sespeensis Arnold	×						×
Pecten sespeensis var. hydei Arnold		×				×	
Pecten n. sp. *a*		?					
Dosinia cf. D. mathewsoni Gabb						×	
Panope n. sp.						×	
Saxidomus n. sp.							×
Venus cf. V. pertenuis Gabb.						×	
Balanus concavus		×				×	
Scutella fairbanksi Arnold	×			×	×		×

8128. Top of small ridge west of right-hand branch of Sulphur Canyon, in NE. ¼ sec. 17, T. 3 N., R. 20 W.
8129. On ridge east of Wiley Canyon, in NW. ¼ sec. 6, T. 3 N., R. 18 W., just south of axis of Oak Ridge anticline, near middle of Vaqueros section.
8130. Little Sespe Creek immediately above mouth, near wells of Sudden & Emslie Oil Co., at old dry well in SW. ¼ sec. 6, T. 4 N., R. 19 W.
8132. On north side of Oak Ridge south of Torrey Canyon oil-field camp, in middle of sec. 5, T. 3 N., R. 19 W.
8133. Two miles northeast of Pan American Petroleum Co.'s Scarab lease wells, on north side of Simi Valley, near top of spur extending south from highest western point on long east-west ridge capped by shale south of Happy Camp Canyon, not far above base of Vaqueros formation.
8137. In NE. ¼ sec. 8, T. 3 N., R. 19 W., west of Shiells Canyon, south of Montebello Oil Co.'s Elkins well No. 1, on south side Santa Clara River valley.
8138. On west slope of 2,250-foot hill, east of Guiberson Canyon, in SW. ¼ sec. 2, T. 4 N., R. 19 W.

In addition to the species listed above the following have been listed by Eldridge[33] from the same horizon on Oak Ridge:

Mytilus mathewsoni Gabb var. expansus Arnold.
Ostrea eldridgei Arnold.
Pecten (Hinnites) giganteus Gray.

[33] U. S. Geol. Survey Bull. 309, p. 17, 1907.

The fauna occurring in the Vaqueros of this region may be correlated with that in the Vaqueros of the type section on Vaqueros Creek, in Monterey County. This fauna has not yet been published in detail, but Hamlin [34] in his original description of it lists the following species:

Balanus sp.
Mytilus sp., probably M. mathewsoni Gabb.
Ostrea tayloriana Gabb (Young)?
Pecten magnolia Conrad.
Turritella hoffmanni Gabb=T. ineziana Conrad.
Chione mathewsoni Gabb.
Chione n. sp. (large, characteristic of this horizon).
Mactra aff. M. catilliformis Conrad.
Pecten estrellanus Conrad.
Pecten (Chlamys) n. sp. S.
Pecten (Plagiotenium) n. sp. A.

In a comparison of the two faunas only two species are found to be common, *Turritella ineziana* Conrad and *Pecten magnolia* Conrad. As these forms are very characteristic and are not known to occur except at this horizon, they seem to offer a fairly safe basis of correlation.

RELATION TO PETROLEUM.

Oil occurs in the Vaqueros formation only in the area lying east of Sespe Creek and northwest of Hopper Mountain. Here the sands in the lower part contain oil in commercial quantity along the flanks of a broad anticline. As the Vaqueros is made up in part of shaly strata that contain some organic material the petroleum may have either originated in the shales themselves or migrated from the Sespe oil-bearing sands below or from the organic shales of the Modelo formation above.

TOPANGA FORMATION (MIDDLE MIOCENE).

NAME AND DEFINITION.

In the report on Simi Valley [35] the series of strata here named Topanga formation were included in part in the Vaqueros formation and in part in the Modelo formation. Later work has shown that these rocks, which are well exposed along the Topanga anticline, should be separated as a distinct formation. Wherever recognized they are unconformably overlain by the Modelo formation as here restricted. Their relation to the underlying deposits carrying the typical Vaqueros fauna is not so clear, and although an un-

[34] Hamlin, Homer, Water resources of the Salinas Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 89, 1904.

[35] Kew, W. S. W., Structure and oil resources of the Simi Valley, southern California: U. S. Geol. Survey Bull. 691, pp. 330–333, 1919.

conformity probably exists between the two it has not been recognized. In general it may be stated that the Topanga formation is characterized by a fauna similar to that of the "Temblor formation"[36] of San Joaquin Valley, whereas the Vaqueros contains a markedly different fauna at its type locality on Vaqueros Creek, Monterey County. The Topanga formation consists mainly of well-bedded tan and brown sandstone containing large round concretions and minor thicknesses of conglomerate. Fossils are common at certain horizons.

The Vaqueros, on the other hand, is composed largely of coarse conglomerate and interbedded sandstone and grades downward into the variegated sand, conglomerate, and clay of the Sespe formation. Although the Topanga formation is best developed on the Santa Monica Mountains, it also crops out south and west of the Simi Hills and along the Santa Susana fault north of Fernando Valley. It is possible that the lower part of the Modelo formation exposed east of Sespe Creek may represent the Topanga, but it seems more probable that the Modelo rests directly and unconformably upon the Vaqueros and that the Topanga formation is not represented north of the Santa Susana Mountains and Oak Ridge. (See p. 58.) Work subsequent to the field studies for the present report shows that both the Topanga and Vaqueros formations are well developed in the eastern part of the Santa Monica Mountains as far east as Pasadena. As the greatest exposure of the series of strata described above within the region covered by this report is in the vicinity of Topanga Canyon, and as the fauna characterizing it has been for a number of years known as the "Topanga Canyon fauna," the local name Topanga formation is here adopted for it.

GENERAL FEATURES.

The best section for the study of the Topanga formation is in the region south of the Simi Hills, directly south of Calabasas and west of the old Topanga Canyon road through Dry Canyon. About 6,000 feet of strata can be measured here on the nose of the Topanga anticline, where the beds range in dip from 25° to 60°. They consist mainly of tan, brown, and gray sandstones, in places coarse-grained and conglomeratic and derived in a large measure from granitic rocks. Here and there a bed of white sandstone is present, and thin layers of a light-colored shaly sandstone are commonly intercalated with the sandstone. A greenish-brown medium-grained sandstone forms the crest of the Santa Monica Mountains from the

[36] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., Geology, vol. 2, pp. 156–250, 1905; A further study in the Mount Diablo Range of California: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 1–40, 1908.

summit of the old Topanga Canyon road to Calabasas Peak. This sandstone is highly fossiliferous and contains a fauna, commonly known as the "Topanga Canyon fauna," which has in part been described by Arnold.[37] Intrusions of basalt are rather common in the Topanga formation of this region.

In the vicinity of Russell and Conejo valleys basal conglomerate and sandstone are present below diatomaceous shale. These beds vary in thickness but reach a maximum of 300 feet. The strata have been derived entirely from the neighboring rocks, which in this region are mainly the lower Miocene igneous series. In some places the conglomerate so closely resembles the Miocene andesitic breccia that here forms a large part of the igneous series that the Modelo rocks can be distinguished only by the presence in them of rounded and polished boulders.

Between Newbury Park and Las Virgenes Creek the lower sandstone underlying the shale is very thin. It contains some conglomerate and is composed mainly of detritus from the Miocene volcanic rocks upon which it rests.

On the south side of the Simi Hills and north of Newbury Park the sandstone of the Topanga is rather coarse, quartzitic, and light brown or gray. It closely resembles the Cretaceous, upon which it rests and from which it has been largely derived, and for that reason it is usually very difficult to separate from the Cretaceous. Poorly preserved casts of fossils occur in some places, and these are a distinguishing mark, as none have been found in the Cretaceous massive sandstone beds. The upper beds of sandstone and conglomerate are rarely exposed, being overlapped by Modelo shale. In the region of Bell Canyon, where a considerable thickness crops out, a soft nearly pure-white quartzose sand lies above a brownish sandstone and is overlain by a massive conglomerate and conglomeratic sandstone, consisting of pebbles and boulders of various metamorphic and granitic rocks embedded in a matrix of light-brown sandstone. In places, as in Dayton Canyon, the lower part of the sandstone is highly calcareous and outcrops of limestone are present. In early days the Indians burned this rock for lime, which was used in the building of the San Fernando Mission.

The other area of the Topanga formation in the Simi region is near the head of Aliso Canyon, a branch of Devil Creek, which drains into the northwest corner of San Fernando Valley. At this locality the Topanga rests directly on the Meganos formation, the Tejon, Sespe, and Vaqueros apparently being absent. No fault is present between the two formations. Lithologically the Modelo is composed

[37] Arnold, Ralph, New and characteristic species of fossil mollusks from the oil-bearing Tertiary formations of southern California: U. S. Nat. Mus. Proc., vol. 32, pp. 525–546, 1907.

of about 250 feet of coarse sandstone and conglomeratic sandstone of a yellow, brownish, and grayish color in which were obtained *Turritella ocoyana* Conrad, *Dosinia* cf. *D. ponderosa* Gray, and a few other Miocene forms. On weathering the sandstone becomes mottled in places and is seen to be very irregularly bedded. Hard dark-brown concretions are not uncommon. Apparently interbedded with the sandstone are layers of soft brown fine-grained sandstone and shale which grade up into the shale member of the Modelo formation.

EVIDENCE OF AGE.

The stratigraphic position of the Topanga formation indicates that it is of middle Miocene age, for it lies above the Vaqueros formation, which is considered to be lower Miocene, and below the Modelo formation, which is of upper Miocene age. Paleontologic evidence shows that the Topanga formation belongs to the Miocene epoch and is older than the upper Miocene. The Vaqueros, on the other hand, contains a fauna markedly different from that of the Topanga, and wherever the two faunas are present in the same section of strata the Topanga formation invariably lies above the Vaqueros. Up to the present time no unconformity between the two formations has been found within the area covered by this report, nor has one been described in the literature on California geology, but an unconformity has been reported from the Santa Ana Mountains, where both formations are present.

The following species of mollusks have been collected from the Topanga formation in the area covered by this report:

Fossils from the Topanga formation in the Los Angeles-Ventura region.

	Topanga Canyon.	Alba Villa ranch.	Aliso Canyon (8127).
Actaeon sp			×
Calyptraea costellata Conrad		×	
Calyptraea filosa (Gabb)	×	×	
Cancellaria condoni (Copper)	×		
Cerithium topangensis Arnold	×	×	
Conus owenianus Anderson		×	
Conus n. sp			×
Murex (Ocinebra) edmondi (Arnold)	×		
Murex (Ocinebra) topangensis (Arnold)	×		
Natica callosa Gabb		×	
Neverita recluziana var. andersoni Clark	×	×	×
Oliva californica Anderson	×		
Surcula buwaldana Anderson and Martin	×		
Surcula oschneri Anderson and Martin	×		
Surcula (Bathytoma) keepi (Arnold)	×		
Terebra n. sp. (short)	×		
Terebra n. sp. (collared)	×		
Tegula dalli Arnold	×		
Trophon kernensis Anderson	×		
Trophon sp	×		
Trophosycon kernianum Cooper		×	
Turbo topangensis Arnold	×		
Turritella ocoyana Conrad	×	×	×
Turritella topangensis Richards (MS)	×	×	
Urosalpinx dumblei (Anderson)	×		

Fossils from the Topanga formation in the Los Angeles-Ventura region—Contd.

	Topanga Canyon	Alba Villa ranch	Aliso Canyon (8127)
Antigona diabloensis (Anderson)	....	×	....
Arca montereyana var. barkeriana Clark	×	?	....
Cardium n. sp	×	×	....
Chione temblorensis Anderson	×	×	....
Diplodonta harfordi Anderson	×	×	....
Dosinia mathewsoni Gabb	×	....	....
Dosinia sp	....	×	....
Leda oschneri Anderson and Martin	....	....	×
Mytilus expansus Arnold	....	×	....
Mytilus n. sp	×	....	....
Ostrea bourgeoisii Rémond	×	....	....
Pecten cf. V. andersoni Arnold	....	....	×
Pecten crassicardo n. var	×	....	....
Phacoides richtofeni Gabb	×	×	....
Phacoides sanctaecrucis Arnold	....	×	....
Schizotherus n. sp	....	×	....
Spisula n. sp	×	....	....
Tellina arctata	×	....	....
Tellina nevadensis Anderson	....	×	....
Tivela n. sp	×	....	....
Venus cf. V. conradianus Anderson	×	....	....
Venus pertenuis Gabb	....	....	×

The fauna listed above is similar to that occurring at Kern River near Bakersfield, described by Anderson and Martin,[38] and also to that of the lower Miocene at Coalinga, described by Arnold[39] as the Vaqueros formation and by Anderson as the "Temblor formation." A comparison of the Topanga fauna of the Los Angeles-Ventura region with the large and well preserved fauna of the Kern River region shows that a large number of species are common to the two. These include *Calyptraea filosa* (Gabb), *Cancellaria condoni* Anderson, *Cancellaria dalliana* Anderson, *Ficus kernensis* (Cooper), *Neverita recluziana* var. *andersoni* Clark, *Oliva californica* Anderson, *Surcula buwaldana* Anderson and Martin, *Surcula* (*Bathytoma*) *keepi* (Arnold), *Surcula oschneri* Anderson and Martin, *Trophon kernensis* Anderson, and *Turritella ocoyana* Conrad.

RELATION TO PETROLEUM.

Wherever recognized in the area here discussed the Topanga formation is not oil bearing. No oil sands in this formation are exposed, and the shale in it, which occurs as very thin laminations between comparatively thick sands, could not act as a source for oil. Any oil that may be present in the overlying Modelo formation has not entered the Topanga formation. The strata of the Topanga are of exceptionally good quality to act as a storage reservoir for oil, should they come into contact with an oil-bearing formation.

[38] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., Geology, vol. 2, pp. 156–250, 1905. Anderson, F. M., and Martin, Bruce, Neocene record in the Temblor basin, Calif., and Neocene deposits of the San Juan district, San Luis Obispo County: California Acad. Sci. Proc., 4th ser., vol. 4, pp. 15–112, 1914.

[39] Arnold, Ralph, Paleontology of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 396, 1910.

MINT CANYON FORMATION (UPPER MIOCENE).

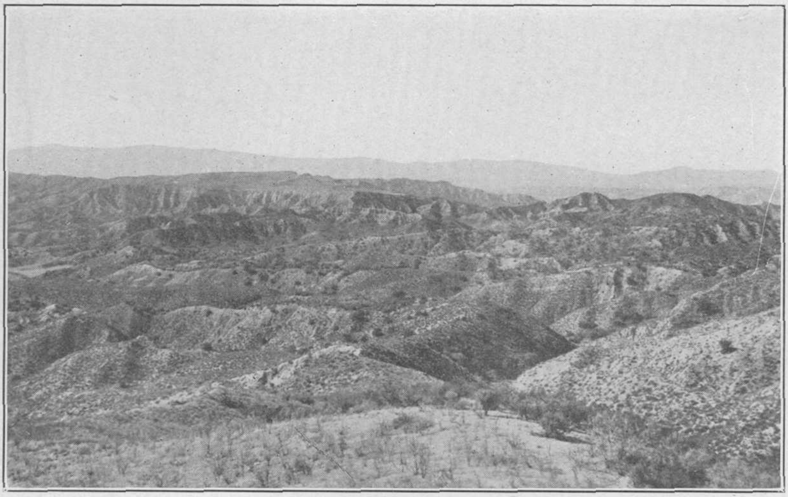
GENERAL FEATURES AND DISTRIBUTION.

Above the conglomerates of the Sespe (?) formation in the upper part of Santa Clara Valley are beds several thousand feet thick which have been called by Hershey[40] the "Mellenia series" and which from their stratigraphic position and fauna are believed to be of upper Miocene age. As the term "Mellenia," so far as could be ascertained, is not a place name, and its origin is doubtful, this series of strata is here renamed, to correspond to the rules of nomenclature of the United States Geological Survey, and the term Mint Canyon formation is adopted because the beds are particularly well developed in the Mint Canyon region. They lie in a large westward-plunging syncline in the upper part of Santa Clara Valley, extending from Agua Dulce Canyon west as far as Haskell Canyon, where the formation is overlapped by the Modelo (?) and Saugus formations. In Haskell Canyon (see Pl. VII, *A*) these beds rest beneath the Modelo (?) sandstone and shale with a marked unconformity, which is shown by a considerable difference in dip and strike. Evidently the Vaqueros marine strata were not deposited this far east.

As the description below indicates, the Mint Canyon formation is in many respects similar to the Sespe formation, occurring on the south side of Santa Clara Valley along the Oak Ridge anticline and in Simi Valley. According to Hershey, the beds overlie the Sespe (?) formation (called by Hershey the "Escondido series") unconformably, and this fact is substantiated from the mapping between Deadman and Mint canyons. The Mint Canyon formation in a general way may be separated into two parts—a lower part consisting of conglomerate, sandstone, and clay of various colors, such as red, green, and gray, though predominantly reddish, and an upper part comprising mainly light-gray to nearly white gravel interbedded with greenish clay or fine sand. A few beds of red clay and sand may be present in this upper part also. The character of the sediments indicates that they were derived largely from granitic and metamorphic rock. Vertebrate remains are fairly common and these are found at numerous horizons, in both upper and lower parts. Fresh-water shells also occur in certain beds. Most of the strata are soft and tend to weather into a topography of badland type.

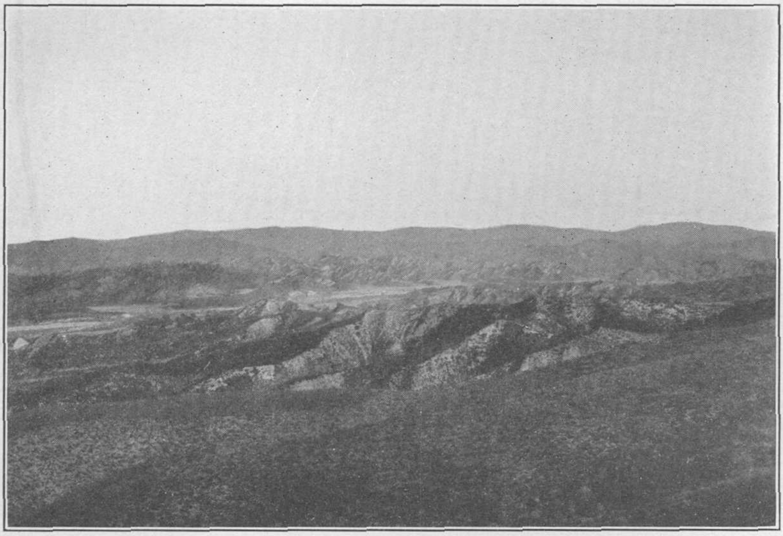
West of Mint Canyon (see Pl. VI, *A*) this formation consists of yellow, gray, white, and reddish sandstone and conglomerate, together with well-sorted sand and clay beds or marls which have some conglomeratic material in them. The strata are lenticular and

[40] Hershey, O. H., Some Tertiary formations of southern California: Am. Geologist, vol. 29, pp. 356–358, 1902.



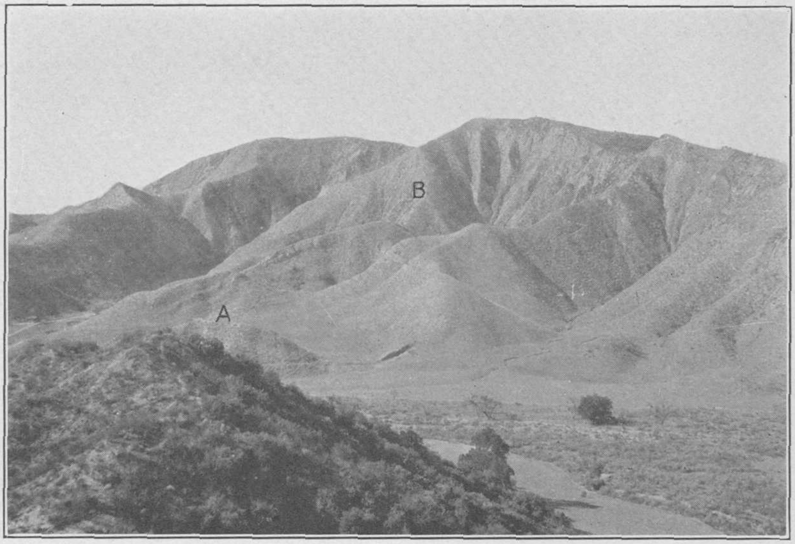
A. REMNANT OF TERRACE CUT INTO STRATA OF MINT CANYON FORMATION.

Looking southwest along divide between Mint and Deadman (Boquet) canyons. Immediate foreground, the basement rocks, with Mint Canyon formation (upper Miocene) faulted against them. Vertebrate-fossil locality at foot of terrace on east side.



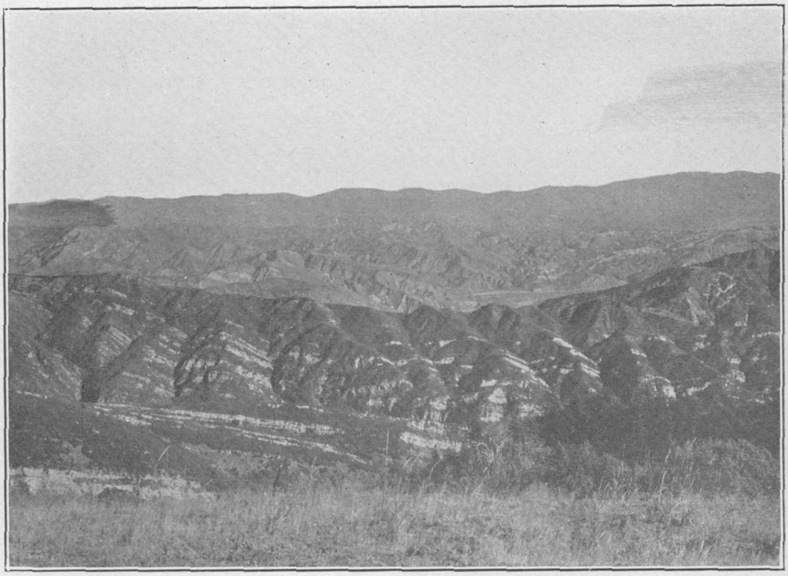
B. MINT CANYON FORMATION IN SANTA CLARA VALLEY.

Looking from ridge south of Sand Canyon north across Santa Clara Valley, up Tick Canyon, Note great thickness of Mint Canyon formation (upper Miocene) dipping westward on north side of valley.



A. ANTICLINE IN HASKELL CANYON, LOS ANGELES COUNTY.

Looking west across Haskell Canyon, immediately below forks in sec. 36, T. 4 N., R. 16 W. A, Mint Canyon formation (upper Miocene); B, Modelo (?) formation (upper Miocene).



B. MODELO SANDSTONE IN HOPPER CANYON, VENTURA COUNTY.

Looking east from top of Hopper Mountain across Hopper Canyon and down Reasoner Canyon to Piru Canyon. Massive sandstone of Modelo formation (upper Miocene) in foreground. Photograph by George H. Eldridge.

vary a good deal from one locality to another. On the southeast side of Deadman Canyon the formation is made up mainly of coarse, light-colored conglomerate, followed by soft sand and clay of greenish and brown color, some of which is slightly purplish. Within these softer beds are thin layers of a hard brown flaggy sandstone. There are also two distinct zones of white tuffaceous material which occur as lenses. These beds, nowhere more than 10 feet thick, are separated by about 100 feet of soft clay and fine sand, and form a unit that is easily recognizable from a distance. Above the zone of clays there is a series composed largely of light-colored conglomerate and pebbly sandstone interbedded with thin layers of gray clay. These beds are well exposed at the head of Plum Canyon and attain a considerable thickness in the vicinity of Mint and Tick canyons (Pl. VI, *B*). The Saugus formation (upper Pliocene and Pleistocene) overlaps these beds, and in some places the distinction between the two is hard to make, owing to their lithologic similarity. As a rule, however, the conglomerate of the Mint Canyon is lighter colored and contains soft gray clay and fine sand, which are absent in the Saugus. The detritus forming both sets of beds appears to have had the same original source, though the sand and conglomerate of the Saugus formation may be reworked detritus from the Mint Canyon formation.

South of Santa Clara River, in the vicinity of Sand Canyon, the lithology is similar, though the clay and sand have a greenish color. Some beds of impure limestone are present in the shale. The soft clay and sand have a tendency to slide in this region, though north of the valley a badland type of topography is produced. Near the head of Placerita Canyon the Mint Canyon formation consists of buff sandstone interbedded with greenish soft sandstone and clay. Faulting along the north side of the San Gabriel Mountains has cut out the lower beds of the Mint Canyon formation and has caused the strata in this vicinity to be greatly broken.

A study of the lithologic conditions of the Mint Canyon formation indicates that it must have been deposited under subaerial conditions. The region at that time was probably a large valley surrounded by mountains composed largely of granitic and metamorphic rocks and similar to large valleys in the southern California of to-day. The beds of conglomerate and sandstone, all of which are more or less unsorted, are lenticular and appear to have been deposited as large alluvial fans. At different stages in the course of deposition and at different places lakes existed, as is shown by the presence of abundant fresh-water mollusks. The remains of land mammals found in the finer-grained beds probably accumulated in lacustrine beds also for in some places the vertebrate material was found associated with the fresh-water shells.

EVIDENCE OF AGE.

The Mint Canyon formation has yielded a small collection of vertebrate fossils, which are important not only in the determination of the age of the formation itself, but also in that they serve as a link in the problem of correlation between the terrestrial formations of the Great Basin and the marine coastal formations.

The vertebrate remains have been studied by Dr. Chester Stock, of the University of California, who reports on them as follows:

Unfortunately the vertebrate remains are too fragmentary to permit a satisfactory specific determination in any case. However, some of the genera can be distinguished. The fauna may be listed as follows:

Parahippus?
Merychippus or Protohippus sp.
Procamelus sp.
Mastodon remains, possibly belonging to Tetrabelodon.
Rabbit.
Very large tortoise.

The fauna seems to be somewhere near the upper Miocene stage. The horse remains are not directly comparable to anything found in the Barstow formation of the Mohave Desert. They represent a form larger than species from the Barstow but, so far as size is concerned, may still be included within the limits of the genus *Merychippus* as known from upper Miocene deposits. The camel skull referred to *Procamelus* is interesting because of positive indication of retention of the second as well as the third incisor teeth in the upper jaw. The early camels (Oligocene) possess a full complement of upper incisor teeth, while during the Miocene the first and second incisors are gradually lost. The Mint Canyon species shows, therefore, rather a primitive character in the retention of the second incisor. The mastodon remains are not generically determinable, for no complete teeth could be assembled from the fragments available. In the Tertiary of North America mastodon forms are not known earlier than middle Miocene. The tortoise is much larger than the species known from the Barstow beds. The specimen of *Parahippus*, a lower jaw collected in Mint Canyon by Mr. J. W. Mitchell, of Lang, Calif., is of the short-crowned type of horse. Horses with short-crowned teeth also occur in the Barstow formation, but here again suitable comparison with the latter can not be made because of the fragmentary nature of the material.

A few fresh-water gastropods also occur in the Mint Canyon formation, in places together with the vertebrate fossils. Dr. G. D. Hanna, of the California Academy of Sciences, was kind enough to examine the small fresh-water gastropods and identifies one of the forms as *Paludestrina imitator* Pilsbry. Dr. Hanna notes further that in one of the rock samples there was a fragment pertaining apparently to a larger species, which, however, can not be determined at present.

RELATION TO PETROLEUM.

The value of the Mint Canyon formation as an oil-bearing formation is slight. Its stratigraphic relation to the Modelo formation is not known, but in Haskell Canyon, north of Saugus, it underlies unconformably strata thought to belong to the Modelo. Owing to this relation there is little chance that oil may have migrated into the Mint Canyon formation from lower strata, in the manner that the oil has accumulated in the Pico and Saugus formations from the Modelo. A well lately drilled in the SE. ¼ sec. 25, T. 4 N., R. 15 W., has shown that the sands in this formation are barren.

MODELO FORMATION (UPPER MIOCENE).

GENERAL FEATURES.

The Modelo formation, as exposed in the region covered by the map, may be divided into two main areas, each of which is a unit. The larger area is that forming the mountains north of Santa Clara River between Sespe and Piru creeks and the greater part of the Santa Susana Mountains (see Pl. IV, *B*), extending westward along the top of Oak Ridge and South Mountain. The other area lies in the syncline between the Simi Hills and the Santa Monica Mountains. A very small outcrop of shale that has been correlated with the Modelo occurs just west of the Tierra Rejada.

All these areas are characterized by laminated hard siliceous shale, in part diatomaceous. As these types of shale are closely associated with the occurrence of oil in California their presence in this region is of considerable economic importance.

In general lithology the Modelo is fairly distinctive, and its characteristic features are usually similar in the different parts of the region, so that it can easily be separated from the other formations. It is composed primarily of shale, within which are several large lenses of coarse sandstone, in many places conglomeratic. In the type section of the Modelo, which lies north of Santa Clara Valley in the vicinity of Modelo Canyon and which forms a part of the large northern exposure of the formation, the strata comprise two shale and three sandstone members, the whole being about equally divided as to sandstone and shale. Though these lithologic divisions are prominent in some places, in others they are rather difficult to distinguish, owing to intergradations between them. This similarity is especially evident at the head of Reasoner Canyon and on the west side of the Santa Susana Mountains, where the sandstone apparently grades into the shale. South of the Simi Hills and in the Santa Monica Mountains the Modelo formation is composed mainly of shale, within which are lenses of sandstone, though not of as great thickness or extent as those occurring in the northern area.

The maximum thicknesses of the several lithologic divisions in the Modelo as distinguished on the geologic map (Pl. I, in pocket) are given below. The total of these thicknesses, however, is considerably greater than the actual thickness of the Modelo, for the sandstone in part replaces the shale and vice versa.

Generalized section of Modelo formation north of Santa Clara River.

	Feet.
Clay and diatomaceous shale, locally impregnated with oil	1,200
Brown and buff sandstone as a lens; locally oil bearing	1,500
Gray clay shale, partly diatomaceous; locally impregnated with oil	500
Brown and buff coarse to medium grained sandstone as a lens; locally oil stained	2,500
Clay and diatomaceous shale with thin interbeds of sandstone; locally impregnated with oil	1,500
Massive gray to buff sandstone as a lens; locally oil bearing	4,000
Dark-gray clay, in part diatomaceous, and shale with limy lenses and nodules; locally impregnated with oil	1,100

Generalized section of Modelo formation south of Santa Clara River.

	Feet.
Coarse brown and tan well-bedded sandstone, in places nodular; cut out in eastern part of Santa Susana Mountains by Santa Susana fault	3,000
Clay and diatomaceous shale, somewhat sandy at top	1,700
Coarse brown to white hard sandstone; locally impregnated with oil	2,500
Diatomaceous shale, in places cherty, with minor intervals of clay shale	1,500

The shale consists of a great variety of types. In the Los Angeles-Ventura region may be found examples of typical diatomaceous earth, siliceous shale, argillaceous shale, chert, limestone, tuff, and sandstone,[41] all of which may contain more or less bitumen. In the area mapped the shale of the Modelo is composed mainly of an argillaceous variety containing a considerable percentage of organic matter. On fresh surfaces its color is a dark bluish gray to black, but it weathers a light gray, forming a buff or brownish soil. In this shale there are zones or layers of light-yellowish chert which are very hard and break down into small rectangular fragments. This chert is a characteristic feature of the Modelo and equivalent rocks wherever found in California. Calcareous yellow concretions and thin layers that occur commonly in the clay shale are also very distinctive. The lower shale, prevalent south of Santa Clara River, is of the characteristic soft diatomaceous variety, having a white, cream, or light-pinkish color. Chert and limestone layers are also present. At some localities, as on Oak Ridge and South Mountain, large areas of this shale have been burned and even fused, thus ac-

[41] For a detailed discussion of the lithology and origin of shales and cherts similar to those of the Modelo, see Davis, E. F., The radiolarian cherts of the Franciscan group: California Univ. Dept. Geology Bull., vol. 11, pp. 278–304, 1918.

quiring a deep-red color. The only fossils except foraminifers and diatoms known to occur in the shale are a few imperfectly preserved casts of what are probably *Pecten* cf. *P. pedroanus* Trask and *Tellina* sp.

The sandstone is rather coarse-grained, in places conglomeratic. Clay shale in thin layers may be interbedded with it. These layers become more numerous where the sandstone grades into the shale. In color the sandstone is ordinarily brown, tan, buff, or white, though tan is the prevailing shade. In most places it is well indurated, so that it weathers into prominent ridges and peaks, forming a rough country, which is in marked contrast to the shale areas. As a rule it supports a heavy growth of brush, whereas the shale is largely covered with wild oats and grass.

In the northeastern part of San Fernando Valley the Modelo contains comparatively little shale, being composed largely of conglomerate and sandstone, though shale beds enter the section toward its top. Basalt flows occur near the base of the formation in some areas.

DISTRIBUTION AND LITHOLOGY.

SANTA CLARA VALLEY.

North of Santa Clara River.—In the area of Modelo lying east of Sespe Creek the strata may be separated into four lithologic divisions. As a whole the Modelo is essentially a shale with large lenses of coarse sandstone. (See Pl. VII, *B*.) Distinct contacts between the shale and sandstone are difficult to discover, for the sandstone may include beds of shale as much as several hundred feet thick, and on the other hand the shale may even grade into sandstone, as it does north of Reasoner Canyon. A typical section, somewhat generalized, taken in Piru Canyon is as follows:

Section of Modelo formation in Piru Canyon north of Holser Canyon.

	Feet.
Shale with fine white sands and yellowish siliceous concretions and bands. Much of the shale is of a chocolate-brown color with yellow mottlings. Toward the top the shale is harder and uniformly finely laminated, with yellow concretionary bands	400
Sandstone, light colored, coarse grained, and interbedded with shale at the base; loose yellowish and tan sandstone above	200–300
Shale, hard, siliceous, thin bedded, brownish	200–250
Sandstone, coarse, white, massive, with thin shale interbeds; exposed along axis of anticline	300
	1,100–1,250

At this point the divisions are comparatively thin. The lower sandstone is thicker than any other one member; north and east of Hopper Mountain it measures more than 4,000 feet. This sandstone thins very rapidly to the south, however, and disappears entirely on Oat Mountain, a distance of about 7 miles southward along the trace of the outcrop.

The lower shale is well exposed on Little Sespe Creek and to the north, where its thickness is about 1,100 feet. It lies apparently conformably on the Vaqueros, which here is a shaly sandstone containing grayish nodules in which are typical Vaqueros fossils. The apparent conformity of the Vaqueros and Modelo here and on Oak Ridge presents a peculiar situation, inasmuch as everywhere south of Oak Ridge the Topanga formation (middle Miocene) intervenes between them. Two explanations for this anomaly can be advanced. The Modelo formation in the Santa Clara area may include the Topanga formation, the sandstones of which may be represented by shales in the basal part of the Modelo formation, or, on the other hand, the Topanga formation may never have been deposited in that area, the Modelo shales having been laid down by a transgressing sea. The latter explanation seems the more plausible, and it is thought that an unconformity will at some time be located.

The Modelo is rather difficult to distinguish from the Vaqueros, and it has been separated mainly on the basis of lithology. The more sandy beds containing fossils have been mapped as the older formation. The Modelo includes at the base blackish-gray and bluish-gray shale containing numerous calcareous concretions which, though dark gray on a fresh surface, weather yellow or orange. Above this are blue-gray thin-bedded fine-grained sandstone and shale, followed by the massive lower sandstone. In Pole Canyon the shale that elsewhere lies above the lower sandstone comes into contact with the shale below, as the sandstone is absent. The shale here lies stratigraphically above the black shale with yellow concretions. This upper shale is thin bedded and is nearly black on a fresh surface, but weathers blue gray or buff. It contains a considerable amount of organic material and when struck with a hammer gives off a strong fetid odor. Some beds are more or less siliceous or cherty and weather out on the surface into small oblong blocks of a cream or rusty color. The shale lying above the lower sandstone can be traced eastward in a narrow band to Oil Ridge, where it forms the crest. Continuing northward it becomes more sandy and its limits are not easily made out. At the head of Reasoner Canyon the shale passes into a fine-grained sandstone with thin shale layers. The uppermost part of the shale is exposed along the north side of the river in Piru Canyon. In Tom's Canyon, east of Hutton

Peak, where it is shown to advantage, it consists of about 250 feet of very thinly bedded blue-black shale in which a few thin beds of fine-grained buff sandstone are interstratified. Some of the beds are calcareous and weather to an orange color, but as a whole the black shale weathers a dark bluish gray. Above this series is softer black shale containing yellow calcareous beds. These rocks weather more readily and form the low-lying hills and flats in this region.

The beds of sandstone in the Modelo form conspicuous bluffs and sharp ridges (Pl. VII, *B*). Although they are lenticular, they are very helpful in working out the many complicated folds that involve the Modelo strata. The lowest sandstone member is exposed in a widening band extending from Oat Mountain northward beyond Hopper Mountain. North of Hopper Mountain the sandstone forms the top of a prominent escarpment, east of which it covers a large area. These massive sandstones are a very noticeable feature in the area lying between the Tar Creek country and Hopper and Piru creeks, as they may be seen for many miles. The other sandstones are more or less of this same type but vary in lithology, containing a greater number of shale beds in one place than in another. Here and there, as near Modelo Canyon, several hundred feet of shale may be present between the sandstones. In the vicinity of the Hopper ranch the Modelo sandstones are well developed. The lower 150 feet of sandstone is somewhat thinly bedded but contains two hard massive beds. There is also a section of about 50 feet of blue-gray shale with thin limestone beds, above which comes the massive light-buff sandstone. Some of the beds are nearly white; others are dark brown. In texture the sandstone ranges from medium to coarse.

A second sandstone is exposed along the west side of Piru Creek north of Blanchard Canyon. This outcrop resembles the other sandstone exposures, but the rock becomes finer grained toward the north and appears to merge with the shale above. The change is rather gradual, as the shale interfingers with the massive sandstone beds. These become prominent north of Reasoner Canyon and extend eastward north of Devil Canyon, so that the shale and sandstone divisions can not be distinguished from one another with any degree of certainty.

East of Devil Canyon the Modelo consists of thin-bedded fine-grained sandstone interstratified with which are a few thin beds of diatomaceous shale. A few massive beds of sandstone are present, but these are lenticular. One bed about 25 feet thick on the north side of Devil Canyon is impregnated with petroleum. In general, toward the east the sandstone becomes less massive and finer grained. In Santa Felicia Canyon the Modelo includes in its lower part fine-grained sandstone interbedded with brown coarse-grained and gravelly beds. The finer-grained material is colored brown, gray, buff, and steel-gray. As a whole, the beds weather easily, giving rise to rounded grassy slopes. The upper part is, in general, similar but of a lighter color and contains no coarse beds. Calcareous thin-bedded shaly strata are common.

In Modelo Canyon, where the lower sandstone is characteristically exposed, it is of a cream to yellowish-buff color and is interbedded with thin layers of a muddy, fine-grained sandstone. A large part of the sandstone is coarse grained and not well sorted, some individual grains reaching a quarter of an inch in diameter. The larger grains or pebbles are darker than the matrix and are derived from basic igneous rocks. The upper 75 or 100 feet of sandstone is darkened by petroleum, which has saturated these beds. This part of the sandstone member also contains numerous nodules of a hard sandy nature, many of which are a foot or more in diameter and which on weathering out give the sandstone a pitted appearance.

The upper sandstone crops out in a synclinal area extending from a locality immediately east of Oak Mountain past Hutton Peak to Piru Creek, whence it continues northward as a narrow strip to Santa Felicia Creek. North of Fillmore and east of Pole Canyon the sandstone forms a small shallow syncline. At the mouth of Hopper Canyon it connects with the larger body near Nigger Canyon. Just east of Fillmore this sandstone is medium grained and rather massive and has a characteristic chocolate color, due to its impregnation by petroleum. Where it is not discolored the sandstone is almost white, with rusty stains through it. Above this sandstone there are soft fine-grained sandstone and clay. The relation between this sandstone and the shale immediately to the north is not exactly clear. It has been correlated with the upper sandstone on the basis of lithology, as it is remarkably similar in character to the upper sandstone exposed at the mouth of Hopper Canyon, but under normal conditions the structure east of Fillmore would indicate that this sandstone is below the shale. It is very likely that the fractured zone of the San Cayetano fault separates the two, as the strata are greatly broken. In Pole Canyon, where the upper sandstone is well exposed, the strata are hard, massive-bedded, medium to coarse grained, and yellowish brown, and are considerably harder than the beds exposed at the mouth of Hopper Canyon.

South of Santa Clara River.—The main mass of the Santa Susana Mountains and the east end of Oak Ridge consist of rocks belonging to the Modelo formation. (See Pl. IV, *B*.) As a rule these rocks are not folded as complexly as those north of Santa Clara River, though along the south side of the mountains the thrust fault has disturbed and cut out some of the strata. Two beds of sandstone and two of shale are present here, though the upper shale grades into sandstone at the west end of the Santa Susana Mountains. The lower shale is confined to Oak Ridge and the area south of the Santa Susana fault, but the two sandstones and the upper shale form the Santa Susana Mountains, extending westward on Oak Ridge as far as Torrey Canyon. All the sandstone and shale strata of the Modelo lying above what is designated in this report the lower shale were mapped by Eldridge as Vaqueros. These beds are not of Vaqueros age but belong to the same series of beds as occur in the type section of the Modelo north of Santa Clara River, and they are here included in the Modelo.

The lower shale member, which has a maximum thickness of 1,500 feet, extends unbrokenly from the south end of South Mountain along Oak Ridge (see Pl. XIV, *A*, p. 164), following the crest for the entire distance. Near Sulphur Canyon it arches over the Oak Ridge anticline and reaches the foot of the hills. In its east end it broadens out as a result of folding. The shale here rests conformably above the Vaqueros formation, but at the top, the Pico (lower Pliocene) and Saugus (upper Pliocene and Pleistocene) formations overlie the Modelo with marked unconformity. Lithologically this shale is more like the typical bituminous or "Monterey" shale than the upper shale member of this formation. It is well exposed on Oak Ridge and consists mainly of organic shale interbedded with a few thin strata of sandstone. Some is of a soft chalky variety of white to pinkish color; other parts are of a hard, siliceous type. Gray clay shale is also present but is not so conspicuous as the diatomaceous shale. The organic shales have been burned locally, probably having caught fire at some remote time through spontaneous combustion. In some places the strata have merely been discolored to a bright red, but in others, they have been fused into an obsidian-like mass. The shale ordinarily is soft, powdery, and flaky, though true bedding planes within it are rather indistinct. It absorbs moisture very readily, and beds of this character are used to some extent as a substitute for fuller's earth. Limestone bands or lenses are commonly associated with all varieties of the shale.

The sandstone strata that almost invariably accompany the shale form a minor proportion of the series. These beds, few of which are more than 5 feet thick, are of a light-yellow to lemon color. They are coarse-grained, some of the grains being a quarter of an inch in diameter, and are for the most part rather unconsolidated and porous. Considerable gypsum is present in the shale, and near the head of Grimes Canyon, in the SW. ¼ sec. 8, T. 3 N., R. 19 W., gypsum has been mined from the broken shale. It is of poor grade and essentially a gypsite. In the eastern part of Oak Ridge the shale is more cherty and less chalky. On the ridge south of Happy

Camp Canyon the shale is largely of the chalky type, with limestone, sandstone, and tuffaceous strata interbedded. The shale here lies unconformably on the Vaqueros, overlapping both the Vaqueros and the Sespe formation east of Tapo Canyon. Near the base the Modelo is sandy but of a light-brown punky nature and grades into the chalky variety of shale. The upper part of the section at the top of the ridge south of Happy Camp Canyon is capped by the hard white siliceous or cherty type. The lower soft, chalky shale thickens toward the west, comprising at least 600 feet of beds. Near Tapo Canyon the soft shale below the siliceous strata is less than 300 feet thick. Part of this shale has been burned and in places fused, as on Oak Ridge. This same type of Modelo rock extends eastward to Aliso Canyon, where it forms part of the strata in the Happy Camp syncline. On the north side of this fold the Modelo is present at the head of Dry Canyon. The Saugus strata, overlying the shale unconformably, almost entirely overlap it in places.

The upper shale of the Modelo differs from the lower strata in not being soft and chalky. It is largely of the clay type but includes a considerable proportion of the hard, siliceous diatomaceous rock. The siliceous shale is apparently more prevalent in the lower part, grading toward the top into the clay variety. The clay shale passes, in turn, into the sandstone member above. This shale crops out principally along the top and south side of the Santa Susana Mountains, north of or above the thrust fault that follows the foot of the mountains. North of the mountains, the shale is exposed along the axis of the Pico anticline (see Pl. XVII, *A*, p. 178), in Dewitt Canyon and in a larger area that extends from Towsley Canyon to East Canyon. This shale member is about 1,700 feet thick, but varies on account of faulting along the base of its exposure. The lower part consists mainly of the laminated hard diatomaceous type, which is similar to that north of Santa Clara River. A few bands of yellowish-brown medium to coarse-grained sandstone are in places interbedded with the shale and locally attain a considerable thickness as lenses. Interbedded with the siliceous shale is a softer dark-gray or chocolate-colored sandy clay shale containing remains of Foraminifera. Beds of this kind of shale become more numerous toward the top of the formation and in the upper 300 feet they comprise practically all the strata. In the shale are thin beds of a flaky calcareous rock that is full of organic material, oil impregnated, and colored a dark chocolate-brown. At the west end of the Santa Susana Mountains this shale becomes more sandy.

The sandstone of the Modelo exposed on the north side of the Santa Susana Mountains is remarkably similar in lithology to the

Pico formation, and some difficulty was experienced in making a division between the two. As a whole the Modelo consists mainly of massive beds of medium-grained brown to buff sandstone, though beds of nearly pure white occur, as on Sand Rock Peak. Several prominent zones or beds of conglomerate are present, and some of these may be traced for several miles. The conglomerate that is so well exposed at the first sharp bend above the mouth of Towsley Canyon forms a reef-like bed which may be followed from Wiley Canyon west to Salt Canyon. The strata west of the Santa Susana Mountains are of a somewhat lighter color, and in Torrey, Chaffee, and Eureka canyons the beds are practically identical with those exposed in Modelo Canyon, north of Santa Clara River.

In Towsley Canyon the Modelo sandstones are well shown along the stream bed. At the axis of the Pico anticline the shale member lying below the sandstone crops out. It is composed of lavender-gray shale, in places stained yellow from sulphur and bearing yellowish limy concretions. Above this there is a well-bedded series of bluish-gray medium-grained compact sandstone interbedded with gray sandy shale. Above this series are brown massive concretionary conglomeratic sandstone and conglomerate about 300 feet thick. These beds are very hard and have produced a very narrow opening in Towsley Canyon and also constitute a reef-like bed in this vicinity. The boulders in the conglomerate are derived mainly from granitic rocks and are subangular. These beds are succeeded by somewhat softer tan sandstone with interbedded finer soft sandstone and sandy shale. The beds vary in detail from place to place, but the above description gives a general idea of the strata north of the Pico anticline. South of the anticline the beds form a large syncline and are in general similar but perhaps have a more massive aspect and form a rougher topography. They are dark brown to buff and very commonly nodular. The cavities left when the nodules fall out give the rock a cavernous appearance. Narrow, steep-sided canyons, with waterfalls in their courses, are a characteristic of the surface underlain by these rocks and a dense and almost impenetrable growth of brush thrives on the soil they produce.

In the vicinity of Torrey, Eureka, and Tapo canyons the sandstones are rather massive, though in the aggregate well bedded. Like the sandstones of Modelo Canyon, they are nodular and in places are coarse grained, containing dark-colored pebbles derived from a basic igneous rock. A considerable proportion of the sandstone and shale beds, especially on the north side of Eureka Canyon and in Tapo Canyon, are oil stained, and oil seeps are common in the vicinity of Tapo Canyon.

To the east, in the vicinity of Tapo Canyon, the lower sandstone beds of the Modelo, about 150 feet thick, crop out beneath the shale.

They are composed of hard calcareous brown conglomeratic sandstone at the base, followed by light-gray fine-grained quartzose thin-bedded sandstone stained in part a rusty color, containing poorly preserved indeterminate fossils. At the top is a light tan-brown fine-grained sandstone containing calcareous concretions and in places numerous whale bones.

SOUTH OF SIMI HILLS.

South of the Simi Hills a series of rocks is exposed which have been correlated with the Modelo of Santa Clara Valley on the basis of their lithology, stratigraphic position, and fauna. These beds form a synclinorium in what is known as the Calabasas region, which lies south of the Simi Hills and includes a large part of the north side of the Santa Monica Mountains. The most westerly outcrop of the Modelo in this synclinorium is immediately north of Conejo Valley and extends eastward, gradually widening, to San Fernando Valley, where, except along the north side of the Santa Monica Mountains, it is covered by the Pico formation and the valley alluvium. It is probably connected with the Modelo of the Santa Susana Mountains under the alluvium of San Fernando Valley. In stratigraphic position it rests unconformably above the Sespe (Oligocene?), Vaqueros, and Topanga formations. Its lithology closely resembles that in the type section of the Modelo of Santa Clara Valley in that it consists for the most part of siliceous and clay shale in which are interbedded laminated fine-grained sandstone in layers and coarse-grained sandstone in lenses of considerable magnitude.

At the base of the Modelo formation there is usually a bed of sandstone, in places fossiliferous and conglomeratic, though the shale may rest directly upon the underlying formation. The conditions of deposition are best disclosed in the Santa Monica Mountains, where the unconformable relations of the Modelo with the older rocks are strongly brought out. The unconformable contact of the Modelo and Topanga formations is clearly exposed in a cut on the new Topanga Canyon road at the bend about 300 feet east of the Magnesia Mineral Springs, which are south of the main divide. At this point the base of the Modelo as well as the beds it rests upon are conglomeratic. The unconformable relation between the two formations is also seen in the vicinity of Dry Canyon directly south of Calabasas, where a fossiliferous sandstone that follows the main ridge to Calabasas Peak is half a mile to a mile distant from the Modelo contact, whereas south of the Alba Villa ranch, in the NE. ¼ sec. 31, T. 1 N., R. 16 W., the Modelo overlaps this same fossiliferous bed and in turn the probable Vaqueros and Sespe onto the schist.

The shale that forms the greater part of the Modelo here and occupies the central part of the Calabasas synclinorium is of the cream-colored, platy, siliceous variety, locally highly folded and commonly stained a rusty color. Interbedded with it is a large amount of purplish-brown to gray thin-bedded sandy shale. The diatomaceous shale and thin-bedded sandy shale occupy zones several hundred feet thick and include massive sandstone lenses, two of which are about 400 to 500 feet thick. These lenses are especially well developed in the Santa Monica Mountains on the south side of San Fernando Valley. The lower one may be traced from a point near the edge of San Fernando Valley south of the station of Reseda, where it is overlapped by the Pico formation westward over the divide nearly to Dry Canyon. The upper one follows closely the edge of the valley and has about the same length. The boundaries of these sandstone lenses as mapped are more or less generalized, for they grade both laterally and vertically into the more shaly parts of the Modelo. Lithologically both of the lenses are very similar, consisting mainly of a coarse brownish-tan sandstone in which conglomerate is commonly present. Many of the beds contain round calcareous concretions, which weather out of the softer sandstone and give it a pitted appearance. The vegetation on the sandstone is a dense chaparral, in contrast with that on the shaly part of the Modelo, which supports a growth of grass, burr sage, and wild walnut trees. The walnuts appear to grow only in soil formed from Modelo and Pico shales.

WEST OF THE TIERRA REJADA.

The Modelo shale and sandstone crop out in a narrow belt extending westward a few miles from the Tierra Rejada. The strata are composed of clay and diatomaceous whitish-gray shales which grade up from a series of tuff, sandstone, and conglomerate about 100 feet thick. These beds are rather closely associated with the igneous rocks in this vicinity. A few sandstone beds of a light color are also interstratified with the shale.

NORTHEASTERN PART OF SAN FERNANDO VALLEY.

East of the town of Fernando the Modelo formation rests directly upon the crystalline rocks of the basement complex. This contact is excellently exposed on the north side of the Verdugo Hills directly south of Sunland and in the isolated hill near Pacoima. The basal beds of the Modelo are composed of conglomerate, which is usually coarse and commonly contains basalt flows. This is followed by brown well-bedded coarse sandstone grading upward into fine-grained sandstone and shale. Some of the shale is diatomaceous. A few thin beds of an impure gray limestone here and there occur in the shale.

At the head of Little Tujunga Canyon and on the divide between Gold Canyon and Tujunga Canyon occur blocks of conglomerate and basalt which are correlated on lithologic grounds with the Modelo formation. These rocks have been greatly crushed, so that no definite lines between the kinds of rock are decipherable.

EVIDENCE OF AGE.

As no diagnostic fossils have been found in the Modelo formation at the type locality in Santa Clara Valley determination of its age must be based mainly upon its stratigraphic position with reference to other formations whose age is known. The Modelo shales are traceable southward to the Santa Monica Mountains, where, at the head of Sepulveda Creek, in the Santa Monica quadrangle, 1 mile east of the Calabasas quadrangle, the basal sands of this formation contain a meager fauna characterized by *Pecten raymondi* Clark, an upper Miocene species not recognized in strata older than the San Pablo formation (upper Miocene) of the San Francisco Bay region. Wherever the Modelo is exposed in the Santa Monica Mountains it rests unconformably upon the Topanga formation, which is considered to be of middle Miocene age and younger than the Vaqueros formation (lower Miocene). This relation is also seen at the head of Aliso Canyon (west), northwest of San Fernando Valley. In the area north of Saugus beds that are tentatively considered to be Modelo rest unconformably upon the Mint Canyon formation, which from its vertebrate fauna is probably of upper Miocene age. From this evidence, which is not conclusive but strongly suggestive, the Modelo formation should be considered to represent the upper part of the Miocene.

RELATION TO PETROLEUM.

The Modelo formation, which consists in large part of diatomaceous and foraminiferal shales, is thought to be the source of the oil that is now found in the sandstone of the Modelo and in the overlying Miocene and Pliocene formations. The petroleum, having formed from the minute organisms that are abundant in the shale, has collected, where found in commercial quantity, in the more porous strata. It has also collected in the sands interbedded with the shales themselves, or in the overlying Miocene and Pliocene coarse-grained strata. A considerable part of the more sandy shale of the Modelo, which also contains numerous remains of foraminifers and diatoms, is commonly stained a chocolate color by the petroleum and gives off an odor of crude oil.

The Modelo shales and sandstones, however, are not everywhere petroliferous, for south of the Santa Susana fault, in the Calabasas and Santa Susana quadrangles, no oil appears to be present either as seeps or in impregnated sands in these or younger strata. The only evidence of hydrocarbons in strata of Miocene or Pliocene age is in the areas of burned shale on Oak Ridge and South Mountain and in Las Virgenes Canyon, in the Calabasas region. The lowermost shale of the Modelo formation is commonly oil-stained in the Santa Monica Mountains.

In the Santa Clara Valley and Santa Susana Mountain area the greater part of the shale and fine-grained sandstone show traces of oil, and where the structure is favorable for its accumulation considerable deposits have formed, such as occur along the Modelo and Pico anticlines. The Pico and Saugus formations offer exceptionally good facilities for the retention of oil, as they are composed mainly of sandstone and conglomerate. In some localities near Newhall and east of Piru Creek these formations rest unconformably upon the Modelo shales. The petroleum given off from the Modelo shales has impregnated the overlying sandstones at certain horizons, where under favorable structural conditions they have given rise to deposits of commercial importance. Where sandstones are not in contact with Modelo diatomaceous and foraminiferal shale they are barren.

MODELO (?) FORMATION OF UPPER SANTA CLARA VALLEY.

GENERAL FEATURES.

The occurrence in the upper part of the Santa Clara Valley of strata thought to belong to the Modelo formation is extremely interesting in that it brings the marine sediments into touch with the nonmarine strata containing a vertebrate fauna correlated with the Barstow fauna, from the Mohave Desert or the Great Basin province. In general appearance these marine strata resemble phases of the Modelo formation farther west at the type locality. They are composed primarily of brown sandstone, sandy shale, diatomaceous shale, and local beds of tuff. Their relation to the Modelo formation near Modelo Canyon is not yet known, but it is thought that the Modelo (?) east of Saugus is probably to be correlated with the upper part of Modelo of the type section. Further areal geologic work north of the Camulos quadrangle should bring out the relations of these areas.

DISTRIBUTION AND LITHOLOGY.

The strata here mapped as Modelo (?) extend in a relatively narrow zone from Castac Valley in a southwesterly direction to Deadman Canyon, where they crop out from beneath the Saugus formation. The mapping of these strata has not been carried beyond the northern limits of the Santa Susana quadrangle, but it is likely that they may, in whole or in part, connect with the beds west of Loma

Verde Mountain that comprise a part of the type section of the Modelo. They rest unconformably upon the colored clay and brown coarse sandstone and conglomerate of the Mint Canyon formation (upper Miocene), and the discordance between the two formations is particularly noticeable in Haskell Canyon. (See Pl. VII, *A*.) The Modelo (?) at this place consists of about 400 to 1,000 feet of well-bedded yellowish-brown to buff sandstone interbedded with gray shale and is essentially a sandy formation. It is massive in the upper part but at the base becomes a light-gray coarse conglomeratic sandstone. Near the lower part there is a zone of very light gray tuff and a few thin beds of diatomaceous shale. One bed of sandstone, a few feet above this tuff, is fossiliferous. The fossils, though not very abundant in number and in species, are of upper Miocene age and can be compared with forms occurring in the San Pablo formation (upper Miocene) of middle California.

West of Haskell Canyon the strata consist mainly of fine-grained shaly and usually well-bedded sandstone. It weathers readily, and good outcrops are not common. Within it are lenses of calcareous shale and layers of hard brown calcareous sandstone which at Dry Canyon, immediately east of the Los Angeles aqueduct reservoir, are very fossiliferous. Massive brownish-buff concretionary beds are also present about 150 feet above the fossiliferous beds, and at Dry Canyon none of these strata yield fossils.

Shale resembling the Modelo in other parts of the area mapped crops out in a relatively narrow zone that extends along a ridge lying immediately north of the divide between Placerita and Sand canyons. It has a prevailing light-gray to yellowish-white color and consists of a clayey diatomaceous shale, together with some clay shale and interbeds of a light-tan sandstone. A few beds contain poor casts of fossils. This shale lies unconformably above the Mint Canyon formation and unconformably below the Pico.

EVIDENCE OF AGE.

At the present time it is difficult to determine definitely the age of this series of strata, as the paleontologic collections are more or less incomplete, the preservation of the shells is not particularly good, and many of the gastropods that should be of determinative value are probably new species whose worth as horizon markers is not yet known. The species that have been determined by Dr. Bruce L. Clark, of the University of California, are as follows:

Amphyssa n. sp.
Ostrea titan Conrad.
Pecten crassicardo Conrad.
Pecten raymondi Clark.

These forms were found on the hill west of the forks in Haskell Canyon in the NE. ¼ NW. ¼ sec. 36, T. 5 N., R. 16 W., and directly east of the Los Angeles Aqueduct reservoir in Dry Canyon, in the SW. ¼ SE. ¼ sec. 26, T. 5 N., R. 16 W. This assemblage of fossils has tentatively been correlated by Doctor Clark with the upper part of the San Pablo formation (upper Miocene) of middle California. *Pecten raymondi* Clark is a species common in the basal sandstone beds of the Modelo formation in the Santa Monica Mountains.

RELATION TO PETROLEUM.

Within the area mapped the Modelo (?) has given evidence that it neither contains nor has generated oil in commercial quantity, although it contains some diatomaceous shale. On Castac Creek a little north of the Santa Susana quadrangle, a small amount of oil was obtained from a number of holes that were drilled in the Modelo (?), but it is thought that the oil may have come from older oil-bearing shale. None of the wells were commercially productive and all have been abandoned.

The Saugus strata on the ridge west of the Los Angeles Aqueduct dam in Dry Canyon show oil saturation at their base. This oil probably comes from the Modelo (?), so the formation can not be absolutely disregarded when the oil-yielding possibilities of the region are being considered.

PLIOCENE SERIES.

FERNANDO GROUP.

The term Fernando as hitherto used in southern California included the rocks of Pliocene and Pleistocene age that are here divided into two formations—the Pico and Saugus. As originally defined by Homer Hamlin in unpublished manuscript, the Fernando included " the beds above the siliceous shale skirting the sides of the San Fernando Valley, Los Angeles County—the general equivalents of all post-Modelo and pre-Saugus beds in the Santa Clara province." [42] Saugus, however, as used in this quotation, was applied to the Pleistocene terrace deposits and not to the upper Pliocene deposits that Hershey in 1902 named the Saugus " division." The latter deposits are the Saugus formation of this report. In remapping this district the writer has found it necessary to divide the Pliocene deposits (all heretofore included in the Fernando formation) into two formations. The lower formation is here named Pico formation, and Hershey's name Saugus is adopted for the upper one.

[42] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California: U. S. Geol. Survey Bull. 309, p. 22, 1907.

Both formations are present at the Fernando type locality on the north side of San Fernando Valley. Recent work has proved that all of the Fernando group as mapped by the writer in Simi Valley [43] belongs to the Saugus formation as here described.

The Pico formation was deposited entirely under marine conditions, which produced a variety of sediments according to the type of strand line. The beds range from the massive conglomerate laid down near the San Gabriel Mountains to the pure diatomaceous shale that occurs in San Fernando Valley. A large proportion of the Pico formation consists of gray and rusty-colored fine thin-bedded sandstone. Rock of this type is particularly well exposed near Pico Canyon. Fossils, as a rule, are not uncommon in the Pico and indicate lower Pliocene age.

The upper or Saugus formation, constituting the upper part of the Pliocene series and in places in the Santa Clara Valley region extending into the Pleistocene, is well exposed near the town of Saugus. This formation, which in most places unconformably overlies the Pico formation, is made up largely of cross-bedded sandstone and gravel, which in the main are of terrestrial origin, though they grade toward the west into marine strata. Marine fossils found in these beds contain many recent forms and have been referred to the upper Pliocene and lower Pleistocene.

PICO FORMATION (LOWER PLIOCENE).

NAME AND DEFINITION.

The lower formation of the Fernando group in this region is here named Pico formation, from its exposures in the vicinity of Pico Canyon. It is of marine origin and consists mainly of both fine and coarse grained sandstones with a few interbedded strata of conglomerate. It rests unconformably on the Modelo formation and is unconformably overlain by the Saugus formation. In the vicinity of Pico Canyon, where a good section of the formation is exposed (see Pl. IV, *B*, p. 30), the lower sandstone is separated from the underlying Modelo formation with considerable difficulty, owing to their lithologic similarity. At other places the unconformity between the two is marked, and the separation is made largely on that basis. A characteristic feature of the Pico formation is the presence of limonitic concretions in the fine-grained bluish-gray sandstone. The fauna in the Pico, from which large collections have been made at Elsmere Canyon, indicates that it is of lower Pliocene age.

[43] Kew, W. S. W., Structure and oil resources of the Simi Valley, southern California: U. S. Geol. Survey Bull. 691, pp. 323–347, 1919.

GENERAL FEATURES.

As exposed in the area covered by this report (Pl. I, in pocket), the Pico formation occurs in three more or less separate areas or basins. The largest of these areas includes the exposures in the Santa Clara Valley and Fernando Pass region, where the formation is well exposed in the vicinity of Pico Canyon; another area lies on the south side of Oak Ridge and South Mountain; and the third is in San Fernando Valley. The strata in all three areas have in general the same lithology, being composed of light-colored conglomerate, coarse sandstone, soft bluish-gray shaly sand, clay shale, and diatomaceous shale. The lower part of the formation in the Santa Clara Valley region and on the south side of the San Gabriel Mountains is usually made up of conglomerate and sandstone with minor amounts of shale and fine sandstone above. This coarser material, which in some respects closely resembles the Modelo sandstone and conglomerate, is of a light buff or brown color and includes some white quartzitic sandstone. These beds weather out boldly, in marked contrast to the softer rocks. In the vicinity of Elsmere Canyon and Piru Canyon certain zones are saturated with petroleum, which gives them a dark chocolate color. The type of material varies considerably along the strike, and in the area south of South Mountain the fine sandstone rests directly upon Modelo shale. This variation is probably caused by the existence of varying conditions along the strand line at the time the beds were being deposited. In San Fernando Valley, especially in the southern and western parts, diatomaceous shale forms a prominent part of the formation.

DISTRIBUTION AND LITHOLOGY.

SANTA CLARA VALLEY AND FERNANDO PASS.

The easternmost exposure of the Pico formation in this area is a small more or less isolated synclinal remnant that lies south of Humphreys station and west of Sand Canyon. Here the Pico formation is plainly seen to rest with a marked unconformity above the Modelo (?) and Mint Canyon formations and below the Saugus formation. A very small outcrop is present in the NW. ¼ sec. 33 and the NE. ¼ sec. 32, T. 4 N., R. 15 W. Both of these areas consist almost entirely of fine-grained material. At the base of the eastern area there is 10 to 15 feet of light-buff to rusty-colored fine-grained soft sandstone in which are calcareous concretions containing fossils similar to those found in the lowest beds of Elsmere Canyon. This is followed by 200 to 300 feet of fine-grained soft clayey sand of a greenish tinge, which weathers to a light tan. Small limonitic concretions are a characteristic feature in the clayey sandstone.

The largest area extends from San Gabriel Mountains, where the Pico rests normally upon the granite and metamorphic rocks, westward across Fernando Pass and thence as a relatively narrow band along the north flank of Santa Susana Mountains to Santa Clara River. North of the river the Pico occupies an area lying almost wholly east of Piru Creek and extending north for a short distance beyond the edge of the Camulos quadrangle. Its eastern limit is not well defined, as in the area north of San Martinez Chiquito Canyon it was impossible, within the time available, to separate the Pico from the Saugus formation, owing to their similarity in lithology.

At Elsmere Canyon and Fernando Pass the beds rest normally upon the basement complex. A basal conglomerate about 10 feet thick in which is found a lower Pliocene fauna characteristic of the Pico formation is composed of well-worn boulders derived from granitic and metamorphic rocks. It is overlain by shaly sandstone containing limy concretions a foot or so in diameter. Well-preserved fossils are obtainable from these concretions. Both the conglomerate and the sandstone are saturated with oil, and numerous seepages issue from these beds. The petroleum gives a prevailing dark chocolate color to the rocks. Above the sandstone there is about 150 feet of tan-colored rather massive medium-grained sandstone, not oil stained. This sandstone is hard and weathers into bluffs at Elsmere Canyon. It is followed by shale that grades upward into fine-grained soft thin-bedded sandstone stained a chocolate color by petroleum and streaked yellow by sulphur. The Saugus gravel overlies this rock uncomformably. (See Pl. IX, *B*, p. 94.) Both the stratigraphy and the fauna of this section, which measures 700 to 800 feet, have been described by English.[44]

South of Elsmere Canyon, at Fernando Pass, and east of Grapevine Canyon the beds are not so strongly impregnated with oil and therefore are of a lighter color. Also, the strata are composed of coarser material, quartzitic sandstone and conglomerate forming a large percentage of the rock.

Along the north flank of the Santa Susana Mountains the Pico rests upon Modelo sandstone, apparently conformably, though the mapping shows that the sandstone is considerably thinner at Rice Canyon than farther west. On account of the absence of fossils in the Modelo and in the lowest beds of the Pico, and on account of the remarkable lithologic similarity between the two formations, it is

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[44] English, W. A., The Fernando group near Newhall, Calif.: California Univ. Dept. Geology Bull., vol. 8, pp. 205–218, 1914.

difficult to separate them in this region. In can be done satisfactorily only by tracing through strata whose stratigraphic position is known either to the east or to the west, where their separation is more distinct. The lower limit of the Pico has been put at the base of the massive conglomeratic sandstone lying below the soft fine-grained gray sandstone that contains the limonitic concretions. A section of the beds in the canyon between Towsley and Dewitt canyons is as follows:

Section of Pico formation west of Towsley Canyon.

	Feet.
Saugus formation.	
Unconformity.	
Mainly brownish fine sandstone, soft, with hard nodules; very little conglomerate, but a few hard sandstone beds; fossiliferous	395
Coarse white sandstone with gravel	20
Gray sandy shale or shaly sandstone; contains numerous small limonitic concretions in upper part	1,240
Gray shale and sandstone with concretions, essentially same as overlying material	240
Reef conglomerate and yellow sandstone, with coarse sandstone lenses	75
	1,970

In the region of Pico Canyon and westward the Pico formation in its lower part consists of soft sandstone with interbedded conglomerate and hard coarse sandstone; these beds become thicker and more numerous toward the west. The upper part, which is exposed in considerable thickness west of Pico Canyon, is a series of soft fine-grained powdery sandstones of a mustard and dark brownish-gray color, and fossils, present in beds near the top, indicate that they are of Pliocene age. These soft sandstone beds have formed a potrero, or broad valley, west of Pico Canyon, which drains into Santa Clara River. On the ridge at the north side of the valley a very marked unconformity with the overlying gravel of the Saugus formation is plainly visible. The mapping in this region also brings out this relation strongly. Farther west, in the vicinity of Eureka Canyon, the separation of the Modelo and Pico is not so difficult. In general, the younger formation is characterized by gravelly sand, sandier and darker shale, and bluish fine-grained sand with small concretions, instead of the dark-brown calcareous layers that occur in the shaly parts of the Pico. The base of the Pico in this region is taken at the dark-colored, rather massive looking conglomerate which overlies the white and yellow quartzitic sandstone of the Modelo.

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North of Santa Clara River near Piru the lowest Pico strata are sandstone and conglomerate in which the boulders consist of material derived from the basement complex. This conglomerate is very hard in places, and a few fossils occur in it. Between 3,000 and 4,000 feet of strata are exposed in the many folds of this region, though this thickness probably varies, owing to overlapping by the Saugus formation. The rocks consist primarily of conglomerate, coarse quartzitic sandstone, and shaly sandstone containing small limonitic concretions similar to those occurring in other places. Several zones of sandstone and conglomerate saturated with oil crop out around the large eastward-plunging anticline between Holser and Santa Felicia canyons. No exact dividing line has been determined for the separation of the Pico and Saugus formations north of San Martinez Chiquito Canyon, but it is thought probable that the division should be at the base of the light-colored gravel which in Santa Felicia Creek overlies the fine gray sandstone typical of the Pico. This line of contact could not be traced southward to the river, as the strata along the divide between Holser and San Martinez Grande canyons are so much alike that no separation could be made with any degree of certainty.

The Pico formation crops out from beneath the Pleistocene terrace gravels in a few small areas south of San Cayetano Mountain. The greater part of the beds near Sespe Creek are composed of coarse sandstone and gravel. In several places the sandstone is red, owing to the fact that the sand forming it was derived from the Sespe red beds, which are exposed immediately to the north. To the west the strata are typical of the Pico, consisting mainly of bluish clayey sandstone. The beds are considerably crushed, owing to the thrusting of older formations over them, and their bedding planes are usually completely obliterated. Frequent slumping and the rapid cutting of streams have caused a very rough country.

OAK RIDGE AND SOUTH MOUNTAIN.

The Pico formation crops out along Oak Ridge and South Mountain and underlies the north side of Las Posas Valley. Resting unconformably above Modelo shale, it extends in a gradually narrowing area from the west end of South Mountain to Wiley Canyon. A comparatively small thickness is present east of Grimes Canyon, where it is overlapped by Saugus gravel. A very good section of the strata may be obtained just east of Sulphur Canyon, where about 2,850 feet of strata are exposed. Throughout the section the type of rock is very much the same, the lower 2,400 feet being a nearly homogeneous sequence of fine light bluish-gray sandstone containing small orange-colored concretions similar to those in the Pico formation of the Santa Clara Valley region. Above this is a conglomerate, followed by fine-grained brown standstone. The section in more detail is as follows:

Section of Pico formation east of Sulphur Canyon.

	Feet.
Light-tan and gray unsorted sandstone	100
Soft light bluish-gray fine-grained sandstone, thin bedded and weathering light brown; contains small irregular-shaped orange-colored concretions and poor casts of fossils	2,300
Lenticular conglomerate and coarse sandstone	100
Fine-grained gray sandstone, same as above; contains a fauna characteristic of the Pico	350
	2,850

Beds of approximately the same type are found on South Mountain. Owing to the unconformity between the Pico and Saugus formations the bluish-gray clayey sandstone member thins very rapidly along Redrock Canyon, the west fork of Grimes Canyon, decreasing in thickness from approximately 2,400 feet at Sulphur Canyon to 750 or 800 feet at Redrock Canyon, and to 50 or 100 feet at Grimes Canyon. This narrow outcrop of the lower formation continues eastward until it is finally overlapped by Saugus gravel near Wiley Canyon. A lens of sandstone and pebbly conglomerate 25 to 50 feet thick comes in at the base near Sulphur Canyon. This bed lenses out near Shiells Canyon, so that farther east the fine gray sandstone again rests upon Modelo shale.

SAN FERNANDO VALLEY.

A series of comparatively loosely consolidated strata, lying with marked unconformity upon the Modelo formation, forms the foothills of the Santa Monica Mountains along the south side of San Fernando Valley and extends westward from the valley to Las Virgenes Canyon, where it comprises the youngest beds in a syncline. This series of rocks is here correlated with the Pico formation. Its lower part consists of laminated gray sandy shale, thin beds of medium-grained gray sandstone, soft whitish diatomaceous shale, tough brownish-gray sandy shale, and tuff, which aggregate a thickness of about 1,000 feet. The upper part comprises about 250 feet of well-bedded medium-grained tough gray sandstone and soft loose tan and gray sandstone, some of it conglomeratic. In general this formation may be distinguished from the underlying Modelo shale and sandstone by its subdued topography, which is due to the fact that it is less strongly consolidated and weathers more easily.

Two distinct lenses of diatomaceous shale occur in this section. One is at the base of the formation near the Hollywood Country Club and the other one, which is about 100 feet thick and with which are associated several beds of gray limestone, appears about midway in the section. The second lens can be traced around the syncline lying between the Simi Hills and the Ventura Boulevard. This zone is also well shown at the summit of Chalk Hill on the Ventura Boulevard. About 30 feet of pinkish, massive, tough clay shale containing numerous diatoms lies directly above the diatomaceous beds. Some of the lower beds of clay shale contain sporadic polished granite cobbles as much as 4 inches in diameter. As they are well rounded, it is probable that they were rolled into their present position by currents in the shallow water where the clay and diatomaceous deposits were being laid down.

The upper beds in this region consist of a soft light-yellow to gray medium-grained sandstone which in some places has very little cementing material. In the hills that extend farthest north of Ventura Boulevard some of the strata consist of a quartzitic sand which weathers readily and blows into dunes. At other places, particularly in the area west of San Fernando Valley, the sands are tougher, but they become coarser toward the top of the section, and near the top are conglomeratic, containing boulders and pebbles of white silicified shale, probably derived from the Modelo formation, granite, quartzite, and numerous fragments of bone. At one horizon near the base of the sandstone member there are many large boulders of a hard quartzitic gray sandstone as much as 5 feet in diameter, and smaller ones of granite. These boulders are waterworn and have been bored by mollusks. Above this boulder zone there is a 2-foot bed of gray tuff.

A small area of diatomaceous shale that crops out on the east side of the San Fernando reservoir of the Los Angeles Aqueduct system should probably be grouped with the Pico formation, and represents the north limb of the large syncline under the valley. The shale, here faulted on the north side against the Saugus strata, is exposed in patches beneath a covering of terrace gravel. Lithologically this shale is similar to Pico exposures near Calabasas, being mainly a soft laminated clay and diatomaceous shale of a rusty color.

No determinative fossils have so far been collected from the Pico formation in the western part of San Fernando Valley. With the exception of a few imperfectly preserved mollusks the only other fossils collected have been diatoms and foraminifers, which have not yet been studied in sufficient detail to yield results of value for the determination of the geologic age of these beds. Their stratigraphic position in the San Fernando Valley indicates that they are younger than the Modelo formation (upper Miocene), above which they lie unconformably, and are older than the Saugus formation (upper Pliocene and Pleistocene), so that there is little doubt that they are to be correlated with the Pico formation.

In the northeastern part of San Fernando Valley a complete section of the Pico formation is exposed, resting unconformably upon the Modelo formation (upper Miocene). The Saugus formation (upper Pliocene and lower Pleistocene) is apparently conformable above the Pico, though at the end of Pico time the conditions of deposition changed abruptly from marine to terrestrial. The lower part of the section is composed largely of massive brown conglomerate, which is prominently exposed along the front of the hills. Brown sandstone, sandy shale, and shale in zones 10 to 50 feet thick, in which are some layers of diatomaceous shale, are interbedded with the conglomerate. The zone of conglomerate is followed by soft thin-bedded shaly sandstone, which contains limonitic nodules. Fossils in some of the beds near the base of the series indicate that it is of Pico age.

EVIDENCE OF AGE.

The fauna of the Pico formation includes the lower Fernando fauna and middle Fernando fauna as listed by Eldridge and Arnold[45] in 1907.

The upper Fernando fauna of Eldridge and Arnold is the fauna contained in the deposits here named the Saugus formation. The Fernando fauna has more recently been studied by English,[46] who states that in the eastern part of the Santa Clara River valley the marine strata contain "a fauna characteristic of the lower part of the Fernando group. It is approximately equal in age to the lower Purisima and probably belongs near the base of the Pliocene in the standard time scale." He further states that the Fernando of the Puente Hills also "belongs to the lower part of the Fernando" and that "it is probable that the lower Fernando and the Etchegoin do not differ greatly in age."

The fauna listed below is a compilation of the species enumerated by English and those collected and determined by the writer:

Fossils from the Pico formation of the Los Angeles-Ventura region.

	1601, 1602	1603	1637	3587	3588	3589	3590	3591	8140	8142	8143	8146
Echinodermata:												
Astrodapsis fernandoensis Pack	×											
Dendraster diegoensis diegeonsis Kew											×	
Dendraster excentricus Eschscholtz	×					×						
Dendraster cf. D. gibbsii var. humilis Kew										×		
Pelecypoda:												
Amiantis cf. A. callosa Carpenter	×	×	×									
Arca camuloensis Osmont			×						×			
Arca trilineata Conrad	×											
Cardium quadrigenarium var. fernandoensis Arnold	×	×										
Cardium sp	×											

[45] U. S. Geol. Survey Bull. 309, pp. 24–25.

[46] English, W. A., The Fernando group near Newhall, Calif.; California Univ. Dept. Geology Bull., vol. 8, p. 214, 1914.

Fossils from the Pico formation of the Los Angeles-Ventura region—Contd.

	1601, 1602	1603	1637	3587	3588	3589	3590	3591	8140	8142	8143	8146
Pelecypoda—Continued.												
Chione elsmerensis English	×											
Chione fernandoensis English	×	×	×					×	×			×
Cryptomya cf. C. ovalis Conrad	×		×									
Dosinia ponderosa Gray (n. var.?)	×		×									
Dosinia sp					×							
Glycimeris septentrionalis Middendorf										×		
Leda taphria Dall	×	×	×									
Macoma indentata Carpenter	×		×									
Macoma nasuta Conrad			×									
Macoma secta Conrad			×									
Macoma sp												×
Marcia subdiaphana Carpenter	×		×									×
Metis alta Conrad	×		×									
Modiolus sp.?	×		×									
Mytilus sp.?	×											
Nucula castrensis Hinds	×	×										
Ostrea veatchii Gabb			×									
Panope generosa Gould	×		×									
Paphia tenerrima Carpenter			×									
Pecten ashleyi Arnold	×								×			
Pecten cerrosensis Gabb	×		×									
Pecten hastatus Sowerby										×		
Pecten hastatus var. hericius Gould										×		×
Pecten healeyi Arnold	×		×	×		×						
Pecten hemphilli Dall										×	×	
Pecten oweni Arnold	×		×									
Phacoides annulatus Reeve	×		×		×			×				
Phacoides nuttalli Conrad	×		×					×				
Phacoides richtofeni Gabb	×		×						×			
Phacoides californicus Conrad												×
Phacoides sanctaecrucis Arnold	×		×					?				
Pododesmus (Monia) machroschisma Deshayes										×		
Protocardia centifilosa Carpenter		×										
Psammobia edentula Gabb			×									
Solen sicarius Gould	×	×	×									×
Spisula catilliformis Conrad			×									
Tellina idae Dall	×		×					?				
Tellina sp						×						
Tivela sp							×					
Venericardia californica Dall	×		×									
Yoldia cooperi Gabb		×										
Gastropoda:												
Actaeon (Rictaxis) cf. A. punctocoelata Carpenter								×				
Amphissa sp.?	×											
Astralium sp.?	×		×									
Bittium cf. B. asperum Gabb	×		×									
Bulla punctulata Adams?		×	×									
Calyptraea filosa (Gabb)	×	×										×
Calyptraea radians (Lamarck)			×									
Cancellaria elsmerensis English	×							×				
Cancellaria fernandoensis Arnold	×							×				
Cancellaria tritonidea Gabb	×			×				×				×
Calliostoma cf. C. gemmulatum Cooper												×
Chrysodomus arnoldi Rivers?	×	×	×									
Chrysodomus sp.?	×											
Columbella (Astyris) cf. C. tuberosa Carpenter								×				
Conus californicus Hinds	×		×									
Crepidula onyx Sowerby			×									
Crepidula princeps Conrad	×		×									
Cypraea fernandoensis Arnold	×											
Drillia johnsoni Arnold			×									×
Fusinus barberensis Trask	×	×	×									
Gyrineum elsmerense English	×											
Mangilia sp.?	×											
Mitra idae Dall	×											
Mitra tristris Swain								×				
Nassa californiana Conrad								×	×			×
Nassa waldorfensis Arnold	×	×	×									
Natica recluziana Petit	×	×	×	×	×			×				×
Neptunea recurva Gabb												×
Olivella intorta Carpenter			×									
Olivella pedroana Conrad												×
Pisania fortis var. angulata Arnold			×									
Polynices sp.?	×	×										
Sinum scopulosum Conrad		×	×	×								
Siphonalia kelleti Forbes	×		×									
Surcula sp.?											×	
Terebra martini English			×									

Fossils from the Pico formation of the Los Angeles-Ventura region—Contd.

	1601, 1602	1603	1637	3587	3588	3589	3590	3591	8140	8142	8143	8146
Gastropoda—Continued.												
Terebra simplex Cooper								×				×
Trophon sp.?	×		×									
Trophoscyon nodiferum (Gabb)	×			×	×		×	×				
Turris elsmerensis English	×											
Turris fernandoensis English	×											
Turris (Bathytoma) carpenteriana Gabb var. fernandoana Arnold	×		×									
Turris (Bathytoma) cooperi Arnold								×				×
Turritella cooperi Carpenter	×	×	×	×				×	×	×		×
Turritella jewetti Carpenter?										×		
Brachiopoda:												
Terebratalia smithi Arnold			×									
Vertebrata:												
Fish vertebrae			×									
Cetacean bones	×											
Camel bones cf. Procamelus	×											
Seal metapodial				×								

1601 (California Univ.). Elsmere Canyon, Los Angeles County, extreme southwest corner of NW. ¼ sec. 8, T. 3 N., R. 15 W.; 100 yards up small gulch that branches off to northwest about 150 yards downstream from contact with granite in bed of main canyon. W. A. English, collector.

1602 (California Univ.). Elsmere Canyon, Los Angeles County, in NE. ¼ SE. ¼ sec. 7, T. 3 N., R. 15 W., in bed of Elsmere Creek 200 feet west of line between secs. 7 and 8, about 100 yards east of locality 1601. W. A. English, collector.

1603 (California Univ.). Pico Canyon, a quarter of a mile northwest of superintendent's house at Pico, near tank on summit of ridge. W. A. English, collector.

1637 (California Univ.). Holser Canyon, in steep gulch on north side of small canyon near center of SW. ¼ sec. 12, T. 4 N., R. 18 W. W. A. English, collector.

3587 (California Univ.). Three-fifths mile S. 33° E. of Humphreys station, on north side of 2006-foot hill in SW. ¼ NW. ¼ sec. 27, T. 4 N., R. 15 W.

3588 (California Univ.). On top of ridge at head of Elsmere Canyon, in SW. ¼ sec. 17, T. 4 N., R. 15 W.

3589 (California Univ.). On top of prominent 2150-foot hill 1⅓ miles due north of Sylmar, in SW. ¼ NE. ¼ sec. 20, T. 3 N., R. 15 W.

3590 (California Univ.). Half a mile S. 20° E. of Humphreys station, near center of sec. 27, T. 4 N., R. 15 W.

3591 (California Univ.). On ridge extending northward in northeast corner sec. 32. T. 4 N., R. 15 W.

The following are U. S. National Museum localities:

8140. North of Santa Clara River on top of prominent 2223-foot hill on divide between Holser and San Martinez Grande canyons, in SE. ¼ NE. ¼ sec. 7, T. 4 N., R. 17 W. From hard brown beds in yellowish sands.

8142. Just below top of steep southern escarpment of ridge north of potrero or flat-bottomed valley west of bend in Pico Canyon, 6,500 feet N. 40° W. of Pico.

8143. East side of Smith Canyon (first canyon east of Torrey Canyon) near its mouth. Base of Pico formation.

8146. Two-fifths mile south of north line of T. 3 N. and one-tenth mile east of parallel 118° 35′, on ridge immediately north of bend in creek, in SE. ¼ NW. ¼ sec. 5, T. 3 N., R. 16 W. Immediately below gravel of Saugus formation.

As the echinoids are a group which as a rule have comparatively short geologic ranges,[47] their presence may shed some light on the age of the Pico formation. *Astrodapsis fernandoensis* Pack, which occurs in the lowest beds of the Pico at Elsmere Canyon, suggests that there may be a close time relation between these beds and those of the Jacalitos formation of the Coalinga district, for the genus *Astrodapsis* is not known to occur in any other part of California in strata younger than the Jacalitos. Moreover, *A. fernandoensis* appears to be closely related to the forms found in the Jacalitos formation. The presence in the Pico of *Dendraster excentricus* Eschscholtz, which is a species now living on the west coast, indi-

[47] Kew, W. S. W., Cretaceous and Cenozoic echinoids of the Pacific coast of North America: California Univ. Dept. Geology Bull., vol. 12, pp. 23–236, pls. 3–32, 1920.

cates either a later age for these beds or a remarkably long range for this species. On the other hand, *A. fernandoensis* may be a species of *Astrodapsis* that lived later in the southern region than the species farther north in the Coalinga region.

The Pico fauna is distinguished easily by its many characteristic species, such as *Astrodapsis fernandoensis* Pack, *Arca camuloensis* Osmont, *Chione fernandoensis* English, *Pecten ashleyi* Arnold, *Cancellaria elsmerensis* English, *Cancellaria fernandoensis* English, *Drillia johnsoni* Arnold, *Gyrineum elsmerense* English, *Nassa waldorfensis* Arnold, *Terebra martini* English, *Trophoscyon nodiferum* (Gabb), *Turris fernandoensis* English, *Turris elsmerensis* English, and *Turris* (*Bathytoma*) *carpenteriana* Gabb var. *fernandoana* Arnold.

The seal remains collected south of Humphreys station were submitted to Remington Kellogg, of the United States Biological Survey, who states that the foot bones, in their structural modification, seem to belong rather to the Pliocene than to the Miocene.

The deposits at all the localities are closely related in age, though the faunas are not identical. According to English[48] the Holser Canyon and Pico Canyon fauna may be grouped with that of Elsmere Canyon "as a single faunal zone." This is also true of the fauna collected south of Humphreys station. Of the species listed above, 54 per cent are living. This percentage is in marked contrast to that in the Saugus fauna, which consists almost entirely of recent forms.

RELATION TO PETROLEUM.

As the Pico formation consists largely of sandstone, which is in places coarse and conglomeratic, it offers exceptionally good facilities for the retention of oil. Overlying the shale of the Modelo formation, which acts as the source of the petroleum, the sands near the base of the Pico have become impregnated, and under favorable structural conditions important accumulations of oil have formed. This formation constitutes the reservoir from which oil is obtained at Elsmere Canyon and Fernando Pass. Thick oil sands also occur near the base of the Pico on the large anticline east of Piru Creek.

The Pico is not everywhere oil bearing, even where underlain by Modelo diatomaceous shale, for the sands that crop out on the south side of Oak Ridge and South Mountain and also in San Fernando Valley, where they have apparently had an excellent opportunity to become impregnated, are in large areas wholly barren. This can be explained only by the supposition that either conditions were not favorable for the formation of oil in the diatomaceous shale of the Modelo, or, more probably, that the oil had dissipated during the

[48] Op. cit., p. 211.

time the Modelo was exposed to erosion prior to the deposition of the Pico. Small ball-like pieces of asphaltic material are found near the base of the Pico on South Mountain, but the surrounding sands contain no trace of petroleum. These chunks were probably washed into the sea from eroding oil sands and buried during the deposition of the Pico formation.

North of Tujunga Canyon the Pico contains no oil-saturated sands, though it overlies the Modelo formation, which is more or less petroliferous in this region.

In the western part of San Fernando Valley no indications of oil were found in any of the strata. This condition seems strange in view of the fact that the formation contains comparatively thick zones of diatomaceous shale, the material that is supposed to be the source of a large part of the oil in California, and the Pico formation contains one of the main oil-bearing zones in the Los Angeles district, to the southeast. Probably if oil has ever been present in these beds it has disappeared and all traces of it have been leached out, or, as is more likely, the conditions that prevailed during the deposition of the sediments were not favorable for the formation of oil, even though the sea abounded in organic life.

SAUGUS FORMATION (UPPER PLIOCENE AND LOWER PLEISTOCENE).

NAME AND DEFINITION.

The Saugus formation, which is the uppermost formation of the Pliocene series and extends into the Pleistocene, was first recognized by Hershey [49] as the "Saugus division of the upper Pliocene series." He described it as "a great series of unlithified sand, gravel, and clay * * * whose physical characters are unmistakably those of an alluvial deposit, a river delta, progressively sinking. The terrane occupies a central position in the basin and has an estimated thickness of 2,000 feet. It is splendidly exposed * * * in Soledad Canyon near Saugus." With the Saugus Hershey included what he designated the "Lang division" and the "Soledad division," but these divisions are now thought by the writer to be equivalent, in greater part at least, to the upper part of the Mint Canyon formation of this report. In previous reports the Saugus deposits have been included in the Fernando formation, of which they constitute the upper unconformable part. In this report the deposits are treated as a distinct formation, and the Fernando is made a group. In most places the Saugus formation rests unconformably on the Pico or lower formation of the Fernando group and is unconformably overlain by Pleistocene terrace deposits. It contains a younger fauna than the Pico formation.

[49] Hershey, O. H., Am. Geologist, vol. 29, pp. 359-362, 1902.

GENERAL FEATURES.

The Saugus formation occupies a relatively large area within the limits of the area mapped (Pl. I) and can be grouped into two major districts—that in Santa Clara Valley and that south of the San Gabriel and Santa Susana mountains and Oak Ridge. The first district is the basin-like area whose center is in the vicinity of Saugus.

Here the Saugus rests upon the Pico with marked unconformity, so that it frequently overlaps that formation, where on the north and east sides it is in contact with the Modelo (?) formation, the Mint Canyon formation, and the basement complex. The second district includes a number of separate exposures, which are probably continuous below later deposits of Pleistocene terrace gravels. These outcrops overlie the Pico formation. The Saugus composes the central part of the Happy Camp Canyon syncline and underlies Las Posas Valley, including the ridge to the south and the hills north of Camarillo.

In general the Saugus formation is uniform in lithology, consisting mainly of light-colored gravel and sand, usually more or less unconsolidated, with interbedded soft fine sandstone. The greater part of it is of marine origin, but it grades eastward and northward into strata that are probably of fluviatile origin or alluvial-fan deposits. These comprise unsorted sands and conglomerates which for many years have been worked as dry placers for their gold content. The marine deposits are fairly well bedded and contain fossils at several horizons. The gravel and sandstone beds form prominent outcrops in the vicinity of Pico Canyon (see Pl. IV, *B*, p. 30) and Castac Canyon, where they are nearly white and highly tilted. East of these canyons they have been deformed but little and dip gently toward Santa Clara River. The terrestrial deposits of the Saugus are similar in lithologic character to the overlying Pleistocene gravel, but the gravel was deposited after the Pico beds had been tilted.

DISTRIBUTION AND LITHOLOGY.

SANTA CLARA VALLEY.

East of Saugus, where the Saugus formation rests upon the Mint Canyon formation, the lithology of the two is remarkably similar, as they consist largely of coarse conglomerate and sandstone of terrestrial origin. However, the Mint Canyon contains gray clay and soft sandstone, which are lacking in the Saugus formation, and is in most places colored a light gray, in contrast to the rusty-brown color of the Saugus. There is also a marked difference in dip and strike between the two. The boulders in the conglomerate attain a maximum of 4 feet in diameter and have been derived from granite, mica and hornblende schist, and volcanic rocks of various kinds. In some places, where the strata rest upon the basement complex, the lower 300 to 400 feet of beds have a dark greenish-brown color and appear to be derived wholly from the rocks of the San Gabriel Mountains.

North and northeast of the town of Saugus the Saugus formation is probably entirely of terrestrial origin. The beds here are made up, for the most part, of unsorted and cross-bedded conglomerate consisting mainly of rounded and semirounded pebbles and boulders of schist, with minor amounts of granite, quartzite, and hard sandstone, in which the boulders are as much as 2 feet in diameter. The detritus appears to have come from the older sedimentary rocks and the metamorphic and igneous rocks exposed immediately to the north. The rocks are considerably darker in color than those on the south side of Santa Clara River, being here usually reddish brown or light buff to grayish tan and interbedded with a few layers of light-gray sand and red clay.

At one horizon there is a light-gray to white coarse sandstone and conglomerate stained brown to a large extent by petroleum, and, in places, a light yellow by sulphur. An outcrop of this rock occurs on the ridge west of the Los Angeles Aqueduct dam in Dry Canyon, in the SW. ¼ sec. 26, T. 5 N., R. 16 W. This is the only known occurrence of oil sand in the Saugus formation of this region, north of Santa Clara River. Where the Saugus rests upon the Modelo (?) formation there is a considerable difference in dip between the two sets of beds, which in Haskell Canyon amounts to 15°. West of San Francisquito Canyon the Saugus on the ridge tops is overlain by the nearly flat-lying terrace gravel. West of Castac Valley the fossils and the much better sorting of the material indicate that the Saugus formation is largely of marine origin. Strata of this same type extend southward across the river and are present in considerable thickness north of Pico Canyon.

In the eastern part of the area south of Santa Clara River, in the vicinity of Placerita and Elsmere canyons, the deposits of the Saugus are probably of terrestrial origin, but farther west they become partly marine, as shown by fossils found at a few horizons. Generally the gravel and sand are barren of fossils. The rock, though mainly conglomeratic, shows some slight differences in lithology from that north of the river, in that the boulders are smaller, few of them being a foot in diameter. They are derived mainly from granite instead of schist and the material is of a lighter color, which seems to indicate that the source of material was more distant. Southeast of Saugus the gravel and sandstone, though originally gray, have in large part been stained a rusty color, and the beds at one horizon are in places saturated with oil. This oil sand crops out on the north side of Placerita Creek in secs. 31 and 32, T. 4 N.,

R. 15 W. It may be found also in the vicinity of Elsmere Canyon, where several seeps occur in the Saugus gravels. No oil sands in the Saugus were noted on the south side west of Fernando Pass.

AREA SOUTH OF SAN GABRIEL AND SANTA SUSANA MOUNTAINS AND OAK RIDGE.

The Saugus beds that extend along the north side of San Fernando Valley are in general similar in lithology to those farther north, in the Santa Clara Valley region, the eastern part being nonmarine but grading westward into strata of marine origin. As a rule the beds lie unconformably above the Pico formation except in the area north of Tujunga River, where no break in sedimentation is apparent other than a change from marine to terrestrial conditions of deposition. The Saugus formation on the south side of the San Gabriel Mountains in the region of Little Tujunga Canyon overlaps the Pico formation and rests directly on the basement complex (see Pl. XII, *B*, p. 101), with no older sedimentary strata present, though near the mouth of this canyon it lies upon the Pico formation. (See structure section M–M′, Pl. II, in pocket). It consists mainly of conglomerate or gravel with sandstone, all of which are more or less unconsolidated. A few calcareous beds that weather out more prominently than the other beds stand up as reefs.

On the south side of the San Gabriel Mountains, at Fernando Pass, and in the low hills near the Fernando reservoir of the Los Angeles Aqueduct the Saugus consists mainly of light-gray to buff unsorted gravel and coarse sandstone with some gray, red, and green clay. A few beds are fairly well cemented, but as a rule the beds are not consolidated and weather readily, giving rise to very few outcrops of a reddish-brown color. These strata were probably deposited under nonmarine conditions, for marine fossils have not been found in the beds east of Bull Canyon, near the east edge of the Santa Susana quadrangle. West of Bull Canyon, near the edge of the valley, a few beds made up partly of shells may be traced for a considerable distance. Northeast of Chatsworth the Saugus rests normally upon the Cretaceous, though farther north it is faulted against the Modelo formation. Near the mouth of Limekiln Canyon the beds exposed resemble in many ways the terrace deposits to the north, which form a considerable area at the foot of the Santa Susana Mountains, as in both areas the beds contain a large proportion of débris derived from Modelo siliceous shale. Although the typical Saugus in this region does not contain shale pebbles, these beds are here included within the Saugus formation for the reason that they appear to grade into the typical Saugus and may represent a higher phase of this formation. Also they are considerably deformed, beds of this type in Limekiln Canyon being tilted as high as 50°.

In Browns Canyon a relatively small detached area of the Saugus formation crops out, which is very fossiliferous and belongs with the distinctly marine strata that make up the remainder of the Saugus exposed to the west. In the region of Browns, Aliso (west), Las Llajas, and Dry canyons the Saugus has been rather intensely folded owing to the action of the Santa Susana fault, and overturning has occurred in several places. In Browns Canyon a partial section was measured which gives a general idea of the nature of the deposits.

Partial section of Saugus formation in Browns Canyon.

Upper member of gravel; unfossiliferous	135±
Yellow cross-bedded sand and conglomerate with sandstone lenses; fossiliferous	201
Brown conglomerate and sand; fossiliferous	85
Buff cavernous and nodular-weathering fine-grained conglomerates; fossiliferous	263
	684±

West of Aliso Canyon (west) and at the foot of the west end of the Santa Susana Mountains are several detached areas of Saugus beds that have been considerably folded and broken, having been involved in the thrusting at the time the Santa Susana fault was formed. These beds consist mainly of gravel and sandstone, more or less fossiliferous. In places they are saturated with petroleum and large seeps issue from the sands. One bed which is very prominent is made up almost entirely of small fragments of shells, well cemented together. This material has been used locally, after burning, for lime. Just south of this locality is the east end of the Happy Camp syncline, the uppermost formation in which is the Saugus. This area of Saugus probably begins with the two small isolated tracts that form the tops of the hills between Aliso and Las Llajas canyons. The main body of this area begins west of Las Llajas Canyon and is continuous beyond Happy Camp Canyon to the west edge of the area mapped, becoming wider toward the west. In this region the Saugus formation can be separated into two lithologic divisions—a lower member consisting mainly of soft brown sandstone with some conglomerate, at the base of which is a fossiliferous light-gray or rusty-colored hard reef bed, and an upper member consisting almost entirely of cross-bedded conglomerate, loosely consolidated and unfossiliferous. This same type of beds may be traced westward, varying somewhat in the proportion of sandstone to conglomerate, as the strata are more or less lenticular. In Las Posas Valley, northwest of Moorpark, the Saugus formation consists almost entirely of slightly deformed beds of gravel with some interbedded loose sand. On the ridge south of the valley the lower beds, about 15 feet thick, exposed on the south side near the east end of the ridge and dipping toward Santa Rosa Valley, are made up largely of detritus from the underlying andesite and breccia. Above these beds is 5 feet of fossiliferous sand and conglomerate followed by 15 feet of light-brown unconsolidated sandstone, at the top of which is a fairly hard gravel bed with sands containing numerous specimens of *Dendraster diegoensis* var. *venturaensis* Kew. At other points the Saugus lies with a marked unconformity on Modelo shale, which is perforated with pholad borings. Another section of the Saugus formation north of the fault that traverses the top of the ridge, at a point about 2 miles east of Somis, consists of the following strata:

Section of Saugus formation east of Somis.

	Feet.
Medium-grained soft light-tan sandstone forming surface of north slope of ridge	25±
Basalt intrusive into sandstone as a small sill	15
Thin-bedded tan and brown sandstone, fine to medium-grained, containing at the top a bryozoan bed; fine-grained beds appear to have been derived from the underlying diatomaceous shale	15
Gray gravel	10–15
Well-bedded medium-grained yellow and tan sandstone	15–20
	65–90±

The small intrusion of igneous rock mentioned in the above section is the only occurrence of its kind in the area mapped. It closely resembles some of the basic rock intruded into the Modelo strata, but probably is an intrusion of later age.

In the hills immediately west of Somis and north of Camarillo, in the Hueneme and Santa Paula quadrangles, strata similar to those on the ridge south of Las Posas Valley are present. These beds are folded into an elongated dome, and the contour of the hills practically reflects the attitude of the strata. The uppermost beds exposed, which cover a large part of the surface, consist of fine, shaly gray sandstone. Below this there is a bed about 5 feet thick which is slightly more resistant to weathering than the other strata, owing to the cementing effect of abundant fossils in it. The species of fossils found in this bed indicate a rather late period of deposition and probable Pleistocene age. This is underlain by a considerable thickness of soft medium-grained tan to buff sandstone which weathers easily, forming a sandy soil.

STRATIGRAPHIC RELATIONS.

The unconformity between the Saugus and Pico formations is well shown at several places along the south side of Santa Clara Valley and is strikingly brought out in Elsmere Canyon and west of Pico Canyon. Hershey[50] recognized that the Saugus rested unconformably upon "beds of San Pablo age," but the unconformity in Elsmere Canyon was first described by Eldridge,[51] though he correlated the beds here called Pico with the Vaqueros formation, basing his correlation on their lithologic similarity to strata in Torrey Canyon that contain lower Miocene fossils. However, Ralph Arnold, who wrote the paleontologic discussion in Eldridge's report, considered these beds in Elsmere Canyon to be of Pliocene age. Watts[52] in 1900 found here "beds of the Middle Neocene resting nonconformably on hard sandstones resembling the Eocene sandstones of the Sespe district." These "Eocene sandstones" are probably quartzites belonging to the basement complex and do not represent the unconformity under discussion. The relations are well shown on the north side of Elsmere Canyon, where there is a difference in dip of several degrees between the strata of the Pico and Saugus formations. Also the beds change abruptly in lithology, from fine-grained marine sandstone to coarse gravelly material of probable fluviatile origin. Within a short distance to the northeast the Saugus completely overlaps the Pico formation and rests directly on the metamorphic rocks. English[53] has described this unconformity in detail and calls attention to the fact that "the conglomerate on the north side of Elsmere Canyon has a strike of N. 50° W. and dips 12° N. The lower part of the shaly beds and the granitic surface on which they were deposited have a strike of N. 65° W. and dip 20° N."

On the north side of the potrero west of Pico Canyon there is a marked difference in attitude of the beds, the Saugus striking N. 58° W. and dipping 30° N., and the Pico striking N. 72° W. and dipping 45° N. The mapping of the Pico, furthermore, shows a marked thickening to the west, hardly to be accounted for other than by an unconformity.

At least an overlap, if not an unconformity, is present on Oak Ridge. Though no actual discrepancy in attitude of the strata of the two formations was seen, nevertheless mapping shows that the Pico formation is completely overlapped by the Saugus, and within so short a distance, in Grimes Canyon, as to imply that an unconformity exists.

On the north side of Tujunga Valley the Saugus formation apparently grades up from the Pico formation and no unconformity is present, though a change from marine to terrestrial conditions of de-

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[50] Hershey, O. H., Am. Geologist, vol. 29, p. 361, 1902.

[51] Eldridge, G. H., U. S. Geol. Survey Bull. 309, pp. 97–98, 1907.

[52] Watts, W. L., California State Min. Bur. Bull. 19, p. 56–57, 1900.

[53] English, W. A., The Fernando group near Newhall, Calif.: California Univ. Dept. Geology Bull., vol. 8, p. 207, 1914.

position took place. At the head of Little Tujunga Canyon the Saugus formation rests directly upon the basement complex.

EVIDENCE OF AGE.

The following species have been found in the Saugus formation by C. M. Wagner and the writer:

Fossils from the Saugus formation in the Los Angeles-Ventura region.

[Locality numbers from U. S. National Museum, except 3592.]

	3592	8139	8141	8144	8145	8147	8149	8150	8151	8153	8154	8157	8158	8159
Echinodermata:														
Dendraster diegoensis diegoensis Kew						×		×		×	×			
Dendraster diegoensis venturaensis Kew			×									×		
Dendraster pacificus Kew									×					×
Brachiopoda:														
Terebratalia smithi Arnold		×		×										
Terebratalia sp		×												
Bryozoa													×	
Pelecypoda:														
Anomia lampe Gray	×													
Chione succincta Valenciennes	×						×							
Glycimeris septentrionalis Middendorf											×			
Ostrea lurida Carpenter	×							×						
Ostrea veatchii Gabb				×							×			×
Phacoides annulatus Reeve		×	×											
Pecten bellus Conrad					×									
Pecten cf. P. caurinus Gould														×
Pecten circularis Sowerby	×													
Pecten circularis var. equisulcatus Carpenter														×
Pecten hastatus Sowerby		×		×										
Pecten hastatus var. hericius Gould														×
Pecten hastatus var. navarchus Dall				×										
Pecten hemphilli Dall										×	×			×
Pecten (Hinnites) giganteus Gray			×											
Pododesma (Monia) macroschisma Deshayes							×				×			
Semele californica Conrad			×											
Venericardia californica Dall			×											
Gastropoda:														
Chrysodomus cf. C. arnoldi Rivers			×											
Columbella (Astyris) carinata Reeve			×											
Conus californicus Hinds			×											
Drillia sp			×											
Fusinus kobelti Dall			×											
Leptothyra bacula Carpenter			×											
Nassa perpinguis Hinds			×											
Nassa tegula Reeve							×							
Natica recluziana Petit														×
Olivella biplicata Sowerby			×											
Priene cf. P. orogonensis Redfield			×											
Siphonalia cf. S. modificata							×							
Terebra simplex Cooper							×							
Turritella cooperi Carpenter			×				×							
Turritella jewetti Carpenter			?											

3592 (California Univ.). On hill north of Camarillo and west of Somis, in Santa Paula and Hueneme quadrangles.

8139. West of first small canyon west of Browns Canyon, about half a mile southwest of old oil well, in SW. ¼ sec. 30, T. 3 N., R. 16 W.

8141. In northwest corner of El Conejo grant, in small gully immediately below top of ridge north of Arroyo Santa Rosa. Same as 8152 and 8156.

8144. On east side of Browns Canyon, on prominent point above house at foot of grade, near center of north line of sec. 31, T. 3 N., R. 16 W.

8145. On east side of small canyon branching eastward from Dry Canyon, 4,850 feet N. 34° W. of 2,165-foot bench mark.

8147. On ridge near Santa Barbara National Forest boundary monument, in southwest corner of sec. 11, T. 4 N., R. 17 W., 1⅜ miles west of Castac. Same as 8155.

8149. Two miles due north of Somis and half a mile east of west edge of Camulos quadrangle, on ridge top south of rounded hill and near axis of anticline.

8150. Immediately below top steep escarpment on south side of ridge north of Potrero, or Broad Valley, 1⅝ miles N. 30° W. of Pico, in Santa Susana quadrangle. At base of Saugus gravels.

8151. North of east end of Simi Valley, about 4,500 feet southwest of 2,165-foot bench mark, in creek between 2,009-foot and 2,205-foot hills. At base of Saugus formation.

8153. On south slope of hill west of Browns Canyon, about half a mile southwest of old oil well in bottom of canyon, in SW. ¼ sec. 30, T. 3 N., R. 16 W. Highest fossiliferous zone.
8154. On west side of Browns Canyon, about half a mile southwest of old oil well in bottom of canyon, in SW. ¼ sec. 30, T. 3 N., R. 16 W. Near base of fossiliferous series.
8157. On prominent hill on east side of Browns Canyon, above house at foot of grade. Zone above locality 8144.
8158. 2.3 miles east of Somis, on south side of ridge north of Arroyo Santa Rosa, immediately below 1,000-foot point.
8159. At top of 2,075-foot hill 2⅝ miles S. 58° W. of 2,165-foot bench mark north of Simi Valley.

Although the Saugus formation appears to have undergone almost as much deformation as the Pico and in some places even the Miocene formations, its fauna indicates that it was deposited during late Pliocene and early Pleistocene time. It represents a considerably later stage of deposition than that of the Pico. With the exception of the echinoids and pectens, which compose about 25 per cent of the fauna, practically all the species are living. Out of a total of 36 species, 14 are found in the Pico, only 5 of which are extinct. Thus it appears that the Saugus formation is faunally distinct from the Pico, and the unconformable relation between the two bears this out. The Saugus may be correlated tentatively with the late Pliocene deposits at Santa Barbara and with the San Diego formation exposed at Pacific Beach.

RELATION TO PETROLEUM.

Like the Pico, the Saugus formation, consisting of coarse material, is suited only to act as a reservoir in which petroleum may be stored. Oil sands and seeps are present east of Newhall and north of Saugus, and some oil is obtained from the lower strata in this formation in the wells east of Newhall. There are two possible sources for the oil in the Saugus formation—migration from the petroliferous sands of the Pico formation, over which it lies unconformably, and migration directly from Modelo shale, which is its ultimate source. In the Newhall region the first hypothesis is probably the more plausible, as in this vicinity the Saugus is not in contact with the Modelo but overlaps the oil sands of the Pico and is therefore in a position to absorb oil from them. The small outcrop of oil sand north of Saugus probably originated in the Modelo.

QUATERNARY SYSTEM.

TERRACE DEPOSITS AND ALLUVIUM.

Pleistocene terrace deposits (see Pls. IV, *B*, and VI, *A*) resting unconformably on the Tertiary formations are not uncommon in this region and chronicle part of the time that has elapsed since the deposition of the Saugus formation. All the Pleistocene material is of terrestrial origin and probably was laid down as flood plains of rivers or as alluvial fans. As a rule the beds lie flat or dip very gently, but they have been so dissected in most places that only remnants are left to indicate their former extent. In Santa Clara Valley the larger deposits occur around Saugus and on the south side of San Cayetano Mountain west of Sespe Creek. The deposit near Saugus evidently represents a previous flood plain of Santa Clara River, which has now been eroded away except in its lower parts. West of Sespe Creek the deposits consist of gravel which has been laid down at the foot of San Cayetano Mountain in alluvial fans. South of the Santa Susana Mountains and Oak Ridge deposits of this type are present in fairly large areas. North of the east end of San Fernando Valley this deposit overlies the Saugus unconformably and dips gently toward the Santa Susana Mountains. This peculiar attitude may have been caused by a late movement along the Santa Susana fault. Another area lies at the foot of Oak Ridge in the upper part of Tapo Canyon. A large proportion of Las Posas Valley is covered by gravelly beds overlying the Saugus, so similar in lithology that their separation is difficult. Other smaller areas are present in Conejo Valley, Simi Valley, and San Fernando Valley.

All the deposits are of the same type, consisting of unsorted and angular to subangular conglomerate or gravel, with a small percentage of finer-grained material interbedded in some places. The boulders are much more angular in the alluvial-fan deposits than in those formed by fluviatile action. The rock constituents vary according to the locality, as the deposits are in large part derived from the neighboring rocks. For instance, in the upper Santa Clara Valley they are mainly granitic, whereas south of the Santa Susana Mountains a large proportion has been derived from the rocks of the Modelo formation and the material abounds in fragments of siliceous diatomaceous shale. The thickness of the deposits also varies, ranging from a few feet up to 100 feet or more. It is recognized that these beds do not represent one period of deposition and that the deposits in different localities are not to be correlated, though it is probable that at least some of them were laid down at the same time. Moreover, several stages of deposition are present in one locality. In the upper Santa Clara Valley there are deposits at two or more altitudes. A very prominent one lies immediately above the present valley level and rises to about 1,500 feet. (See Pl. VI, *A*, p. 52.) The other is represented by only a small remnant at an altitude of about 2,750 feet near the top of the Santa Susana Mountains, at the head of Rice Canyon, where large boulders of granite lie on beds of Modelo shale. In the south side of the San Gabriel Mountains deposits occur at several altitudes, and terraces have been carved in them, the highest 3,000 feet above sea level.

Alluvium fills all the valleys and extends up many of the larger creeks for some distance. It is usually composed of coarse and fine sands with beds of gravel and is flat lying. This alluvium has been dissected by the streams, so that the present stream bed may be as much as 50 feet below the general level of the valley floor.

RELATION TO PETROLEUM.

The Quaternary deposits are of no economic importance, except that they conceal the underlying older rocks and hide structural features that might be favorable for the accumulation of oil. The alluvium in the valleys attains considerable thickness and necessitates deeper drilling to reach the oil-bearing strata.

TERTIARY IGNEOUS ROCKS.

The Tertiary igneous rocks play no part in the accumulation of oil except perhaps in the Conejo Pass region and have not been studied in detail. They include both extrusive and intrusive rocks and consist mainly of basalt, andesite, dacite, tuff, and breccia. These rocks are confined almost entirely to the southwestern part of the region, where they are of Miocene age and represent several stages of igneous activity.

The oldest igneous rocks occur as flows of andesite near the base of the Sespe (?) formation in the region north of Soledad Canyon and east of Mint Canyon. This andesite is nearly everywhere vesicular and contains amygdules of chalcedony as much as 3 inches in diameter. Specimens of this rock submitted to C. S. Ross, of the United States Geological Survey, showed that it was a typical andesite in which euhedral crystals of andesine form about one-third of the rock and augite about 5 per cent. The ground mass is composed of a brown glasslike material and small euhedral crystals of andesine.

West of Las Virgenes Canyon the north side of the Santa Monica Mountains is composed largely of basalt, andesite, and dacite, together with agglomerate and tuff of the same composition. A large part of the rocks are intrusive as well as extrusive. In most places they lie below the Modelo formation and are associated with the Topanga formation, or strata containing the *Turritella ocoyana* fauna, and the Sespe-Vaqueros strata. These rocks can be traced westward beyond Conejo Pass and also northward, where they form the ridge of hills extending to Simi Valley, forming a V-shaped outcrop. At the Tierra Rejada their relations to the sedimentary rocks can be clearly interpreted. Here the igneous rocks, comprising mud flows and vesicular and dense varieties of lava, have evidently covered the Sespe beds to a thickness of about 150 feet and in turn are overlain by sandstone strata containing a

Miocene fauna of Topanga age. Later eruptions have occurred, for basaltic rock intrudes Topanga sandstone north of Newbury Park; and west of the Tierra Rejada igneous rocks rest on Modelo diatomaceous shale. Basalt of approximately the same age also occurs in the Modelo on the south side of the San Gabriel Mountains.

At the west end of Tapo Ridge, north of Simi Valley, a small body of what appears to be either basalt or diabase is present as a sill in the Vaqueros formation. Another intrusion of a similar rock occurs in the Topanga formation at the head of Browns Canyon. This mass lies immediately above the Santa Susana fault and with Modelo strata has been thrust over the Saugus formation. (See Pl. XI, *A*, p. 100.)

An intrusive mass of very fine-grained hornblende andesite in which hornblende has been replaced by pyrite forms the crest of South Mountain. It has come in between the Sespe and Vaqueros formations, but where the andesite is thickest the Vaqueros has been entirely cut out and the andesite is in contact with Modelo shale. The outcrop of this igneous rock extends for 2 miles along the top of the mountain and forms a very prominent feature in the topography, as it stands out in a high bluff above the softer sedimentary rocks. At the contacts the soft sandstone and shale have been baked and brecciated, so that in places they are difficult to separate from the andesite itself.

The following description of this rock, a hornblende andesite in which hornblende has been replaced by pyrite, was written by N. L. Taliaferro, of the University of California:

> Under the microscope the rock is seen to be made up almost entirely of feldspar and secondary pyrite.
>
> The feldspar is in only one generation and occurs as small lath-shaped crystals. These crystals are closely packed together and approach the pilotaxitic texture; they also commonly show fluxion phenomena. In the section examined nearly all were lath-shaped; however, a few more or less equant individuals were seen, and it is probable that most are tabular, parallel to the side pinacoid. Nearly all are twinned according to the albite law, and the twinning frequently is repeated even on the most minute laths. One section parallel to the side pinacoid showed pericline twinning. The largest individual noted was 0.11 by 0.08 millimeter, and the majority are under 0.05 millimeter in length. Zoning is frequent, and it is best seen in section parallel to 010, but may also be seen in the 001 to 100 zone. The feldspar seems to vary from a medium andesine to andesine-oligoclase.
>
> The pyrite occurs in small anhedral grains and exceptionally as anhedral crystals. It is quite abundant and evidently secondary, being a replacement of some ferromagnesian mineral. Occasionally there are definite lath-shaped areas made up of pyrite grains, and one or two cross-sections resembling hornblende were seen. The flow lines, shown by the feldspars, wrap around the larger pyrite areas. No glass is present.

A few small intrusive masses of a basaltic rock occur in the Martinez formation on the north side of the Simi Hills, south of the town of Simi. No definite age can be assigned to these rocks, but it is likely that they belong to the intrusions which took place during the Miocene.

The only record of igneous activity later than the Miocene is that afforded by one small basaltic sill, about 15 feet thick, which cuts the Saugus formation near the highest point on the ridge between Las Posas and Santa Rosa creeks, about 2 miles east of Somis.

STRUCTURE.

GENERAL FEATURES.

The structure of the region mapped on Plate I (in pocket) is typical of the California Coast Ranges, which comprises a series of more or less parallel folds, in places tightly compressed and complicated by faulting. In general, the direction of the structural axes of the Los Angeles-Ventura region is more nearly east than that of the Coast Range proper, and this trend is strikingly reflected in the topography. (See Pl. VIII.) The Los Angeles-Ventura region is a part of the province that includes the Santa Ynez, Topatopa, and Santa Monica mountains, all of which have an approximate east-west direction. A large part of the deformation in these mountains occurred in comparatively late geologic time, and the Tertiary and lower Pleistocene beds have been folded almost as much as the older beds. (See Pl. II, in pocket.) Two main periods of general deformation are indicated by a study of the structure of southern California—one at the end of the depositional period represented by the Modelo formation (upper Miocene) and the other during the Pleistocene epoch, after the deposition of the upper Pliocene and Pleistocene Saugus formation. The folding and faulting did not take place all at once in either period, as some of the strata were folded more than others and younger deposits were laid down upon the upturned and eroded edges of the older beds, and it is largely on this evidence that the different formations have been separated. That these deformative movements are now in progress is evident from the earthquakes that occur now and then in California, caused by slips in the earth's crust. Besides these major uplifts at the end of the depositional periods represented by the Modelo and Saugus formations, movements also took place at the end of Cretaceous time, after the deposition of the Martinez, Meganos, Tejon, Vaqueros, Mint Canyon, and Pico formations.

Evidence such as the reverse fault along the south front of the Santa Susana Mountains and the closely compressed and in places overturned folds indicates that this deformation resulted from compressive stresses exerted in a north-south direction. This does not necessarily mean that a block has been pushed southward, but that a zone of compression was caused in the region lying south of the crystalline rocks of the southern Coast Ranges and Tehachapi Mountains, against which, as a rigid mass, the relatively pliable bedded sedimentary rocks were folded and faulted. It is likely that there was also a rigid block to the south of the Santa Monica Mountains which may be represented in the crystalline rocks of Santa Barbara and Catalina Islands. Thus, if there were a shortening of the distance between these two masses, the comparatively soft strata between would be squeezed so as to produce folds and faults such as are found in the region under discussion.

For convenience in describing the structure of the Los Angeles-Ventura region it may be divided into three areas, the main division, however, being based on the San Cayetano-Santa Susana fault, which separates the area mapped into two nearly equal parts. These divisions are as follows:

1. The area north of the San Cayetano-Santa Susana-Sierra Madre fault, which includes the district north of Santa Clara River, the Santa Susana Mountains, the Soledad Canyon area, and the west end of the San Gabriel Mountains.

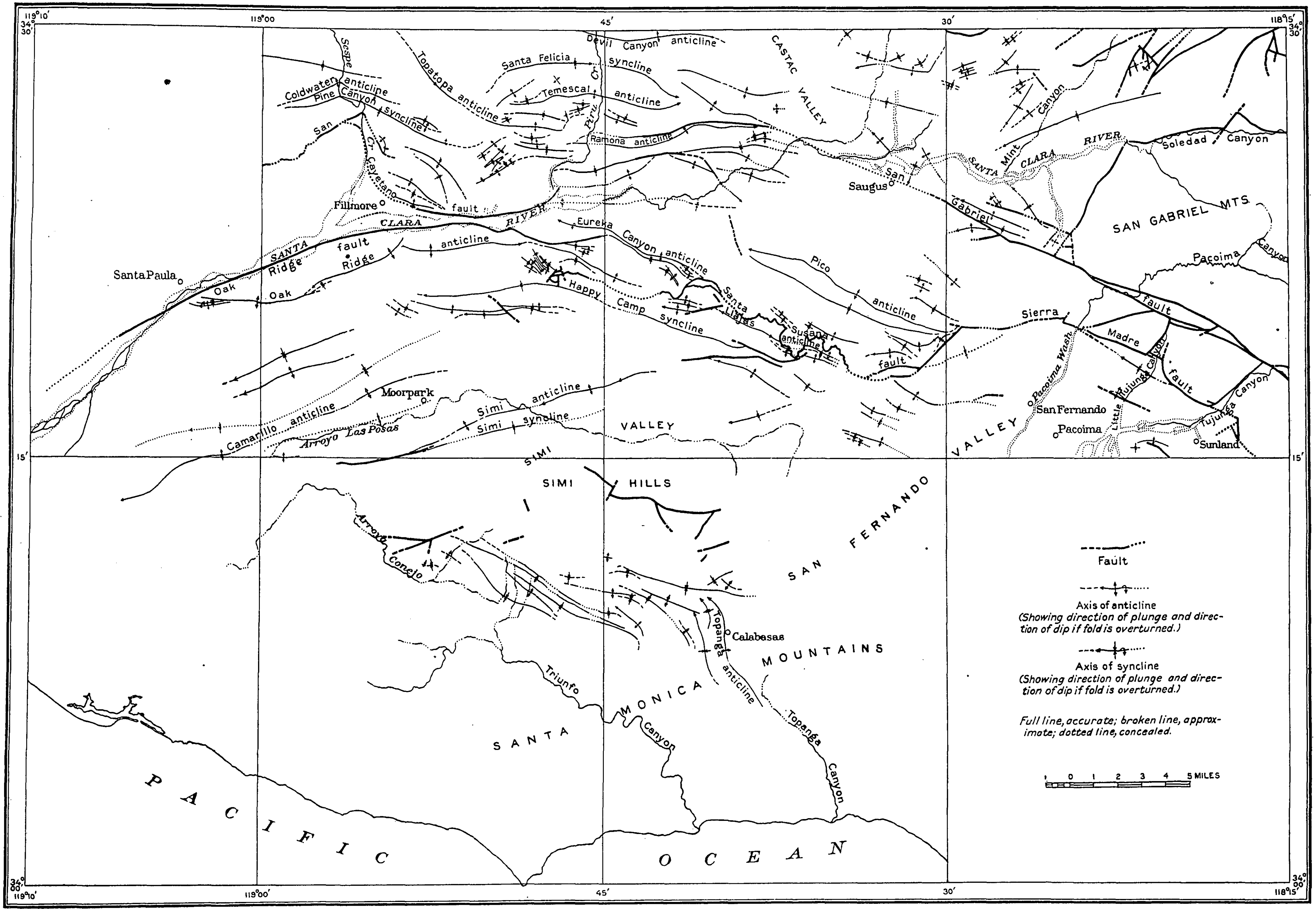
2. The area south of the San Cayetano-Santa Susana-Sierra Madre fault, which includes South Mountain, Oak Ridge, Simi Valley, the Simi Hills, and San Fernando Valley.

3. The area south of the Simi Hills, which comprises the Calabasas country and the Santa Monica Mountains.

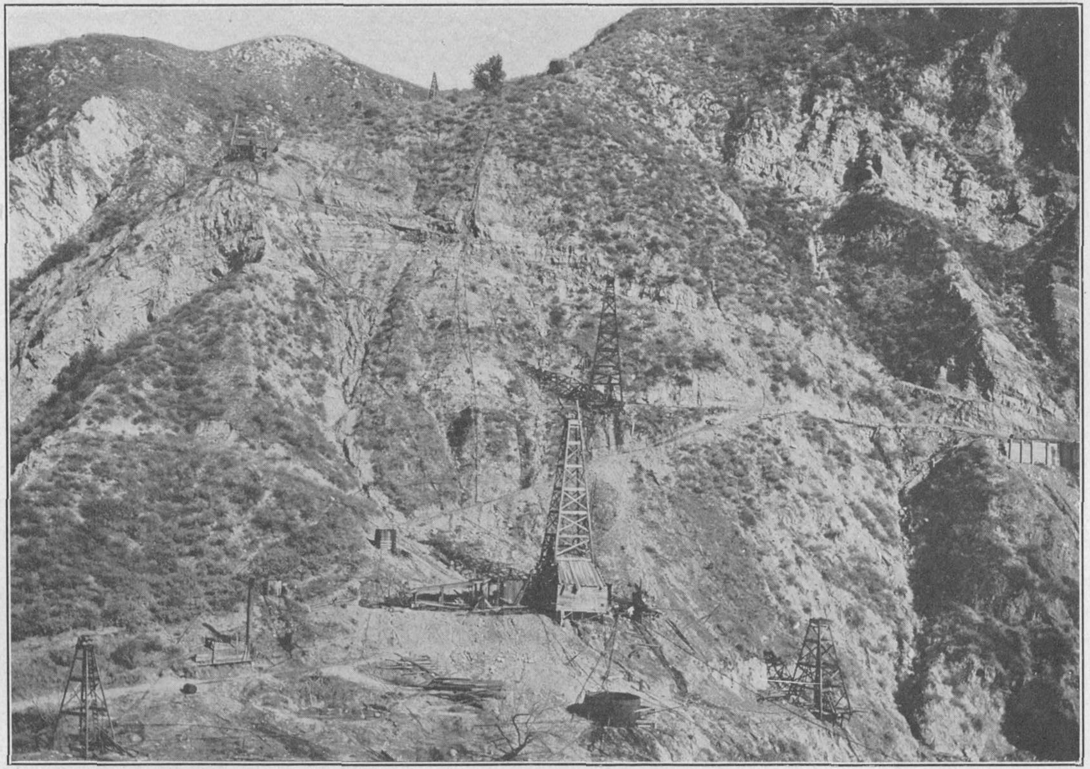
STRUCTURAL DETAILS.

NORTH OF SAN CAYETANO-SANTA SUSANA-SIERRA MADRE FAULT.

The dominant structural feature of the area north of Santa Clara River is the southeastward continuation of the Topatopa anticline. (See Pl. VIII.) Although little is known of this large fold, it can be seen from some of the higher points in this region to lie immediately north of the Sespe Creek district, extending westward for a long distance. It is composed of the hard rocks of the Eocene formations, which, plunging to the east, are in turn wrapped about with younger Sespe, Vaqueros, Modelo, Pico, and finally Saugus strata. This fold, on which the oil wells on Bear and Elm creeks are drilled, trends southeastward, crossing Hopper Canyon about 2¾ miles above its mouth (see Pl. IX), whence it continues down Modelo Canyon. This fold is the one on which the Modelo Canyon oil field is located. On the ridge between Hopper and Oat mountains the anticline is very broad and is practically only a wide swing in the beds. However, east of this ridge the Modelo shales and sandstones have been so folded and buckled that they are commonly tilted to very high angles and considerably crushed. (See structure section D–D′, Pl. II, in pocket.) The amount of deformation is greater



SKETCH MAP OF THE LOS ANGELES-VENTURA DISTRICT SHOWING DISTRIBUTION AND TREND OF THE ANTICLINES, SYNCLINES, AND FAULTS, AND THEIR RELATION TO THE MORE PROMINENT DRAINAGE FEATURES OF THE REGION.



TOPATOPA ANTICLINE IN HOPPER CANYON, VENTURA COUNTY.

Looking east across Hopper Canyon, showing wells of Ventura Pacific Oil Co. (Hopper Canyon field) on anticline in shale and sandstone of Modelo formation (upper Miocene). Photograph by Ralph Arnold.

east of Hopper Canyon, but toward Blanchard Canyon the fold becomes so broken that it can not be traced farther. The folding in the region, even as far east as Castac Creek, is probably a result of the forces that produced the Topatopa anticline, but here several axes were formed instead of one.

West of Sespe Creek, in the northwest corner of the Camulos quadrangle, the Sespe red beds occupy a broad flat syncline which has formed what is called the " plateau," an area which almost perfectly reflects the structures. (See section B–B′, Pl. II.) South of this simple fold the structure changes to that of a closely compressed anticline and syncline, the former being known as the Coldwater anticline, from its location in Coldwater Canyon and the latter as the Pine Canyon syncline. (See Pl. IV, *A*, p. 30.) The Coldwater anticline can not be traced beyond Oat Mountain. On the other hand, the syncline extends to Hopper Canyon and possibly nearly to Modelo Canyon, though it is interrupted by subsidiary folds. Minor buckling is present along the San Cayetano fault in the vicinity of Sespe Creek.

Taken as a whole, the region between Sespe Creek and Castac Valley is characterized by a great number of folds. (See Pl. VIII.) The folds in the Modelo strata are more complicated than those in the Pico and Saugus strata, but this may be due to a dying out of the compressive forces toward the east, or to the alternations of sandstone and shale in the Modelo, which appears to be fairly pliable. As mentioned above, the principal fold is the continuation of the Topatopa anticline, but many other folds were formed at the same time, and in a general way all the axes are parallel. The Devil Canyon anticline is one of the larger anticlines. (See structure section E–E′, Pl. II.) It lies near the north edge of the area mapped, crossing Devil Canyon and extending to Loma Verde, where it dies out in the Pliocene formations. Another large fold, the Temescal anticline, crosses Piru Canyon between Holser and Oak canyons and forms a prominent structural feature in this region. It is also important in that it may be favorable for the accumulation of oil, as some of the Modelo and Pico strata involved in the folding are saturated with petroleum. The Nigger Canyon anticline, confined to the Modelo strata, is considerably compressed and is overturned at its east end. A large syncline called the Santa Felicia syncline extends down Reasoner Canyon, crossing Santa Felicia Canyon, but dies out at the divide east of Piru Canyon. This syncline is rather broad, but in the vicinity of Piru Canyon the strata are tilted very steeply, much more steeply than on either end.

Santa Clara Valley east of Piru is broadly synclinal, the strata composing the Santa Susana Mountains forming its south limb. A number of folds confined entirely to the Fernando group extend in an east-west direction. (See structure section F–F′, Pl. II.) The axis of the main syncline underlies the channel of Santa Clara River and may possibly continue westward nearly to Fillmore, its continuation depending on whether the structure beneath the river is one of faulting or folding. A closely parallel anticline and syncline are the other two major folds in the Pliocene beds north of the river. The dips on these folds average between 40° and 50° in Holser Canyon, but east of the divide they decrease to 20° or 25°. The folds can not be traced farther than the point opposite Castac, though they may continue a short distance under the terrace covering. Other folds of some prominence lie in Hasley Canyon, and extend from the divide east to Castac Valley. None of the strata involved in these folds dip over 25°, and the folds plunge regularly to the east. A few other minor folds are present along the north side of Santa Clara River, and some of them cross to the south side.

North of Saugus there are a few folds of relatively small size both in the Saugus formation and in older rocks, and these may be of some economic importance, owing to the fact that an oil sand is known to occur in the Saugus north of the valley. (See structure sections I–I′ and K–K′, Pl. II.) A sharp westward-plunging anticline, or what it may be more nearly correct to call an abrupt and marked flexure in the strike of the beds, is present opposite Saugus between San Francisquito and Dry canyons. This fold, which can be plainly seen from the town of Saugus, has a plunge of at least 10°. About 3 miles to the north, in the northeast corner of the Santa Susana quadrangle, there is another anticline of considerable size. (See Pl. VII, *A*, p. 53.) It starts in the Mint Canyon formation northeast of Haskell Canyon, but where it enters the Modelo (?) formation it makes a nearly right-angle bend, turning west and continuing on the west side of San Francisquito Canyon. This anticline plunges steeply to the west. Between these two anticlines the strata dip at low angles toward the axis of a shallow syncline which trends in an easterly direction, about midway between them.

The Mint Canyon formation, which composes the eastern part of the Santa Clara Valley synclinorium, has been folded into numerous synclines and anticlines in the upper Santa Clara Valley and Deadman Canyon. These folds are relatively short, as a rule, though where traceable the dips are moderately high, ranging from 15° to 30°. All the folds have a northeasterly direction north of Santa Clara River. South of the river the trend is northwest. The folding of the Mint Canyon formation took place both before and after the deposition of the Saugus formation (upper Pliocene and Pleistocene), as the strata of the Saugus are relatively little folded in the vicinity of Mint Canyon.

As stated above, the Santa Susana Mountains and the east end of Oak Ridge represent a faulted anticline, only the north flank remaining, which comprises the south limb of the Santa Clara Valley synclinorium. (See structure section I–I′, Pl. II.) Except at the top of the ridge, all the beds are steeply tilted and in a number of places are overturned. Vertical, or nearly vertical strata extend from Torrey Canyon eastward to the Santa Susana Mountains, where they gradually lessen in degree of dip, though they still maintain dips of 65° along the Pico anticline. East of Wiley Canyon, however, the dips do not exceed 50°, but at the east end of the mountain the strata are considerably twisted and stand nearly vertical. Although the broad Santa Clara River channel separates this area from the northern area, it is thought that the structural features are continuous across the river and not entirely distinct, as Eldridge[53] believed. (See structure sections C–C′ and D–D′, Pl. II.) Eldridge evidently failed to recognize the fault that crosses Torrey Canyon and correlated the Vaqueros formation involved in the Oak Ridge anticline with typical Modelo sandstone of Torrey and Eureka canyons. This necessitated calling all the pre-Fernando formations on the Santa Susana Mountains Vaqueros and thus placed an entirely different interpretation on the structure.

The structure of the Modelo strata from Torrey Canyon to the Santa Susana Mountains is extremely complicated and very difficult to unravel. (See structure sections E–E′ and F–F′, Pl. II.) Many of the beds stand nearly vertical or are in places overturned, so that the standstone in Eureka Canyon appears to be a continuous section from the shale through the Pico formation. The principal structural feature in Eureka Canyon is a closely compressed anticline, the axis of which extends up the bottom of that canyon and continues eastward across the headwaters of Tapo Canyon (north), where the fold is somewhat crumpled and finally is cut off by the Santa Susana fault. This fold is overturned toward the north, as is shown by the southerly dips along the ridge on the north side of Eureka Canyon. This overturning is represented by dips as low as 45°. The Pico, though overturned, rests upon the Modelo unconformably and near the mouth of Eureka and Torrey canyons crosses the strike of Modelo sandstones obliquely. Between Oak Ridge and the Santa Susana Mountains sandstone of the Modelo is greatly deformed and at least two small folds, an anticline and a syncline, are present. Several small folds occur in the shale on the north side of Oak Ridge, but on the south side the Oak Ridge anticline extends between the Santa Susana fault and the fault in Torrey Canyon, which is considered to be the continuation of the San Cayetano fault. The fold is discussed beyond (pp. 160–161).

[53] Eldridge, G. H., U. S. Geol. Survey Bull. 309, p. 29, 1907.

The Pico anticline and its accompanying syncline to the south are well-defined folds that extend along the north flank of the Santa Susana Mountains for nearly its entire distance, ending against the basement complex of the San Gabriel Mountains. (See structure section I–I′, Pl. II.) The Pico anticline is important in its relation to oil, as along it are the Pico Canyon and Wiley Canyon fields, the former the oldest in California. Except at the east end, the folding is entirely within the Modelo sandstone and shale; the shale is exposed along the axis of the anticline in Dewitt Canyon and in a wider area between Towsley and East canyons. In general the anticline is tightly folded (see Pl. XVII, *A*), more so than the syncline; the dips average 60° in the vicinity of Pico Canyon but are somewhat less steep on the south flank farther east, so that the fold is asymmetric. At the east end of the Santa Susana Mountains the strata dip about 30°–45° and the anticline plunges rapidly under the Pico formation. It rises again east of Fernando Pass and probably forms the nose of Pico and Saugus strata that encircle the crystalline rocks of San Gabriel Mountains. The syncline is a prominent fold in massive Modelo sandstone, and it is reflected in the topography of the country in that it follows for several miles the bottom of Towsley Canyon and to a less extent Rice Canyon. The dips in this fold are regular near the axis, averaging between 45° and 60° but becoming less toward the top of the mountains.

The crest and south slope of the Santa Susana Mountains above the fault are formed almost entirely of Modelo shale, which, though crumpled, generally dips gently (about 20° N.). (See structure section I–I′, Pl. II.) Near the Santa Susana fault several small folds or crumples occur in the pliable shale, such as would be expected along the fault line. At the east end of the mountains, in the upper part of Aliso Canyon, all the beds appear to dip away from a central point. Owing in part to erosion by the creek, the lower sandstone member of the Modelo has been exposed.

A great deal of crumpling and to some extent fracturing has taken place just east of Mission Point and in the vicinity of Fernando Pass. The structure in this area is rather complex, for the sedimentary rocks have undergone the twisting that necessarily takes place during diastrophism where pliable rocks join a rigid granitic and metamorphic mass. (See structure section K–K′, Pl. II.) The result has been the formation of a few short folds, together with crumpling and breaking of the beds in Bee and Grapevine canyons. The Elsmere Canyon oil field is on a noselike small fold or flexure caused by the warping of the Pico and Saugus beds about the basement complex. The axis of this fold can not be traced with any degree of certainty west of Elsmere Ridge. Between Elsmere Canyon and Placerita Canyon the strata all dip gently to the northwest, away from the basement complex. On the north side of Placerita Canyon, in secs. 31 and 32, T. 4 N., R. 15 W., there is a small plunging fold with a westerly trend, which is a very minor feature structurally. but is mentioned here for the reason that it may have an important economic bearing.

The sedimentary rocks on the north side of the San Gabriel Mountains are separated from the basement complex of the mountains by two faults that intersect each other at right angles. One has a trend of N. 65° W. and follows Placerita Canyon for a short distance, east of which it extends into the San Gabriel Mountains. This fault cuts both the Mint Canyon and Saugus formations, so the movement must have taken place after the deposition of the Saugus beds and probably occurred during the general diastrophic disturbance in Pleistocene time. (See structure section L–L′, Pl. II.) The other fault trends about N. 30° E. from its junction with the San Gabriel fault toward Santa Clara River near Lang Station. This fault extends east up Soledad Canyon beyond the edge of the area mapped, at least as far as Ravenna. At the contact with the granite the sedimentary beds usually dip gently away from it, though in places they are nearly flat with low dips here and there toward the granite. Relatively little crushing has taken place in the sedimentary rock except in a narrow zone, but the Mint Canyon clay and soft sand are considerably brecciated within the angle formed by the faults east of Placerita Canyon. The granite, however, is brecciated in places for a width of 300 feet.

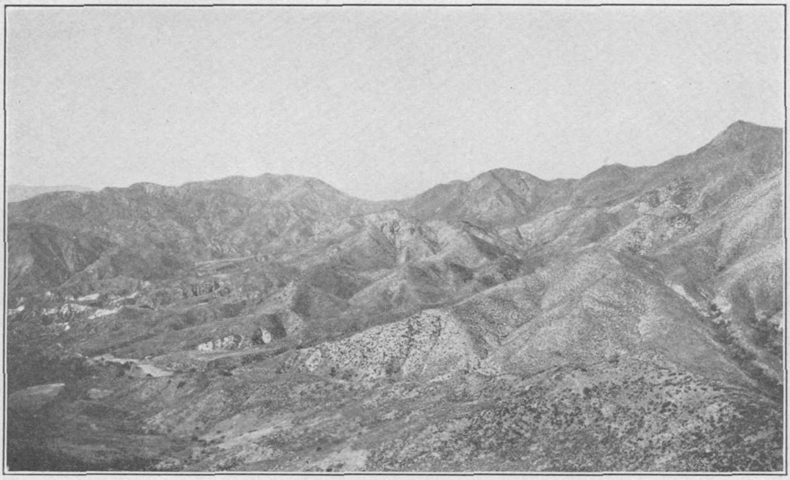
A prominent fault, designated the San Gabriel fault, extends along the south side of the San Gabriel Mountains from Tujunga Canyon northwestward along the upper part of Little Tujunga Canyon and across the divide between Pacoima Canyon and Santa Clara River. (See Pl. X, *A*, *B*.) Beyond the crystalline rocks this fault follows the north side of Placerita Canyon and extends down Santa Clara River to Castac Valley, whence it continues in the same direction through the hills to Holser Canyon, where the fracturing passes into close folding. The San Gabriel fault is particularly well exposed in the upper part of Little Tujunga Canyon, where it has split, with blocks of Modelo (upper Miocene) rocks dropped down between the fractures. Topographic features usually associated with faulting are present along the trace of this fault. At the east edge of the area mapped on Plate I the fault divides again, the main fracture extending beyond this area to the east and west forks of San Gabriel River. Where exposed the dip of the fault plane is 75° or more to the north. (See structure section M–M′, Pl. II.)

Two small faults, a short distance north of the San Gabriel basement complex and west of Sand Canyon, trend parallel to the San Gabriel fault. One of these is very short and perhaps is only a comparatively large break in the crumpled strata that lie in this locality. The larger one has a direction of N. 70° W. and is closely parallel with the San Gabriel fault in Placerita Canyon. This fault cuts both the Mint Canyon and Modelo (?) strata. It does not affect the Pliocene strata, which cover it south of Humphreys Station, and therefore must have been formed prior to the deposition of the Pico formation.

SAN CAYETANO-SANTA SUSANA-SIERRA MADRE FAULT.

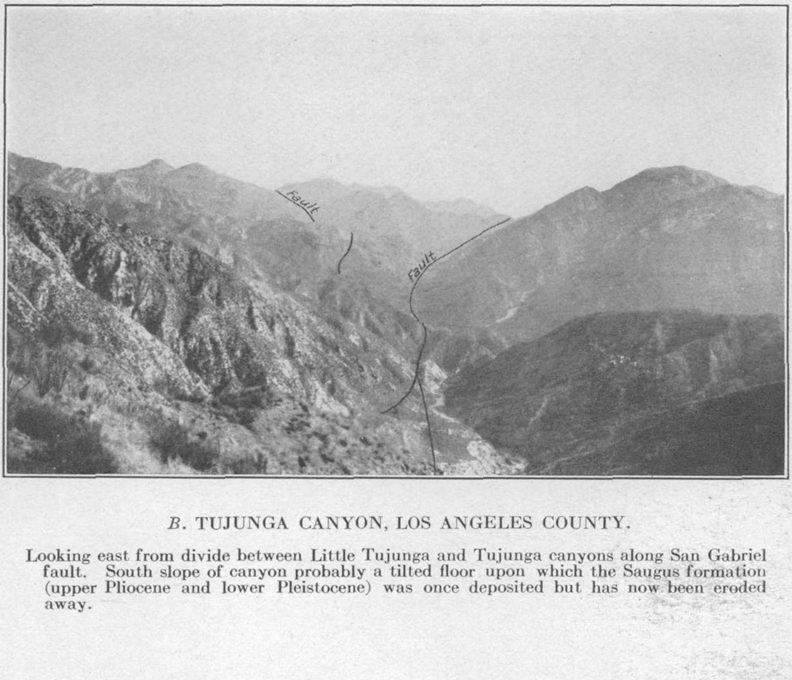
The San Cayetano-Santa Susana-Sierra Madre fault (see Pl. VIII, p. 94) is one of the major structural features of the region, as it forms a distinct dividing line between two areas that are somewhat different both structurally and stratigraphically. (See Pl. I.) This fault, which comprises three more or less distinct faults, extends the entire width of the area mapped and is known to continue westward beyond San Cayetano Mountain into the Ojai Valley country. West of Sespe Creek it is known as the San Cayetano fault. East of the Santa Susana Mountains it extends along the south side of the San Gabriel Mountains, where it is called the Sierra Madre fault. The faulting is of the reverse type—that is, the older beds are elevated relative to the younger beds and in some places are thrust over them. (See structure sections, Pl. II.) This characteristic is clearly evident on examination of the sinuous trace of the fault on the south side of the Santa Susana Mountains. West of Sespe Creek the Eocene strata have been shoved over the lower Pliocene Pico formation. East of Sespe Creek the fault plane or trace is not visible, as it is covered by the alluvium of Santa Clara River and Sespe Creek, but the Modelo strata here have been completely folded and broken, the flexures and fracturing being too small and numerous to show on the map. The fault in the vicinity of Torrey Canyon is the east end of the San Cayetano fault. Here, however, younger rocks are on the upthrown side. Evidently the displacement in this locality was not so great, and the stresses were taken up in close folding, which is well shown in this general area. The area between the San Cayetano and the Santa Susana faults is also made up of closely folded strata, as is indicated on the geologic map (Pl. I). This condition is probably due to the fact that the strata here are more pliable and softer, consisting largely of shale and soft sandstone and gravel. No well-cemented mass such as that formed by the hard Eocene and Oligocene (?) rocks of Sespe Creek is present.

The Santa Susana fault begins opposite Torrey Canyon, on the south side of Oak Ridge. Here again a relatively small amount of displacement has occurred, and the dip of the fault plane is approximately vertical. As the north end of the Simi Hills is approached the



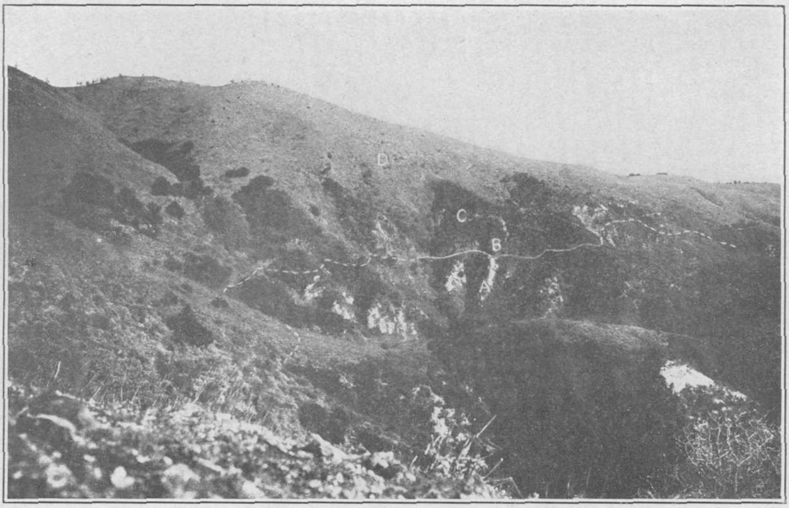
A. LITTLE TUJUNGA CANYON, LOS ANGELES COUNTY.

View along San Gabriel fault from divide between Little Tujunga and Tujunga canyons, looking northwest to divide between Pacoima Creek and Santa Clara River. Note light-colored beds of Saugus formation on extreme left.



B. TUJUNGA CANYON, LOS ANGELES COUNTY.

Looking east from divide between Little Tujunga and Tujunga canyons along San Gabriel fault. South slope of canyon probably a tilted floor upon which the Saugus formation (upper Pliocene and lower Pleistocene) was once deposited but has now been eroded away.

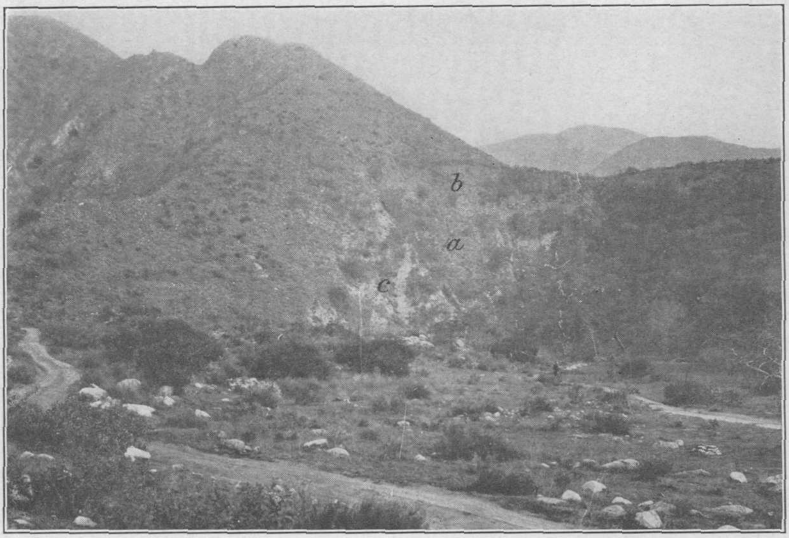


A. THRUST FAULT ON SOUTH SIDE OF SANTA SUSANA MOUNTAINS.

Looking east across head of Browns Canyon. Dashed line shows trace of fault plane. A, Folded fossiliferous white sandstones of Saugus formation (upper Pliocene and lower Pleistocene); B, basaltic igneous rock (upper Miocene); C, Topanga formation (middle Miocene); D, Modelo siliceous and diatomaceous shale (upper Miocene).

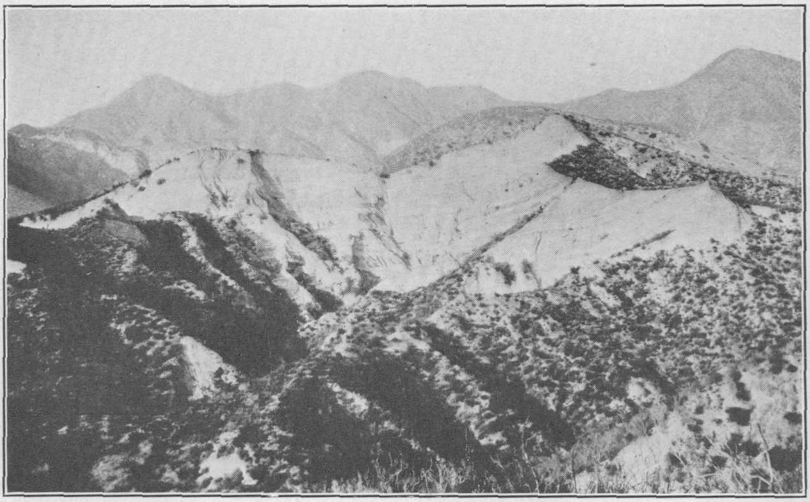
B. TORREY CANYON OIL FIELD ON OAK RIDGE.

Looking northwest across Smith and Torrey canyons along north side of Oak Ridge; Santa Clara Valley in right distance. Photograph by George H. Eldridge.



A. SIERRA MADRE FAULT IN LITTLE TUJUNGA CANYON.

Plane of Sierra Madre fault at south scarp of San Gabriel Mountains in Little Tujunga Canyon; gently dipping Saugus formation (upper Pliocene and lower Pleistocene) (*a*) overlain by terrace gravel (*b*), faulted against crystalline rocks of basement complex (*c*).



B. SAUGUS FORMATION RESTING ON BASEMENT COMPLEX AND DIPPING NORTH TOWARD SAN GABRIEL MOUNTAINS.

Conglomerate and sandstone of Saugus formation on Gold Creek resting upon basement complex and dipping north to San Gabriel fault and against the main mass of the mountains.

fault plane gradually flattens, and here it has a greater horizontal displacement. This is thought to have been the result of thrusting against the rigid buffer-like mass of the Simi Hills, formed of the massive Cretaceous beds, which are not easily folded like the beds both east and west of the hills. It is only between the Simi Hills and the Santa Susana Mountains that the greatest amount of faulting has taken place, and this has been accompanied by the formation of a series of small tight folds, some of which are overturned. At the head of Browns Canyon the fault is clearly exposed and the shale and sandstone of the Modelo can be seen to overlie the fossiliferous strata of the Saugus formation. (See Pl. XI, *A*.) East of Browns Canyon the plane of the fault again becomes nearly vertical. The direction of the fault changes to N. 70° E. in the vicinity of Fernando Pass but resumes an easterly and then southeasterly course along the foot of the San Gabriel Mountains. The break in continuity of the fault is probably the result of complex stresses that take place at the junction of the sedimentary rocks with the solid crystalline mass of the San Gabriel Mountains. Subsidiary faults accompany the main one at the southwest end of the Santa Susana Mountains and at the head of Dry Canyon, a tributary of Tapo Canyon. Double faults are of common occurrence in the typical thrust faults, such as those of northern Scotland. Between the two faults the strata are greatly broken, and this may correspond to the imbricate structure that is another characteristic of true thrust faults.

East of Fernando Pass this fault follows closely the edge of the crystalline rocks forming the San Gabriel Mountains and usually marks the contact between them and the sedimentary strata. Although the plane of the fault dips steeply (55° or more) to the south (see Pl. XII, *A*), the trace is by no means straight. Furthermore, it is complicated by a number of cross faults, which have broken the rocks between this fault and the San Gabriel fault, to the north, into blocks tilted northward. Three main cross faults occur at the heads of Buck, Little Tujunga, and Tujunga canyons. The movement on all the faults appears to have taken place in a vertical direction, the crystalline mass having been uplifted with respect to the sedimentary rocks on the south. (See structure sections L–L′ and M–M′, Pl. II.) The movement occurred along this fault and that to the north during the Pliocene epoch and has continued to Recent time.

SOUTH OF SAN CAYETANO-SANTA SUSANA-SIERRA MADRE FAULT.

The dominant structural features of the area lying between the San Cayetano-Santa Susana-Sierra Madre fault and the Simi Hills are the Oak Ridge anticline and the Simi Valley synclinorium; the latter is the larger feature of the two. (See Pl. I.) The general direction of the folding is about N. 75° E. Except in the vicinity of the Santa Susana fault, which it parallels with a direction of N. 70° W., the folding south of the fault has not been nearly so strong as that north of it. Minor faulting has taken place along the folds, together with tight folding and overturning.

The Oak Ridge anticline is economically the most important structural feature within the region, for along it are the largest oil fields producing high-grade oil in Ventura County. It is not one uninterrupted fold but is made up of three and probably four elongated domes whose axes overlap to a small extent. These axes form a generally continuous line, and if the domes were seen from a distance they would appear as a single anticline. The crest of Oak Ridge does not coincide with the crest of the fold, which is in general far down the north slope, in the vicinity of Bardsdale and close to the Santa Clara River channel. (See structure sections A–A′, B–B′, and C–C′, Pl. II.) Where eroded the Sespe formation has been cut into badlands, and cirquelike excavations have been formed in the north slope of the ridge. This is well shown on South Mountain and in Shiells Canyon. (See Pl. XIV, *A*, p. 164.) The fold is asymmetric, the north side being the steeper. The south flank in places shows very low dips, as low as 5° a short distance away from the axis, but gradually steepening up to 30° or even 40° along the top of the ridge. On the north side the dips are generally high, and in places the beds are overturned, as at South Mountain. Two anticlines are present here, between the overlapping ends of which there is a shallow syncline. The main anticline plunges both west and east from a point in Willard Canyon, but to the west both folds plunge under the sands of the river. To the east the main fold continues, plunging in that direction, to the east side of Sulphur Canyon, where it dies out. At this place another fold commences, which can be traced to Willow Grove School, southeast of Fillmore. The highest part of this fold is on the west side of Grimes Canyon, where the Bardsdale oil field is situated. There is probably another slight rise near Willow Grove School, beyond which the fold may continue to the north below the river gravel. Another fold, meeting this, extends in an easterly direction to Torrey Canyon, whence it turns southeastward along the top of Oak Ridge, between the San Cayetano and Santa Susana faults. Along this fold there are three distinct domelike areas, or "humps"—at Shiells, Wiley, and Torrey canyons. Another rise in the fold is present also where this anticline meets the one to the west near Willow Grove School. These "humps" are clearly shown on Plate I, where the Vaqueros and Modelo strata are mapped as encircling the Sespe formation. Upon this fold are the Montebello oil field, in Shiells and Guiberson canyons, and the Torrey Canyon oil field.

The Simi Valley synclinorium or basin of deposition (see structure sections D–D′ and H–H′, Pl. II) contains within it a number of folds, of which the largest are the Simi anticline and syncline. The Simi anticline is of considerable economic value at the present time. (See Pl. XIV, *B*, p. 164.) Both folds begin at Tapo Canyon and extend about 11 miles in a southwesterly direction along the north side of Simi Valley to the Tierra Rejada, immediately west of which they merge into a fault on the Las Posas Hills. The anticline is low and flat-topped and plunges gently to the west, though near the mouth of Brea Canyon it is slightly domed. For the greater part of its length the anticline is asymmetric, the south limb being the steeper. The beds on the north limb have a rather uniform attitude, dipping from 20° to 35° N., the gentler dips toward the west. The south limb at Tapo Caynon dips about 20°, abruptly away from the axis of the fold and may be slightly faulted. The south dips become steeper toward the west until north of the Tierra Rejada the Sespe sandstones dip as high as 50°. The Simi syncline, which is the structural depression forming Simi Valley and the Tierra Rejada, is a broad asymmetric fold whose axis extends down the north side of the valley and across the Tierra Rejada, passing into the fault on the Las Posas Hills south of Moorpark. The south limb of the fold, the broader limb, dipping gently to the north under the valley, forms the Simi Hills, in which the Oligocene (?), Eocene, and Cretaceous rocks dip from 25° to 65° N., the angles being greater to the west and toward the top of the hills. Another syncline crosses the Simi Hills north of Santa Susana Pass. This is short and broad and plunges steeply to the west under the alluvium. It is closely allied with the Simi syncline, as it forms a part of the synclinal structure of the valley. What may be a continuation of the Simi anticline, or at least the axis of general folding, is the asymmetric anticline in the Chico and Eocene strata at the north end of the Simi Hills. This fold plunges steeply to the west and is truncated by the fault that crosses Las Llajas Canyon.

North of Simi Valley and forming the western part of Tapo Ridge, which extends westward from Tapo Canyon south of Happy Camp Canyon, there is a shallow syncline in Modelo shale, followed to the north by a very asymmetric anticline called the Happy Camp anticline. (See Pl. VIII.) These folds extend from a point a short distance east of the divide between Tapo and Happy Camp canyons nearly to Grimes Canyon. The dip of the north flank of the anticline is as high as 50°. On the other hand, the beds on the south are nearly flat, so that the syncline, lying close to the anticline, is barely perceptible and the structure has the appearance of a monoclinal fold. (See structure section D–D′, Pl. II.) About midway in its length the anticline is broken slightly by a cross fault, west of which it plunges rather steeply into the Saugus formation.

Immediately to the north of the Happy Camp anticline is a very long syncline that extends from a point near the head of Grimes Canyon along Happy Camp Canyon and the upper tributaries of Tapo Canyon and across Las Llajas Canyon nearly to Aliso Canyon, a distance of about 15 miles, and separates the main Oak Ridge and Simi anticlines. The center of the fold is composed of strata of the Saugus formation, the youngest rocks of the region, which have been tilted to a greater degree on the south side than on the north.

West of Simi Valley and Happy Camp Canyon an area of low hills slopes into the Santa Clara River flood plain. This area is underlain in large part by the Saugus formation, which has been folded into two broad anticlines and two synclines (see Pl. VIII), one of which is highly deformed into the prominent domelike uplift that forms the Camarillo Hills, west of Somis. (See structure sections A–A′, B–B′, and C–C′, Pl. II.) The dips on all these folds are less than 10° except on the south side of Oak Ridge and the north side of the Las Posas Hills, where they are as high as 35°. The anticline forming the Camarillo Hills west of Somis is probably a continuation of the southern anticline of the two in Las Posas Valley. The surface of these hills represents the structure of this fold, the top of the hills being the highest point along the axis of the anticline. Over a large part of the hills a stratum of very fossiliferous sandstone covers the surface, dipping more steeply as the edge of the hills is neared. The highest dips are on the south side, northwest of Camarillo, where they attain 35° S. The average dip is 20° to 25° here, but the beds arch regularly over the crest, where they are nearly horizontal for a short distance on either side of the axis. That this fold has been formed in comparatively late geologic time is evident from the fact that the fauna obtained from the beds consists almost entirely of Recent species. The relatively small degree of erosion also indicates a late age for the folding.

Faulting has somewhat complicated the structure on the Las Posas Hills, on the north side of Arroyo Santa Rosa. (See structure section B–B′, Pl. II.) The break here has allowed the south side to drop, thus exposing the Sespe formation and Modelo shale below the Saugus formation. The throw along this fault has not been very great, probably not more than a few hundred feet.

West of the Tierra Rejada some steeply dipping strata of Modelo age appear to be resting normally upon the igneous rock. These beds dip to the north and it is thought that they form the south limb of the westward-plunging syncline which has been truncated at its east end by the fault along the Las Posas Hills. This syncline is probably a continuation of the Simi Valley syncline and may extend down Arroyo Santa Rosa. The steep scarp of igneous rocks along the south side of Arroyo Santa Rosa suggests a fault here, but the structure in this valley is probably synclinal. The south flank of the fold has been in part removed by erosion and covered by valley alluvium.

Along the foot of the steep slope of the Santa Susana Mountains is a zone of acute folding, together with minor faulting. The most pronounced structural feature is the Llajas anticline, which exposes the Meganos formation (middle Eocene) along its axis for about 3 miles west of Aliso Canyon. This fold, which plunges to the west, is faulted immediately west of the Los Angeles-Ventura County line, but probably continues beyond as one of the folds that cross Dry Canyon. East of Aliso Canyon it very probably extends below the lobe of Modelo shale lying above the Santa Susana fault plane and connects with the north anticline at the head of Browns Canyon. Owing to the covering of terrace gravel and the brecciation of the soft beds along the fault the folds can not be traced beyond the east fork of Browns Canyon. The Llajas anticline plunges both east and west from a point near Las Llajas Canyon. This fold is fairly symmetrical, with dips as great as 40° on both flanks. Other folds along this same zone are confined to the Modelo and Saugus formations and in places are tightly compressed and overturned, as is illustrated by the north anticline in Dry Canyon and the south anticline in Browns Canyon.

Several folds occur in the hills along the north side of San Fernando Valley (see Pl. VIII), which extend from the Chico rocks, or from the overthrust side of the Santa Susana fault, in a southwesterly direction toward the valley. All are confined to the Saugus formation, which is overlain to the northwest by terrace gravel. The structural features of this area consist of three anticlines and three synclines, together with a minor synclinal pucker near the mouth of Limekiln Canyon. The most distinct fold is that between Bull and Aliso (east) canyons. (See structure section K–K′, Pl. II.) This is a symmetrical anticline trending slightly northwest, toward the mountains. The other folds lying to the southwest appear to plunge toward the valley. The folding at the mouth of Limekiln Canyon is peculiar in that beds dipping 70° S. are traceable along the south face of the hills on the west side of the canyon, and the attitude of these beds contrasts strongly with the general dip of the strata, which is not more than 15° along the top of the fold. This condition suggests that the less deformed beds are slightly folded terrace deposits overlying the Saugus formation and perhaps do not represent anticlinal folding in the older beds. The low range of hills between Bull Canyon and the town of San Fernando consists of a northward-dipping series of Saugus strata faulted against the Pico (?) shale. Southerly dips are present in this shale near the Los Angeles Aqueduct reservoir and in the Saugus formation southwest of the reservoir. This attitude, together with the fact that Pico (?) shale crops out here, indicates either that the anticline between Bull and Aliso canyons extends along the valley edge toward San Fernando, or that a fault is present along the south edge of the hills. That the axis of the anticline should bend to the east is probable, for the syncline north of Bull Canyon has an east-west direction and the strike of the beds also turns to the east.

The two faults between the Santa Susana Mountains and the Simi Hills, which have somewhat complicated the structure of this area, appear to be of the normal type and were formed prior to the thrusting of the Santa Susana fault. At least this is true of the southern fault, which is overlapped by the Saugus formation, though the northern fault cuts this formation. In both faults the north side has been lowered relative to the south side, and both the Martinez and Meganos formations have been considerably thinned.

The hills at the northeastern edge of San Fernando Valley, on both sides of Tujunga River, are composed of an almost unbroken northward-dipping section of rocks belonging to the Modelo formation and the Fernando group, which rest normally upon the granitic rocks of Verdugo Hills. (See structure section M–M′, Pl. II.) These beds are but slightly complicated by folding. A syncline in the Saugus formation crosses Little Tujunga Canyon, and a thrust fault crosses Kagel Canyon. These features indicate that compressive stresses were exerted during the deformation of this region.

SOUTH OF SIMI HILLS.

The area south of the Simi Hills is a synclinorium of Tertiary rocks that constitutes a westward continuation of the syncline forming San Fernando Valley. The north limb of the syncline, comprising mainly Topanga, Modelo, and Pico strata, rests upon the upturned edges of the Chico strata forming the Simi Hills. Although some faulting is present in the Topanga near Bell Canyon, the contact with the Chico is a normal one and not faulted, as considered by Waring.[54] (See structure sections D–D′ and G–G′, Pl. II.) Faults of pre-Topanga age occur within the Chico area and may account for the steep scarp which these hills present on their south side. On the other hand, this scarp may be due almost entirely to erosion during or prior to the deposition of the Topanga, faulting having played but a minor part in forming it.

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[54] Waring, C. A., Stratigraphic and faunal relations of the Martinez to the Chico and Tejon of southern California: California Acad. Sci., Proc., 4th ser., vol. 7, p. 49, 1917.

A large number of folds having a general northwesterly direction (see Pl. VIII) are found within the central area of Modelo and Pico shale and sandstone, but they merge into two well-defined anticlines and a syncline, which extend into the harder and more rigid rocks of the Santa Monica Mountains. The stresses that produced the folding appear to have acted in both north-south and east-west directions. All the folds extending north from the Santa Monica Mountains have an approximate northerly trend, whereas those of the lower area trend more nearly east. They seem to be closely connected, the folds that come from the south having a distinct turn to the west at their north ends and vice versa. None of the folds are more than 8 miles long, but an anticline and a syncline attain this length northwest of Grape Arbor.

A few large folds extend into the Calabasas area from the Santa Monica Mountains, and of these the largest is the Topanga anticline, which plunges northward from Calabasas Peak, where older rocks, including the Sespe formation, are involved. Each fold dies out on coming into the east-west folded Modelo and Pico strata.

PETROLEUM.

ORIGIN OF THE OIL.

The origin of petroleum has been much discussed all over the world, and a large number of hypotheses have been advanced. All these hypotheses can be classified into two categories, the inorganic and the organic. The inorganic hypotheses find but few adherents at the present time. As a full discussion is given in several papers and publications,[55] only a brief summary of the main hypotheses will be reviewed.

Among the inorganic hypotheses, Berthelot's (1866) was one of the first advanced. He assumed that the earth contained free alkaline metals which, reacting with carbon dioxide, formed acetylides and from them acetylene, which later condensed into higher hydrocarbons. Another was that of Mendeléef, who in 1877 postulated the existence in the interior of the earth of iron carbides, which, on coming into contact with water, formed hydrocarbons. E. Coste has written several papers holding to the theory of the volcanic origin of petroleum and cited the oil fields at Tampico, Mexico, to support it. Others also have advanced inorganic hypotheses, but none of these have yet been proved.

[55] Engler and Hofer, Das Erdöl, vol. 2, pp. 59–142, Leipzig, 1909. Redwood, Boverton, Petroleum and its products, vol. 1, pp. 250–261, 1906. Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, pp. 726–737, 1916. Campbell, M. R., Historical review of theories advanced by American geologists to account for the origin and accumulation of oil: Econ. Geology, vol. 6, pp. 363–395, 1911.

The organic origin of oil is now generally accepted. For a long time it has been known that decayed vegetable matter, such as seaweeds, gives off gases, including methane and other hydrocarbons, and that these reactions can take place even though the matter is buried, but it was largely through the researches of Engler that the belief in the animal and vegetable origin of petroleum was established. Since his time a large number of men have brought together a mass of data tending to show that petroleum has been derived from the decomposition of vegetable and animal remains. Some believe that in certain regions the oil has been derived from fish, others from mollusks, and still others from smaller minute organisms, such as foraminifers, diatoms, and radiolarians. Lesquereux favored the derivation of the Devonian oils from cellular marine plants, such as fucoids, and Watts [56] also suggested this origin for California petroleum, basing his conclusions on the presence of iodine in the analysis.

Salathe [57] in 1892 undertook the investigation in a systematic way of the origin of petroleum in California. From numerous chemical analyses of the oils he found them to contain nitrogen and a number of organic bases of the pyridin and chinolin series, which up to that time had been recognized only in animal tar. He concluded that the petroleum was derived from marine animal matter through a process of slow decomposition. Recent work by Mabery [57a] has confirmed this hypothesis. Watts, a few years later, in discussing the origin of California petroleum, thought that it might have been derived from both the animal and vegetable life that abounded in the sea. Among the sources of this organic matter, brought out by a study of the California formations are foraminifers, diatoms, and seaweeds. That all these organisms contributed to the formation of hydrocarbons is highly probable.

Concerning the origin of the oil in California full discussions have been given by Arnold [58] and more recently by Anderson and Pack.[59] For this reason it is planned to give here only the salient facts of its origin in reference to the occurrence of petroleum in the Los Angeles-Ventura region.

As in the San Joaquin Valley and Santa Maria districts, the oil in the region under discussion is closely associated with shales of organic constitution, and it is the writer's opinion that the oil has been derived from them. In the Coalinga field two such formations

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[56] Watts, W. L., California State Min. Bur. Bull. 19, pp. 201–202, 1900.

[57] Salathe, Frederick, California State Min. Bur. Bull. 11, p. 73, 1897.

[57a] Mabery, C. F., Am. Chem. Soc. Jour., vol. 30, p. 429, 1906.

[58] Arnold, Ralph, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Calif.: U. S. Geol. Survey Bull. 322, pp. 109–113, 1907.

[59] Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Calif.: U. S. Geol. Survey Bull. 603, pp. 194–203, 1915. Pack, R. W., The Sunset-Midway oil field, Calif., Part I: U. S. Geol. Survey Prof. Paper 116, pp. 70–71, 1920.

are present—the Moreno (Upper Cretaceous) and the Kreyenhagen shale (Oligocene?). In the McKittrick, Midway, and Sunset fields, to the south, the oil-bearing strata are intimately connected with the middle Miocene shale of the Monterey group and with the Santa Margarita (upper Miocene) shale.

The middle Miocene shale is also well developed along the coast, where it forms the source for the oil in the Santa Maria district. Two distinct sources of oil are present in the Los Angeles-Ventura region—the Martinez, Meganos, and Tejon formations (Eocene) and the shale of the Modelo formation (upper Miocene), which is probably equivalent in age to the upper Miocene shale in the other districts. Although the older beds do not contain so much organic matter, or evidence of it, as the Modelo, still they contain numerous skeletons of foraminifers, which are readily seen with the aid of a hand lens.

At the time of the deposition of these formations the seas swarmed with countless numbers of minute organisms, which on dying dropped to the bottom and accumulated in the silts or in some places formed oozes consisting almost entirely of their own remains. Of these organisms the diatoms were the most numerous. They are microscopic vegetable organisms which secrete siliceous tests having a great variety of shapes. The foraminifers, somewhat larger than the diatoms, have tests of various rounded and elongated shapes made of calcium carbonate. A few Radiolaria have been found in the Salinas ("Monterey") shale (middle Miocene) by Arnold, but they are not common. Their tests are usually siliceous and form exceedingly delicate skeletons having intricate patterns. The oozes which these animals formed are probably comparable to the globigerina, diatom, and radiolarian oozes now forming in the ocean, though not as a rule in deep water. The organic matter within the calcareous and siliceous tests slowly decomposes and undergoes chemical changes. The exact reactions are not definitely known, but they probably have been influenced by geologic conditions, such as pressure and moderate heat.

That the oil in the Los Angeles-Ventura region has been derived from the organic shales of the Eocene and Miocene is extremely probable. In the Eocene Martinez and Meganos formations tests for oil may be obtained from most of the shale. Oil in commercial quantities also occurs in the sandy strata associated with the shale where it has accumulated under favorable structural conditions. The oil occurring in the Sespe is also thought to have originated from the Eocene shales. At no place is the oil found in the Sespe unless the Eocene oil-bearing formations are present beneath it. How the petroleum reached its present horizon in the Sespe is not exactly clear, but it probably migrated upward, either through avenues made available by the lenticular nature of the sands, or through fissures. That the oil could originate within the Sespe formation itself is not conceivable, for none of the Sespe beds contain any organic matter, at least in sufficient quantity to form oil. In large part they are composed of coarse sand and conglomerate, interbedded with clay shale. None of the strata except those that contain oil show any sign of petroleum, nor do they appear to have ever held any. The oil-bearing Sespe rocks occur on Sespe Creek, along the north side of Oak Ridge and South Mountain, and on the north side of Simi Valley. In the Sespe Creek and Simi Valley areas the Sespe formation is known to overlie the oil-bearing Eocene rocks. The area along Oak Ridge lies between the two other localities, and, although no Eocene is exposed there, it is very probably present below.

The second type of occurrence of oil in this region is that in which the oil is very closely associated with the siliceous, diatomaceous, and foraminiferal shales of the Modelo formation (Miocene). These organic shales, a detailed description of which may be found on pages 56–57, constitute a considerable part of the formation. The occurrence of the petroleum is somewhat similar to that in the fields of the southern part of San Joaquin Valley, where the interbedded sandstone and sandy shale have been saturated and stained with the oil that has originated in the organic shale and later migrated into the more porous sandstone. It is also very evident that a large part of the Modelo shales, especially those which are composed of silty material, are petroliferous. Chocolate-colored petroliferous sands interbedded with the shale crop out on Piru Creek and in the Santa Susana Mountains over a large area, and in places oil seeps from them. Petroleum in commercial quantities is obtained from sandy strata within the shale, and it is from such sands that the oil in the Pico anticline is pumped. Where the Modelo shales are unconformably overlain by coarse strata such as the Pliocene formations, the lower beds are commonly saturated with petroleum, and under suitable conditions considerable deposits have accumulated, the coarse sands acting as reservoirs into which the oil has migrated from the Moledo shales below. The Elsmere Canyon fields and the oil-bearing beds occurring east of Piru Creek are examples of this type. These, as well as others, show the close association of the Modelo shales with the occurrence of petroleum in this region.

ACCUMULATION OF THE OIL.

In the Los Angeles-Ventura region, and in fact over all of California, four conditions are requisite for the accumulation of petroleum. First, the formations that are the original source of the oil must be present; second, strata favorable for holding oil must be in contact with the source; third, these strata must be folded into anticlines or other structural features that will trap the oil and allow it to accumulate; and fourth, water must be circulating in the sands to carry the oil to the places favorable for concentration.[60] A discussion of these conditions recently given by Pack[61] applies not only to the west side of San Joaquin Valley but to California in general. The origin of the oil and the type of sediments that constitute its source and reservoir have been set forth in the preceding section of this report.

A large proportion of the sedimentary formations of this region are highly porous, being formed of sandstone and conglomerate which make exceptionally good reservoirs for petroleum. The interbedded and lenticular sands within the shale, though not of very coarse grain, form the gathering places for the oil in the Meganos formation (middle Eocene) in Simi Valley. In the Sespe Creek district the top sandstone (locally called "Coldwater sandstone") of the upper Eocene Tejon formation holds the oil. The Sespe formation (Oligocene?), composed largely of porous coarse-grained rocks and lying directly above the Eocene oil-bearing rocks, has also become petroliferous in the Oak Ridge and Simi districts and to some extent in the Sespe Creek district. Where the Sespe is not underlain by the Eocene, however, it is barren of oil. Although primarily consisting of porous rocks the Sespe oil-bearing sands are limited to a comparatively few zones. This may be due to the lenticular nature of the sands or to the capping of the sands by impervious layers, which restrict the migration of the oil and keep it within certain channels, thus causing it to concentrate at favorable localities. For the oil originating in the Modelo formation (upper Miocene) the sandstones within this formation act as reservoirs. In some places these are thin layers interbedded with the more shaly beds, but in others considerable parts of large sandstone lenses have been impregnated. The oil has also migrated into the sandstone and conglomerate of the Pico (lower Pliocene) and Saugus (upper Pliocene and Pleistocene) formations, where these strata overlie the oil-bearing Modelo rocks unconformably. In the vicinity of Newhall fairly large accumulations occur near the base of these formations.

A review of the structure in conjunction with the development of the region, or a glance at the map (Pl. I), shows that the anticline is the dominant factor controlling the accumulation of petroleum

[60] Rich, J. L., Moving underground water as a primary cause of the migration and accumulation of oil and gas: Econ. Geology, vol. 16, pp. 347–371, 1921.

[61] Pack, R. W., The Sunset-Midway oil field, Calif., Part I: U. S. Geol. Survey Prof. Paper 116, pp. 71–75, 1920.

irrespective of topography. The close association of the oil with structural features of this type or its modifications is not unique to this district but is found in all the large fields of the world, as is indicated by a study of the fields of Russia, India, Rumania, Mexico, and the United States. The presence of anticlines can of course be of importance only where rocks known to be petroliferous are involved in or near the folds and where part of the strata are porous enough to act as reservoirs.

Originally the anticlinal theory, formulated by White,[62] assumed that the oil, being lighter than water rises above it, following certain porous beds to the highest part of the anticline, where it is trapped below impervious strata that cover the oil-bearing sands. The question has naturally been raised whether water is the only means by which the oil has been forced into the crests of the anticlines. If water has forced the petroleum before it up the sands it should take the place of the oil when the oil has been exhausted. In some fields this happens, but not in every field. Furthermore, it should be expected that on drilling farther down the slopes of the fold water would be found in place of oil.

Although this is true for some fields, such as the Coalinga field, it does not regularly occur in the Los Angeles-Ventura region. Moreover, it has been found that in many fields the water and oil sands are entirely distinct, and it is probable that a considerable part of the water pumped with the oil may have come in from other sands. Anderson and Pack[63] support the argument that hydrostatic pressure has caused the oil in the Coalinga district to be forced into the higher parts of the strata and state that

> The conclusion appears unavoidable that the dominant factor influencing the accumulation of oil along the east flank of the Coast Ranges is the presence of anticlinal folds bordering the San Joaquin Valley and the corresponding synclines back of these anticlines. A factor almost equally essential is doubtless to be found in the prevailing underground water system of this great valley. * * * The forces causing this migration can not be stated definitely, but the writers believe that meteoric waters have played a large part in the process.

Many other hypotheses have been advanced to account for the upward migration of oil, but as these have all resulted from a study of the conditions in the Appalachian fields they are not applicable in every respect to the California fields, where the structural and lithologic conditions are considerably different. The principal causes postulated by these hypotheses are the weight of overlying rock or diastrophic forces, capillary action, underground circulating waters, and the action of gas, which is so intimately associated with the oil

[62] White, I. C., The geology of natural gas: Science, vol. 5, pp. 521–522, 1885.

[63] Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Calif.: U. S. Geol. Survey Bull. 603, pp. 117, 119, 1915.

in nearly every field. The hypothesis that the weight of the overlying rocks is the prime cause of the migration of oil in the rocks has now been virtually abandoned, for actual experimentation shows that even friable rock is capable of sustaining great weight, though the compacting of mud into shale may have caused a squeezing out of the oil into more porous strata. Closely connected with this hypothesis is that of Mrazec,[64] and later of Daly,[65] who considered that the orogenic forces which have produced the deformative movements in the earth's crust are the most potent cause of the migration of oil along channels of least resistance. This force may have some connection with the migration of oil in highly disturbed regions such as Rumania and California, but even in California, where the oil occurs in folded strata, its accumulation is in no way proportional to the amount of deformation which the strata have undergone. In fact, in most places very highly inclined beds are known to be detrimental to the accumulation of oil in large quantities. Furthermore, the great deposits of oil in the Mid-Continent and Gulf fields of the United States occur in very slightly deformed strata, the folding being in places almost imperceptible. However, Pack[66] considers that the hydraulic pressure in the Sunset-Midway oil field might be caused by deformation as described by Daly.

By experiment it has been found that capillarity may exert a considerable force in the migration of oil. This may account for the driving out of the oil from shale into coarser rocks where water is present, but the movement upward into the tops of the anticlines required other means. In substance, the hypothesis is that water, which is usually present in the strata, having a surface tension approximately three times as great as that of oil and therefore a correspondingly greater capillary force, will drive out the oil from the finer into the coarser grained rocks that are within the range of capillary action. This hypothesis was advocated by Washburne[67] and later was made the basis for experimentation by McCoy,[68] who arrived at the conclusion "that the segregation of oil and water in openings of ordinary oil rocks is not according to the general hydrostatic idea, but that the water forces the oil into the larger openings, regardless of elevation or structure."

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[64] Mrazec, L., Les gisements de pétrole: L'industrie du pétrole en Roumanie, Ministère de l'industrie et du commerce, 1910.

[65] Daly, Marcel, The diastrophic theory: Am. Inst. Min. Eng. Trans., vol. 56, pp. 733–753, 1917.

[66] Pack, R. W., The Sunset-Midway oil field, Calif., Part I: U. S. Geol. Survey Prof. Paper 116, p. 75, 1920.

[67] Washburne, C. W., The capillary concentration of gas and oil: Amer. Inst. Min. Eng. Trans., vol. 50, pp. 829–842, 1914.

[68] McCoy, A. C., Effects of capillarity on oil accumulation: Jour. Geology, vol. 24, pp. 798–805, 1916; On the migration of petroleum through sedimentary rocks: Am. Assoc. Petroleum Geologists Bull., vol. 1, pp. 168–171, 1918; Notes on principles of oil accumulation: Jour. Geology vol. 27, pp. 252–262, 1919.

The hydraulic hypothesis was formulated by Munn [69] to explain certain facts not reconcilable with the anticlinal theory. He considers that the action of underground circulating water, together with the capillary action of water, drives the oil as small globules before it. The oil then accumulates in pools where these circulating waters conflict and form eddies. The various paths of the waters have been influenced by structure in consequence of which the eddies are formed. This hypothesis appears plausible in Pennsylvania, where the average dip of the rocks is low, but it is hard to conceive that conflicting currents of water have caused the accumulation of oil in the California fields, where the oil is usually found along anticlines, many of them plunging and steeply dipping, though Pack [70] states that this hypothesis "seems more nearly to fit the observed facts in the fields along the west side of San Joaquin Valley."

Shaw [71] advocated the idea that underground water in its artesian circulation in the geosynclines exerts a powerful influence on the accumulation of oil in favorable places under the influence of selective buoyancy. Later Rich [72] enlarged upon this idea, applying it to certain Mid-Continent and Coastal Plain fields. Although no areas in California, except perhaps San Joaquin Valley, are favorable for the circulation of ground waters, nevertheless it is the opinion of the writer that circulating artesian water is of considerable importance in the migration of the oil in California fields, and that certain structural features, such as anticlines and faults, have acted as traps in which the oil was caught.

Arnold and Anderson [73] arrived at the conclusion that in the Santa Maria field of California

> the migratory faculty may be ascribed entirely to the presence of the associated gas, which would cause the oil to fill every crevice offering a point of escape or a point of lodgment. * * * It is therefore possible that in the Santa Maria district the gas pressure is the chief agent in giving the oil mobility, and that the condition of the rocks is the chief factor that controls the matter of where the oil is stored most abundantly. Hydrostatic pressure may not play an important part.

As gas is intimately associated with the oil in the Santa Clara Valley fields it may have been of at least some assistance in forcing the oil to seek higher levels.

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[69] Munn, M. J., The anticlinal and hydraulic theories of oil and gas accumulation: Econ. Geology, vol. 4, pp. 509–529, 1909.

[70] Pack, R. W., The Sunset-Midway oil field, Calif., Part I: U. S. Geol. Survey Prof. Paper 116, p. 75, 1920.

[71] Shaw, E. W., The absence of water in certain sandstones of the Appalachian oil fields: Econ. Geology, vol. 12, pp. 610–628, 1917; Oil, gas, and water contents of Dakota sand in Canada and United States: Am. Inst. Min. Eng. Bull. 108, pp. 2428–2430, 1915.

[72] Rich, J. L., Moving underground water as a primary cause of the migration and accumulation of oil and gas: Econ. Geology, vol. 16, pp. 247–271, 1921.

[73] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Calif.: U. S. Geol. Survey Bull. 322, pp. 73–74, 1907.

In the Santa Clara Valley district of Los Angeles and Ventura counties a variety of conditions are encountered, as the fields, though small, are many and varied in underground conditions, especially in the character of the sands and complexity of structure. In general, the accumulation of oil appears to have followed the same methods here as in other fields. Water is commonly associated with the oil, and edge water is met on the lower parts of the folds, so that, in the writer's opinion, circulating waters have exerted some influence on the accumulation. Oil in many places is also found coming up with the water at springs. Capillarity is probably the main factor in forcing the oil from the shale in which it originated into the more porous strata. In causing it to rise to the top of anticlines, other means probably come into play, such as gas pressure or gravity. It is hard to conceive why certain sands in a formation, as for example, the Sespe, become oil bearing and others do not, although they are of the same lithologic type. Furthermore, why do only certain definite zones become impregnated, whereas the oil probably originated in the underlying Eocene and must have had an opportunity to saturate other sands lower down in the section? Lenticularity of sands also complicates the working out of any hypothesis as to the cause of the migration, so that no definite conclusions have yet been reached.

SURFACE EVIDENCES OF OIL.

GENERAL CHARACTER AND SIGNIFICANCE.

In California oil seepages, brea deposits, outcropping oil sands, and burned shale are important criteria in determining the favorableness or unfavorableness of any locality for oil. Although surface indications of this type do not prove that paying quantities of oil may be obtained by drilling, they do show that oil is present in certain strata of the region. Even though the organic shales from which the oil is derived are present and the structure is conducive to the accumulation of petroleum, the chances of striking oil are much greater if surface indications can be found at some place where the supposed oil-bearing formation crops out. For example, the typical oil-bearing Modelo strata underlie a large part of the Calabasas country between the Simi Hills and the Santa Monica Mountains, but no seeps or oil sands occur there, although the strata have been folded sufficiently to expose the sands and give rise to seeps. Therefore a report on this area, even if not actually condemning it, can not be very favorable, although the structure and character of the formations are satisfactory for an oil-bearing region. It is recognized that no surface indications of oil are seen in some of the California oil fields, as at Huntington

Beach, south of Los Angeles. However, in that area surface indications are present at the margin of the sedimentary basin, where the oil-bearing strata crop out in Los Angeles City and the Puente Hills. The California fields can not be compared to other fields of North America, which are largely confined to pre-Tertiary rocks, as the mode of accumulation of the oil in them is different. On the other hand, they must be compared to the Tertiary fields of other parts of the world, such as those in Rumania, Galicia, Japan, and Russia, where the conditions of lithology and structure are more or less similar. It is markedly noticeable that all these fields are characterized by many large seepages and outcropping oil sands, features which, together with complex and highly folded strata, seem to be common in oil fields in Tertiary rocks over the world.

The surface evidences of oil are closely associated with the formations in which the oil originates—that is, the Martinez, Meganos, Tejon, and Modelo formations—as well as the sands into which it has migrated—the Sespe, Pico, and Saugus formations. These formations include all the strata above the Chico formation (Upper Cretaceous). The most important seeps and oil sands occur in the Modelo formation. Los Angeles and Ventura counties have been noted since the early days for their numerous and striking oil indications, which are conspicuous in the Santa Clara River valley, and it was on account of these indications of petroleum that the first real oil industry in California was started in Pico Canyon, west of Newhall.

The surface indications in the Santa Clara Valley region are too numerous to list completely, but the more prominent ones and those that have a bearing on the development of oil are here described and are shown on the geologic map (Pl. II).

SESPE CREEK DISTRICT.

West of Sespe Creek oil-saturated sands of the Pico formation and fractured shale of the Modelo formation occur south of the San Cayetano fault. One area which is particularly noticeable is that in broken Modelo shale in the NW. ¼ sec. 12, T. 4 N., R. 20 W. In fact, east of Sespe Creek the fault zone may be traced by the presence of this fractured shale and sand impregnated with oil. Immediately back of Fillmore and along the highway cuts to the east oil sands are exposed over a considerable area.

Oil seeps and oil-stained sand in the top sandstone of the Tejon formation occur near Devilsgate on Sespe Creek along the axis of the Coldwater anticline. Near these seeps a few wells were drilled, all of which failed to get any oil, though they passed through tarry sands at a shallow depth. Seeps also occur at this same horizon at the bend in Sespe Creek above the mouth of Tar Creek. A short distance farther up the creek the Tejon shales also yield a few small seeps. Surface indications of oil in the red beds of the Sespe formation occur near the group of wells northeast of Sespe Creek in the NE. ¼ sec. 1, T. 4 N., R. 20 W. This seep is also along the Coldwater anticline, and the oil comes out of sands interbedded in red clays. An oil sand occurs in the Vaqueros on Little Sespe Creek a short distance above its mouth.

AREA BETWEEN SESPE AND PIRU CREEKS.

Between Sespe and Piru creeks practically the only rocks exposed are the sandstone and shale of the Modelo formation. Oil-impregnated sandstone is common between the shale beds and is found at a number of horizons. At many places where it is cut through by streams oil seeps occur. Some of the most conspicuous of these are in Hopper Canyon in secs. 1, 12, and 13, T. 4 N., R. 19 W. These sands vary in thickness, some of them reaching several hundred feet. The oil changes the Modelo sandstone from its usual buff color to a chocolate brown. Most of the sands at the surface now contain practically no petroleum, as it has disappeared through evaporation and weathering, leaving only the brown stain.

AREA BETWEEN PIRU CREEK AND CASTAC VALLEY.

Seepages of petroleum are fairly common in the canyons draining into Piru Creek, but east of the divide into Castac Creek neither seeps nor oil sands occur. The Pico formation here overlies the Modelo formation, and in turn underlies the Saugus formation and covers the greater part of this area. Into it has seeped a considerable quantity of oil from the Modelo beds below. As a result several thick oil sands crop out on the large eastward-plunging anticline that crosses Piru Creek between Santa Felicia and Holser canyons. One of these sands occurs at the top of the Modelo on the north side of Holser Canyon, and two other prominent ones are in the lower part of the Pico formation and can be traced for several miles through secs. 11 and 12, T. 4 N., R. 18 W., secs. 6 and 7, T. 4 N., R. 17 W., and sec. 1, T. 5 N., R. 18 W.

A seep in Nuevo Canyon in sec. 14, T. 4 N., R. 18 W., comes out of the petroliferous Pico beds but from a somewhat higher horizon than the oil sands mentioned above. Another oil sand about 25 feet thick in the Modelo formation crops out along the north side of Devil Canyon. Farther east, in Santa Felicia Canyon, a small oil seep is present in sec. 20, T. 5 N., R. 17 W., near which a well was sunk a good many years ago.

EAST OF CASTAC VALLEY.

Only one outcrop of petroliferous strata is known to occur north of Santa Clara River valley east of Castac Creek. This is an oil-impregnated sandstone in the Saugus formation on the divide between Dry and San Francisquito canyons, in the SW. ¼ sec. 26, T. 5 N., R. 16 W. The oil-stained sand is about 25 to 30 feet thick in a comparatively small outlying patch of the Saugus formation, which here unconformably overlies the Modelo (?) formation. The occurrence of an oil sand in this region is important in that it shows that oil is present north of Saugus as well as to the south.

SOUTH SIDE OF SANTA CLARA VALLEY.

As in the area of Modelo between Sespe and Piru creeks, the Modelo strata of the Santa Susana Mountains contain oil sands which in some places give rise to large seepages. The oil sands, many of which are only sands discolored by petroleum, crop out at different horizons from a point east of Torrey Canyon to Fernando Pass. They are exceptionally well exposed in Eureka and Tapo canyons, and in the vicinity of Tapo Canyon several large seeps occur. Petroliferous sandy shale from which oil frequently seeps in the canyon is also present along the Pico anticline.

West of Fernando Pass neither the Pico nor the Saugus formation contains any oil sands that crop out at the surface. Whether this is due to the fact that the Pico is apparently conformable with the Modelo along the north side of the Santa Susana Mountains and the oil was not able to pass into the upper strata is not known. East of the pass both Pico and Saugus formations contain thick oil sands. These formations, which dip toward the valley with minor undulations, rest upon the granite and schist complex of the San Gabriel Mountains. As no Modelo is exposed here the later formations evidently overlap the Pico and Saugus with marked unconformity. The basal sand and conglomerate of the Pico is saturated with a heavy oil, which seeps out in Elsmere Canyon and runs down the creek bottom. About 150 feet above the lowest oil sand there is a fine-grained sandstone which has also been stained a dark chocolate color by the oil. The Saugus formation, unconformably overlying the Pico, contains some thick oil sands not far above its base. These are well exposed on Elsmere Ridge and north of Elsmere Canyon to Placerita Canyon. Oil seeps occur in this sand on the north side of Elsmere Canyon and in a small canyon heading north from Placerita Canyon in the SW. ¼ sec. 32, T. 4 N., R. 15 W.

Oil-stained sands crop out along the front of the hills east of the town of Fernando from Pacoima Wash eastward beyond Little

Tujunga Canyon. These sands occur near the top of the Modelo formation and are associated with organic shale.

SOUTH MOUNTAIN AND OAK RIDGE.

Although the best producing oil fields in this region lie along Oak Ridge and South Mountain, no oil seeps are present there, nor do any oil sands crop out west of the San Cayetano fault at Torrey Canyon. Several hundred feet of diatomaceous shale, which is considered the source of the oil in other parts of the district, forms a zone extending the entire distance of this ridge, but the only indication of hydrocarbons in this vicinity consists of a number of areas of burned shale. This burned shale can be seen at intervals all along this ridge, but some of the most prominent areas are east of Grimes Canyon and on the south side of South Mountain.

VICINITY OF SANTA SUSANA FAULT

In the strata both north and south of the Santa Susana fault oil sands, brea deposits, and seeps are common. The westernmost brea bed along the fault is near the south line of sec. 11, T. 3 N., R. 18 W. At this place the brecciated diatomaceous and clay shale has been impregnated with oil rising along the fault. Three wells, abandoned long ago, are reported to have been drilled close to this brea deposit. To the east, from the line between Rs. 17 and 18 W., in T. 3 N., to Las Llajas Canyon, the rocks are considerably broken, so that oil has saturated the Modelo sands north of the fault, the Saugus formation south of it, and also the terrace deposits. Some of the most prominent of these seeps are in the SW. ¼ sec. 9 and the NW. ¼ sec. 16, T. 3 N., R. 17 W. The oil here has impregnated both the Modelo and to a greater degree the coarse porous sandstone of the Saugus formation. In sec. 16 it is used for fuel in a near-by limekiln. Near the head of the east fork of Browns Canyon a coarse sandstone in the Saugus formation has been stained brown by petroleum. Within the limits of the area mapped the easternmost seep known to occur along the fault, is in Aliso Canyon, where some oil oozes out of Modelo shale just north of the fault line.

SIMI VALLEY REGION.

An oil sand about midway in the section of the Sespe formation crops out west of Alamos Canyon, in the southeast corner of sec. 36, T. 3 N., R. 19 W., where a seepage occurs. In Brea Canyon, in the SE. ¼ sec. 32, T. 3 N., R. 18 W., oil with water seeps from this sand, and here brea deposits of considerable size have formed. A few hundred feet north of this seep is the Union Oil Co.'s well, from which a small amount of oil is pumped, and farther north and east are wells of the Pan-American Petroleum Co. The oil sand is at the base of a massive light-buff conglomeratic sandstone above a zone of colored sand and clay.

Immediately north of the east end of Simi Valley, at the group of wells owned by the Santa Susana Syndicate, in the SE. ¼ sec. 30, T. 3 N., R. 17 W., a few fairly large oil seeps and brea deposits occur in a conglomerate and overlying sandstone of the Meganos formation. A fault that parallels the conglomerate on the south is probably the main cause for the rise of the petroleum at this particular place. Two other seeps in the Meganos occur in Las Llajas Canyon close to the line between secs. 22 and 23, T. 3 N., R. 17 W. The oil seeps from Meganos strata situated approximately on the axis of the Llajas anticline. Although these seeps are not as large as the others, they have yielded enough oil to extend for a few hundred feet down the gulch. On the south side of Simi Valley the only indications of oil are in some beds of shale directly southwest of the town of Santa Susana. It is reported that these shales on being tested with chloroform show signs of petroleum.

SOUTH OF SIMI HILLS.

In all the area south of the Simi Hills, including a part of the Santa Monica Mountains, no seeps or oil sands of any description are known. Some have been reported, but when investigated either they have turned out to be dark-colored sands or they could not be located. This is remarkable, because the Modelo formation, a considerable part of which is composed of diatomaceous shale, crops out over a large part of the area. The only indication that hydrocarbons have ever been present here is in a small area of burned slaggy shale in Las Virgenes Canyon, immediately south of the county line. This appears to have been caused by the burning of either gas or oil in the shale, and the rock thus formed is similar to that which is common in burned areas on South Mountain and Oak Ridge.

OCCURRENCE AND FUTURE POSSIBILITIES OF OIL.

During the early development of the oil industry in California a great deal of time and money was wasted in drilling wells in places where the geologic structure is unfavorable and in places where the possibility that oil may occur is exceedingly remote. With a proper knowledge of the geologic conditions much better results could have been obtained. Therefore, in the following pages will be set forth not only the occurrence and future possibilities for the development of oil in already proved territory and in those likely to yield oil but also the criteria that should lead to condemnation of the areas in which the chances for obtaining oil are unfavorable or entirely lacking. A detailed discussion of the underground geology has not been attempted, as this work is now being done by the California State Mining Bureau.

As the region under consideration is stratigraphically, structurally, and physiographically complex, it is difficult to divide satisfactorily into units for discussion, but three arbitrary divisions have been made, as follows: (1) The Santa Clara Valley district, which includes the greater part of the Santa Susana Mountains and extends northward to the northern limit of the area mapped; (2) the Simi Valley and Las Posas district; and (3) the Calabasas and San Fernando Valley district, which includes the territory south of Simi Hills east of Conejo Valley, and the north flank of the Santa Monica Mountains. In the first district the oil occurs in the Meganos (middle Eocene) and Sespe (Oligocene?) formations along Sespe Creek and in the Modelo (upper Miocene), Pico (lower Pliocene), and Saugus (upper Pliocene and Pleistocene) formations farther east and in the Santa Susana Mountains. In the second district the petroleum so far obtained is associated with the Meganos and Sespe strata. No oil has yet been produced from the Las Posas portion of this district. The third district is unproductive at present, though oil may be found along the north side of San Fernando Valley either in the Modelo formation or the Fernando group.

In recording the development work in this region (see Pl. I), the writer has made frequent use of information given in the publications of the California State Mining Bureau.[74]

SANTA CLARA VALLEY DISTRICT.

SESPE CREEK AREA.

GENERAL FEATURES.

The Sespe Creek area lies about 3 miles north of Fillmore, within the drainage basin of the lower part of Sespe Creek, including that of Tar and Little Sespe creeks. (See Pl. I.) Its northern limit extends but a short distance beyond the northern boundary of the area mapped, but practically all the oil produced in it has been obtained from wells drilled south of this line. In this area drilling was started in 1887, but as the wells were only small producers and many were failures, the fields have remained small, and few wells have been completed within the last few years.

[74] Petroleum in southern California: California Min. Bur. Bull. 63, 1913; Petroleum industry of California: Bull. 69, 1914; Second annual report of State oil and gas supervisor: Bull. 82, 1918; Third annual report of State oil and gas supervisor: Bull. 84, 1918.

The general structure of this area is anticlinal, as the main fold is the southeast end of the Topatopa anticline, which, branching shortly after it enters the Sespe country, crosses the northeastern part of this area, near Elm Creek. Other folds occur south of the Topatopa anticline, namely, a shallow syncline that crosses Sespe Creek above Devilsgate, the Coldwater anticline, and another syncline that passes down Pine Canyon and crosses Sespe Creek and Oat Mountain. (See Pl. IV, *A*, p. 30.) The oil is obtained from anticlinal folds as a rule, though in one small field the production comes from wells drilled along a syncline. The sandstone that lies at the top of the Tejon and unconformably below the Sespe red beds is the lowest oil-bearing bed. The upper oil sands are in the red beds of the Sespe and the lower part of the Vaqueros. These sands have given practically the entire production from the Sespe Creek area.

None of the wells that were drilled in the top sandstone of the Tejon formation (locally called "Coldwater sandstone") have been commercially successful. Eight wells were sunk on Sespe Creek near the mouth of Tar Creek, but they are all now abandoned. The first wells were put down by the Union Consolidated Oil Co. at the big bend in Sespe Creek about half a mile north of Tar Creek, opposite the mouth of a small canyon. Later three wells were drilled both here and at the mouth of Tar Creek, and another one about a mile above the bend in Sespe Creek. In drilling all these wells the object was to obtain oil from the petroliferous zone near the base of the "Coldwater sandstone" or from the upper part of the underlying shale of the Tejon formation. Seepages of oil occur near by at both horizons. At the time of the writer's visit in November, 1917, the Big Sespe Oil Co. had taken over the property and was drilling a test well at the big bend in Sespe Creek. At that time a 20-inch hole had been sunk to a depth of 140 feet, at which it was in the heavy oil sand of the "Coldwater sandstone." The well was later abandoned. All the wells are on the south flank of the Topatopa anticline, upon which is superimposed a slight flexure trending southward down Sespe Creek. This minor anticlinal flexure has probably been the cause of a small accumulation of petroleum here. Although a pipe line was laid to these wells from Brownstone station, at the mouth of Sespe Canyon, no commercial production was ever attained. A few of the wells pumped about 15 barrels of fluid a day, most of which was water, but hardly enough oil was produced to run the boilers. The oil was of a low grade, its specific gravity being about 0.979 (13° Baumé).

The oil, which is found in the "Coldwater sandstone," originated in the shales lower down in the Tejon formation and migrated upward through fissures. The lack of production here is thought to be due to the cutting through by Sespe Creek of the oil-bearing sand at the crest of the anticline. This permitted the oil to seep out, and therefore no accumulation under pressure took place. It is possible that drilling deeper into the underlying strata of the Tejon formation would yield better results, for there are seepages below the "Coldwater sandstone" on the Topatopa anticline north of the area mapped.

COLDWATER ANTICLINE.

In the vicinity of Devilsgate, in Sespe Canyon, two wells were drilled on the Coldwater anticline (see Pl. IV, *A*) by Crawford, Henley & Co. in 1899 and 1900. These wells are said to have obtained at first from 2 to 4 barrels a day of heavy oil having a specific gravity of 0.9929 (11° Baumé), from a reddish shale between 80 and 132 feet deep. Well No. 1 was carried to a depth of 562 feet, and No. 2 to 760 feet, but no oil and only a small amount of gas was struck below the oil zone. The drill penetrated only the "Coldwater sandstone." About half a mile north of these wells a hole was put down to a depth of 1,120 feet by the Sespe Crude Oil Co., but other than a few traces, no oil was found in it.

The Coldwater anticline, which extends in a northeasterly direction down Coldwater Canyon, makes a sharp bend to the southeast after crossing Sespe Creek and apparently dies out east of Little Sespe Creek. The "Coldwater sandstone" is here covered by the Sespe red beds. Two small groups of wells have been sunk on the eastern part of this fold. One, in the NE. ¼ sec. 1, T. 4 N., R. 20 W., on what is known as the Razzle Dazzle claim, is now owned by the Pacific Crude Oil Co. but was formerly the property of the California Oil Co. and the Big Sespe Oil Co. (California). Where the anticline makes the bend on the east side of Sespe Creek it is considerably broken, and the south limb has been overturned for a short distance. The north limb, on the other hand, has a comparatively low dip, about 25°. The fold is still asymmetric where the wells have been put down in sec. 1, but it becomes more nearly symmetrical in Little Sespe Canyon. The wells of the Razzle Dazzle claim are four in number and, starting in the Sespe red beds, penetrate 800 to 1,200 feet of red and yellow sandstone interbedded with dark-colored shale. The best oil horizon is in the Sespe at a depth of about 615 feet, but oil sands occur about every 60 feet below. The first well, on reaching a depth of 805 feet, flowed twice a day for the first month. After that it pumped 160 barrels a day for the next year. The average monthly production in 1917 was about 600 barrels.

The Foot-of-the-Hill field, or the Los Angeles lease of the Union Oil Co., is at the junction of Little Sespe and Fourfork creeks, in sec. 6, T. 4 N., R. 19 W. The wells in this field, of which there are about 11, are on the south limb of the Coldwater anticline and probably obtain their oil from the same horizon as the wells of the Sespe Crude Oil Co. The first well was drilled by the Union Oil Co. in 1891. In 1917 only four of the wells were pumping and all but seven had been abandoned. The daily production from all was only 8 barrels, but there was very little water with the oil. These wells start either close to the top of the Sespe red beds or near the base of the Vaqueros formation. They reach depths of 750 to 1,548 feet and pass through two or three oil sands. The Coldwater anticline plunges here very steeply (about 50° SE.), so that the depth to the oil sands increases rapidly toward the southeast.

The tests that have already been made on the Coldwater anticline show that there is a possibility of extending the producing fields, especially between the property of the Pacific Crude Oil Co. (Razzle Dazzle claim) and the Foot-of-the-Hill wells. From the tests made at Devilsgate it seems hardly probable that commercial quantities of oil may be obtained west of the NE. ¼ sec. 1, T. 4 N., R. 20 W. East of Devilsgate the oil-bearing zone in the "Coldwater sandstone" has not been tested out. There is a possibility that this zone may yield oil commercially in quantities, and it is recommended that a well be drilled deep enough to test this possibility. The most favorable place for a test would be along the anticline in the NE. ¼ sec. 1. No large producing wells could be expected, but with oil at a fairly high price small wells might pay. The greatest difficulties in drilling here would lie in the roughness of the country and the hardness of certain steeply dipping strata which increases the possibility of a crooked hole. Water is not troublesome, the main water sand being above the oil and between 50 and 200 feet deep in the Foot-of-the-Hill wells.

PINE CANYON SYNCLINE.

The group of wells in the Pine Canyon syncline (Pl. IV, *A*, p. 30), forming what will be called the Little Sespe Creek field, includes the wells on the Kentuck and Star claims of Mrs. J. C. Ivors and the wells of the Sudden & Emslie Oil Co., all in the SE. ¼ sec. 1, T. 4 N., R. 20 W. The syncline along which these wells are drilled roughly parallels the Coldwater anticline and apparently has undergone about the same amount of deformation. On the east side of Sespe Creek it is slightly overturned, but east of the point in the canyon it becomes normal again. This fold is exceptionally well exposed in the bottom of Sespe Creek at the sharp bend, where it plunges steeply to the east and southeast. These wells obtain their oil from two sands in the Sespe red beds.

At the Kentuck lease there is a shallow oil sand at a depth of about 150 feet and another at about 500 or 600 feet. These same sands are probably pierced in the Sudden & Emslie Co.'s property, to the south, where the oil occurs at depths of 600 to 1,000 feet and where the wells start close to the contact between the Sespe and Vaqueros formations.

The first well in this area was drilled by the Union Oil Co., which leased the property on the Kentuck claim in 1889. This well was a small producer, but the second well flowed 500 barrels a day for two months and then declined. At present all the wells along the syncline are small producers, none giving over 6 barrels a day of oil having a specific gravity of 0.9032 to 0.8917 (25° to 27° Baumé). These wells are the only productive wells situated along a syncline in the Los Angeles-Ventura region. An interesting fact in this connection is that the strata are free from water, except for a small water sand above the oil zones noted in a few of the wells at about 245 feet. However, it is thought that the lack of water in these sands does not account for the presence of the oil in the syncline, for the water is present in adjacent anticlines. The area is one of intense folding and faulting, and the oil probably rose from the underlying top strata ("Coldwater sandstone") of the Tejon formation (upper Eocene) along fissures and was trapped in some manner unknown at the present time—perhaps through faulting of the red clays against a sandstone. At present a few of the wells are pumping some water, which increases in amount after a rain. Very little of the water comes in with the oil.

In the writer's opinion the productive territory along this fold is pretty well outlined. Whether commercially producing wells could be drilled west of the present limits is problematic, as the strata become considerably more crushed in this direction, a condition which is not conducive to an accumulation of oil in paying quantities.

TOPATOPA ANTICLINE.

The oldest and largest group of wells in the Sespe area is on the Topatopa anticline and includes the Tar Creek and Fourforks wells. The principal leases are the Fourforks, Cosmopolitan, White Star, Cesapi, and Black Jack, at the head of Tar Creek. The Cesapi and Black Jack are developed by the Union Oil Co. All the wells are around the broad nose of the plunging Topatopa anticline, which swings southeastward from Sulphur Peak a few miles north of the north boundary of the area mapped. At Sulphur Peak the Tejon formation (upper Eocene) is exposed, with the Sespe resting upon it, and this in turn covered by the Vaqueros (lower Miocene) and the Modelo (upper Miocene). The sandstone of the Modelo is a massive light-buff rock, which here forms a cliff bordering the amphitheater-like area that has been eroded out of the soft Modelo and Vaqueros shaly strata. The wells are but a short distance north and west of this bluff, and most of them start in the Vaqueros.

The Union Oil Co. began operations here in 1887, and between that time and 1900 put down 37 wells, most of them before 1891. The oil sands were found both at the base of the Vaqueros and top of the Sespe, which are reached at a depth of less than 1,000 feet. Some sands are as shallow as 55 feet, the depth depending on the location of the well. Several sands appear to be present, but from the poorly kept well logs no definite statement can be made concerning the number and thickness of the sands. Water is present, and this was a hindrance in drilling, especially as modern methods of shutting off water were not known at that time.

All the formations are apparently conformable and dip about 20° S. around the nose of a plunging anticline. The Tar Creek field is about a mile north of the axis of the Topatopa anticline, which is here broad and comparatively flat on top. The White Star and Cosmopolitan properties appear to be on the highest part of the same fold, which continues to the southeast, taking the place of the main fold. This anticline accounts for the accumulation of oil at this locality.

Wells drilled between the two fields are either dry or not commercially productive. The well drilled by the Mutual Oil Co. in the SW. ¼ SE. ¼ sec. 33, T. 5 N., R. 19 W., pierced the Miocene rocks and entered the red beds of the Sespe formation at a depth of 3,236 feet. A few petroliferous strata were penetrated in the Miocene, but none were productive. The well is on the axis of the Topatopa anticline and obtains its oil from the same sands as the Tar Creek wells—that is, at the base of the Vaqueros and in the upper part of the Sespe formation. It came in at 80 barrels a day, but in 1917 its production amounted to only about 16 barrels of oil a day. The oil had a specific gravity of 0.8642 (32° Baumé).

A few sporadic wells have been put down at other places without regard to structure. One well, the Thirty-six well of the Union Oil Co. was in sec. 36, T. 5 N., R. 20 W., on a flat at the top of the ridge east of Sespe Creek and not far from the axis of a syncline. This well started in the Sespe red beds and reached a depth of 2,190 feet. Only a trace of oil was obtained. A few wells were drilled in sec. 7, T. 4 N., R. 19 W. One of them obtained a very small amount of oil but not enough to make it a paying producer.

SUMMARY.

The limits of the Sespe Creek area have been pretty well defined (see Pl. I), and it is thought that the production here will never be increased to any great extent. The properties are not entirely drilled up, and new wells, which would at first be fair producers, could probably be put down at a comparatively small cost. It is a characteristic of the wells already completed that they give a fair production at first, amounting in some wells to as much as 200 barrels a day, but within a short time they begin to fall off and finally only a very small yield is maintained. This decline is due primarily to the rapid exhaustion of the gas pressure.

The most favorable areas along Sespe Creek have been pretty thoroughly tested, and no new wells of greater yield can be expected there. There is a chance of reaching a deep oil sand in the Tejon formation below the "Coldwater sandstone." Seeps occur in the hard greenish-gray sandstone interbedded with greenish-brown laminated shale of the Tejon, but this zone, so far as known, has not yet been penetrated by any of the wells.

Further extension along the Pine Canyon syncline will probably bring in new wells, but none larger than those already developed can be expected. Deeper drilling to reach the oil sands will be necessary toward the south; to the north the depth should be somewhat less, as the syncline plunges to the southeast.

The Mutual Oil Co.'s well in sec. 33 shows that oil can be obtained farther south along the Topatopa anticline, but the oil sands lie too deep south of the ridge to make the wells pay. From 1,500 to 2,000 feet of drilling may be saved by starting the wells north of the scarplike ridge that lies south of Little Sespe and Tar creeks. The test wells on Maple Creek and Tar Creek show that it is unlikely that development along the Topatopa anticline can be carried farther to the northwest.

AREA BETWEEN LITTLE SESPE CREEK AND CASTAC VALLEY.

GENERAL FEATURES.

The area described in this section lies north of Santa Clara River and includes all the territory east of the Sespe Creek area or the ridge between Oat and Hopper mountains and Castac Valley. Structurally it is bounded on the southwest by the San Cayetano fault and forms a part of the large synclinal block which extends from the northwest corner of the Camulos quadrangle eastward to the head of Santa Clara Valley, the south limb of this syncline forming the Santa Susana Mountains. This block, especially in its western and southern parts, has been complexly folded, in large measure as the result of the compressive stresses that were acting at the time of the formation of the San Cayetano-Santa Susana thrust fault. This probably took place at the end of or during the Pleistocene. (See structure sections D–D′ and E–E′, Pl. II.)

The rocks of the area are of Miocene and Pliocene age and were laid down under marine conditions, except a part of the Saugus formation (upper Pliocene and Pleistocene), which is of terrestrial origin. The whole series evidently rests upon the Sespe (Oligocene?) rocks, which are exposed in the Sespe Creek area. Between Sespe Creek and Piru Creek the beds of the Modelo formation underlie almost the entire surface. These beds have been intensely folded and have in general an easterly trend. Contrary to Eldridge's view that both lithologically and structurally the two sides of Santa Clara River are discontinuous and separated by a large fault extending up the valley, the accompanying geologic map (Pl. I) shows that all the country north of the San Cayetano-Santa Susana fault is a unit and that the structural features and formations found in the area between Sespe and Piru creeks continue into the Santa Susana Mountains.

The oil bearing strata in this area occur in the Modelo and Pico formations. In the Modelo oil sands are encountered at numerous horizons throughout, but the most productive are in the upper part. Several sands occur in the Pico formation near its base. These sands crop out on the Temescal anticline north of Holser Canyon. Wells have been sunk at a large number of places, especially in the area underlain by the Modelo rocks, on account of the many seeps and oil sands that are present in that formation. The best fields in the area are in Hopper and Piru canyons, though the yield of the wells is small in comparison with that of wells in the other fields on the south side of Santa Clara River. Nearly all the wells in these two fields, which contain the only producing wells in the district, have been failures, but although they are scattered over nearly every part of the area, none have been located according to scientific principles. On account of this hit-or-miss practice of locating wells satisfactory tests have not always been made along favorable structural features.

TOPATOPA ANTICLINE.

The Topatopa anticlinal fold continues southeastward from the Sespe Creek area. Probably owing to the plastic nature of the strata more complex folding has taken place here than to the northwest, and the main fold is broken up into a series of lesser anticlines and synclines, which extend eastward as far as Castac Creek. The Topatopa anticline proper extends to Piru Creek as a fairly regular fold plunging to the east. (See Pl. IX, *A*, p. 94.) East of Hopper Canyon it has hitherto been known as the Modelo anticline, but there is little doubt that the fold thus designated is continuous with the Topatopa anticline, though in the vicinity of the Hopper ranch the soft Modelo shale, which has slumped down the hill, has obscured the structure. In this area the structure is also complicated by two subsidiary folds, an anticline and a syncline lying in the NE. ¼ sec. 12, T. 4 N., R. 19 W. The main fold is somewhat asymmetric, as its south limb stands nearly vertical. This asymmetry extends westward nearly to Pole Canyon. At the head of Modelo Canyon the fold is symmetrical with dips of 55° on both sides. Still plunging to the east it crosses Modelo Canyon, but it can not be followed beyond Blanchard Canyon. Here a small syncline and an anticline are present, which probably can be considered as subsidiaries of the larger fold. The whole tract between Modelo and Lime canyons appears to be characterized by an extraordinary amount of crushing and twisting, for overturning and steeply dipping beds are the rule. This complex folding is well shown north of the Diamond Valley Oil Co.'s property, between Modelo and Blanchard canyons.

That this anticline is oil bearing has been proved in the wells of the Modelo Canyon field and those in Hopper Canyon belonging to the Sunset Oil Co. (see Pl. IX, *A*) and the Ibex Oil Co. (now leased by the C. C. Harris Oil Co.). The Mutual Oil Co.'s well on the ridge northeast of Oat Mountain, though getting showings of oil in the Modelo strata, obtained all the oil it produced from the base of the Vaqueros and the upper beds of the Sespe formation. At the present time the yield of petroleum from the Sespe and Vaqueros is not sufficient to warrant drilling to a depth of more than 3,000 feet, which is necessary east of the ridge between Oat and Hopper mountains.

From the wells already drilled it seems reasonable to expect that oil may be found at other places along the Topatopa anticline. In Hopper Canyon 11 wells put down by the Sunset Oil Co. obtained a black oil having a specific gravity of 0.9722 (14° Baumé). All the wells are shallow, the deepest going down slightly more than 1,000 feet. Although this property is not on the axis of the Topatopa anticline itself it is on a subsidiary anticline within a comparatively short distance north of the main fold. The wells of the Ibex Oil Co., drilled less than 1,000 feet south of the axis of the main fold, have also obtained a small quantity of oil.

At the head of Modelo Canyon about 20 wells were drilled by the Modelo Oil Co., and oil was obtained from most of them. None are more than 1,320 feet in depth, although they penetrate several oil sands. No new development has taken place for the last ten years or more, and in 1917, 10 wells were being pumped which yielded between 500 and 600 barrels a month of a greenish-black oil having a specific gravity of 0.8945 to 0.8861 (26.5 to 28° Baumé). Some gas is given off, the greater part of it coming from wells in the eastern part of the property.

From the tests thus far made along this anticline it seems probable that the producing territory could be materially extended. No very serious attempt has been made to do this, and the development has been confined to the more accessible parts, such as the canyon bottoms. Between Hopper and Modelo canyons, in the central parts of sec. 12, T. 4 N., R. 19 W., and sec. 7, T. 4 N., R. 18 W., small productive wells yielding a medium-gravity oil ought to be obtained at a depth of about 1,000 feet. An extension west of Hopper Canyon is also possible as far as the west edge of sec. 12. As logs are unavailable for the wells drilled along the Topatopa anticline no definite statement can be made as to the source of the oil, but it evidently comes from the lower part of the lower sandstone member of the Modelo, which crops out over a large part of the Hopper Canyon country. Although the depth to be drilled to reach the oil is not great, still considerable expense is necessary in drilling owing to the roughness and inaccessibility of the country. The roads are generally poor, and the canyons are steepsided and narrow, so that the winter rains do much damage to roads and material in the canyon bottoms.

PINE CANYON SYNCLINE.

The Pine Canyon syncline, forming with the Topatopa anticline the major folds of the territory west of Piru Creek, extends from the Sespe Creek area eastward to Hopper Canyon. Beyond this point the strata become greatly crushed, so that several minor short synclines and anticlines in the incompetent Modelo shale form a complex area between Hopper and Piru canyons. Along the north side of Santa Clara River these minor folds have a different direction from the others, trending northwestward across Piru Creek. The Pine Canyon syncline is a closely compressed fold in the Sespe rocks but widens out to the southwest. Numerous minor crumplings are present, however, and overturned strata are not uncommon. In this area, besides the Vaqueros formation, two large sandstone members in the Modelo formation are involved in the folding. These sandstones greatly facilitate the unraveling of the structure. Though the syncline plunges to the east in Pole Canyon, a reversal of this attitude takes place in the vicinity of Hutton Peak, east of which the fold can not be followed.

Although oil is obtained from Sespe strata in the Pine Canyon syncline in the Sespe Creek area, it is doubtful whether the conditions are favorable for the accumulation and retention of oil in a structural feature of this type in strata of the Modelo formation in the territory west of Sespe Creek, even though the strata are known to be oil-bearing. In view of the small quantity of oil, if any, that would probably be obtained from the beds at lower horizons, the great depth at which these beds lie is the deciding factor against drilling here.

OTHER STRUCTURAL FEATURES ON NORTH SIDE OF SANTA CLARA RIVER.

A number of wells have been drilled along the east side of Sespe Creek and back of Fillmore (see Pl. I), but oil in commercial quantities has never been struck. The San Cayetano fault extends along the edge of these hills and probably passes under Fillmore. (See structure section C–C′, Pl. II.) For this reason the shale along the front of the hills has been greatly brecciated, and enough oil has seeped up through it to soak it thoroughly. The only anticline along the fault lies directly north of Fillmore, where it parallels the edge of the valley. A coarse oil-stained sandstone forms the central part of this fold. In Eldridge's report [75] this sandstone was considered to be of lower Pliocene age, but no evidence to that effect has been found. Lithologically it somewhat resembles the Pico formation, but on the other hand it appears to be identical with a white sandstone of Modelo age, in large part stained brown by petroleum, which crosses Hopper Canyon near its mouth. From this similarity in lithology the writer considers this sandstone to be a member of the Modelo formation.

On account of the close proximity of the San Cayetano fault, which has so greatly broken the strata all along the front of the hills, the chance of obtaining commercial quantities of oil here is remote. The wells already sunk have pretty thoroughly tested this area. None of these wells are more than 1,000 feet deep, but tarry sands or broken shale were usually encountered, and a little oil was obtained, though not enough to pay. Deeper wells might result in more success, yet this is doubtful.

Two anticlines and two synclines cross Pole Canyon and extend in a southeasterly direction nearly to Santa Clara Valley. Although a considerable amount of breaking has attended the deformation of the anticline along the valley's edge, these folds are not greatly compressed. The southern anticline is well shown in a section in Pole Canyon in the S. ½ sec. 20, T. 4 N., R. 19 W. On account of the crushing in the shale north of Pole Canyon it can be traced but a short distance to the north. The northern anticline and syncline extend from Fairview Canyon across Pole Canyon, but they do not continue far on the north side. The syncline is shallow, and the uppermost beds are composed of one of the sandstone members of the Modelo formation. The fold is asymmetric, and the more steeply dipping beds are on the north side. From the steepness of the dips here and from the fact that the contact follows a strike ridge Eldridge was led to assume that a fault extends along the

[75] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California: U. S. Geol. Survey Bull. 309, p. 23, 1907.

north side of this sandstone area. No evidence of faulting was seen, and there are no marked changes in dip or strike on either side of the contact. This anticline has never been tested for oil, and as it is comparable to the anticline farther southwest crossing Pole Canyon, on which dry holes have been drilled, it is unlikely to yield oil.

Between Fairview Canyon and Sulphur Mountain the strata make a distinct change in strike, swinging from southeast to northeast. This change is not strong enough to form a distinct syncline, though the beds, dipping toward the north, form a northward-plunging troughlike fold. In these hills the outcrops of shale are meager and the deciphering of the structure is extremely difficult. Several wells were drilled in Fairview Canyon near the axis of this swing in the beds. The deepest one, reported to have been drilled by the Pacific Consolidated Oil Co. to a depth of 1,800 feet, got a showing of oil in broken shale. Another was put down by the Southland Oil Co. in 1900 and obtained traces of oil. The Union Oil Co. also drilled a dry hole near this place.

In Haines Canyon several wells have been drilled by different companies. The Le Bard well of the United Oil Co. was started about 1915 and went to a depth of 2,000 feet. It encountered a fair gas flow but no oil. At the mouth of Haines Canyon the Kimball Oil Co. drilled to a depth of about 800 feet, getting a showing of oil. A well about half a mile west of Hopper Canyon, in the NE. ¼ sec. 26, T. 4 N., R. 19 W., was put down by W. H. Word, of Fillmore, and reached a depth of 1,100 feet.

Near the mouth of Hopper Canyon several small northeasterly folds cross the creek. The largest one extends from the south side of Sulphur Mountain across Hopper and Nigger canyons to Piru Creek. Both west of Hopper Canyon and about midway to Nigger Canyon this fold is overturned toward the south. It is everywhere closely compressed, and the dips average over 60°, though near Piru Creek the anticline plunges steeply and the dips become as low as 20° near the mouth of Toms Canyon. Several small folds lie north of this larger anticline, and in these the dips average about 50°. They are well shown in section on the sides of Hopper Canyon. These are probably only minor crumples in the incompetent shale member of the Modelo and can not be traced for any great distance.

Several wells have been drilled in the lower part of Hopper Canyon and in Toms Canyon, most of them close to one of these small folds. At the mouth of Toms Canyon, in the southeast corner of sec. 14, T. 4 N., R. 19 W., the St. Louis Oil Co. in 1901 drilled a 1,000-foot hole but found no indications of oil. The hole was put down close to a point where a small anticline and syncline merge. Farther west, up the canyon, in the SW. ¼ sec. 14, on a small ridge near the forks in Toms Canyon, another dry hole was drilled.

This was not located with respect to any definite structure. On the ridge about a mile east of the junction of Toms Canyon with Hopper Canyon a well was put down in the NW. ¼ SE. ¼ sec. 13, but no evidence could be had that oil was obtained in it. The Bradley Oil Co. in 1900–1 put down two wells in the W. ½ SW. ¼ sec. 13, but both were failures. The first well reached a depth of 1,100 feet, and the second went down 800 feet. Several holes have been drilled near the mouth of Hopper Canyon. The first was drilled in 1876 by the Santa Barbara Oil Co., and the last in 1901. These holes were put down close to the oil sand that crosses Hopper Canyon. None of the holes were more than 1,000 feet in depth, and all were dry, except one that penetrated about 1,700 feet and obtained a trace of oil and a little gas. The holes were unfavorably located in that they are about a quarter of a mile south of an overturned anticline.

In all seven wells have been drilled in Nigger Canyon along the anticline that extends from Hopper Canyon to Piru Creek. Although the limbs of the anticline dip steeply they are not overturned, as they are a short distance farther west. The fold plunges steeply to the east, and toward Piru Creek the dips become as low as 25°. All the wells were put down by four companies between 1900 and 1912. The Santa Ana Oil Co. drilled one well, the Nettleton & Kellerman Oil Co. three, the Colonial Oil Co. one, and the Ventura Oil Development Co. two. The No. 1 well of the Nettleton & Kellerman Co. went to a depth of 1,640 feet, where it struck salt water; at 300 feet it penetrated a lean sand that yielded about 3 barrels of oil a day. Well No. 3 also obtained a little oil at 500 feet. Both of these wells were pumped for a short time in order to furnish fuel for drilling subsequent wells. None of the other wells obtained any oil, though several were carried to a depth of more than 1,000 feet.

FOLDS IN PIRU CANYON

The major structural features in the Piru Canyon area are the Temescal anticline aud the parallel Santa Felicia syncline, about 1½ miles to the north, which cross Piru Creek and involve the strata of the Pico formation (lower Pliocene). (See structure section E–E′, Pl. II.) Both folds, plunging gradually to the east, start immediately east of Hopper Canyon and extend in an easterly direction to Piru Creek, where they turn southward. From Hopper Canyon the Temescal anticline rapidly broadens out, and east of Oil Ridge the sandstone and shale zones extend around its axis in wide curves. Along the north side of the anticline the unconformity between the Modelo and the Pico is well shown, in Santa Felicia Canyon, where two shale beds and a sandstone member of the Modelo are cut out within a distance of 3 miles. A discrepancy in strike of 20° is also present, but the difference in dip is less apparent. East of Piru Creek the fold plunges at angles between 15° and 25°. For the most part the anticline is symmetrical, though in places steeper dips are found on the south limb. Both the syncline and the anticline come close together near the divide between Piru Creek and Santa Clara River, but they do not continue beyond this point. The Santa Felicia syncline extends down Reasoner Canyon, which seems to be a structural as well as a topographic feature. A few small folds are associated with these larger ones. In Hopper Canyon a short anticline, traceable for about 2 miles in a northeasterly direction, extends up a small canyon in sec. 1, T. 4 N., R. 19 W., to Oil Ridge. This anticline is well defined in Hopper Canyon but becomes less distinct to the east. A small syncline lies immediately to the south. A small anticline, a subsidiary flexure on the north side of the Temescal anticline, extends for a short distance between Lime and Reasoner canyons. On this anticline in Hopper Canyon, three wells have been drilled by the San Cayetano Oil Co., and the Oil King Co. in sec. 1, T. 4 N., R. 19 W. These were shallow, the deepest well being only 600 feet deep, and no oil was found in any of them.

Comparatively few wells have been drilled along the Temescal anticline, and of these only one has been located along its axis. (See Pl. I.) This well was put down a great many years ago by the Piru Oil & Land Co. on the hill immediately north of Lime Canyon. No oil was found, and from the available reports, which are very meager, the holes were not very deep. In the SE. ¼ sec. 12, T. 4 N., R. 18 W., on the north side of Holser Canyon, the Ramona Home Oil Co. drilled a well to a depth of about 4,000 feet and obtained at 2,000 feet a showing of oil having a low specific gravity. At least two distinct oil sands occur in the Pico and one in the immediately underlying Modelo formation along the south side and top of the Temescal anticline, and it is these sands which this well was evidently intended to penetrate. This well is about half a mile south of the axis of the fold, and the beds here dip steeply to the south. For this reason the well is thought to be not favorably located to test the possibilities of the anticline. Two other wells have been drilled in Leckler Canyon, a branch of Santa Felicia Canyon. One in the NE. ¼ sec. 1, T. 4 N., R. 18 W., was put down by the Berkeley Oil Co. in 1901 to a depth of 750 feet, but found no indications of oil. To the east in the same canyon, in the NW. ¼ sec. 6, T. 4. N., R. 17 W., the East Piru Co. drilled a dry hole to a depth of 1,900 feet. Both of these wells were about half a mile north of the axis of the Temescal anticline and nearer the axis of the Santa Felicia syncline.

From the facts that several oil sands are exposed along the Temescal anticline and that it plunges slightly to the east, it seems reasonable to expect that oil might be obtained in wells drilled along its axis east of the outcropping oil sands. None of the wells thus far drilled have adequately tested the possibilities of this fold. In order to test it a hole should be put down close to the axis of the anticline, preferably on the south side somewhere near the middle of the south line of sec. 6, T. 4 N., R. 17 W. No large producing wells could be expected, but as the depth to the first sand would probably not be more than 1,000 feet, the expense of drilling would not be great.

An anticline and a syncline, subsidiary folds on the south flank of the Temescal anticline, are present on the north side of Holser Canyon. These are rather steep folds and involve both the Modelo and Pico formations. A dry hole was drilled by the Crown King Oil Co. in the NW. ¼ sec. 12, T. 4 N., R. 18 W., on the axis of the syncline.

Near the north boundary of the Camulos quadrangle an anticline of considerable size extends in an easterly direction from a point west of Piru Creek and north of the quadrangle to Loma Verde Mountain. Like the other folds of this vicinity it plunges to the east and involves both Modelo and Pico strata. It plunges slightly less than the Temescal anticline, but in other respects closely resembles that fold. Toward its east end, in Santa Felicia Creek, it has flattened out until the dips are about 5°. No oil sands have been noticed along this fold, though the Modelo beds include some sands that may have been slightly discolored by oil. An oil seep is reported to be located near a well that was drilled a good many years ago by the Piru Oil & Land Co. on the anticline where it crosses Santa Felicia Creek, in sec. 20, T. 5 N., R. 17 W. The well is said to be 800 feet deep and to have been capable of producing about 1 barrel of oil a day. Although this well is comparatively shallow it is thought to penetrate oil sands at the top of the Modelo or base of the Pico, which crop out close to the well. Oil is evidently present along this fold, and a more satisfactory test of it could be made farther east, in the SW. ¼ sec. 21, at the western foot of Loma Verde Mountain.

FOLDS BETWEEN PIRU CREEK AND CASTAC VALLEY.

Between Piru Creek and Castac Valley the Pico and Saugus formations are involved in a number of folds which have a rather sinuous trend, turning slightly southward east of the divide but in general having an easterly direction. Some of the folds extend across Santa Clara River, but these do not continue far on the south side. The two longest folds are an anticline and a syncline that closely parallel each other from Piru Creek to the junction of Castac Creek and Santa Clara River. Both folds plunge slightly to the east, but the degree of plunge of the anticline is apparently greater than that of the syncline. (See Pl. I.) In San Martinez Chiquito Canyon, in the NW. ¼ sec. 8, T. 4 N., R. 17 W., two wells were sunk for oil by the Aetna Oil Co. in 1901. The first reached a depth of 845 feet and when abandoned was reported to have had a good showing of oil in the hole. The second went to 960 feet without striking any oil. As these wells are on the axis of the syncline, an adequate test of this territory has not been made. Oil was reported from one of the wells, and this is a good indication that oil might be found in this vicinity in paying quantities if a well were put down close to the axis of the anticline, which lies immediately to the south. Other wells have been drilled on the flanks of the anticline south of Holser Canyon, but none of them obtained any oil. In the NE. ¼ sec. 13, T. 4 N., R. 18 W., the Ramona Home Oil Co. in 1912 drilled a well 1,300 feet deep but found no oil. To the southwest, in Ramona Canyon, in the SW. ¼ sec. 13, the Ramona Oil Co. put down a well in 1901 that went more than 900 feet without result. The Nuevo Camulos Oil Co.'s well in Nuevo Canyon in the SE. ¼ sec. 14, which went down 880 feet, was also barren. These two wells are a considerable distance from the axis of the anticline, and the one in Nuevo Canyon is considerably closer to a syncline on the south than to the anticline. The Ramona Home Oil Co.'s well in sec. 13 has probably made the best test of the anticline, as it is only about 750 feet north of the anticlinal axis, but whether oil was found in this well or not is not known. From the tests thus far made the possibilities for oil along this anticline do not seem very good.

In Hasley Canyon there are two other folds of considerable size which parallel each other, the syncline forming the canyon and the anticline the ridge on the south side. These folds, like the others to the south, plunge eastward, but they die out near Castac Creek. (See structure section F–F′, Pl. II.) A test for oil was recently made about 1,700 feet south of the axis of the anticline in the SE. ¼ NW. ¼ sec. 5, T. 4 N., R. 17 W. It is not unlikely, however that oil sands underlie the exposed Pico and Saugus strata along the anticline, but whether oil would be found in paying quantities can be ascertained only by drilling. Any test should preferably be made in the NE. ¼ sec. 5, T. 4 N., R. 17 W., close to the axis of the anticline.

Along the north side of Santa Clara Valley several folds are present, but the most important economically is a faulted anticline that crosses the river in a southeasterly direction immediately south of San Martinez Grande Canyon. This anticline plunges steeply to the southeast and is symmetrical in outline, having dips of about 25° on either side. The rocks involved in the fold are entirely of the Pico formation but are fairly high up in the section, which in this vicinity is thick. At the present time drilling on this anticline is not warranted until further tests have been made on other more favorable folds to the north. The drill would also have to go deeper here to reach the sands at the base of the Pico or at the top of the Modelo.

Another anticline and syncline extend along the north side of Santa Clara River east of the town of Piru. (See Pl. I.) These folds are confined to the Pico formation and are quite compressed, their limbs dipping more than 50°. Oil sands that might prove productive probably underlie the surface along this anticline at a comparatively shallow depth.

SUMMARY.

The area between Little Sespe Creek and Castac Valley offers a great variety of structure (see Pl. I), especially in the western part, where the strata, composed mainly of rocks of the Modelo formation, have been greatly folded. Of the producing fields (see Pl. I) those in Modelo Canyon and Hopper Canyon are the best, but their yield is comparatively small. An extension of the producing area of these fields along the Topatopa anticline is possible, but this may be difficult owing to the exceeding roughness of the country, which entails serious difficulties in drilling. Although the Pine Canyon syncline is productive in the Sespe Creek area, whether it contains oil farther south is doubtful; the depth necessary to reach the oil-bearing formations is also a deciding factor against this fold. A number of smaller anticlines are present along the north side of Santa Clara Valley, but except on the one in Nigger Canyon, the tests of them so far made have given no satisfactory results. In Nigger Canyon so little oil was produced that further drilling is not advisable.

The Temescal anticline, which crosses Piru Creek between Santa Felicia and Holser canyons, is the largest and the most promising one in the area. A number of oil sands crop out along its flanks, and as these have never been thoroughly tested it is recommended that a test be made of this fold near the south line of sec. 6, T. 4 N., R. 17 W. The anticline that extends west from Loma Verde to Piru Creek near the north edge of the Camulos quadrangle also offers some possibilities. Any test of this fold should preferably be made in the SW. ¼ sec. 21, T. 5 N., R. 17 W.

The long anticline extending from the mouth of Castac Valley to Piru Creek also offers favorable structure for drilling. Unsatisfactory tests have been made near this fold, but none of the wells were advantageously located. Other folds of a like nature in the Pico and Saugus strata may be worth testing should oil be obtained from some of the larger folds mentioned above. These lie in Hasley Canyon and along the north side of Santa Clara River, directly east of Piru.

AREA EAST OF CASTAC VALLEY.

GENERAL FEATURES.

The formations exposed east of Castac Valley comprise the Sespe (?) formation (Oligocene?; see Pl. V, *A*, p. 31), the Mint Canyon formation (probably upper Miocene; see Pl. VII, p. 53), the Modelo (?) formation (upper Miocene), and the Saugus formation (upper Pliocene and Pleistocene). In general these formations constitute the north flank of a synclinorium, the lowest part of which approximately follows Santa Clara River. (See structure section K–K′, Pl. II.) The Sespe (?) rocks can not be considered of importance in regard to oil, for they neither contain organic shale that might act as a source for oil, nor do they overlie oil-bearing formations, as does the typical Sespe formation in Simi Valley and Oak Ridge. Furthermore, no surface indications of oil in the Sespe (?) formation are known to occur in the upper part of the Santa Clara Valley, so these rocks can be ruled out in the discussion of the oil possibilities of this region.

The Mint Canyon formation, which in lithology closely resembles the Sespe formation in Simi Valley and South Mountain, is of upper Miocene age. (See p. 54.) It is not known to overlie oil-bearing rocks, and it underlies strata that have been tentatively correlated with the Modelo formation, the source of the oil in the adjacent Newhall district. It is a formation of terrestrial origin and contains numerous sands capable of acting as reservoirs for oil, but it is known to overlie only the Sespe (?) rocks, which in this vicinity show no signs of carrying oil. Like the Sespe formation, the Mint Canyon formation contains no organic shale or strata having the requisite composition to serve as a source for oil. Moreover no surface indications that this formation contains oil have been found, nor did a well drilled into it to a depth of 3,514 feet indicate the presence of oil. This well was drilled by the General Petroleum Corporation in 1921 in the SE. ¼ sec. 30, T. 4 N., R. 15 W., on the axis of an anticline, and is considered a good test for oil in the Mint Canyon formation.

A little oil has been obtained from the Modelo (?) strata in Castac Valley, and oil sands are present in the Saugus formation near Newhall, so that these formations are the most promising for oil. The Pico formation, which is known to be oil bearing in the Newhall district, is not exposed on the north side of the valley, having been overlapped by the Saugus formation. Deformation has not been nearly so great in this territory as in that to the west, and there are but few folds that are tightly compressed. In the upper Santa Clara Valley, north of Mint Canyon, the deformation is more acute, and a number of small folds have been developed in the Mint Canyon formation.

The only anticline in this area that has been exploited for oil in any way is that in the Modelo (?) formation, which crosses Castac and Charlie canyons a short distance north of the Camulos quadrangle. A number of holes have been drilled along this fold, and it was reported that oil was obtained from several of them. According to the California State Mining Bureau[76] the Rose Oil Co.'s well, in the SW. ¼ sec. 18, T. 5 N., R. 16 W., drilled to a depth of 1,700 feet, "developed some high-gravity oil, which is now flowing from the casing head." This well, sunk close to the axis of the anticline, appears to have made a good test of this fold. Other wells, one of which was carried to a depth of 2,500 feet, have contributed to the testing of this area and shown that not enough oil can be developed here for commercial production. It is not likely that further drilling would give better results, at least in the vicinity of Castac Valley.

The most prominent anticline in this area crosses Haskell and San Francisquito canyons in the southeastern part of T. 5 N., R. 16 W. (See Pl. VII, *A*, p. 53.) This fold, which plunges to the south and west, begins in the Mint Canyon rocks east of Haskell Canyon and extends in a southwesterly direction to that canyon, where Modelo (?) strata are met. Here it makes an abrupt swing directly west and continues in that direction past San Francisquito Canyon. Beyond the point where it enters the Saugus formation it can not be traced, either because the Saugus beds are unconformable on the Modelo (?) or, more probably, because the fold dies out. The difference in dip and strike between the Mint Canyon and Modelo (?) strata is accounted for by an unconformity, which is well shown in Haskell Canyon near its forks. The only evidence for oil along this anticline is in the SW. ¼ sec. 26, T. 5 N., R. 16 W., where sands of the Saugus formation, overlying the Modelo (?), are stained with petroleum. This oil has probably seeped into these sands from the older formation. Although oil sands occur in the Saugus formation in the vicinity of Newhall, none are known to be present north of Santa Clara River except in sec. 26. The local nature of this occurrence leads to the inference that the impregnation of the sand at this spot has been due to a seepage of the oil from the underlying Modelo (?) formation. This fold is comparable to that in Castac Canyon, described above, for the same formations are involved in it. As the tests made on the Castac fold did not give good results the prospects for oil along the fold under discussion are not very bright. Any

[76] California State Min. Bur. Bull. 63, p. 158, 1913.

tests should preferably be made in San Francisquito Canyon close to the line between secs. 27 and 34, T. 5 N., R. 16 W.

Directly north of Saugus, near the south end of the ridge between San Francisquito and Dry canyons, there is a steeply northwestward-plunging anticline. This is not a well-defined anticline but is more in the nature of a sharp change in strike of the strata. The fold is short and apparently dies out after crossing San Francisquito Canyon. The presence of good oil sands yielding a fair production in both Saugus and Pico formations at a comparatively short distance south of this locality near Newhall, gives this fold some economic value. The oil sand near the base of the Saugus formation, which is exposed on the ridge dividing San Francisquito and Dry canyons in the SW. ¼ sec. 26, T. 5 N., R. 16 W., is favorable evidence and suggests that oil sands may be present in this formation in this vicinity where anticlinal folds are present and where the Modelo rocks underlie it.

The Mint Canyon strata in the upper Santa Clara Valley have been folded into a number of comparatively small anticlines and synclines. These are of no economic importance, as none of the rocks in this region are known to be oil-bearing. A recent test well more than 3,600 feet deep, drilled by the Tick Canyon Oil Syndicate on the west side of Mint Canyon in the southwest corner of sec. 35, T. 5 N., R. 15 W., has been abandoned as a dry hole.

SUMMARY.

In the area north of Santa Clara Valley and east of Castac Valley several anticlines are present, only one of which has been exploited. This fold crosses Castac and Charlie canyons north of the area mapped and is confined to Modelo (?) strata. Although a little oil was found, no commercial production was obtained. In the northeast corner of the Santa Susana quadrangle another anticline involving both the Modelo (?) strata and the Mint Canyon formation lies between Haskell and San Francisquito canyons. As the Mint Canyon formation is not petroliferous in this region and as the Modelo (?) rocks tested in Charlie Canyon did not yield oil in commercial quantities, it is thought that drilling on this fold is not warranted. A third anticline immediately north of Saugus offers some possibility of yielding oil from sands in the Saugus formation.

SANTA SUSANA AND SAN GABRIEL MOUNTAINS.

GENERAL FEATURES.

The area included in the Santa Susana and San Gabriel mountains lies south of Santa Clara River and extends from a point about a mile west of Torrey Canyon eastward to the edge of the region mapped (Pl. I). Its southern limit is the San Cayetano-Santa Susana fault, which, crossing Oak Ridge, extends along the south side of the Santa Susana and San Gabriel mountains. The rocks within this district consist only of the Modelo (upper Miocene), Pico (lower Pliocene), and Saugus (upper Pliocene and Pleistocene) formations. The Pico and Saugus formations rest upon the granitic complex of the San Gabriel Mountains. This district contains the southeastward continuation of the formations and structure that prevail north of Santa Clara River and is the south side of the great synclinorium of Santa Clara Valley. The Santa Susana Mountains in general are anticlinal, faulted on the south side by the Santa Susana fault. Other large folds, such as the Eureka Canyon anticline and the Pico anticline, lie to the north in the foothills. North of these folds all the strata dip to the north, at gradually diminishing angles as Santa Clara River is approached. The Modelo and Pliocene strata dip steeply on the north sides of the mountains and are even overturned in Eureka and Tapo canyons. The folds likewise are acute and tightly folded for their entire extent. East of the Fernando Pass the Pliocene strata dip away from the granitic complex, and the contact is normal on the west and south sides of the granite but faulted on the north along Placerita Canyon.

Although not nearly as much "wildcatting" has been done on the south side of Santa Clara River as to the north between Sespe and Piru creeks, nevertheless much larger fields have been developed here. (See Pl. I.) Producing fields lie at intervals along the north side of the Santa Susana Mountains from Eureka Canyon to the east side of Fernando Pass. The oldest field in California is in Pico Canyon, and the wells here are giving a fair production to-day. The fields of Pico Canyon, Wiley Canyon, and Newhall are the best in this district. The fields in Tapo Canyon and Eureka Canyon constitute the remaining productive areas. With the exception of the wells in Tapo Canyon all the wells have been put down along anticlinal folds, and here, as in other districts, the oil has been found to be closely associated with these folds.

EUREKA CANYON ANTICLINE.

Deformation has been severe in the rocks along the north slope of the eastern part of Oak Ridge, for besides the faulting the folds in Modelo sandstone and shale have been so closely compressed that the structure is very difficult to interpret. In the vicinity of Tapo Canyon the greater part of the strata dip northward and, overlain unconformably by the Pico formation, are in normal sequence. (See structure sections E–E′ and F–F′, Pl. II.) Farther west, however, the strata stand practically vertical, and near the mouths of

Eureka Canyon and Smith Canyon they are overturned. At the mouth of Eureka Canyon the basal beds of the Pico formation are also overturned. At first glance the Modelo strata in Eureka Canyon appear to form a southward-dipping monoclinical series of beds, but closer examination of the structure reveals a closely compressed anticline, whose axis follows the course of the canyon. This anticline very probably joins the fold that is plainly exposed near the head of Tapo Canyon. The dips on the south side of the fold near the mouth of Eureka Canyon are comparatively low, ranging from 30° S. near the axis to 55° S. farther south. On the ridge east of Torrey Canyon a great diversity in the attitude of the strata is apparent and no definite structural feature can be discerned. This diversity in attitude is evidently the result of the proximity of this ridge to the San Cayetano fault, which crosses the head of Torrey Canyon. In the upper parts of Eureka Canyon and Tapo Canyon the beds are steeply upturned and some overturning is noticeable. A small anticline and syncline are plainly visible in the sandstone near the contact with the shale, and the anticline probably connects with the main fold in Eureka Canyon. The syncline evidently runs into the San Cayetano fault, which here ends along the south side of Oak Ridge. Both of the folds are small and apparently are only minor flexures. (See Pl. I.) No faults are present between the Modelo sandstone and the shale that forms the crest of the ridge to the south, and the shale is plainly seen to underlie the sandstone. These folds probably continue to the area between Oak Ridge and the Santa Susana Mountains, where they are cut off by the Santa Susana fault. The structure in this area is exceedingly complex, all the strata dipping steeply or even being overturned, and for this reason it is difficult to trace the many folds. Some faulting may have taken place here.

The Tapo Canyon field is the largest producer along the Eureka Canyon anticline. In a strict sense, this field probably can not be considered as being on an anticline, for the wells are drilled a considerable distance north of the axis into the steeply northward-dipping beds and penetrate oil sands that crop out to the south, where they are saturated with tar. The oil has evidently been trapped in certain sands by the sealing of the beds at the surface due to the hardening of the oil on coming into contact with the atmosphere. Producing wells have been put down in the two west forks of Tapo Canyon, in the S. ½ sec. 36 and the SE. ¼ sec. 35, T. 4 N., R. 18 W. The first wells were drilled in 1882 by Thomas R. Bard and others by several companies and individuals. The first were rather shallow and gave only nonpaying quantities of oil. Shortly afterward, in 1893, holes over 1,000 feet deep were sunk, and in 1900 six of these produced 300 barrels a month. One well, drilled by the Canadian

Queen Oil Co. to a depth of 2,000 feet or more, gave as high as 100 barrels a day. At the present time two companies are operating in this field. The Union Oil Co. controls most of the producing wells; the Beatty Oil Co. has three wells and in 1919 was drilling another. Of the total fluid pumped at present about 25 per cent is water.

At the mouth of Eureka Canyon the South Pacific Oil Co. (formerly the Eureka Oil Co.) pumps 12 wells, which from March, 1917, to December, 1919, inclusive, yielded an average monthly production of 463 barrels. Two years before this their production was 700 barrels a month. The specific gravity of the oil is 0.9032 (25° Baumé), and the depth at which the oil is reached ranges from 700 to 1,500 feet. These wells are on the north limb of the Eureka anticline, which at this point is overturned to the north. Some oil sands crop out here, but the wells probably derive their oil from zones that lie below and are not exposed.

Several other wells, now abandoned, have been drilled along the north side of Eureka Canyon. Among these were three wells owned by the Winnepeg Oil Co. which produced from 1 to 4 barrels a day together with a considerable amount of water. The depth of the deepest well is 1,157 feet, and this produced oil of 0.9091 specific gravity (24° Baumé). The Eureka Canyon Syndicate put down three wells and the Tepusquet Oil Co. one well farther east, in Eureka Canyon. These wells were on the north side of the anticline, and it was their object to penetrate oil sands cropping out near by. None of these wells were producers.

In Smith Canyon, directly west of the South Pacific Oil Co.'s property in Eureka Canyon, two wells, now abandoned, were drilled by the Cameron Oil Co. These were shallow, as the first one was sunk to obtain water. With their oil sand at a depth of 60 feet, they were able to produce about 2 barrels of oil a day. A well, now abandoned, at the foot of the Torrey Canyon grade, drilled into Modelo sandstone close to the San Cayetano fault, yielded a slight amount of oil but not enough to pay.

The Eureka Canyon anticline does not appear to offer much inducement for an increase in production, except in drilling wells at places already proved. The entire length of the fold has been pretty well prospected, and only at two places have the wells yielded oil in sufficient quantities to pay, namely, at the mouth of Eureka Canyon and in the west branches of Tapo Canyon. Where oil is obtained the dip of the strata is not as high as at other places—for example, along Eureka Canyon, where the beds range in attitude from 60° to vertical. As a rule, in California oil does not accumulate to any large extent in strata dipping at a higher angle than 60°. Steeply dipping beds also militate against easy drilling, especially in the Modelo formation, where alternating hard and soft strata tend to cause crooked holes. No large producing wells can be expected in this area, but the history of wells already drilled indicates that new wells will probably be long-lived.

PICO ANTICLINE.

PICO CANYON FIELD.

On the north slope of the Santa Susana Mountains the only areas considered to be oil bearing are along the Pico anticline. This is a closely compressed fold (see Pl. XVII, *A*, p. 178), which extends in an approximately straight line from Salt Canyon to Fernando Pass. For the greater part of its length only the rocks of the Modelo formation are involved. Most of the outcropping surface strata belong to the sandstone member of this formation, but the underlying shale is exposed in lenticular areas along the axis of the fold from Towsley Canyon to East Canyon and in Dewitt Canyon. The Pico formation covers the east end of the fold near Fernando Pass and also lies above Modelo sandstone toward the valley. South of the anticline there is a large well-defined syncline which has the same length and direction as the anticline. The surface rocks in this syncline consist entirely of Modelo sandstone, though the top of the Santa Susana Mountains, forming the south limb of the syncline, is composed of the underlying shale member. The syncline is reflected very noticeably in the topography, as erosion has cut deep canyons along its axis. (See structure section I–I′, Pl. II). The strata along both folds dip at relatively high angles, averaging 50° to 60°, though at either end of the fold, where it plunges, they become less steep.

The Pico Canyon field (see fig. 2), in the central part of secs. 1 and 2, T. 3 N., R. 17 W., is at the west end of the anticline, which here plunges slightly to the west. The surface strata in Pico Canyon are the coarse sandstones of the Modelo formation, which, though essentially sandstone, contain varying amounts of conglomerate and shale. The sandstones are mainly massive, white and tan to yellowish brown, and interbedded with thin beds of dark-gray or chocolate-colored shale. The wells are grouped close to the axis of the anticline, and practically all the producers are on the north flank. According to the logs of the wells, which are not very complete for the holes first drilled, they penetrated mainly sandstone with interbedded shale.

Some of the shale zones, however, are equal in thickness to those of the sandstone. Correlations between the wells are difficult, probably owing to the lenticular nature of the strata. Some rather indefinite correlations can be made for a few wells close together, but correlation for distances of 500 feet or more is extremely doubtful. The oil zones do not appear to occupy any definite position over the field, but, like the lithologic zones, vary in horizontal extent and in thickness. Although several zones are present in the field, only a few of the deeper wells have penetrated more than one. The oil is found at various depths along the axis, ranging from 170 feet to nearly 900 feet. The depth of course increases rapidly to the north and south, owing to the steep dip of the strata. Furthermore, the upper oil sand does not extend down the flanks of the anticline very far from the axis so that most of the wells drilled even 500 feet north of the axis must obtain their oil from a deeper sand, which is reached in some wells at slightly more than 2,000 feet. Most of the wells are between 1,000 and 2,000 feet deep, four are more than 2,000 feet, and one was drilled to 3,445 feet. No satisfactory explanation can

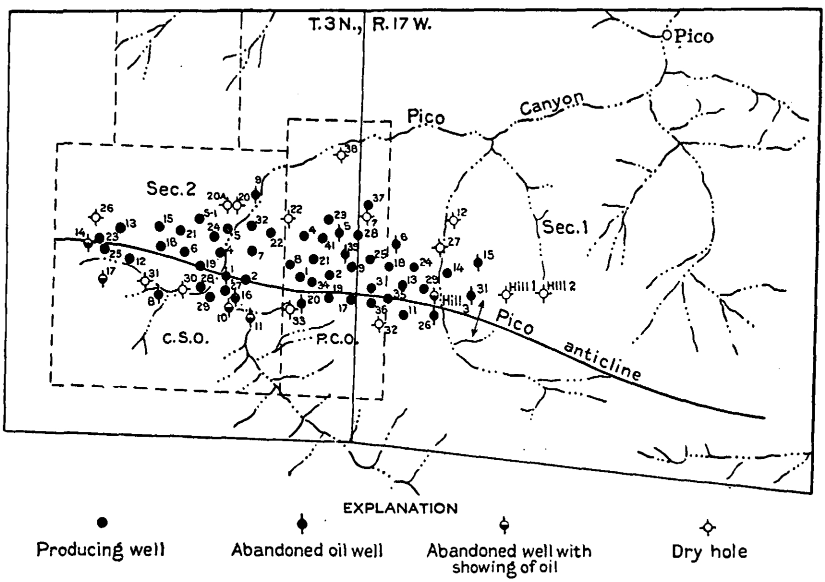


FIGURE 2.—Map of Pico Canyon oil field, Los Angeles County, Calif., showing location of wells in relation to axis of Pico anticline.

be given for this peculiar arrangement of the oil sands unless it is due to lenticularity of strata or to fracturing in the highly compressed fold, which has allowed the oil to pass from one stratum to another. Neither of these suggestions appears to be substantiated from surface evidence, for the strata do not appear to be particularly lenticular, nor are they broken. The thin bedding of the sands and shales indicates that they might have been easily folded with a minimum amount of fracturing.

Since 1902 the Standard Oil Co. (California) has owned all the wells in the Pico Canyon field, this being the first property the company acquired in the State. As early as 1850 oil was collected from this canyon for use at the San Fernando Mission. A well is said to have been drilled in 1869 by the spring-pole method to a depth of 140 feet. The first producing company was the California Star Oil Co., which started operations in 1875. In 1879 the Pacific Coast Oil Co. began drilling, and soon afterward it took over the California Star Co. The Hardison & Stewart Oil Co. also drilled three wells in this vicinity on what is known as the Hill tract. In all 78 wells have been sunk in the Pico field, and of these about one-half were producing in 1918. The oil is of very high grade, its specific gravity averaging about 0.8333 (38° Baumé). It gives a large yield of gasoline and kerosene with very small quantities of lubricants or asphalt residue. A typical analysis of this oil is as follows:

Analysis of oil from Pico No. 4 well of Standard Oil Co. (California), Pico Canyon field.[77]

Gravity, 37.3° Baumé.
Viscosity at 60° F., 1.40 Redwood.
Viscosity at 185° F., 1.07 Redwood.
Flash, below 60° F.?, Abel-Pensky test.
Sulphur, 0.28 per cent by weight.
Thermal value, 20,054 British thermal units.
Distillation: A sample of 200 cubic centimeters, distilled from a glass flask without steam or gas:

	Per cent.	Gravity (° Baumé).
Below 212° F.	10.5	57.3
212° to 302°	20.4	53.0
302° to 392°	13.8	44.1
392° to 482°	13.0	37.5
482° to 572°	11.1	32.7
572° to grade A	16.9	27.9
572° to grade B	6.8	30.5
Asphalt (grade D, about)	6.8	
Loss	.7	
	100.0	

These figures are closely equivalent to the following commercial analysis:

	Per cent.
Gasoline (61° Baumé)	6.0
Engine distillate (52° Baumé)	29.0
Kerosene (42° Baumé)	13.0
Stove oil (33° Baumé)	29.0
Middlings and lubricants (28.4° Baumé) (not separated)	15.5
Asphalt (grade D) (23.9 pounds per barrel)	6.8
Loss	.7
	100.0

The limits of the Pico Canyon field are pretty well defined at the present time, and it can probably not be enlarged to any marked degree. The field might be drilled more closely within the proved

[77] California State Min. Bur. Bull. 63, p. 186, 1913 (analysis No. 7444, by H. N. Cooper).

territory, but the roughness of the country does not allow a regular spacing for the wells.

DEWITT CANYON.

The next group of wells east of Pico Canyon is in Dewitt Canyon, in the N. ½ sec. 7, T. 3 N., R. 16 W. These wells have been drilled on the Pico anticline, either close to its axis or on its north flank. The fold here is closely compressed but well defined, with dips of more than 70° on its north limb. (See structure section I–I′, Pl. II.) Below the sandstone member of the Modelo, which forms the greater part of the fold, a narrow belt of what is probably the shale member is exposed in the canyon along the axis. Only a very few rig timbers are left to indicate that drilling was done here. Wells were sunk in both upper branches of Dewitt Canyon, which are known as Little Moore and Big Moore canyons. This group comprises seven wells, of which the first was drilled by the Hardison & Stewart Oil Co. in 1882–83. The Pacific Coast Oil Co. also drilled a few, but very little is known about these wells. One is reported to have reached a depth of 1,600 feet, another to have yielded a barrel of oil a day. None of the holes were producers, and it is very unlikely that further drilling would attain better results. As a general rule in California, folds which have been so tightly compressed that their limbs dip at a steeper angle than 70° are not commercially productive.

TOWSLEY CANYON.

All the wells in Towsley Canyon have been abandoned. According to reports 11 wells were drilled in a group in the northwest corner of the NE. ¼ sec. 17 and the southeast corner of the SE. ¼ sec. 8, T. 3 N., R. 16 W. (See Pl. I.) Another, the St. Bernard well, is several miles farther up Towsley Canyon, in the NE. ¼ sec. 18. This well was drilled in 1903 to a depth of 2,100 feet, but, though reporting oil at several horizons, it never produced. It is practically on the axis of the large syncline north of the Pico anticline.

Six wells in the Towsley Canyon group were drilled on or within 300 feet of the axis of the Pico anticline. One well on the axis was 1,000 feet deep; another, 1,700 feet. Several of the wells now flow water with a slight amount of oil. All of them obtained a little oil from shallow depths, but none produced over 30 barrels a day. The oil has a specific gravity of 0.8974 (26° Baumé). The rocks penetrated were mainly shale with little or no sand. At present the property is owned by the General Petroleum Corporation. Although the oil obtained from the wells is of good quality, it is doubtful whether commercial production could be maintained should new wells be drilled or the old ones rehabilitated. Seepages of oil occur along the axis of the fold in the canyon bottom.

WILEY CANYON FIELD.

The geology of the Wiley Canyon field is practically the same as that of other parts of the Pico anticline. The anticline is here a closely compressed fold in Modelo shale and sandstone, the shale being exposed in a narrow strip along the axis, but the dips, which range between 40° and 60°, are not so steep as those to the west. The wells are in the central part of sec. 16, T. 3 N., R. 16 W. along both flanks of the anticline, but close to the axis. (See fig. 3.) Twenty-nine wells had been drilled by 1917, which are owned by the Standard Oil Co. (California). The first 13 wells were drilled by the Pacific Coast Oil Co., which started operations here before 1887. None of the wells are large producers, and 16 of them have

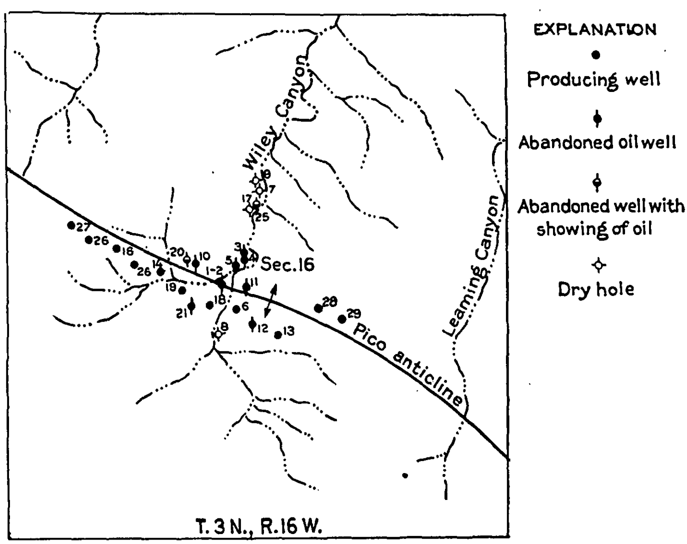


FIGURE 3.—Map of Wiley Canyon oil field, Los Angeles County, Calif., showing location of wells in relation to axis of Pico anticline.

been abandoned. These wells, moreover, are not as long-lived as those in Pico Canyon, nor is the specific gravity of the oil as high, being about 0.8750 (30° Baumé). Most of the wells are about 1,600 feet in depth, but they range from 400 to 2,600 feet. The greater part of the formation penetrated is shale. The deepest hole, which is between 800 and 900 feet north of the axis in the canyon, reached a depth of 3,835 feet. No oil sands were struck in this hole, and it has been abandoned. As in the Pico Canyon field, the productive limits in Wiley Canyon have been defined and show that the wells must be located near the axis of the fold. The production from this field is small, and whether it will ever be increased is extremely doubtful.

EAST OF WILEY CANYON.

In Rice Canyon 10 wells have been drilled, of which 7 were sunk by the Rice Canyon Oil Co., in the NW. ¼ sec. 22, T. 3 N., R. 16 W., in 1889–90. (See Pl. I.) These wells range from 825 to 1,600 feet in depth and are drilled into sandy brown shale that contains thin beds of chert and yellowish calcareous concretions. All these wells are a few hundred feet south of the axis. The anticline in Rice Canyon is not so acute as to the west, but the north side in general is somewhat steeper than the south side. The dips on the south limb are about 50° S. near the axis but rapidly become less farther south. Those on the north limb, though having about the same degree of steepness at the axis, do not flatten very rapidly to the north. The yield of the wells was small. All are now idle, and at the time of the writer's visit most of the derricks had fallen down. Some of the wells were flowing water with a very little oil. The specific gravity of the oil is reported to be about 0.8750 (30° Baumé). Two other wells were drilled by the Pacific Coast Oil Co., now owned by the Standard Oil Co. (California), near the south line of section 15, which adjoins the Rice Canyon Oil Co.'s property. These wells appear to be approximately on the axis of the fold. They are about 500 and 800 feet deep, and one is reported to have been capable of producing 3 barrels of oil a day. Another well was drilled by the Newhall Mountain Oil Co. in the NW. ¼ NE. ¼ sec. 21, to a depth of 1,800 feet. This well is practically on the axis of the syncline that parallels the Pico anticline to the south, and it found no trace of oil.

In East Canyon two wells have been drilled. The geologic conditions are about the same as in Rice Canyon, though the Pico anticline here is not so tightly folded, the dips averaging less than 40°. The axis plunges about 10° to the east. One well, drilled by Bradshaw & Beville in the SE. ¼ NE. ¼ sec. 22, had a good show of oil at about 800 feet but was never pumped. The other well, drilled by the Grapevine Canyon Oil Co., is a short distance to the north. It was abandoned at a depth of 300 feet. This well is approximately on the axis of the anticline, whereas the first well is about 700 feet to the south. From the tests already made there is little encouragement to warrant further drilling in East Canyon.

Two wells in Gavin Canyon, one drilled by the Dividend Oil Co., near the south line of section 10 and the other on the south side of the canyon in the NE. ¼ sec. 14, were shallow, and neither found any sign of oil. Although the northern well is on the strike of a small anticline which is present at Fernando Pass, this fold does not continue as far west as this well. Both wells are on northward-dipping strata of the Pico formation.

Near the Fernando Pass highway, three wells have been sunk. The Padua Oil Co. drilled one in the SW. ¼ NW. ¼ sec. 24 to a depth of 1,200 feet, but only a little oil near the top of the hole was encountered. The Alliance Oil Co. drilled one in the NE. ¼ sec. 24 near the south portal of the railroad tunnel, on the north flank of the Pico anticline to a depth of 700 feet. This hole struck a tarry oil close to the surface and was abandoned. At the time of the writer's visit a well was being drilled in the canyon immediately south of the axis of the anticline in the SW. ¼ SE. ¼ sec. 24, but without favorable results.

SAN GABRIEL MOUNTAINS.

ELSMERE FIELD.

Although the Elsmere field is usually grouped with the fields on the Pico anticline, it is distinct both geographically and geologically. This field includes the territory extending from Fernando Pass northeastward along the flanks of the San Gabriel Mountains to the eastern border of the area mapped, in the vicinity of Sand Canyon. At present all the productive wells are confined to a small area between the pass and Placerita Canyon, which extends less than 2 miles east of the Southern Pacific Railroad tracks and the State highway. The productive measures of this field are in the Pico and Saugus formations. Fine-grained marine strata compose the Pico, whereas the Saugus appears to be of fluviatile origin and consists almost entirely of coarse-bedded sandstone and conglomerate, resting unconformably upon the Pico. The Saugus overlaps the Pico to the north, and near Placerita Canyon it lies directly on the basement complex. Although the Pico rests upon the Modelo formation in the Santa Susana Mountains, it has here overlapped the Modelo and lies directly on the granite, except north of Placerita Canyon, where patches of the Pico are in contact with the Mint Canyon formation (probably upper Miocene). South of Placerita Canyon the contact of the Tertiary rocks with the basement complex is normal, but in the eastern part of this canyon the Pico and Saugus strata have been faulted down against the crystalline complex of the San Gabriel Mountains, the fault, or rather two faults, extending up Placerita Canyon to the head of Sand Canyon and thence northeastward beyond Lang. The Pliocene strata, dipping away from the basement complex east of Fernando Pass at an average angle of about 20°, have been gently folded into a few anticlines and synclines, which do not continue westward far beyond the tracks of the Southern Pacific Railroad. Oil sands are exposed at a number of places in the Elsmere field, notably in Elsmere

Canyon, where the lower beds of the Pico and Saugus formations are saturated with petroleum. Seeps also occur in this canyon and at several places north of it as far as Placerita Canyon.

The main anticline of this field is in Elsmere Canyon. This is a broad, steeply plunging fold overlying the west end of the basement complex of the San Gabriel Mountains. (See Pl. I.) The axis of the fold extends in a northwesterly direction down Elsmere Canyon and across the end of Elsmere Ridge. Beyond this point it is not

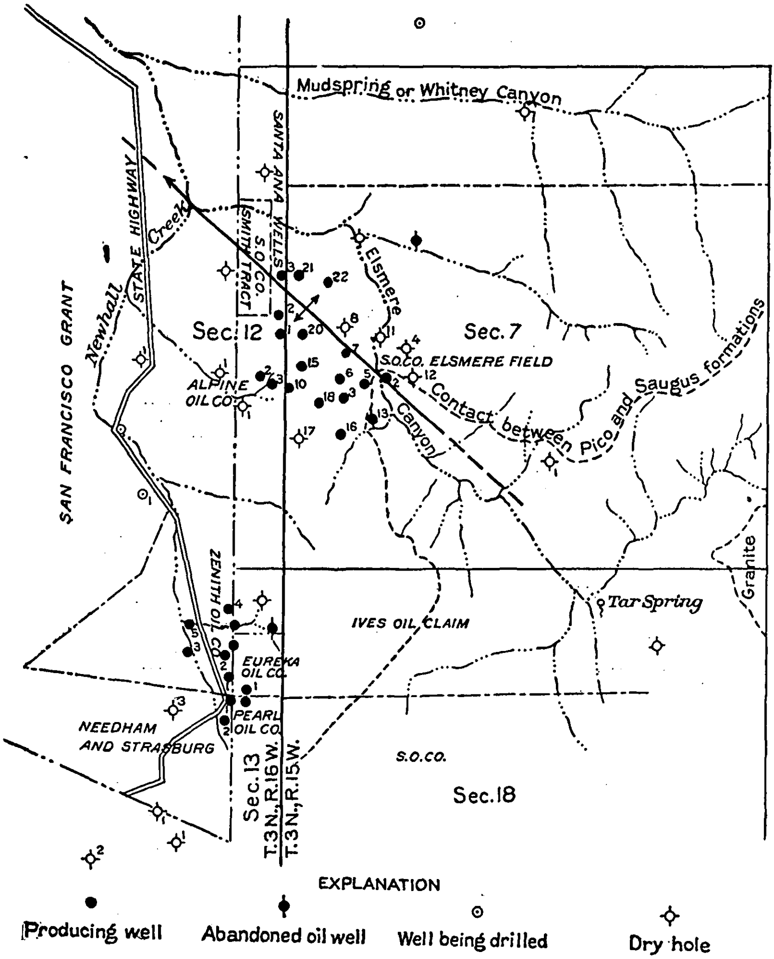


FIGURE 4.—Map of Elsmere oil field, Los Angeles County, Calif.

traceable with certainty, but it may continue for a short distance west of Newhall Creek. (See structure section K–K′, Pl. II.)

The Standard Oil Co. (California) is the largest operator in the Elsmere field, having drilled 21 wells along this fold. All are relatively shallow, ranging in depth from 500 to 1,895 feet, and only six are more than 1,000 feet deep. About half of the wells are nonproductive. The first 15 wells were drilled as early as 1889 by the California Star Oil Co., from which the Standard Oil Co. purchased the property in 1903. Most of the wells of the Elsmere lease are on Elsmere Ridge, particularly on its north slope, and in Elsmere Canyon. The well logs show that there is usually a tar sand a very short distance below the surface, and in some places the wells are started in an oil sand. Three or four other oil sands are penetrated at different depths down to 1,000 feet, though this depth varies according to the location. There is a chance that deeper oil sands may be present in this field, and it is recommended that a well be sunk deep enough to test this possibility, or, on the other hand, if the Modelo formation is comparatively thin here, to reach the crystalline rocks. A typical log is that of one well at the point of Elsmere Ridge, as follows:

Log of Standard Oil Co.'s Elsmere well No. 21, near Newhall, Los Angeles County, Calif.

	Thickness.	Depth.
	Feet.	*Feet.*
Coarse sand; 8 barrels of surface water at 42 feet	42	42
Tar sand; hole caving badly at 276 to 320 feet	343	385
Sandy shale	15	400
Blue shale	28	428
Brea beds	2	430
Tar sand (probably base of Saugus formation)	25	455
Blue shale (Pico formation)	100	555
Brown sand	5	560
Blue shale; water at 620 feet	60	620
Coarse sand	65	685
Coarse sand; showing a little oil	30	715
Coarse sand	10	725
Hard shell	2	727
Blue shale	38	765
Fine shale	5	770
Blue shale	15	785
Fine sand; showing a little gas at 785 feet	13	798
Coarse gray sand	5	803
Fine brown sand; showing some oil	6	809
Coarse sand	31	840
Blue shale	54	894
Yellow shale	1	895
Blue shale	23	918
Coarse sand	7	925
Coarse sand; showing little gas and oil	7	932
Coarse sand	3	935
Blue shale	40	975
Blue shale and sand	23	998
Fine sand	16	1,014
Blue shale and sand	72	1,086
Blue shale and sand; slight showing of oil	14	1,100
Coarse sand; slight showing of oil	10	1,110
Hard shell (probably Modelo formation)	3	1,113
Blue shale	7	1,120
Blue shale and sand	20	1,140
Blue shale	40	1,180
Blue shale and sand	49	1,229
Brown shale	6	1,235
Blue shale	5	1,240
Hard sand	19	1,259
Blue shale	51	1,310
Hard gray sand	8	1,318
Blue shale	17	1,335
Hard shell	2	1,337
Blue shale	16	1,353
Hard shell	5	1,358
Blue shale	20	1,378
Hard shell	2	1,380
Hard sand	10	1,390
Blue shale	27	1,417
Sandy brown shale	18	1,435
Blue shale	76	1,511
Hard shell	2	1,513
Blue shale	79	1,592
Gray sand; slight showing of gas	5	1,597
Blue shale; hole caving badly	14	1,611

Two wells were drilled in 1900 at the head of Elsmere Canyon, in the NW. ¼ sec. 17, T. 3 N., R. 15 W., by the Graves Oil Co. and the California Oil Co. The former went 1,500 feet and the latter 1,200 feet. Both wells are on the metamorphic and granitic mass of the San Gabriel Mountains and must have gone through crystalline rocks for their entire depth. It is needless to state that both were barren. The Goodluck Oil Co. in the same year drilled a nonproductive well in the SE. ¼ sec. 7, which is reported to have struck a little oil and a good deal of water.

AREA BETWEEN ELSMERE AND PLACERITA CANYONS.

In Newhall Canyon, which is immediately southwest of Elsmere Canyon, there is another group of wells (see fig. 4), a few of which are now producing. The companies operating here are the Pearl Oil Co., Zenith Oil Co., Newhall Petroleum Co. (San Miguel Oil & Development Co.), Safe Oil Co., Squaw Flat Oil Co., and E. A. & D. L. Clampitt. The Clampitts have bought the properties of the Santa Ana Oil Co., Alpine Oil Co., Commercial Oil Co., and Eureka Crude Oil Co. The wells put down by these companies are all grouped in the upper part of Newhall Canyon and close to the State highway, in the NE. ¼ sec. 13 and the E. ½ sec. 12, T. 3 N., R. 16 W. Up to 1912 21 wells had been drilled here, and in 1917 two more were being sunk on the Clampitt properties. Of the wells drilled only about half are now productive. The tests made by a number of these wells have determined the southern and western limits of the productive territory in the Elsmere field. The productive area in Newhall Canyon extends but a very short distance west of the State highway and does not reach south of the Zenith Oil Co.'s property, which lies along the State highway in the NE. ¼ NE. ¼ sec. 13. To the east producing wells are not obtained beyond the east line of sec. 13. Thus the productive territory in Newhall Canyon is limited to a small tract on the east side of the canyon. Between the wells in Elsmere Canyon and those in Newhall Canyon a small area in the southeast corner of sec. 12 is at present undrilled. There is no reason to believe that wells such as are pumping on the Zenith Oil Co.'s property could not be brought in here.

In the northern branch of Newhall Canyon, known as Mud Springs Canyon or Whitney Canyon, a few wells have been put down by the Nettleton & Kellerman Oil Co., D. A. Connell, the Banner Oil Co., the Golden West Oil Co., and the Yankee Doodle Oil Co. None of these wells are producing at the present time. Out of eight wells put down between 1893 and 1908 six struck oil and several produced for a time. These wells are on both sides of the creek close to the line between secs. 6 and 7, T. 3 N., R. 15 W. Structurally they are on the general Elsmere fold, though the folding is not so distinct here as at Elsmere Canyon. On the ridge between the two creeks the oil-saturated sandstones and conglomerate of the Saugus formation crop out, and in one of the small gulches a large oil seep is present. The wells drilled here were from 600 to 1,450 feet in depth. The deepest well, put down by the Nettleton & Kellerman

Co., penetrated three oil sands but at 1,450 feet struck granite. The deepest sand gave a bright-green oil of low specific gravity, which is in marked contrast to the heavy oil of the other wells in this district. Some of the wells came in with a good yield but soon fell off to 2 or 3 barrels per day. Water trouble was the main difficulty in this group of wells, and most of the holes were lost on this account. With modern drilling knowledge this difficulty should be obviated. That the territory is already ruined through lack of precaution in shutting off the water is very likely. In the tests made by these wells three oil sands were found. The first, about 600 feet deep, carried a very heavy oil, probably similar to that in Elsmere Canyon. The second yielded a brownish-green oil of about 0.9524 specific gravity (17° Baumé), and the third an oil of 0.8235 (40° Baumé). The wells have evidently been drilled through the Saugus and Pico formations and perhaps a part of the Modelo. The high specific gravity of the oil in the lower strata suggests that it comes from the Modelo, in view of the fact that a similar oil is obtained in the Pico Canyon field, where the Modelo is the source for the oil. There is also a suggestion that the high-gravity oil that occurs in the granite in Placerita Canyon is an exceptional light oil of local occurrence, which has been derived from the same source.

On the ridge between Mud Springs Canyon and Placerita Canyon two wells have been drilled by the Tunnel Petroleum Co. in the NW. ¼ SE. ¼ sec. 6, T. 3 N., R. 15 W. (See Pl. I.) These wells are closely associated structurally and lithologically with the wells in Mud Springs Canyon. No well-defined fold is present other than a general swing in the Pliocene strata around the west end of the San Gabriel Mountains. The wells start in the conglomerate of the Saugus formation and probably penetrate the Pico sand below. The first well struck a heavy oil at 1,042 feet, but the main oil sand is between 1,178 and 1,240 feet. Water sand was met at about 1,325 feet, below which no more oil was encountered. In 1917 this well was producing daily 40 barrels of oil having a specific gravity of 0.9722 (14° Baumé). The second well produces about 20 barrels a day. In 1919 another well was being drilled by the General Petroleum Co. in a tributary of Placerita Canyon in the SE. ¼ sec. 31, T. 4 N., R. 15 W., on a relatively small westward-plunging anticline that extends across the west side of sec. 32 and the east side of sec. 31. Cropping out around this fold is a thick stratum of oil sand from which oil is seeping near the head of the gulch, in sec. 31. This fold is similar to the one in Elsmere Canyon—that is, it is not a well-defined anticline but more of a flexure caused by a sharp change in the strike of the strata. No productive well has yet been obtained on this fold.

SOUTH SIDE OF SAN GABRIEL MOUNTAINS.

A few wells have been drilled south of Fernando Pass. The Enterprise Oil Co. drilled two wells in the NW. ¼ SE. ¼ sec. 13, T. 3 N., R. 16 W., to depths of about 700 feet but obtained only traces of heavy oil near the surface. The Santa Ana Oil Co. drilled a well in the SW. ¼ SE. ¼ sec. 18, T. 3 N., R. 15 W., to a depth of 600 feet and at 585 feet struck an oil sand that was capable of producing 12 barrels of oil a day, but the hole was lost later through mechanical trouble. In 1917 the Buick Oil Co. drilled near by on top of the ridge, in the NW. ¼ SE. ¼ sec. 18, but no commercial quantity of oil was found in this well. Two drill holes along the south slope were dry—the Mentey well, in Grapevine Canyon, in the NE. ¼ sec. 20, and the Pacoima Oil Co.'s well, in the canyon to the east, in the SW. ¼ sec. 20. South of the divide the Pico strata are highly deformed, a very tightly compressed syncline passing westward near the head of Grapevine Canyon. South of this syncline, along the foothills, the eastern part of the Santa Susana fault cuts off the Pico strata, and this type of structure probably has not been conducive to the accumulation of oil. (See structure section L–L′, Pl. II.)

PLACERITA CANYON.

On the south side of Placerita Canyon near the east line of the NE. ¼ sec. 4, T. 3 N., R. 15 W., eight wells have been drilled by three companies. (See Pl. I.) The Freeman & Nelson White Oil Co. sunk three holes in 1899–1900, of which the deepest one reached 1,030 feet. North of this property the New Century Oil Co. drilled four wells in 1900–1901, ranging in depth from 700 to 1,000 feet. In 1912 the Los Angeles & Kern Oil Mining Co., leasing land from the Freeman & Nelson Co., put down a shallow well. Farther east a few other holes have been drilled in the rocks of the basement complex. One in Los Pinetos Canyon, put down by the Pioneer White Oil Co., and also known as the Freeman & Elston well, went 1,270 feet and got some gas, a very little white oil, and a good deal of water. Two others were in Coyote Canyon, in the NW. ¼ of NE. ¼ sec. 12. One well, 1,150 feet deep obtained some gas. Colors of oil were found in a second hole. The low specific gravity of this oil, which is estimated to be close to 0.7777 (50° Baumé), its water-like appearance and odor of kerosene, and its unique occurrence in crystalline rocks have been of considerable interest ever since the wells were drilled. None of the wells were capable of producing over 3 barrels of oil a day. With this oil a great deal of water was pumped, and at present very little oil comes up with the water. The wells are immediately south of the San Gabriel fault, which here has let down the strata of the Saugus formation against the basement complex. The northernmost well is drilled practically on the fault; the others are all in the crystalline rocks, which here consist of a hornblende schist intruded by aplite dikes. The planes of schistosity in these rocks along the contact in general dip 50°–80° N. and strike N. 70° W. The sandstone of the Saugus formation, abutting against the hard rocks, is almost flat, though having in most places a slight northward dip. About half a mile farther west the fault contact is plainly seen in sections where the strata have been cut through by the creek. Here the rocks within a few feet of the fault plane have been tilted to the north at angles as high as 50°, but beyond the fault the average dip is about 20° N.

The Saugus formation close to the fault consists of a dark greenish-brown coarse sandstone and conglomerate which appears to have been derived principally from the rocks of the basement complex, overlain by about 400 feet of massive light rusty-gray conglomerate similar to those on Elsmere Ridge. The peculiar occurrence of the oil in Placerita Canyon has often been used as an argument in favor of the inorganic origin of oil. It has also been suggested that the oil originated in the sediments from which the schist has been formed, and that the highly refined condition of the oil is the result of the great pressure and heat to which the sediments were subjected during their transformation into schist. This is impossible, for, as Eldridge[78] explains, "the lighter hydrocarbons would have been the first to have been given off in the heat, pressure, and fracturing to which the rocks have been subjected, and if anything remained, it should have been the asphaltic or paraffine residue." The explanation of the presence of the oil in the schist that is borne out by the geologic conditions is that the oil originated in the Tertiary rocks, probably the Modelo formation, and thence migrated into the Pico and Saugus formations; that the oil sands of these formations, which are known to be oil bearing a few miles away, have been faulted down against the basement complex rocks; and that the oil has seeped up along the fault into the fractured schist near the contact. The light specific gravity of the oil has been accounted for by a process of distillation brought about during its migration. Experiments on this subject have been carried on by Day[79] with fuller's earth as the medium, but it has been recognized that other dry sediments will also have a selective influence on petroleum during its migration.

[78] U. S. Geol. Survey Bull. 309, pp. 100–101, 1917.

[79] Day, D. T., A suggestion as to the origin of Pennsylvania petroleum: Am. Philos. Soc. Proc., vol. 36, No. 154, 1897.

SOUTH SIDE OF SANTA CLARA VALLEY.

East of Saugus between the San Gabriel fault and Santa Clara River the lithologic conditions are not directly favorable for the accumulation of oil, as the greater part of the area is underlain by the Mint Canyon formation (upper Miocene?), which is not known to be oil bearing (see pp. 54–55), and the Modelo formation, the source for the oil in this region, where present, overlies the Mint Canyon. (See structure section L–L′, Pl. II.) Both the Pico and Saugus formations rest unconformably upon the Mint Canyon and Modelo beds, and the areas of these rocks in this territory represent the feather edges of these formations. No oil sands or other surface indications of oil have been found in any of the formations in this area north of the fault. One fairly well defined fold, the Soledad anticline, extends in a northwesterly direction along the north side of the ridge north of Placerita Canyon, but the folding was confined almost entirely to Mint Canyon strata, which are of no economic importance. Considerable faulting has also occurred to break up any continuity in the formations. A well drilled by the General Petroleum Corporation on this fold near the west line of the SE. ¼ sec. 30, T. 4 N., R. 15 W., struck considerable gas at 1,200 feet, but when carried to 3,514 feet showed the strata to be barren of oil.

Two wells have been drilled north of the San Gabriel fault in upper Placerita Canyon. The well of the San Miguel Oil & Development Co., on the north side of the canyon in the NE. ¼ NW. ¼ sec. 3, T. 3 N., R. 15 W., was about 1,000 feet deep and is reported to have found traces of white oil similar to that obtained farther west in the wells in the schist. It was sunk into northward-dipping strata of what appears to be the Mint Canyon formation. The strata here are greatly broken, owing to their proximity to the fault, and this fault may have been the channel along which the oil migrated into beds of this age. Another well, known as the Harrison well, was drilled into the same formation about half a mile farther east along the county road, near the east edge of sec. 3. It is said to have been 2,100 feet deep, but found no indications of oil.

SUMMARY.

The source of the oil in the fields east of Newhall has evidently been the Modelo shales, which are known to be oil bearing to the west along the Pico anticline. That the Modelo shales are present beneath the Saugus and Pico formations at Elsmere Canyon is known from the logs of the deeper wells, which have pierced the Pliocene coarse sediments and entered the Miocene shales of the Modelo. The Pico and Saugus lie unconformably above the Modelo, and this condition allows the escape of hydrocarbons from the truncated edges of the Modelo into the highly porous strata of the Saugus. The oil has migrated into several rather indefinite zones, and has risen to the highest parts of the formation—that is, along its upturned edges at the west end of the San Gabriel Mountains. That this oil has not escaped is probably due to its oxidation at the surface, forming asphaltum, which has effectively sealed up the exposed edges of the oil sands. As the oil is of high specific gravity (0.9722, or 14° Baumé), this sealing was easily accomplished.

To judge by the underground conditions, supplemented by the practical tests made by the many wells drilled in this area, the oil appears to have collected along a zone that extends from Fernando Pass northward to the ridge on the north side of Placerita Canyon. South of Placerita Canyon this zone is comparatively narrow, as is shown by the tests made around Elsmere and Newhall canyons, and it is logical to assume that the zone is also narrow north of the canyon. Therefore commercially productive territory north of Mud Springs Canyon should not be sought for outside of sec. 6, T. 3 N., R. 15 W., and the S. ½ secs. 31 and 32, T. 4 N., R. 15 W., south of the Placerita Canyon fault.

SOUTH SIDE OF SANTA SUSANA MOUNTAINS.

The top and south side of the Santa Susana Mountains (see p. 97) is in general anticlinal, with the south limb cut by the Santa Susana fault. The surface rocks are composed largely of the Modelo formation, comprising two sandstone members separated by shale, but the Topanga formation is exposed along the fault at the head of Browns Canyon and to the east in Aliso Canyon. Well-defined folds are rare in the Santa Susana Mountains, and it is only at the east end that a few definite anticlines are present which may be considered in relation to their oil possibilities. (See structure sections I–I′ and K–K′, Pl. II.) One, indicated on the map (Pl. I), paralleling the crest of the mountains, is close to the headwaters of Browns Canyon. This fold is not of any great importance, for, although it is traceable for over 2 miles, it is more like a shallow crumple than a definite anticline. It is probably the result of compression at the time the Santa Susana fault was formed. Another fold, which has a domelike shape, extends in a westerly direction across the upper part of Aliso Creek (east). Owing partly to the elevation of the strata in the fold and partly to the erosion by Aliso Creek, the sandstone of the Topanga formation has been exposed. On the north side the coarse brown and white sandstone dips 35°–50° N., but on the south side it shows some variations in attitude. On the west side the dips are comparatively gentle (20° S.), but toward the east they are much steeper, the beds being in places nearly vertical. Considerable crumpling has occurred in the narrow part of the canyon as a result of faulting. A well was drilled by Capt. O. J. Stowe (see Pl. I) in 1916–1918 along the axis of this fold in the NE. ¼ SW. ¼ sec. 27, T. 3 N., R. 16 W. The well was sold in 1919 to the Los Angeles-Ventura Oil Fields Co. An incomplete generalized log of this well, which reached a depth of about 2,900 feet, is as follows:

Incomplete log of Stowe well, in sec. 27, T. 3 N., R. 16 W.

	Thickness.	Depth.
	Feet.	*Feet.*
Brown shale becoming darker until nearly black	450	450
Clean blue shale	2,210	2,660
Chocolate-colored shale	48	2,708
Hard shell with Eocene fossils	2	2,710
Sand. Heavy gas pressure with a good saturation of light oil (38°–40° Baumé). Lower part is hard sand showing almost black in water, but washes out a fine hard sand. Gas throws up drillings in the hole	135	2,845

The hole started in the sands of the Topanga formation on the Santa Susana Mountains, below the beds that are oil bearing in the Pico anticline. Underlying the Topanga should come the Vaqueros, Sespe, and Eocene, but from the log of the well the coarse sand and conglomerate of the Vaqueros and Sespe appear to be absent, and Eocene fossils are obtained after passing through 2,708 feet of shale also probably of Eocene age, which lies directly below the Topanga. The small amount of oil that was struck occurs in the Eocene beds at probably the same horizons as that in the Simi field. No production was ever made, and the well has been abandoned.

An asymmetric anticline follows the south side of Bee Canyon to its bend, thence trending northeastward. It plunges to the east, and the plunge becomes markedly steep beyond Bee Canyon, where the Pico strata are involved. The dips on the south side of the fold in Bee Canyon are much less than those on the north side, which are as high as 80° N. East of the canyon the sandstones of the Modelo and the conglomerates of the Pico are wrapped around the shale area, and their strike makes a nearly right-angled turn on the nose of the fold. No oil seeps or oil sands were noticed along this fold, and should oil be present some surface evidence of it ought to show, for the strata that are oil bearing in the Pico and Elsmere fields are exposed here.

SUMMARY.

The district included in the Santa Susana and San Gabriel mountains was one of the first in California to be exploited for oil, wells being drilled at Pico Canyon as early as 1875. By 1918 a total of 235 wells had been drilled in this area. About 150 of these are now abandoned, however, and the production of the others averages only about 5 barrels a day. In the Newhall field, which includes the Pico anticline and Elsmere wells, the total production[80] for the fiscal year 1916–17 was 119,289 barrels of oil, with 132,656 barrels of water—that is, the water formed 52.7 per cent of the total fluid pumped.

The greatest part of the district has been tested, at one time or another, especially along the Eureka Canyon and Pico anticlines and on the Elsmere and Placerita folds, which are the only areas where future production may be expected. The Eureka Canyon anticline offers little opportunity for the opening up of any new country, as the tests already made along it indicate that productive territory can be extended only in the vicinity of the existing fields. Along the Pico anticline the conditions are similar, though considerably larger production is obtained from the two fields at Pico and Wiley canyons. At a number of other places along this fold oil is known to occur, but so far it has not been developed in quantities of economic importance. With the aid of modern and scientific drilling methods, however, small but paying wells might be completed east of Pico Canyon, if water from the old wells has not already driven the oil out of the sands. In the Elsmere field more wells could be put down satisfactorily between the areas of proved territory. By obviating the water menace in the wells of Mud Springs Canyon a few small but probably paying wells could be obtained. A test of a small fold in Placerita Canyon resulted in no commercial production. Another anticline, lying south of Santa Clara River in the Mint Canyon formation, is an attractive-looking fold, but this formation is not oil-bearing, as has been demonstrated by the drill.

Although oil sands are present in the territory east of the town of Fernando, the fact that wells already drilled there have proved unproductive and the lack of favorable structure for the accumulation of oil seem to constitute a strong argument against further work in this territory. However, the exposed oil sand has not been tested by a well drilled north of the outcrop and down the dip of the oil-bearing sand.

OAK RIDGE AND SOUTH MOUNTAIN.

GENERAL FEATURES.

In comparison with the area north of the San Cayetano fault the structure in Oak Ridge and South Mountain is simple. Oak Ridge itself is the result of a single line of folding, generally known as the

[80] California State Min. Bur. Bull. 84, p. 236, 1918.

Oak Ridge anticline, though four separate anticlines are present. (See Pl. I.) West of Torrey Canyon these anticlines are arranged in a series of arcs, with the concave side to the north, which overlap one another more or less. East of Torrey Canyon the Oak Ridge anticline turns southeastward, and north of Tapo Canyon it finally dies out or is cut off by the Santa Susana fault. The axes of these anticlines do not follow the crest of the ridge but lie on the north slope and in the vicinity of Bardsdale are close to the valley's edge. As a whole the fold is asymmetric, the north side being the steeper, and in places is overturned. The top is flat but breaks away abruptly on the north side. (See structure sections A–A′, B–B′, and C–C′, Pl. II.) The axes of this folding do not plunge in one direction but are undulating, thus forming domes. It is along the comparatively flat tops of these domes that the oil has accumulated.

The formations involved in the Oak Ridge anticline constitute a complete section comprising the Sespe (Oligocene?), Vaqueros (lower Miocene), Modelo (upper Miocene), Pico (lower Pliocene), and Saugus (upper Pliocene and Pleistocene). These formations are arranged along the axes of the folds, the Sespe being exposed in oval areas in the higher parts of the anticlines. (See Pls. XI, *B*, and XIV, *A*.) The Miocene formations are wrapped around the Sespe, and where they have not been eroded away they entirely surround it, as in Wiley and Torrey canyons. The Pico and Saugus formations rest unconformably upon the Modelo and form the greater part of the south side and crest of Oak Ridge and South Mountain. They dip southward at angles of 30° or less, the dips becoming lower as the axes of the Happy Camp Canyon and Las Posas synclines are approached. The beds on the south side of the fold rarely attain dips greater than 35° S., but those on the north side commonly dip 40°–50° N. or even more, especially along South Mountain and in the vicinity of Shiells Canyon.

The Sespe formation, in which the oil largely occurs, is composed primarily of yellow sandstone and conglomerate interbedded with red and green clay and soft sand. The harder yellow conglomeratic sandstone does not weather so easily as the clay and stands out in bluffs where it is easily traceable around the domes at Bardsdale and Shiells canyons. Below the surface the logs of the wells show that about equal amounts of blue and brown shale and brown, gray, red, and white sand are passed through. A few thin "shells" are also indicated, as well as beds of limestone in some logs. No indication of organic matter has been found at any horizon, and no fossils occur. The strata are exceedingly lenticular, so that it is difficult to trace the beds for any great distance, and correlation of well logs is impossible. The correlation of the strata with the type section of the Sespe across Santa Clara River in Sespe Creek has been based on similarity of lithology and stratigraphic occurrence, the Sespe on either side apparently underlying the true Vaqueros formation conformably. A more detailed description of these beds is given on pages 31–36.

Along the Oak Ridge anticline are the Torrey Canyon, Shiells Canyon, Bardsdale, and South Mountain oil fields. (See Pl. I.) The Bardsdale and Shiells Canyon fields are usually grouped together under the name Bardsdale, but as the two fields are on separate folds, or domes, it is thought best to discuss them individually. The oil occurs in the middle and lower parts of the Sespe formation in all the fields, but the sands are found at different depths below the surface. The oil probably has the same origin as that in Simi Valley, where it is evidently derived from organic shales in the Martinez and Meganos formations (lower and middle Eocene). From these shales it has migrated through fissures into sands of the Sespe. Oil is also obtained from the Sespe in Simi Valley in Brea Canyon and at the Scarab wells. The horizon in the Sespe at which the oil occurs along the Oak Ridge anticline is similar to that in Simi Valley, and it is very probable that they are the same.

TORREY CANYON FIELD.

A field has been developed by the Union Oil Co. of California near the head of Torrey Canyon, which is directly south of the town of Piru. (See Pl. I.) Structurally it is on one of the domelike uplifts at the east end of the Oak Ridge anticline. The San Cayetano fault cuts the strata immediately to the north, and for this reason the dome is markedly asymmetric, the north flank being nearly vertical and in part truncated by the fault. (See structure section E–E′, Pl. II.) Directly south, on the opposite side of the ridge, the Santa Susana fault is present, so that this field is practically situated between two faults. In the highest part of the dome the Sespe formation is exposed in a relatively small oval area. (See Pl. XI, *B*.) Encircling it is the Vaqueros, which is cut by the San Cayetano fault on the north and brought into contact with the massive sandstones of the Modelo formation. The shale of the Modelo rests conformably above the Vaqueros south of the San Cayetano fault. The anticline or dome is flat-topped. The beds of the south flank become very gradually steeper until at the crest of the ridge they dip between 25° and 30° S. The north flank breaks away abruptly, and the beds within a very short distance of the axis are nearly vertical.

The oil zones in the Torrey Canyon field are found in the Sespe formation at various depths, ranging from 75 to 1,965 feet. No well-defined oil sands appear to be present, though from an examination of the well logs two fairly distinct zones occur, the first one at a depth between 100 and 500 feet and the second between 650 and 1,000 feet, the depth varying according to the distance from the axis of the fold. As many as six sands have been penetrated in a single well. Nearly 50 wells were drilled in this field between 1889 and 1900, and of these 42 were pumping in 1917, producing a total of about 275 barrels of oil a month. The specific gravity of the oil is between 0.8861 and 0.8750 (28°–30° Baumé). About 500,000 cubic feet a day of gas is given off, but this is allowed to escape into the air. Tests have shown it to contain about 1 gallon of high-gravity gasoline in 1,000 cubic feet of gas.

The productive limits of the Torrey Canyon field have been pretty accurately determined as embracing a comparatively small circular area about half a mile in diameter lying on both sides of the anticlinal axis, though the greater number of producing wells are on the south flank. There is but little chance of extending this field, though closer drilling of wells could probably be done. No large wells should be expected, but with the high grade of oil obtained, the comparatively shallow depth of drilling, and the low cost of pumping by using natural gas for producing power, new wells should pay. Deeper drilling should pierce other oil sands, for in the Shiells Canyon field producing sands were encountered to a depth of nearly 3,500 feet. The same sands at Torrey Canyon, if present, would be somewhat deeper, owing to a less degree of erosion in the Sespe strata.

WILEY CANYON.

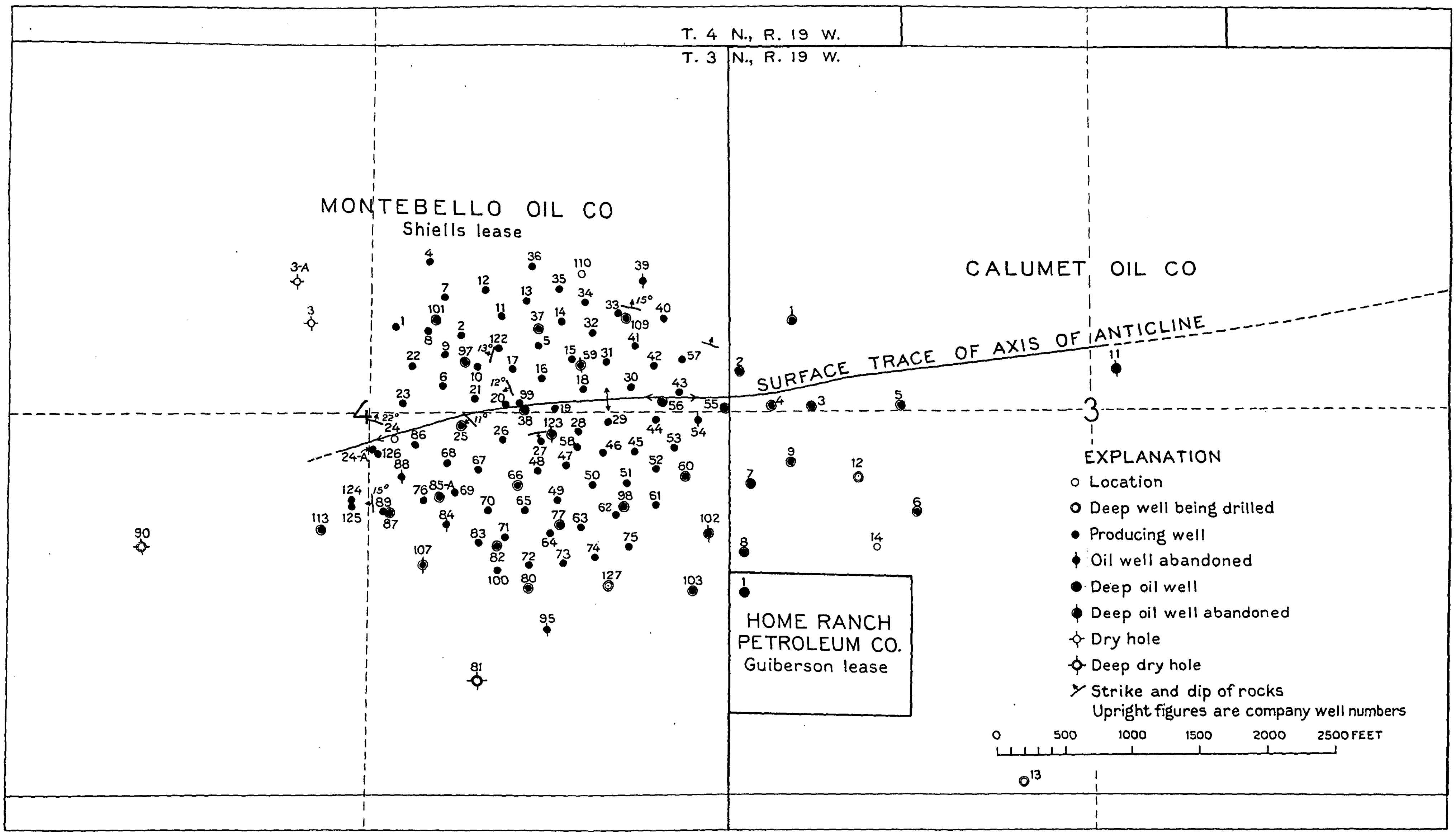
Three test wells have been sunk in Wiley Canyon (see Pl. I), but no oil was found. The geology of the area is closely similar to that in Torrey and Shiells canyons, and the wells were drilled along the same fold. As in the other producing areas the structure is that of an elongated dome and the same formations are involved. The exposure of Sespe strata is somewhat larger than at Torrey Canyon, in which stratigraphically lower beds of this formation crop out.

The second well was put down in 1913–1916 and the third in 1923 by the Ventura Consolidated Oil Fields. The second penetrated 3,555 feet of strata, of which at least the larger part is of Sespe age. The lower 500 feet or so may represent the Eocene. No oil sands were struck, though some gas was encountered. The third well made a very careful deep test without getting even a show of oil. These wells have now been abandoned. That no trace of oil was found seems rather peculiar and even remarkable, for producing fields at about equal distances on either side of it along the same fold have the same structural and lithologic conditions. No definite explanation can be given for this anomaly. Perhaps it is due to some geologic condition that is not apparent from the surface, such as lenticularity of sands or the absence of avenues of migration from below. On the other hand, future drilling may strike a pocket of petroleum, as in the Shiells Canyon field three wells were drilled before oil was obtained.

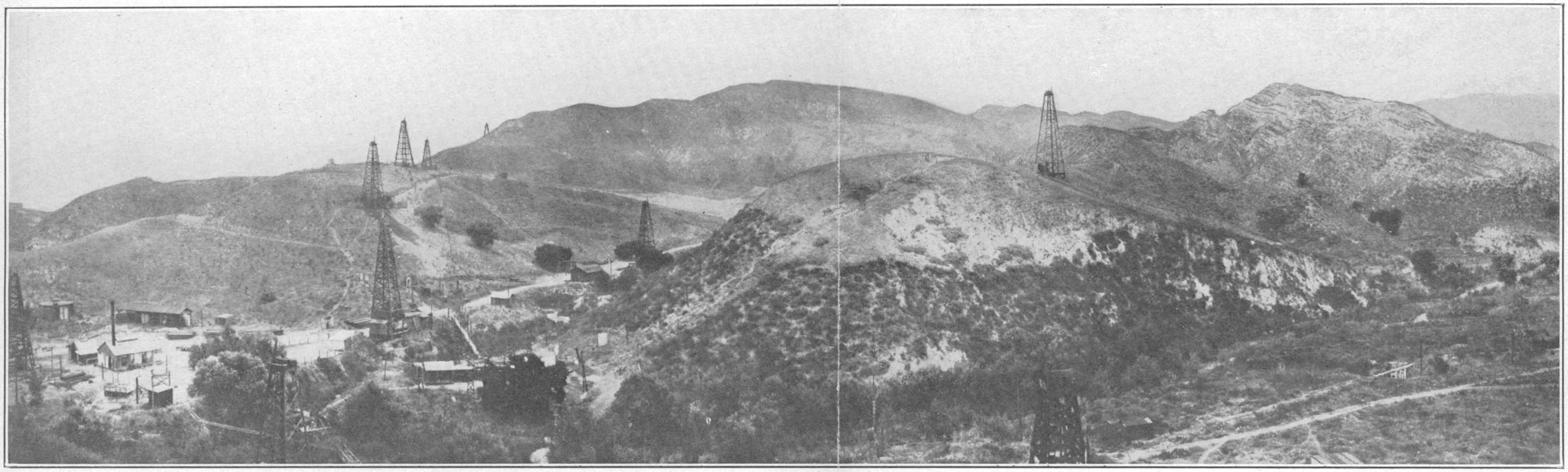
SHIELLS CANYON FIELD.

The Shiells Canyon field (commonly called the Montebello oil field), on the Oak Ridge anticline, is the largest producer in Ventura County and covers a larger area than any other. (See Pls. I and XIII.) It extends from the west side of Shiells Canyon to the next canyon on the east, a distance of about three-quarters of a mile. Its greatest width is slightly less than half a mile. Structurally it is at the west end of one of the anticlines composing the Oak Ridge fold. This anticline apparently dies out a mile or so west of Shiells Canyon. The upper part of the Sespe formation is exposed over a large part of the area, but this is overlain on both north and south sides by the Vaqueros, which entirely covers the Sespe between Guiberson and Wiley canyons. Near the top of Oak Ridge the Modelo and Pico formations are present. None of the strata above the Sespe, however, are of importance in this field in regard to petroleum. As in the other fields in this district, the structure is that of a dome along the anticline. This fold is broad topped and asymmetric, the north limb dipping at a higher angle than the south limb. As seen in Plate XIV, *A*, the strata arch gently to the south, not over 15°, as far as the crest of Oak Ridge, where the angle of dip increases to 25° or 30° S. On the north side the dip steepens rapidly to 50° N. near the valley's edge. (See structure section C–C′, Pl. II.) The wells are all located on the crest of this dome, and as a rule those nearest the highest part of the dome are the most productive. Drilling is started in the Sespe formation, usually in red and greenish clay and sand below massive brown conglomeratic sandstone, the outcrops of which approximately outline the field. Though the strata dip less steeply to the south, the productive territory is only slightly larger on that side.

Most of the oil is obtained from lenticular sands interbedded with shales in the Sespe formation. From a study of the well logs no marked change in lithology is apparent except that less sand is present in the deeper strata. Furthermore, correlation of sands even between adjoining wells is extremely difficult and practically impossible. For this reason any separation of the strata into formations underground is very uncertain. The oil sands occur at numerous intervals from depths of less than 100 feet down to 3,500 feet. The sands may be divided into two classes—shallow and deep. They are not well-defined extensive sands that underlie the whole field but

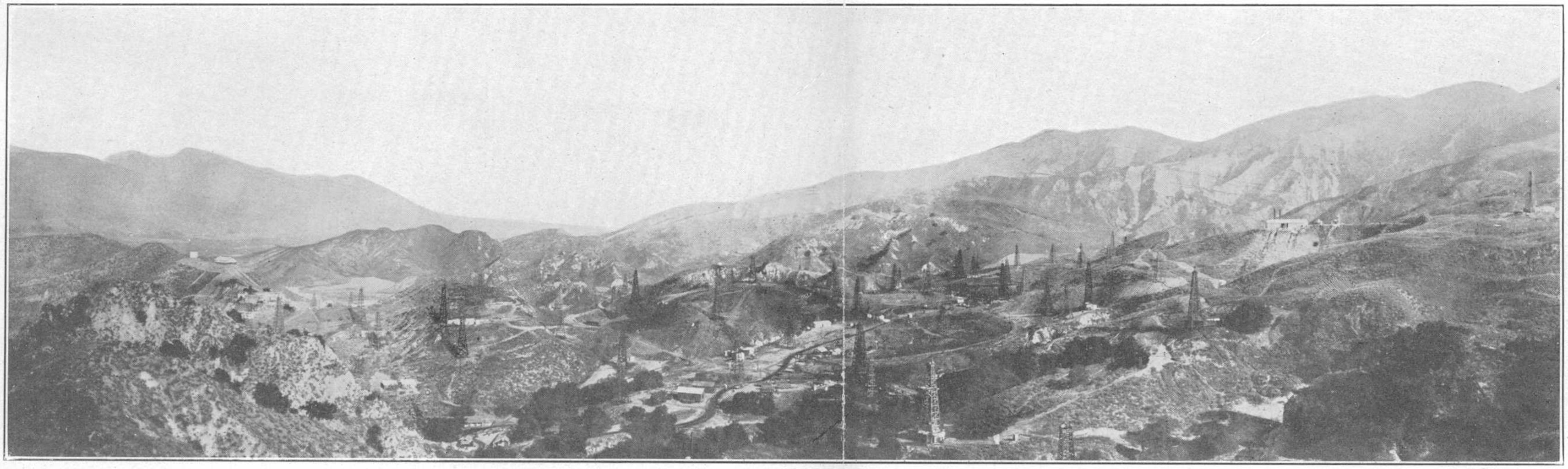


MAP OF SHIELLS CANYON OIL FIELD, VENTURA COUNTY, SHOWING LOCATION OF OIL WELLS IN RELATION TO AXIS OF OAK RIDGE ANTICLINE.



A. SHIELLS CANYON OIL FIELD ON OAK RIDGE ANTICLINE, VENTURA COUNTY.

Looking east along north side of Oak Ridge across Shiells Canyon. Wells on Sespe formation (Oligocene?); light-colored beds above and in arch in distance, Vaqueros formation (lower Miocene) and Modelo shale (upper Miocene).



B. SIMI OIL FIELD, VENTURA COUNTY.

Looking west across Tapo Canyon, along Simi anticline, approximately indicated by line of wells. All strata shown belong to Sespe formation (Oligocene?). Camera standing on Meganos (middle Eocene) strata.

appear to be a group of lenses that form a zone. The shallow zone is usually penetrated at depths of less than 700 feet; the deeper zones extend from about 800 feet to 3,500 feet. The oil sands vary greatly in thickness and from the evidence of well logs appear to be sandy lenses within shale. The thickness of the barren strata between the upper and the two lower zones also shows a marked variation. In a single section across the field the thickness ranges from 387 feet to 651 feet, the maximum interval being found close to the

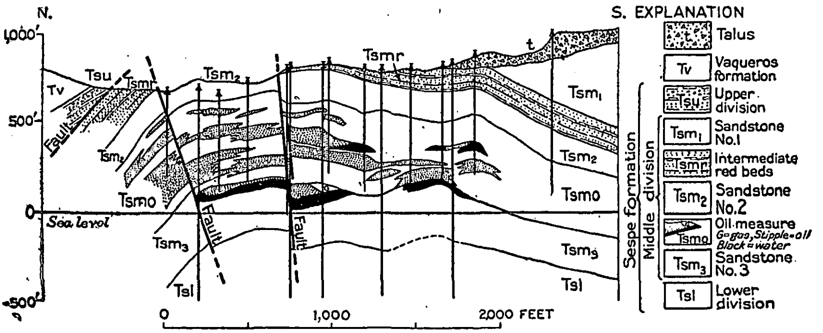


FIGURE 5.—Geologic structure along north-south line through crest of dome showing shallow oil zones in Shiells Canyon oil field, Ventura County, Calif. (Reproduced by courtesy of Ventura Consolidated Oil Fields; F. S. Hudson, geologist.)

highest point on the dome. (See fig. 5.) According to M. J. Kirwan [81] the underground structure of the Montebello field is as follows:

Three well-defined oil zones have been encountered on the property of the Montebello Oil Co., and two on the Calumet and Home Ranch Petroleum companies, the first zone being unproductive on the latter properties.

Two well-defined zones, carrying salt water, have also been penetrated on these properties. The first water zone lies between the first and second oil zones, and the lower salt water lies between the second and third oil zones.

As a result of peg model study by Irving V. Augur [82] the following has been added to our knowledge of the underground conditions in this field:

A third salt water zone was encountered below the third oil zone mentioned in this report [Bull. 82]. For a considerable time it has been recognized that the first oil zone in this area is not as extensive laterally as the second oil zone. The first zone is not productive east of the line between secs. 3 and 4, T. 3 N., R. 19 W., San Bernardino base and meridian. The oil sands of this zone are encountered in the area but have been found to contain no oil. It has been the policy of companies which have drilled through this top productive oil horizon to land a water string below both the oil horizon and the first salt-water zone and immediately above the second oil zone. This policy may be found, in the future, to be responsible for considerable water trouble in the first oil horizon, which is productive in wells to the west. It may at

[81] California State Min. Bur. Bull. 82, p. 179, 1917.
[82] California State Min. Bur. Bull. 84, pp. 323–324, 1918.

some time be necessary, on account of the prohibitive amounts of water, to change the depth of water shut-off in wells which have penetrated both the first oil and the first water horizons, or to abandon gradually the shallow wells now producing from the top oil zone. The amount of water entering the top oil zone has increased 23 per cent from November, 1916, up to June, 1918. A definite policy should be adopted in drilling new wells in this area, looking toward the mudding and protection of the top oil zone in all new wells drilled.

Not only is the first oil zone nonproductive in the eastern portion of this field, but several hundred feet at the top of the second zone are nonproductive. Original plans for shutting off water in this area called for a uniform stratigraphic shut-off above the second oil zone, irrespective of the productiveness or nonproductiveness of the top portion of this zone. Recently the tendency has been to carry water from the first salt-water zone into the nonproductive portion of the second oil zone. The results of such a policy, if continued, may introduce water trouble, which may not for the time being be noticeable in adjoining wells. This policy should be discouraged unless the portion of the oil zone to be cased off has been fully protected from top water.

Another feature of interest is the discovery, on the eastern edge of the field, of the existence of probable edge water in the lower portion of the second oil zone. Several wells having encountered this probable edge water have been plugged back ostensibly as having encountered the third salt-water zone. One well which encountered this probable edge water has been deepened farther into the oil zone to obtain greater production and is now producing considerable water of the edge-water sand or sands. This condition must be anticipated in future drilling in this area and steps taken to prevent the infiltration of water into the oil sands in any well to be drilled or already completed. A cooperative spirit must prevail in all operations, in order that the water problem may be handled efficiently and the danger from infiltration avoided.

At the present time water conditions are not serious, but the source of possible water trouble must be recognized and future operations be guided by definite protective policies.

The production of the individual wells in this field varies considerably, though this variation seems to be dependent largely on the quality of the sands penetrated rather than the proximity of the wells to the crest of the anticline. All the shallow wells are small producers, whereas many of the deeper ones flow at first large quantities of oil. In 1918 the largest producer was the Montebello Oil Co. of the Ventura Consolidated Oil Fields, well No. 107, which yielded over 4,000 barrels a month. During the first month, after being brought in (October, 1915) it produced nearly 6,000 barrels.

The first well was put down in this field in 1901 by the Central Union Oil Co. After going 800 feet it was abandoned as a dry hole. It was in Shiells Canyon, on the northwest edge of the now producing Montebello Oil Co.'s field. It was not until 1911 that the Montebello Oil Co. of the Ventura Consolidated Oil Fields commenced its first well, a short distance south of the Central Union hole. This well is nearer the axis of the anticline and struck its first oil sand at 340 feet. It was drilled to 650 feet and penetrated the top oil zone, from which it still produces. From then on other wells were rapidly drilled. In 1918 107 wells had been put down in the Shiells Canyon field, of which 97 are on the property of the Montebello Oil Co., and all are producing except 8 that are abandoned. Their total monthly production is about 40,000 barrels of oil having a specific gravity of 0.8642 (32° Baumé). The producing property is all in the E. ½ sec. 4, T. 3 N., R. 19 W., and is about equally distributed areally on both flanks of the anticline, though a greater number of wells have been drilled on the south side.

The Calumet Oil Co. owns 831 acres, chiefly in sec. 3, which adjoins the property of the Montebello Oil Co. on the east. (See Pl. XIII.) Nine producing wells have been drilled by this company. They produce from the two lower oil zones, the oil being absent in the sands of the upper zone. One well has been sunk by the Home Ranch Petroleum Co. on the Guiberson property, immediately to the south, and the oil sands penetrated are the same as those in the Calumet wells.

So far as can be judged from the well logs and statistics of production the limits of drilling have not been reached for the Shiells Canyon field, but it is doubtful if these limits can be extended very far. The Calumet Oil Co. has proved up considerable territory which is not all drilled. A further extension to the east can not be made with any degree of surety, for edge water has already begun to appear in some of this company's wells. The two deeper sands in the Montebello property have been reached by comparatively few wells. As these are by far the most productive measures the Montebello field can be said to have a good future before it. The deeper sands, moreover, have a larger areal extent than the shallow sand, and the oil they yield is of higher gravity. To the west productive territory probably will not be found in the W. ½ sec. 4, as the Montebello Oil Co.'s well No. 113, which showed no productive sands, made a test of this tract. The oil-bearing sands therefore appear to be confined to a comparatively small oval area about half a mile wide and three-quarters of a mile long, on the crest of the dome.

WILLOW GROVE SCHOOL.

Another small domelike uplift that has lately been tested by the Petroleum Midway Co. (Ltd.) (Waddle-Jenkins lease), lies in the NW. ¼ sec. 5, T. 3 N., R. 19 W. (See Pl. I.) The formations involved in this area are similar to those in the Shiells Canyon and Bardsdale fields, the outcropping formations being the Sespe (Oligocene?), Vaqueros (lower Miocene), and later strata. The structure is somewhat different, and the uplift is really composed of two anticlines. The anticline extending southwestward, on which the Bardsdale field is located, appears to be the principal fold at this point. A fold extending eastward across Shiells Canyon to Torrey Canyon plunges off from the other fold. This plunge continues eastward nearly to the west line of sec. 4, where the beds rise to form the Montebello dome. The westward fold does not show any marked plunge to the west.

The Waddell-Jenkins well No. 1, sunk in this area by the Petroleum Midway Co. (Ltd.), was started in 1917, completed a little over a year later, and recently abandoned, having struck but a few oil showings. The small quantity of oil that accumulated here probably migrated up along strata in the eastern anticline and found its way into the domelike area formed by the junction of these two anticlines. As the Waddle-Jenkins well tested this area, and as the structure is not particularly favorable, further drilling here is not recommended.

BARDSDALE FIELD.

The Bardsdale field proper is situated in the N. ½ sec. 12 and the SE. ¼ sec. 1, T. 3 N., R. 20 W., and the SW. ¼ sec. 6, T. 3 N., R. 19 W., along the south side of Santa Clara River opposite the town of Fillmore. (See Pl. I.) The geology of this field is similar to that of the other fields on the Oak Ridge fold. (See structure section B–B′, Pl. II.) The most important oil-bearing formation involved in this field is the Sespe. At the surface this formation is composed of brown and gray sandstone, interbedded with the red, green, and gray marl and fine sand that are characteristic of the Sespe formation south of Santa Clara River. These strata crop out around the axis of the anticline, where, though exceedingly lenticular, they can be traced in zones, especially along the south flank of the fold. The anticline on which the Bardsdale field is situated is primarily an elongated dome (see Pl. I), for this fold is distinct from any of the others and plunges in either direction from a point in the NE. ¼ sec. 12, a very short distance west of Grimes Canyon. The plunge is slightly steeper at first on the east side but quickly flattens out. To the west it is more gradual, extending from a point near the Willow Grove School in the northwest corner of sec. 5, T. 3 N., R. 19 W., in a southwesterly direction along the south side of the valley nearly to Sulphur Canyon, sec. 15, T. 3 N., R. 20 W. No other dome is present on this anticline except at its northeast end, where there is a slight elevation on which the Waddle-Jenkins well of the Petroleum Midway Co. (Ltd.) was drilled.

Structurally the Bardsdale field (see fig. 6) lies along the crest of the elongated dome. Producing wells are found farther to the west of the highest point than to the east, owing to the less degree of plunge in the westerly direction. The first well was drilled in 1896 by the Union Oil Co., and up to the present time more

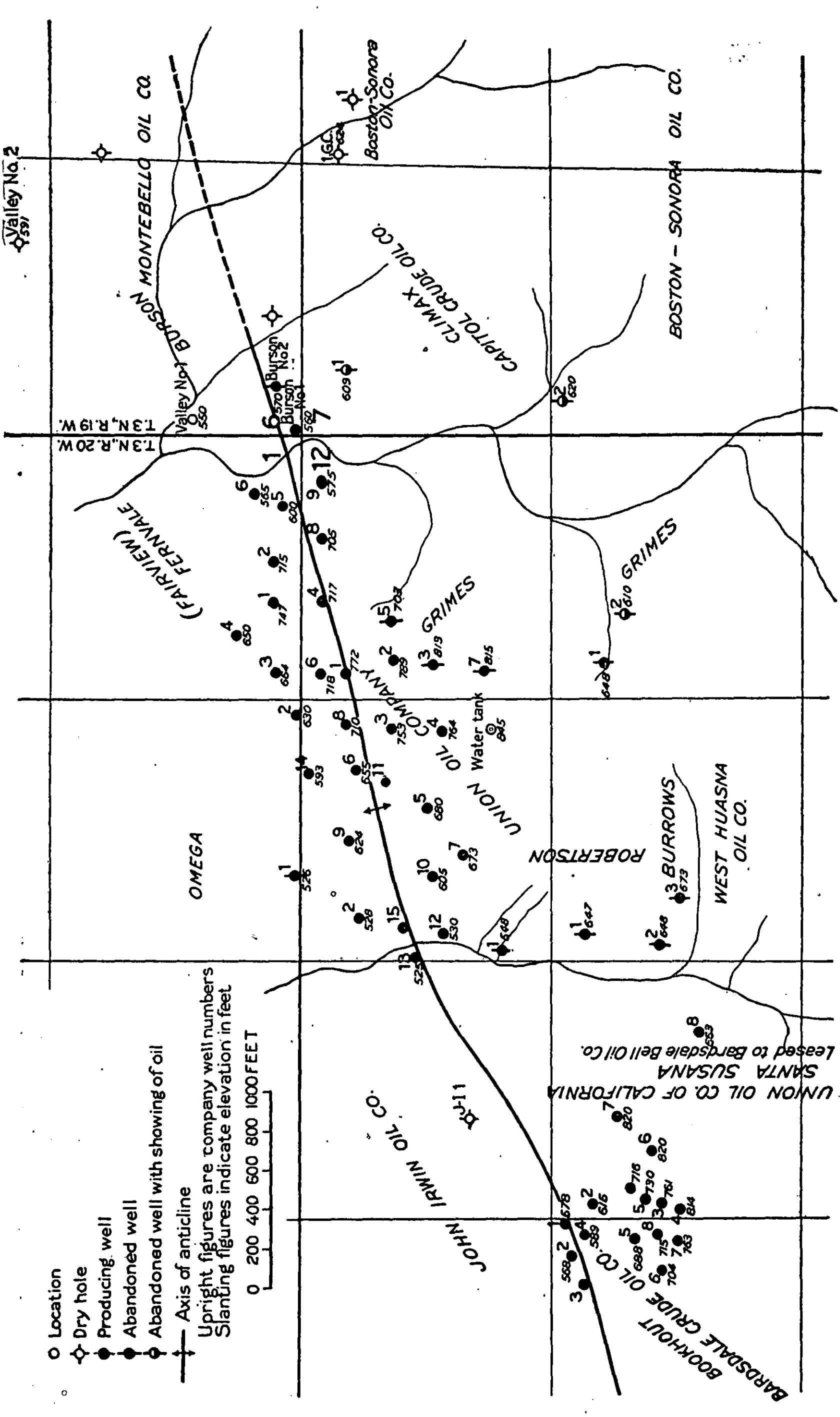


FIGURE 6.—Map of Bardsdale oil field, Ventura County, Calif., showing location of wells in relation to axis of anticline.

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than 60 wells have been sunk in this vicinity. As the result of this drilling the limits of the field are well established, and moreover the peak of its production has been passed, so that it may now be considered a declining field. The main oil zone is about 400 feet thick and is usually penetrated at depths of 600 to 1,000 feet. According to Irving V. Augur,[83] the underground structure is described as follows:

From data as shown by the peg models, it is evident that most of the production up to the present time in the Bardsdale dome is derived from an oil horizon approximately 400 feet in thickness and is obtained close to the apex of the fold. Wells on the edge of the field are now idle or have been abandoned. It is noticeable that certain wells drilled in the western portion of the field have encountered and are producing from an oil horizon which overlies the main productive horizon and outcrops before reaching the apex of the fold. The oil is of a comparatively low gravity, and considerable water is produced with the oil, oil and water being frequently reported as occurring in the same sand. Several wells in this area have been deepened to the main productive horizon, increasing very materially the production and gravity of the oil:

Erosion has proceeded further on the Bardsdale dome than at either Shiells Canyon or Torrey Canyon, so that very probably the upper oil zone is not present. This zone may be represented by the oil seeps that are comparatively common around the edge of the field. The oil sands encountered, therefore, should represent a horizon corresponding to the middle zone in the Shiells Canyon field.

A large number of companies have drilled wells at different times along this anticline, but only three—the Union Oil Co., the Bardsdale Crude Oil Co., and the Bardsdale Bell Oil Co.—are now operating. The wells of the other companies either did not yield paying quantities of oil or the holes were dry. The Union Oil Co. owns and operates the best leases in this field, which include the Robertson and Grimes tracts, in the SE. ¼ sec. 12, T. 3 N., R. 20 W., and the Fernvale tract, in the SE. ¼ SE. ¼ sec. 17, T. 3 N., R. 20 W. The Bardsdale Crude Oil Co. controls the Bookhout lease, in the SW. ¼ NW. ¼ sec. 12, and the Bardsdale Bell Oil Co. has the Santa Susana lease, which is between the Robertson and Bookhout leases, in the SE. ¼ NW. ¼ sec. 12. All the wells of these companies are along the axis of the anticline, the greater number on the south flank. The daily production[84] from these wells during 1917–18 was 83.6 barrels of oil, with which was pumped 6.1 barrels of water, an average of slightly less than 2 barrels of oil per day per well. In 1917 the Bardsdale Crude Oil Co. was operating eight wells, which produced about 600 barrels a month. The greatest depth reached among the producing wells is 2,100 feet in the Santa Susana No. 4, which is

[83] California State Min. Bur. Bull. 84, p. 323, 1918.
[84] Idem, p. 322.

some distance south of the axis of the fold. A few others are between 1,800 and 1,900 feet deep, but most of them are from 500 to 1,500 feet. The West Huasna Oil Co., later taken over by W. Z. McDonald, in developing the Burrows tract, adjoining the Robertson lease of the Union Oil Co. on the south, deepened a poorly producing well (West Huasna No. 1) to 2,600 feet but without increasing its yield.

Several other wells have been drilled from time to time along the edges of this field, so that its limits have been pretty well defined. At its east end wells on the Burson tract, in the SW. ¼ SW. ¼ sec. 6, T. 3 N., R. 19 W., are nonproductive except one in the bottom of Grimes Canyon, which is still being pumped by the Union Oil Co. Two wells were drilled by this company in 1898–99, one by the Merchants & Traders Oil Co. in 1901, and two by the Montebello Oil Co. in 1910–1912. The Montebello wells went to 2,832 and 1,500 feet, but, though getting a little oil, they were never producers. Other wells in this vicinity include two near the mouth of Grimes Canyon known as the Valley View wells Nos. 1 and 2. No 1, drilled 3,420 feet deep, obtained a little oil and gas at about 850 feet. The Capitol Crude Oil Co. drilled two wells on the Climax lease, in the NW. ¼ NW. ¼ sec. 7, one of which is now being pumped by the Union Oil Co. In 1901 the Grimes Canyon Oil Co. drilled a well 760 feet deep in the SW. ¼ NW. ¼ sec. 7, and in 1902 one 1,000 feet deep in the NE. ¼ NW. ¼ sec. 7. The first was a dry hole; the second obtained only a trace of oil. Of two wells drilled on the Grimes tract, in the SE. ¼ NE. ¼ sec. 12, one produced poorly and the other was a dry hole.

On the north side of the dome a well was drilled in 1912 by the West Huasna Oil Co. on the Omega tract, in the SW. ¼ SE. ¼ sec. 1. This well is reported to have produced 2 barrels a day. An earlier well put down by the John Irwin Oil Co. on the same tract went 1,100 feet without obtaining oil. Another hole, drilled by the same company near a seepage in the NE. ¼ NW. ¼ sec. 12, was abandoned.

The best producing territory in the Bardsdale field apparently is confined to a relatively small area along the crest of the anticline, in the N. ½ sec. 12 and the SE. ¼ sec. 1. Commercially productive wells apparently have not been obtained more than 1,000 feet from the axis of the anticline. The production in this field is small, so that to get the maximum results new wells should not be spaced too close together, and they should be drilled as near to the axis of the anticline as possible. Further drilling in this field should increase its production. Between the Robertson tract of the Union Oil Co. and the Bookhout tract of the Bardsdale Crude Oil Co., there is a considerable area on the Santa Susana (Bardsdale Bell Oil Co.) and John Irwin tracts which is available for future drilling. Oil will probably not be found much farther west than the present producing property of the Bardsdale Crude Oil Co., nor can the field be extended east of the present wells of the Union Oil Co., or the east line of secs. 1 and 12.

SCATTERED WELLS.

In Guiberson Canyon two wells, both of which turned out to be dry holes, were drilled in the northwest corner of the SW. ¼ sec. 2, T. 3 N., R. 19 W. The first was started in 1901 by the Union Oil Co. and went 1,200 feet; the second, by the Erie Oil Co., went 1,600 feet. Both were about a quarter of a mile south of the axis of the Oak Ridge anticline—too far from the axis to make a thorough test of the area. However, it is extremely unlikely that oil would be found this far east on the plunge of the Shiells Canyon dome.

South of the Bardsdale field, in Grimes Canyon, in the NW. ¼ SW. ¼ sec. 7, T. 3 N., R. 20 W., Grimes & Son drilled a hole about 400 feet deep which was dry. This hole is about three-quarters of a mile southeast of the axis of the Oak Ridge anticline.

Between the Bardsdale and South Mountain fields several wells have been put down along the south side of Santa Clara River. In T. 3 N., R. 20 W., the Peter Patterson Oil Co. drilled a hole in the SW. ¼ SE. ¼ sec. 11 but obtained no oil. The hole is in an area of unfavorable structure, about half a mile south of the anticline. A drill hole, known as the Balcom well, was put down by F. O. Wood in the NE. ¼ SE. ¼ sec. 10, T. 3 N., R. 20 W., and is reported to have penetrated 2,000 feet without striking any oil. Another well, drilled by Alger & Gilmore in the NW. ¼ sec. 9, T. 3 N., R. 20 W., went 1,200 feet and was also a failure. Both of these wells were poorly located. The Balcom well is about a quarter of a mile north of the axis of the fold, and the Alger & Gilmore well about a mile. Owing to the continuous westward plunge of the fold from Bardsdale and the eastward plunge from the South Mountain region a saddle has been formed here along the axis. Structure of this kind is extremely poor for the accumulation of oil, and in the Oak Ridge district oil is confined to the higher parts of a fold.

SOUTH MOUNTAIN FIELD.

In the South Mountain field, as in other fields along the Oak Ridge anticline, the important oil-bearing zones are in the Sespe formation. This formation is exposed in a broad area along the anticline which extends westward from a point about a mile west of Sulphur Canyon and composes nearly the whole of the north side of South Mountain. (See Pl. I.) The Sespe formation here as on Oak Ridge, consists of rather massive yellow and brown sandstone and conglomerate interbedded with red, green, gray, and white soft sand and clay, the clay being more prevalent in the lower part of the outcropping strata. A characteristic feature of the Sespe is its tendency to slide, thus allowing the younger formations to come down and obscure the real structure of the region. The Vaqueros, Modelo, and Pico formations overlie the Sespe at the top and on the south side of South Mountain. The fold on which the South Mountain field lies extends from a point a mile or so east of Sulphur Canyon nearly due west along the north side of the mountain to Willard Canyon, where a second minor fold, or slight undulation in the south limb, branches off to the south. Both continue until they are lost beneath the alluvium of Santa Clara Valley opposite Santa Paula. This double fold can be plainly seen in looking westward from Willard Canyon. The anticline along South Mountain is really an elongated dome with its greatest elevation at Willard Canyon, plunging both west and east from this point. The supplementary fold and the shallow syncline between the two, being west of the crest of the fold, plunge only in that direction. The fold is flat-topped and asymmetric. Its north limb in places dips 50° N. to nearly 90°. The south limb is steepest along the crest of the mountain, where the dip averages about 30° S., though it reaches 40° or 50° S. The higher dips, however, are in Modelo shale. (See structure section A–A', Pl. II; also fig. 7.)

The oil has accumulated at the crest of the dome in sands in the middle part of the Sespe formation. As outlined by wells already drilled the producing area is probably not over a mile long and half a mile wide and lies in Morgan and Willard canyons. No outcropping oil sands are known to occur in the Sespe of South Mountain, and the shallowest sands are usually struck at about 600 feet, though in a few holes shows of oil have been reached at less than 300 feet. Oil sands occur as deep as 3,000 feet, all in the Sespe formation. The largest producers in this field are the Ventura Consolidated Oil Fields and its subsidiaries.

Irving V. Augur,[85] who has made a special study of this field for the California State Mining Bureau, gives the following comparison of the South Mountain field with the Shiells Canyon field:

Since the completion of the first well in this field in April, 1916, 21 additional wells have been completed or are drilling, and the field has risen from fifth place to second in point of production in the county. During the fiscal year [1917–18] the daily production from this field amounted to 591 barrels of oil with 0.3 barrel of water daily, as compared with 134 barrels of oil and 0.4 barrel of water for the previous year. The daily production per producing well was 65.7 barrels of oil, as compared with 6.5 barrels of oil per producing well in the Bardsdale field [including the Bardsdale and Shiells Canyon fields of the present report], which has the largest total production of

[85] California State Min. Bur. Bull. 84, p. 326, 1918.

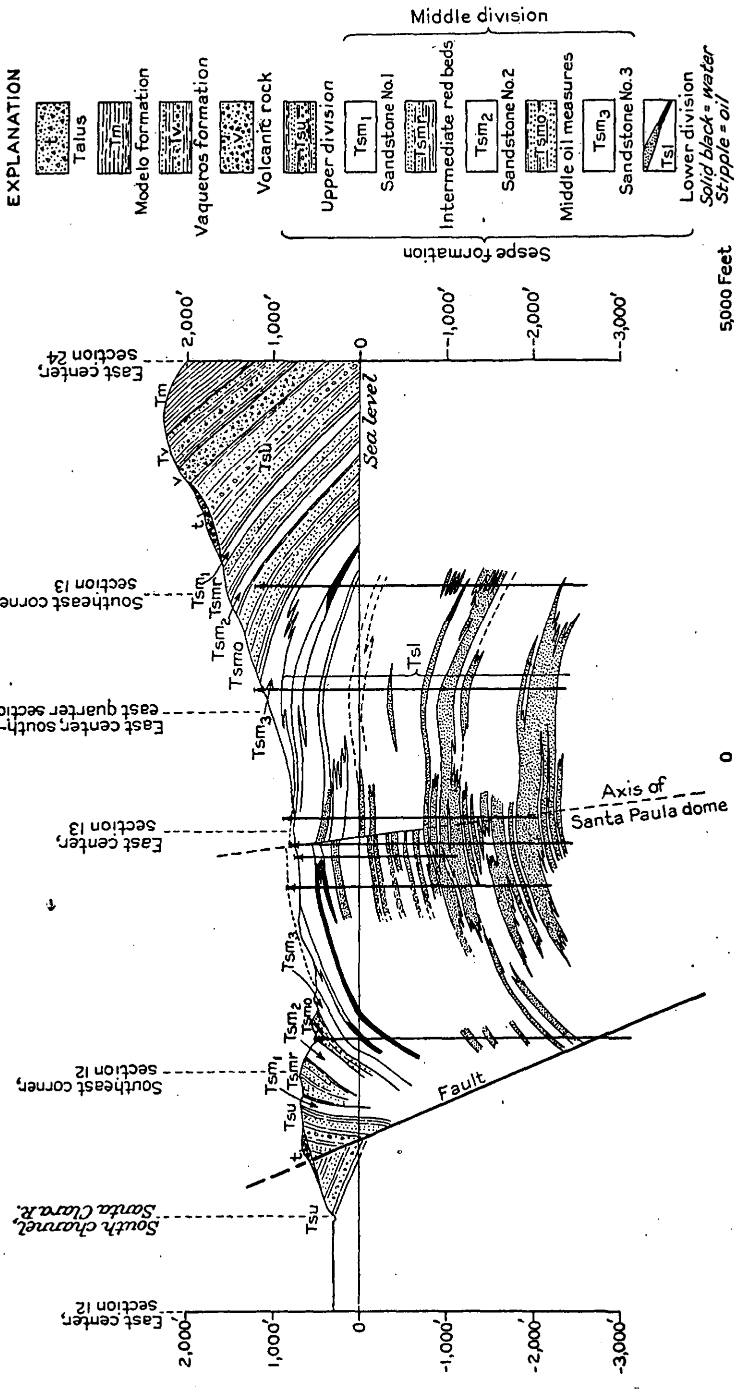
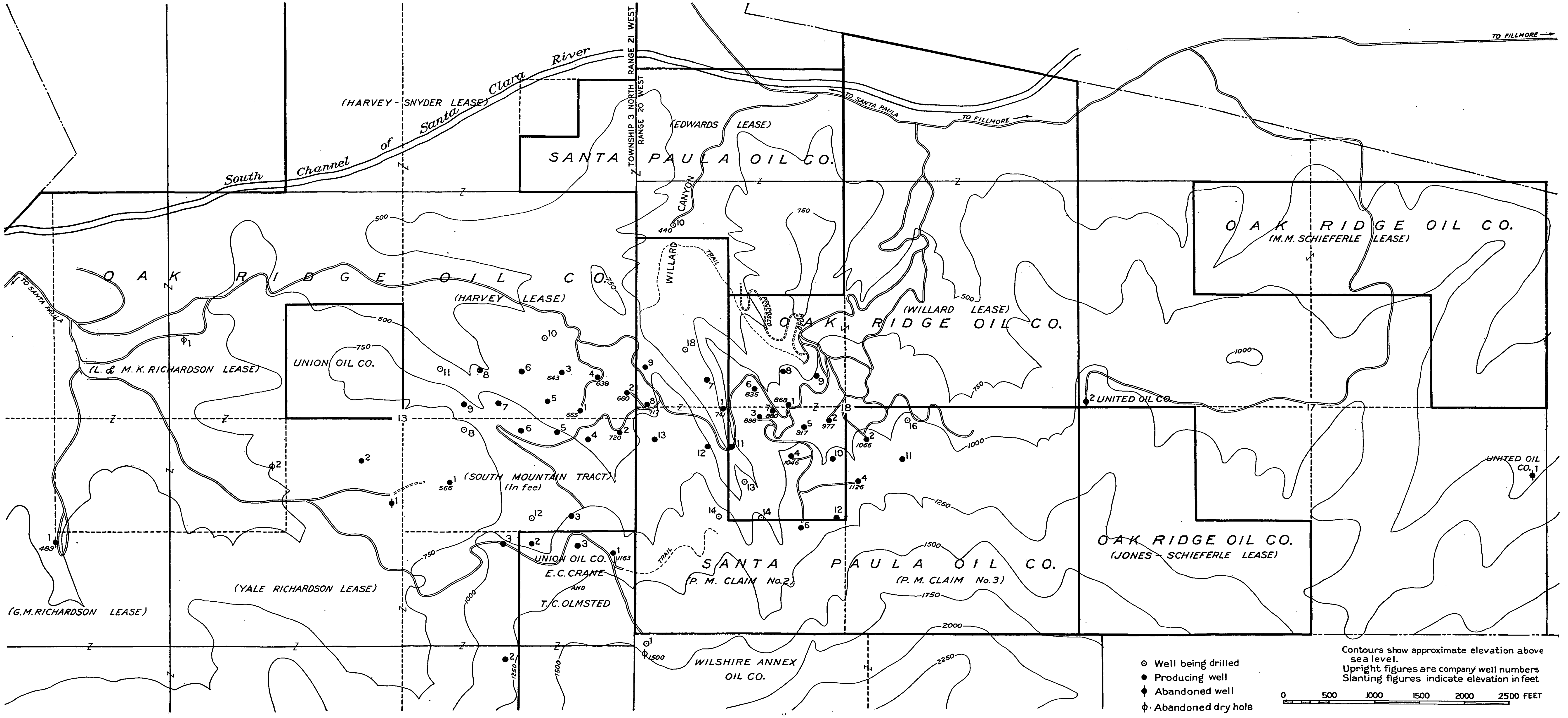


FIGURE 7.—Structure section of South Mountain oil field along north-south township line, showing lenticular and zonal character of oil sands. (Reproduced by courtesy of Ventura Consolidated Oil Fields: F. S. Hudson, Geologist.)



MAP OF SOUTH MOUNTAIN OIL FIELD, VENTURA COUNTY.

all other fields in the district. Such a comparison gives an idea of the production which may be expected in this field in the near future.

A large proportion of the production was obtained from wells which flowed while drilling. If the present rate of progress obtains for the coming year, it is not improbable that the field will produce approximately two-thirds as much oil as the Bardsdale field.

Up to the present time no water-bearing formations have been discovered above the top of the first oil horizon. Drilling operations are therefore much simpler than under the conditions encountered in the Montebello dome of the Bardsdale field, where salt-water zones have been reported.

On the east end of the South Mountain dome (see Pl. XV) two wells have been drilled by the United Oil Co. on the Shieferle property. The first one, in the NE. ¼ SE. ¼ sec. 7, T. 3 N., R. 20 W., went 3,783 feet without encountering any indications of oil except gas, which was struck at 1,385 and 1,526 feet. This well is practically on the axis of the South Mountain anticline and started on shale of the Modelo formation, which, together with the Vaqueros, overlies the Sespe here. After drilling through about 700 feet of the Miocene strata the Sespe was struck, and the hole continued in this formation for the rest of the way. The second well, in the southwest corner of the NW. ¼ sec. 17, was drilled during 1917–18. This well was started in the Sespe formation and was close to the axis of the fold. It was abandoned in 1918, only showings of oil having been struck. Both wells are apparently too far east of the crest of the dome to encounter oil-bearing sands.

SUMMARY.

As a whole, the Torrey Canyon, Shiells Canyon, Bardsdale, and South Mountain fields are the most productive in Ventura County. They lie along the north side of Oak Ridge and South Mountain, where they are intimately associated with domelike uplifts on the Oak Ridge anticline. Except in the South Mountain field their limits are pretty well established, but the production may be increased by drilling to deeper sands. The South Mountain field, the last to be developed, is fast gaining in number of wells and in production, so that it may soon be comparable to the Shiells Canyon field in amount of oil obtained. The Shiells Canyon field offers good possibilities for future development of the deeper sands, as most of the wells reach only the upper horizon. The Torrey Canyon field may also be found to contain deeper sands if tests are made. Wildcat wells drilled in areas of promising structure in Wiley Canyon and near the Willow Grove School have met with favorable results. Some gas was obtained in Wiley Canyon, and this locality may be valuable in the future.

SIMI VALLEY AND LAS POSAS DISTRICT.

GENERAL FEATURES.

The Simi Valley and Las Posas district[86] comprises an area somewhat smaller than the Santa Clara Valley district, which lies immediately to the north. (See Pl. I.) Its northern limit is the Santa Susana fault along the foot of the Santa Susana Mountains and eastern part of Oak Ridge, the crest of the western part of Oak Ridge, and South Mountain. The Simi Hills form its eastern and southern boundary, and to the west it continues in a southwesterly direction to the great flood plain of Santa Clara River. All the sedimentary formations described in this report are represented in this district, and include those ranging in age from the Cretaceous beds that form the Simi Hills to the Recent alluvium in the valley floors. These formations compose a large synclinorium, described on page 103, the south flank of which forms the Simi Hills and the north flank Oak Ridge. Within this synclinorium there are a number of minor folds, of which the most pronounced are the Happy Camp syncline and anticline, the Llajas anticline, the Simi anticline and syncline, and several folds in the Las Posas area. Only the areas along the anticlines are of sufficient economic importance to warrant discussion here.

SIMI VALLEY.

HAPPY CAMP CANYON AREA.

The area comprising Happy Camp Canyon and the ridge on the south includes the Happy Camp syncline, one of the larger structural features of the district, which extends from Las Llajas Canyon westward to the bend in Happy Camp Canyon, a distance of about 15 miles. The Happy Camp anticline is shorter and follows the crest of the ridge that separates Simi Valley from Happy Camp Canyon. The anticline extends westward about 1½ miles beyond the canyon. The outcropping formation along its axis is the lower part of the shale in the Modelo formation (upper Miocene). To the south this shale rests on the Vaqueros (lower Miocene) formation, which in turn overlies the Sespe formation (Oligocene ?). Above the Modelo the Saugus formation (upper Pliocene and Pleistocene) composes the trough of the Happy Camp syncline. The Modelo shale here is diatomaceous and apparently the same as that occurring along Oak Ridge. North of Oak Ridge and the Santa Susana mountains oil is closely associated with Modelo shale of this same type. On top of

[86] Kew, W. S. W., Structure and oil resources of the Simi Valley, southern California: U. S. Geol. Survey Bull. 691, pp. 323–347, 1919. McLaughlin, R. P., and Waring, C. A., California State Min. Bur. Bull. 69, pp. 393–394, pl. 3, 1914 (with atlas).

the Happy Camp anticline, however, the shale is not more than 300 feet thick, and therefore its possibilities as a source and reservoir for oil are not very good. Moreover, no oil seeps are present either in this vicinity or across the canyon on Oak Ridge, and the only evidence of the presence of hydrocarbons in the shale is in the fact that both along this anticline and on Oak Ridge the shale has been burned, presumably by escaping gas or petroleum. The only other formation in which oil might be obtained is the Sespe, as the Vaqueros is not known to be oil bearing south of Santa Clara Valley. The nearest producing wells are at the Scarab lease of the Pan-American Petroleum Co., 2 miles south of this anticline, where the Sespe is known to be oil bearing in its middle and lower parts. The oil zone penetrated by these wells is more than 1,300 feet below the surface, or 3,600 feet below the base of the Vaqueros, which is about 1,800 feet thick on this ridge. Thus in this locality more than 5,000 feet of sediments would have to be penetrated in order to reach the oil-bearing sands, a condition not favorable to prospecting for oil. The anticline itself is not propitious for the accumulation of any large amount of oil. It is exceedingly asymmetric, and, in fact, could be called a monocline. (See structure section D–D′, Pl. II.) A very shallow syncline is present a few hundred feet to the south, so that the anticline has only a very short and slightly dipping south limb. It is thought that the south limb is hardly long enough to allow the accumulation of any appreciable amount of petroleum. Furthermore, a cross fault through the center of the fold is another feature that might hinder the accumulation of oil. The Modelo formation has been removed by erosion on the south side of the ridge.

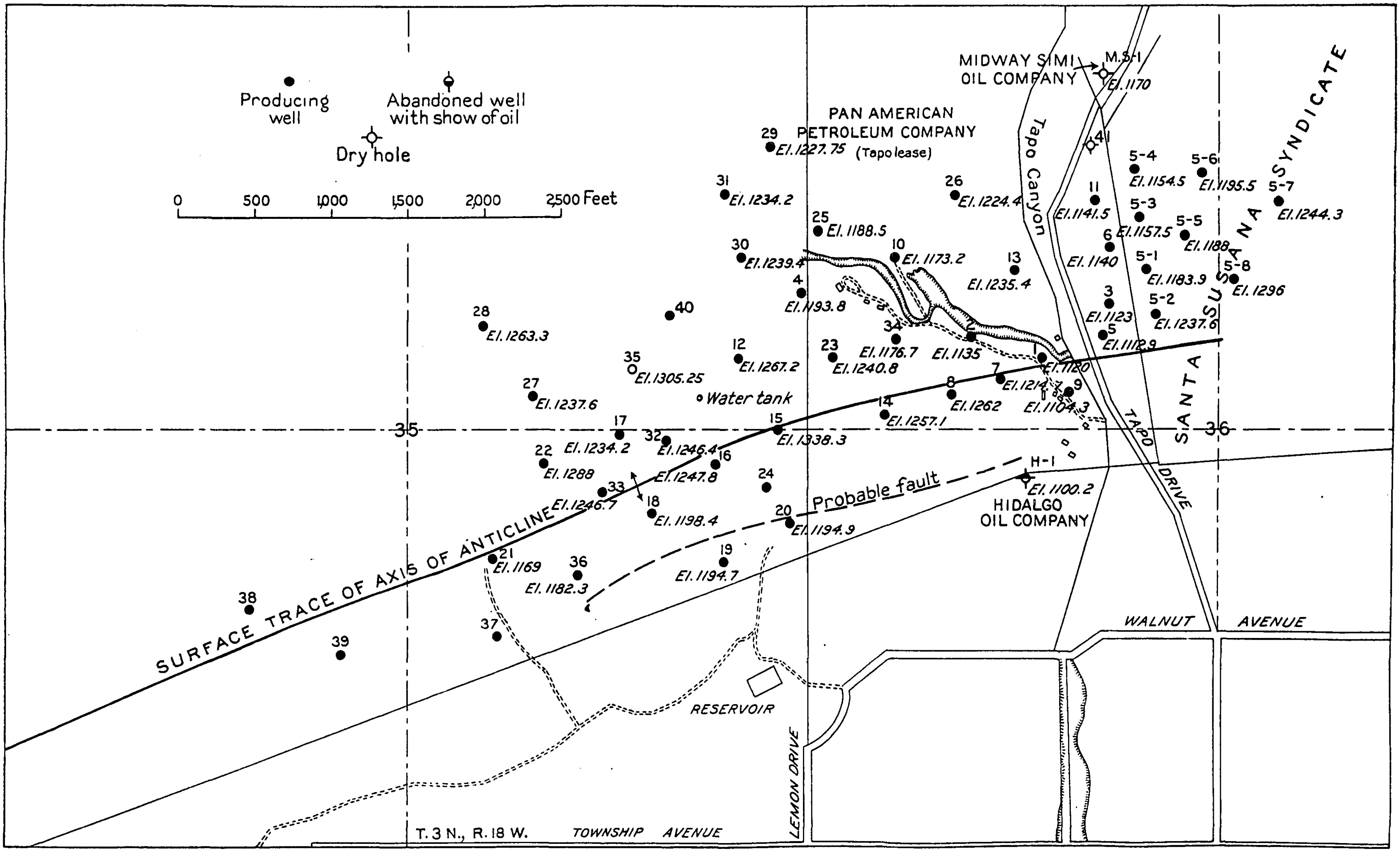
As the Modelo shale is not known to be productive south of Oak Ridge it is extremely unlikely that oil would be found in either the Modelo or Saugus strata that are involved in the same anticline west of Happy Camp Canyon.

SIMI ANTICLINE.

The Simi anticline is one of the longest folds in the region, extending from a point a short distance east of Tapo Canyon in a southwesterly direction along the north side of Simi Valley to the east end of Arroyo Simi, which it crosses, and thence following the hills on the north side of the Tierra Rejada and finally passing into the fault along the Las Posas Hills. (See Pl. I.) This fold is a striking structural feature of these hills and is easily seen at any place along its entire length. Except for a small area of Meganos formation (middle Eocene) at the east end of the fold, the Sespe (Oligocene?) is the only outcropping formation involved in the fold. The Meganos strata consist mainly of gray and brown sandy shale with calcareous concretions and bands, together with some beds of fine sandstone. The Sespe in general consists of tan and brown coarse sandstone and conglomerate, interbedded with variegated clay and soft fine-grained sand. Lithologically it is similar to the Sespe on Oak Ridge, and probably the two areas are continuous beneath the Happy Camp syncline. The anticline is flat-topped and asymmetric, the south limb being the steeper. The south limb is also much the shorter, for the syncline that forms Simi Valley closely parallels the axis of the anticline. Minor faulting has occurred along the south side near Tapo Canyon and may have exerted an influence on the accumulation of the oil, as will be brought out below. The north limb extends as a continuously northward-dipping series of strata to the axis of the Happy Camp syncline and anticline, an average distance of about 6 miles. Simi anticline has a continuous westerly plunge except near the west end of Simi Valley, where there is a slight doming. The steepest plunge is in the vicinity of Tapo Canyon, where it amounts to about 10°.

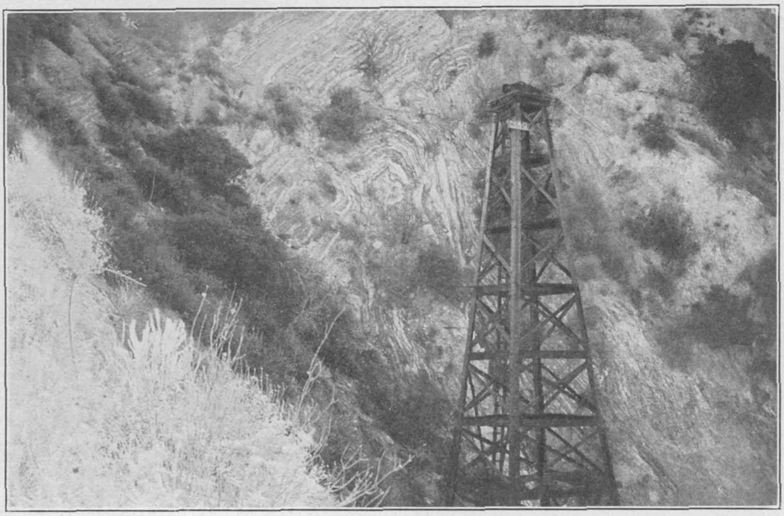
The producing area as now determined extends along the crest of the anticline from the central part of sec. 36, T. 3 N., R. 18 W., to sec. 34. All the producing land in the Tapo Canyon field is owned by two companies. The Pan-American Petroleum Co., formerly the Doheny-Pacific Petroleum Co., controls the property to the west of Tapo Canyon, and the Santa Susana Syndicate owns that to the east, including the small group of wells in the canyon close to the line between secs. 29 and 30, T. 3 N., R. 17 W. (See Pl. XVI.) The nearest surface evidence of oil is at the latter group of wells, where, near an oil seep, the first wells in this area were put down by the Simi Oil Co. in 1900. Later, in 1912, after a geologic report had been made on the north side of Simi Valley, the Petrol Co. sunk its first well in Tapo Canyon. This well yielded a fair quantity of light gravity oil, after which a number of other wells were drilled. The property of the Petrol Co. was bought by the Doheny-Pacific Petroleum Co. and in 1919 was transferred to the Pan-American Petroleum Co. Active development of the field has since been maintained. This field now ranks fourth in size among those in Ventura County, and its oil is one of the best in California, having a low specific gravity and a high gasoline content.

The oil occurs in lenticular sands within the more shaly strata at the top of the Meganos formation. Some wells penetrate a petroliferous sand near the base of the Sespe formation, but this is not productive. A study of the well logs of this field shows a distinct lack of similarity. In fact, the only change in lithology that can be correlated over any considerable distance is the contact of the Sespe sand, conglomerate, and clay with the Meganos forma-



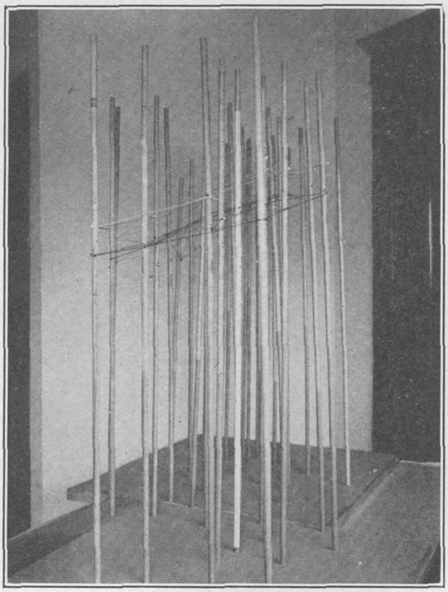
MAP OF SIMI OIL FIELD, VENTURA COUNTY, SHOWING LOCATION OF WELLS IN RELATION TO AXIS OF ANTICLINE.

After map furnished by Pan American Petroleum Co.



A. AXIS OF PICO ANTICLINE IN PICO CANYON, LOS ANGELES COUNTY.

Crumpled Modelo shale (upper Miocene) in axis of Pico anticline, near Standard Oil Co.'s well C. S. O. No. 2, on east side of canyon. Photograph by Ralph Arnold.



B. PEG MODEL OF SIMI OIL FIELD, VENTURA COUNTY.

Looking northeast along axis of the anticline. White network of strings indicates plane of contact between Sespe (Oligocene?) and Meganos (middle Eocene) formations; black strings indicate top oil sand. Note steep dip or break in altitude of strata on south side of fold. Photographed by courtesy of California State Mining Bureau.

tion, which consists of blue and brown shale with beds of fine sand and thin "shells" or calcareous beds. Even this change in lithology is not everywhere marked, and gradations from one to the other formation seem to occur. The oil sands are lenticular and, as in the Oak Ridge and South Mountain fields, occur in zones, so that it is very difficult to correlate the individual oil sands even between neighboring wells.

All the producing wells in the Tapo Canyon field are either close to the axis or on the north limb of the anticline. (See Pl. XVII, *B*.) Every well sunk far from the axis on the south side obtained only showings of oil and gas. Although on the north side wells drilled about 1,000 feet north of the axis yielded oil, a well only a little over 600 feet south of the axis was a failure. This indicates a considerably larger productive territory on the north flank of the fold. Two reasons why the south limb is more unfavorable for the accumulation of oil are apparent. From structure section H–H′ (Pl. II) it is seen that the axis of the syncline underlying Simi Valley closely parallels that of the Simi anticline. Although the axis of the syncline can not be exactly located, owing to the covering of valley alluvium, the attitude of the beds along the edge of the valley indicates that it is not far south of the border of the hills. Because of the presence of water in the sands it is extremely unlikely that oil occurs in the syncline. Furthermore, as oil usually migrates upward in the sands, only a comparatively small area between the axes of the anticline and the syncline would be available as a source of petroleum to accumulate along the axis of the fold. On the other hand, the strata composing the north limb dip northward for about 6 miles and thus form a much more extensive source from which the oil might have been derived. Moreover, the greater part of the flattened area along the top of the fold lies on the north limb, so that better facilities for the accumulation of petroleum are present north of the axis.

The second reason for the unfavorableness of the south limb lies in faulting. The north limb near the axis of the anticline dips as low as 5° N., whereas the south limb breaks off sharply and steepens almost immediately to 30°–50° S. This acute folding has caused some breaking of the beds, as has been revealed by the exposure of the fault plane in road cuts which have recently been made. Furthermore, faulting is suggested from some discrepant dips along the edge of the hills just west of the mouth of Tapo Canyon, where the beds stand at angles ranging from 80° N. to vertical. These anomalous dips may be explained in part by slide, as the Sespe formation has a tendency to slump and produce overturned beds. It is very probable, however, that a reverse fault of small throw extends along the edge of the hills, and this faulting could account for the lack of oil in the sands south of the line of breaking. A definite line seems to divide the productive and nonproductive areas, for the Pan-American Petroleum Co.'s well No. 19 is a very poor producer, and No. 20 is practically a dry hole.

The Pan-American Petroleum Co. is by far the largest operator in this field, having at the present time (1920) 32 wells, which yield about 8,500 barrels a month. Their wells are along the axis of the Simi anticline, and comparatively few have been failures. The Santa Susana Syndicate has eight wells on the east side of Tapo Canyon, where the fold is not very distinct and probably can not be classed as an anticline but is rather a sharp bend in the Meganos strata, the beginning of the Simi anticline. The same underground conditions are present here, though in some wells the upper sands are absent.

The oil produced by these companies ranks among the best in California, averaging in specific gravity about 0.8434 (36° Baumé). Because of its high gasoline content, which ranges between 25 and 36 per cent, it brings a high price. An analysis[87] made by Dr. R. S. Curtiss, of Throop College of Technology, Pasadena, is as follows:

Analysis of oil from Tapo Canyon field, Calif.

Cut.	Per cent.	Gravity (°Baumé).	Product.
1	10	73.4	Gasoline (36 per cent).
2	10	61.3	
3	6.6	53.5	
4	4.8	50.0	
5	5.2	46.2	
6	6.0	42.2	Kerosene (17 per cent).
7	6.0	38.8	
8	5.0	35.8	
9	4.4	33.0	Distillate (4.4 per cent).
10	10.0	31.3	Lubricants (30 per cent).
11	20.0	33.5	

Another sample tested by Curtiss and Tompkins gave the following results:

Base of oil, asphalt.
Paraffin scale, 1.15 per cent.
Gravity: Specific, 0.8449; Baumé, 35.7°.
Flash point (Tagliabue's open tester), below 14° F.
Fire point (Tagliabue's open tester), below 14° F.
Sulphur, 0.46 per cent.
Sand and water, trace.
Heat value: Calories, 10,635; British thermal units, 19,144.
Fractional steam-distillation test; initial distilling point 111° F.; each fraction 10 per cent:

[87] Johnson, H. R., Geologic notes on Santa Susana district: Western Eng., vol. 2, p. 385, 1913.

	Gravity at 60° F.	
	Specific.	° Baumé.
First, up to 217.4° F	0.6890	73.2
Second, 217.4° to 275° F	.7372	59.9
Third, 275° to 311° F	.7688	52.1
Steam introduced.		
Fourth	.7937	46.4
Fifth	.8192	40.9
Sixth	.8552	33.7
Seventh	.8872	27.8
Eighth	.9174	22.6
Residuum or road oil (20 per cent)	.9830	12.4

The above distillation yields commercial products as follows:

	Per cent.	Gravity (° Baumé).
Gasoline group	20	66.0
Benzine or naphtha	10	52.1
Kerosene stock	20	43.3
Distillate or neutral cut	10	33.7
Lubricating stock	20	25.4
Residue or road oil	20	12.4

The striking features of the oil as shown in these analyses are its high-gasoline content, the large amount of kerosene, and the unusual viscosity of the lubricant products.

The first five productive wells drilled in Simi Valley were sunk by the Simi Oil Co. between 1900 and 1902 in the canyon west of Las Llajas Canyon in the SE. ¼ sec. 30, T. 3 N., R. 17 W. Later, the land was leased to the Pittsburg Petroleum Co. in 1910 and to the Ventura Consolidated Oil Co. in 1911. Each company drilled a well about 450 feet, but both were abandoned before they were finished. The Simi Oil Co.'s wells ranged in depth from 1,125 to 1,725 feet, and all obtained a small production of light oil having a specific gravity of 0.8642 (32° Baumé). Four of them are still occasionally pumped. The wells are immediately north of an east-west fault on steeply northward-dipping strata of the Meganos formation. This fault dies out as it crosses the canyon, and the westward-trending beds on the west side of the canyon swing abruptly to the southwest around the end of the fault. Oil seeps from the sandstone and conglomerate at several places along the fault in the canyon, and the strata on the north side of the fault are saturated with petroleum. The wells, drilled a short distance north of the fault, evidently meet the oil-saturated sand which is the source of the oil. This property is now owned by the Santa Susana Syndicate.

Between these wells and the main Tapo Canyon field are two wells drilled by the Santa Susana Syndicate near the edge of the valley, in the NW. ¼ sec. 31, T. 3 N., R. 17 W. (See Pl. XVI.) These wells penetrate northwestward-dipping upper beds of the Meganos formation for 1,500 feet and encounter oil sands at a depth of about 1,000 feet. No anticline is present, for, although the Simi anticline heads in this direction, it probably does not extend this far east. In one of the wells a small yield of oil, which probably seeps in with water, amounts to about 40 barrels a week. Of the amount of fluid pumped about 40 per cent is water.

BREA CANYON AND SCARAB WELLS.

The first attempt at drilling in Simi Valley was made by the Union Oil Co., which in 1890 started a well in Brea Canyon in the SE. ¼ sec. 32, T. 3 N., R. 18 W. As this well was a failure, on account of water and caving sands, another well was drilled in 1891 but was abandoned at 500 feet with an estimated flow of 3,000 barrels of water a day. A third well, about 500 feet north of an outcropping oil sand and brea deposit in the Sespe formation, was drilled in 1900. This well reached a depth of 970 feet and obtained oil at 770 feet. It is now pumped twice a week and yields about 20 barrels of oil having a specific gravity of 0.9396 (19° Baumé).

One of the most productive wells of this region is one on the Scarab lease of the Pan-American Petroleum Co., in the NE. ¼ sec. 31 and the NW. ¼ sec. 32, T. 3 N., R. 18 W. (See Pl. I.) The first well drilled here by the Scarab Oil Co. never produced oil, but the second well, put down by the same company, in 1918 was producing daily about 15 barrels of oil having a specific gravity of 0.9396 to 0.9333 (19° to 20° Baumé). A third well has been drilled by the present owners of the lease but without success. These wells start near the base of the upper sandstone and conglomerate member of the Sespe formation, which dips 20°–30° N. and forms a part of the north limb of the Simi anticline. (See section D–D′, Pl. II.) The producing well, which is 2,593 feet deep, penetrates two oil zones in the colored shale and soft sandy member of the Sespe—one between 1,323 and 1,563 feet below the surface and the second between 1,968 and 2,040 feet. Showings of oil are present at intervals below 1,185 feet, and salt water was struck at 2,500 feet. The upper sand crops out about half a mile south of the wells, where several large seeps occur. The Union Oil Co.'s well in Brea Canyon produces from the second sand.

In 1919 the Pan-American Petroleum Co. was drilling four wells on its Simi lease, in the NW. ¼ and SW. ¼ sec. 34, T. 3 N., R. 18 W. The first well struck producing oil sands that are probably the same as those from which production is obtained in the Union Oil Co.'s well in Brea Canyon. Uncertain water conditions here, however, have hindered production and drilling operations.

Three wells have been drilled near the mouth of Brea Canyon along the axis of the Simi anticline (see Pl. I). In this vicinity the anticline rises somewhat to form a slight dome, the axis plunging east and west from an apex near the center of sec. 5, T. 2 N., R. 18 W. All the wells start in the lower sandstone member of the Sespe formation. Two of the wells were put down in 1913–14—one, known as the Dabney & Roberts well, in the NE. ¼ SE. ¼ sec. 5, T. 2 N., R. 18 W., and the other, drilled by the State Consolidated Oil Co. and known as the Miley-Buley well, in the NW. ¼ SW. ¼ sec. 4. A third well was drilled by the Hidalgo Oil Co. in 1915 in the northeast corner of sec. 6. The Dabney & Roberts well, which is on the axis of the anticline, made a good test of this area, going down 2,680 feet. It penetrated the Sespe formation, which is not over 350 feet thick at this point, and probably went through the greater part of the Meganos, if not into the Martinez formation, passing almost entirely through shale and sandy shale, with an occasional sand stratum and "shell." Gas and some oil were encountered at intervals below 315 feet, though none of the sands were rich enough to make the well productive. The Miley-Buley well went to a depth of 1,160 feet, and the Hidalgo well is reported to have gone about 1,925 feet. Neither of these wells struck any paying oil sand, and the former did not reach even the Eocene strata.

Southwest of Brea Canyon the Simi anticline offers no very favorable structure for drilling. The axis of the fold pitches continuously westward, and no areas suitable for the accumulation of the oil have been found. Moreover, the fact that very little oil was obtained in the Dabney & Roberts well at Brea Canyon suggests that but little oil is present along the western part of the fold.

LLAJAS ANTICLINE.

The Llajas anticline, which may be discussed as a possible source of oil, extends in a northwesterly direction along the foothills of the Santa Susana Mountains, near the head of Las Llajas, Aliso, and Browns canyons. (See Pl. I.) The oldest rocks exposed along this anticline are of Meganos (middle Eocene) age, and it is in these rocks that the oil-bearing strata occur. They consist of massive brown or gray medium to fine-grained sandstone containing calcareous concretions, which are usually fossiliferous. The Meganos is overlain by the Topanga sandstone (middle Miocene) and Modelo shale (upper Miocene), followed by the Saugus formation (upper Pliocene and Pleistocene). These beds have all been compressed into a symmetrical fold whose dips attain 40° in the vicinity of Las Llajas Canyon. The Llajas anticline plunges east and west from a point near the divide between Simi and San Fernando valleys. To the west the amount of inclination is about 10°–15° or perhaps slightly more near Las Llajas Canyon; to the east it is probably less, though the Miocene and Pliocene sediments cover the Eocene in this direction. The Meganos formation is known to be oil bearing, as the productive sands of the Tapo field are in this formation. That they are oil bearing in this area is evident from the fact that several oil seeps occur in Las Llajas Canyon along the axis of the anticline. Here, as in the Simi anticline, the Martinez formation (lower Eocene) probably underlies the Meganos, and both are in part of organic origin and capable of acting as a source for the oil. The drainage area from which the petroleum could migrate includes the territory on the south to the Happy Camp syncline and an unknown area on the north concealed beneath the Santa Susana fault. This fault, which is the largest in the district, probably does not dislocate the Eocene oil-bearing strata in this vicinity, for the fault plane dips gently northward, cutting the Miocene strata. Another fault, on the north side of Devil Creek, cuts the Eocene and later formations on the south flank of the anticline but probably does not extend far enough west to have any material effect on the accumulation of oil. The west end of the anticline is truncated by a diagonal fault east of Dry Canyon. This is evidently the most unfavorable fault in the area, so far as the accumulation of oil is concerned. The amount of displacement along it, however, is not great, and probably it would not materially influence migration of the petroleum.

A minor anticline parallels the main fold a short distance south of it, east of Aliso Canyon. On the preliminary map of this area [88] this southern fold in Browns Canyon was shown as connecting with the main Llajas anticline, but later work has shown that the northern anticline is the main fold. The southern fold is well developed in Brown's Canyon, where it is acutely compressed and even overturned.

The most favorable place to drill to test the Llajas anticline, in the writer's estimation, is along the axis of the anticline in the vicinity of Las Llajas Creek, in secs. 22 and 23, T. 3 N., R. 17 W.—the highest part of the fold.

The seeps in Las Llajas Canyon come from one of the oil sands in the Meganos. To reach this sand on this anticline a well would have to be put down west of the canyon, in sec. 22. On the supposition that this is the upper oil sand and from the fact that in the Tapo field other sands lie below this one it is reasonable to presume that the same condition exists here. Therefore it is possible that oil sands would be encountered should a test well be drilled east of the canyon in sec. 23. A test well, known as the Joughins No. 1, was sunk in 1919 by the General Petroleum Co. No oil sands were reached, though several gas pockets were struck. This well is too far east to test this fold, as it started in strata below the outcropping oil sands and is not on the highest part of the fold.

[88] U. S. Geol. Survey Bull. 691, pl. 41, 1919.

Two wells have been drilled along the Llajas anticline in Browns Canyon, in sec. 30, T. 3 N., R. 16 W., by Dr. F. C. Melton, of the Placerita Oil Co. One of them, in the bottom the canyon, is about midway between the two anticlines and near the axis of the syncline. This well started in lower beds of the Saugus formation (upper Pliocene and Pleistocene) and probably reached the Meganos formation, from which it is reported to have produced 1,500,000 cubic feet of gas a day. The second well, put down immediately north of the axis of the Llajas anticline, was abandoned without having penetrated any gas or oil-bearing formations. From the tests which these two wells have made it appears likely that no more promising results can be obtained by future drilling in Browns Canyon. The small size and highly deformed nature of the folds in this territory militate against any material accumulation of oil.

At the head of Dry Canyon, a northern branch of Tapo Canyon, the Modelo and Saugus formations are folded into two anticlines and a syncline, which may represent a westward continuation of the Llajas fold. The northern anticline has been greatly deformed and at its west end has been overturned. The southern one is not nearly so tightly compressed. Should the Llajas anticline prove productive in the vicinity of Las Llajas Canyon, this southern fold would probably be worth testing, but its close association with faults and highly disturbed strata, which are not very favorable for the accumulation of oil, does not warrant drilling at the present time.

OUTLYING TEST WELLS.

Along the Santa Susana fault seeps and brea deposits occur, the petroleum coming from Modelo shale and saturating the adjacent Saugus formation. On the strength of these evidences of oil several wells have been drilled along the foot of the Santa Susana Mountains. No oil in paying quantities has been found, although tar beds were usually encountered. The McCray Bros. put down two wells in sec. 13, T. 3 N., R. 18 W., and another in sec. 16, T. 3 N., R. 17 W. The Tapo Oil Co. is said to have drilled three holes in 1900–1901 in the NE. ¼ sec. 14, T. 3 N., R. 18 W., in the upper part of Tapo Canyon, which were less than 700 feet deep and were dry. They started in terrace material overlying strata of the Saugus formation on the north side of a syncline, south of some seeps that occur along the Santa Susana fault. The location of these drill holes as shown on the map is only approximate.

On the south side of Simi Valley the Calabasas Oil Co. in 1914 put down a drill hole in the NE. ¼ sec. 13, T. 2 N., R. 18 W., 3 miles southeast of Simi. It penetrated more than 1,900 feet of northward-dipping Meganos and Martinez beds which compose the south limb of the Simi syncline, but encountered no oil and only a little gas.

LAS POSAS AREA.

GENERAL FEATURES.

The Las Posas area really contains the westward continuation of the structural features of the Simi Valley area. (See Pl. I.) The main structural feature is a large synclinorium, the axis of which extends down Little Simi Valley to the flood plain of Santa Clara River. The north side of this synclinorium extends to Oak Ridge and forms the south side of South Mountain. It comprises several low folds—two anticlines and two synclines. The south limit of the synclinorium is short and forms the Las Posas Hills, the ridge that extends westward from the Tierra Rejada. The south side of this ridge is faulted down and is a westward extension of the Simi anticline. Other faults may be present on the south side of Santa Rosa Valley, where the Saugus formation is in contact with the Miocene volcanic rocks.

The Saugus formation (upper Pliocene and Pleistocene) composes the greater part of the strata exposed in this district. The Pico (lower Pliocene) and Modelo (upper Miocene) crop out below it along Oak Ridge and South Mountain, and a small strip of Modelo shale and sandstone is present west of the Tierra Rejada in Arroyo Santa Rosa. The terrace deposits that cover the Saugus formation are large and in many places obscure the structure of the underlying rocks. Along the east side of Little Simi Valley and in the Las Posas Hills the Miocene formations are absent, the Saugus formation resting directly upon the Sespe formation (Oligocene?).

LAS POSAS VALLEY.

In Las Posas Valley the only areas that may be considered as possible sources of petroleum are along the larger anticlines. The continuously southward-dipping series of Miocene and Pliocene strata forming the south side of South Mountain is not suitable for the retention of oil, should any be present. If oil were present in these strata some surface indications should appear along their upturned edges. Petroleum was reported in some of the Pico strata, but the oil-saturated sand proved to be rounded pebbles of hard oil sand which evidently had washed into the Pico from some older formation while it was being deposited.

A well drilled in 1917 by the Hondo Oil Co. on the south side of South Mountain, in the northeast corner of sec. 29, T. 3 N., R. 20 W., found no evidence of oil and was abandoned. It was started in the Pico formation (lower Pliocene) about 4,000 feet south of the Modelo shale contact. Evidently the aim was to reach the base of the Pico, along the outcrops of which oil seeps had been reported.

As the strata dip about 30° S., this horizon should have been reached at a depth of about 2,000 feet.

The two anticlines in this district, being similar in both structure and lithology, may be considered together. The northern fold extends from Fairview southwest to the valley's edge; the southern one is longer, reaching from Happy Camp Canyon along the north edge of the Little Simi Valley beyond the mouth of the valley, and forms the hills immediately west of Somis and north of Camarillo. Except for the folding in these hills the strata in the anticlines have an average dip of less than 10°. Within the low hills north of Little Simi Valley the folds plunge gently to the west, but in the Camarillo Hills a perfect dome is present, and the outline of the hills reflects the folding of the strata.

Two possible sources of oil under this area are the Sespe and the Pico and Saugus strata. The Sespe is known to be oil bearing on the north side of Oak Ridge and South Mountain, a few miles distant, and it is likely that with favorable structure oil would accumulate in it also in the Las Posas area. However, the depth at which the Sespe oil sands lie below the surface here is great and in the western part of the area amounts to at least 5,000 feet, as measured on the south side of Oak Ridge. This depth decreases toward the south but still is great enough to prevent drilling under such uncertain conditions. Toward the east the formations overlying the Sespe rapidly thin out, so that north of Moorpark the Sespe formation can easily be reached.

A well was drilled by the Marine Street Investment Co., in Walnut Canyon 1 mile north of Moorpark, close to the axis of the southern anticline. It went 2,403 feet before abandonment and after piercing a comparatively thin series of the Saugus formation struck the Modelo or the Vaqueros shale and sandy shale and finally, at about 2,350 feet, entered coarse-grained strata containing conglomerate. These strata, which showed some oil, probably represent the base of the Vaqueros formation, which is conglomeratic in the region east of Happy Camp Canyon. In August, 1920, the Standard Oil Co. (California) started its Donlon No. 1 well in the center of the W. ½ sec. 34, T. 3 N., R. 30 W., and in April, 1921, its Gabbert No. 1 well in the NW. ¼ NE. ¼ sec. 6, T. 2 N., R. 19 W. Both anticlines on the north side of Las Posas Valley near Moorpark have been tested by these wells, and no satisfactory results were attained. North of Moorpark the Saugus formation forms but a relatively thin veneer lying unconformably over the northward-dipping Sespe, Vaqueros, and Modelo formations, which are exposed east of Happy Camp Canyon and very probably continue southwestward below Little Simi Valley. Between Moorpark and Epworth the anticlinal structure near the location of the Marine Street Investment Co. well is comparatively faint, the dips being less than 5°, and no anticline is present in the beds below the Saugus formation, though there is probably a terrace. (See structure section B–B′, Pl. II.) The wells after passing through the Saugus formation struck the shale and sandy shale of the Modelo and Vaqueros and then the conglomeratic beds at the base of the Vaqueros. If oil is not present in these formations it is thought that deeper drilling would not be justified, as the Sespe oil horizon lies too deep to be reached by the drill.

CAMARILLO HILLS.

The Camarillo Hills, directly west of Somis, seem to offer the most promising structure for the accumulation of oil in the Las Posas district. The Camarillo anticline, which extends through these hills, is the west end of the fold that follows the northern edge of Little Simi Valley and here forms an elongated dome. The shape of the hills reflects the structure distinctly. (See structure section A–A′, Pl. II.) The strata exposed on the hills belong to the Saugus formation, below which the beds are not very well known except from information obtained from one well log—that of the Dabney well, which is a short distance west of the apex of the dome. As indicated by the structure along the Las Posas Hills the Saugus formation overlaps the Sespe formation, evidently covering the upturned edges of the Modelo and Vaqueros strata that form the south end of the syncline. Therefore it is reasonable to suspect that the same condition is present in the Camarillo Hills. There is a chance that oil may be found at the base of the Pliocene sediments, having been derived from the Modelo shales. The alternative and probably more productive oil zone would be the sands in the Sespe. If the same thickness of strata is present on the Camarillo Hills as on South Mountain about 3,000 feet of strata would have to be penetrated to reach the base of the Pliocene. If the Modelo and Vaqueros are absent at least 1,000 feet of Sespe beds are present above the oil sands that are known to occur at South Mountain and in Simi Valley.

The nearest point to these hills at which oil occurs is at the foot of the Conejo grade, where a small amount of heavy oil is obtained. No evidence from surface or underground conditions indicates from what formation this oil is derived, but its character suggests that it originated from the Modelo. On the other hand, it may have come up from some deeper formation, such as the Sespe (Oligocene?), along a fault that is probably present along the west side of Conejo Mountain. From this supposition there is a chance that oil may be found at the base of the Pliocene strata.

The Dabney well, drilled close to the axis of the Camarillo anticline in 1917–18, went down more than 2,400 feet but struck no indications of oil. Down to 1,520 feet it penetrated sandy shale and sand, which probably represent the Saugus and perhaps the Pico formation. Below this material brown and black shale was penetrated to 2,248 feet, and below that the log indicates blue shale with zones of a sticky hard shell, which under the microscope appears to be a clay with considerable tuffaceous matter. Pebbles of varying size, some as large as a pea, are present. This shaly member may represent the Pico, which is mainly a soft sandy shale on the south side of South Mountain, or it may be the Modelo shale. None of the coarse material of the Sespe formation was reached, and it is doubtful whether the drill passed out of the Pico formation. This well has not adequately tested the Camarillo anticline. The following is a generalized log of the well.

Log of Dabney well, in northwest corner of sec. 23, T. 2 N., R. 21 W.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow sand, with streaks of clay	190	190
Blue shale	30	220
Yellow sand	45	265
Gray sand	225	490
Water sand	20	510
Blue shale	25	535
Water sand	3	538
Blue shale	37	575
Fine blue sand	10	585
Blue shale	55	640
Hard gray sand	90	730
Dark-blue shale	27	757
Hard gray sand	28	785
Blue sandy shale	75	860
Hard gray sand	70	930
Running water sand	5	935
Hard sand	13	948
Blue muddy shale	92	1,040
Hard gray sand	105	1,145
Blue sandy shale	95	1,240
Hard gray sand	128	1,368
Loose running sand and water	2	1,370
Hard gray sand	103	1,473
Blue shale	2	1,475
Hard gray sand	35	1,510
Soft blue sand	7	1,517
Hard shell or black shale	3	1,520
Brown muddy shale with strong sulphur smell	17	1,537
Hard shell of black shale	2	1,539
Brown muddy shale with strong sulphur smell	121	1,660
Hard shell of black shale	2	1,662
Sandy brown shale	16	1,678
Hard shell of black shale	2	1,680
Brown muddy shale with strong sulphur smell	4	1,684
Hard shell of black shale	3	1,687
Brown muddy shale with strong sulphur smell	10	1,697
Brown shale with a few hard shells of black shale, showing of gas at 1,780 feet	393	2,090
Hard gray sand	6	2,096
Brown muddy shale with hard shells of black shale	152	2,248
Soft blue sand and blue shale	10	2,258
Blue sticky shale with hard shells of dark bluish slaty character from 3 to 6 inches thick. Contains tuffaceous material. Caved badly	17	2,275
Hard blue shale	10	2,285
Blue shale, rather soft, with kidneys of hard limy shale, which caved badly and had a tendency to roll casing	5	2,290
Hard blue shale	9	2,299

LAS POSAS HILLS.

The Las Posas Hills, lying between Arroyos Las Posas and Santa Rosa, do not offer very favorable indications for drilling. The dominant structural feature is a faulted anticline, which trends along the south side of the ridge and is a continuation of the Simi anticline. (See structure section B–B′, Pl. II.) Structure of this type is not unfavorable to the accumulation of oil, but, on the other hand, it is thought that some surface indications, such as seeps or oil-impregnated sands, would be present along this fault if petroleum exists in the Sespe formation in this area. As the Sespe strata plunge gently to the west all along the Simi anticline and in this area likewise, and as it has been shown that the accumulation of oil becomes less toward the west from the results of the wells drilled at the mouth of Brea Canyon it seems unlikely that any commercial production would be obtained here, even if oil sands were reached. Near the end of these hills, opposite the town of Somis, a steeply westward-plunging anticline is present which is a continuation of the fold described above, and the same conditions of accumulation exist here as farther east along the fault.

SUMMARY.

Of the large area included in the Simi Valley and Las Posas district the northeastern part, or north side, of Simi Valley offers the best possibilities for the production of oil. A field of considerable size has already been developed at Tapo Canyon, at the east end of the Simi anticline. The production of oil from this field between June 30, 1917, and June 30, 1919, amounted to 73,552 barrels, and the oil is of an exceptionally high grade, having an average specific gravity of 0.8434 (36° Baumé). The westward extension of this field is now taking place, and at present the limits of the productive territory along this fold are pretty well defined. Owing to structural conditions there is a considerably greater productive area north of the axis of the fold than on the south side. As the land is not yet drilled up further increase in production may be looked for in this field. Wells in Brea Canyon and on the Scarab and Simi leases of the Pan-American Petroleum Co., drilled north and east of some seeps in the Sespe formation, have obtained a small quantity of oil. Other wells drilled in this vicinity, especially between the Scarab wells and the outcrop of oil sand, should obtain oil, but no very large wells can be expected. The Llajas anticline, near the head of Las Llajas Canyon, offers some favorable opportunities to test for oil as structural and lithologic conditions similar to those on the Simi anticline are present here, and oil seeps occur along the axis of the anticline. The most favorable localities for testing this fold are in and west of Las Llajas Canyon.

In the Las Posas area, lying between Simi Valley and the flood plain of Santa Clara River, the only areas worth considering are along two anticlines that extend westward on the north side of Little Simi Valley. The southern anticline forms the Camarillo Hills, which offer the best structural conditions for the accumulation of oil. The well recently drilled near the crest of the hills, in the writer's opinion, has not fully tested this anticline. An estimate of the depth necessary to reach the oil is extremely difficult to make. Should no oil be found at the base of the Pico formation the oil sands known to occur in the Sespe formation should be tested. These sands lie at least 1,000 feet below the top of the Sespe. The anticlines east of the Camarillo Hills offer less promise of being oil bearing and should not be drilled until a thorough test has been made in the Camarillo Hills.

CALABASAS AND SAN FERNANDO VALLEY DISTRICT.

GENERAL FEATURES.

As described on pages 106–107, the Calabasas and San Fernando Valley district is structurally a large syncline or synclinorium that forms San Fernando Valley and extends westward between the Simi Hills and Santa Monica Mountains to include Conejo Valley.[89] In this synclinorium of Miocene and Pliocene strata numerous small folds have been developed in the vicinity of Calabasas and along the north side of San Fernando Valley. As the lithologic conditions in the Calabasas area, which also includes the south side of San Fernando Valley, are unlike those on the north side the two will be discussed separately.

CALABASAS AREA.

The formations and structure are uniform throughout the Calabasas area. The rocks of the Topanga, Modelo, and Pico formations are the only ones involved to any marked degree in the folding. They consist of the sandstone or conglomerate of the Topanga, followed by alternating sandstone and shale, in part siliceous and diatomaceous, of the Modelo and Pico. As the Modelo is both a source and a reservoir for oil in the Santa Susana Mountains there is some reason to suppose that it may be petroliferous here also. However, no seeps or outcropping oil sands are known here, and the only evidence of hydrocarbons is found in a small area of burned and fused shale in Las Virgenes Canyon, which may have been caused by ignited gas or oil. As the formations on the south side of the valley crop out in a continuous northward-dipping series some evidence of petroleum ought to appear, if any petroleum is present. Between the Simi Hills and the Santa Monica Mountains the Modelo is comparatively thin, especially the shale member with its included sands, so that a sufficient covering is not present to allow the accumulation and retention of any oil, although the beds are folded into several anticlines. In Conejo Valley the Topanga formation is partly represented by intrusive igneous rocks, and it

[89] A generalized map and description of this district may be found in the California State Min. Bur. Bull. 69, pp. 381–387, pl. 3, 1914.

is very improbable that oil would be associated with this material. Several faults cut this area, but no oil seepages or indications of petroleum occur along them, as would be expected if oil were present. East of Calabasas there are no folds other than an almost imperceptible warping of the strata, so that, in view of the lack of surface evidence of petroleum along the upturned edges of the strata, this territory also is considered unfavorable for prospecting. One well, known as the W. C. Price Hale No. 1 well, was drilled in 1920 in the SW. ¼ sec. 10, T. 1 N., R. 17 W., and abandoned without obtaining satisfactory results.

CONEJO FIELD.

The group of wells, at the foot of the Conejo grade, for many years abandoned except for sporadic pumping, but since 1920 under redevelopment, is about 3 miles east of Camarillo on the State highway. The first well was drilled here in 1892 by the Union Oil Co. In all this company up to 1899 sank 34 shallow wells near some oil seeps and produced a moderate amount of low-grade oil, but the wells were not long lived and they were abandoned in 1899. After 1910 six new wells were drilled by Dolton & Perkins, of Santa Barbara, but at the time of the writer's visit (1917) the wells were idle and apparently abandoned, and evidence of only 19 wells could be found in the field. When pumped the wells averaged less than 1 barrel a day, and as the oil is suitable only for roads and fuel it did not pay to operate them. In 1920 the Ventura Oil Syndicate, now the Cooper Petroleum Co., took over this field and started drilling new wells and enlarging the limits of the field. Since then, owing to the success of this company, many other organizations have entered this field. For the six months ending June 30, 1921, the Conejo field had an average of 29 producing wells and an average oil production of 10.4 barrels and 25.1 barrels of water per day per well, or 29 per cent of oil in the fluid pumped.[90] Many more wells have begun to produce since then, and in 1922 a refinery was being completed to take care of the product.

The average depth of the wells is about 150 feet. They are drilled into the alluvium along the foot of Conejo Mountain and penetrate the andesitic breccia that forms the hills in the immediate vicinity. It is probable that a fault traverses the edge of the valley, and the oil may migrate up along it. Water and oil occur together and seep out at the surface. The Tertiary volcanic rocks that crop out in the hill just north of the wells dip westward at an angle of about 5°, and it is barely possible that the oil has come up along the breccia

[90] California State Min. Bur. Summary of Operations, vol. 7, No. 2, p. 11, August, 1921.

from some point farther out in the valley. Whether the oil is derived from the Eocene formations or from Modelo shale (upper Miocene) is not known. The log of well No. 1, drilled by the Union Oil Co. in 1892, is given below. This hole evidently penetrated the tuff and breccia and entered amygdaloidal lava.

Log of Union Oil Co.'s Calleguas well No. 1, at the foot of the Conejo grade, 2½ miles east of Camarillo, Ventura County, Calif.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
(?)	68	68	Medium grayish sand	80	700
Pyrites (?)	8	76	Medium dark-red sand	30	730
Pyrites and dark mixture carrying water	34	110	Very hard and fine black rock with white sand	10	740
Pyrites and black mixture	210	320	Coarse, blackish rock with small white round grains looking like petrified pearls in it	60	800
Pyrites with fine black sand; very hard rock at 395 feet	75	395	Same, but finer and without white grains	20	820
Black sand	5	400	Same, very fine	15	835
Fine dark-brown sand	8	408	Same, rusty grayish brown	45	880
Medium dark brownish-red sand	2	410	Same, coarser	15	895
Coarse dark brownish-red sand	10	420	Very fine dark-gray sand	15	910
Fine dark brownish-red sand	20	440	Coarser and darker sand	40	950
Medium dark brownish-red sand	70	510	Fine gray sand	11	961
Fine dark grayish-brown sand	80	590			
Medium dark grayish-brown sand	30	620			

NORTH SIDE OF SAN FERNANDO VALLEY.

South of the Santa Susana fault several folds extend obliquely out into San Fernando Valley and disappear beneath the alluvium. The formation exposed is the Saugus, and this is covered by terrace deposits of Pleistocene age that were not involved in the folding. The Saugus formation consists mainly of sandstone and conglomerate, the latter containing numerous pebbles of Modelo diatomaceous shale. A more detailed description of the strata is given on page 82. The largest fold is an anticline that extends from Aliso Canyon in a southeasterly direction to the canyon near the Sunshine ranch between Aliso and Bull canyons. Two other anticlines are present in the vicinity of Limekiln Canyon, but these are not so well defined as the eastern one. (See structure section K–K′, Pl. II.) The anticline near Aliso Canyon plunges markedly toward the northwest and probably is cut off by the Santa Susana fault. The dip of the beds along it varies; the maximum is 70°, but the average is between 30° and 40°. As shown in a well exposed section in the hills on the east side of the San Fernando reservoir of the Los Angeles Aqueduct, the Pico (?) shale underlies the Saugus formation. The Saugus formation is very thick in this area, measuring in the hills west of the reservoir about 5,000 feet. If oil is present it should be found at the base of the Saugus formation or in sandy strata within the Pico (?) shale. A well was drilled by the Standard Oil Co. (California) on this anticline in the NE. ¼ sec. 2, T. 2 N., R. 16 W., but failed to obtain satisfactory results. As considerable erosion has taken place along this fold only about 2,000 feet of Saugus strata remain above the Pico (?) shale. The nearest surface indications of petroleum south of the Santa Susana fault occur east of Fernando in the Tujunga Hills, where oil sands are present near the base of the Pliocene overlying the Miocene shale.

Although numerous evidences of oil also appear north of or along the Santa Susana fault, none in either the Pico (?) or the Saugus strata are known south of it. This fault may have prevented the migration of oil southward. On the other hand, as the anticline near Aliso Canyon plunges toward the fault, oil coming up along the fracture may have migrated from it into the sands of the Saugus formation. A seep at the fault in Aliso Canyon indicates that oil is present here along the fault.

The other two anticlines plunge southeastward away from older rocks of Cretaceous age. (See Pl. I.) The northern one can be followed only a comparatively short distance before being lost in the valley alluvium. The southern fold, although not so prominent, is traceable from a point west of the mouth of Limekiln Canyon into the valley, and probably the low line of hills that continues into the valley is the topographic expression of this fold, as is apparently indicated by a few dips obtained in road and gully cuts along the Chatsworth Boulevard. The anticline is asymmetric, the beds dipping as high as 75° on the south but considerably less on the north side. These high south dips may be the result of faulting. There are no surface evidences of petroleum near these anticlines, and the lack of petroliferous sands on the south side of San Fernando Valley strengthens the inference that no oil sands would be present on the north side either. As the folds plunge toward the valley, any oil accumulating along these anticlines would have to come from this direction. This fold was tested by the Standard Oil Co. in 1921 by a well in the NW. ¼ sec. 24, T. 2 N., R. 16 W., which has been abandoned as a dry hole.

The hills around the San Fernando reservoir of the Los Angeles Aqueduct, 2 miles west of the town of San Fernando, are composed of a continuously northward-dipping series of Saugus strata which rest upon and are in places faulted against oil-stained sand and diatomaceous shale of the Pico formation. (See structure section L–L′, Pl. II.) These beds are exposed along the axis of an anticline on the south side of the hills. The anticline is probably a westward continuation of the one exposed near Aliso Canyon. A well was drilled on this anticline east of the dam in the SE. ¼ sec. 5, T. 2 N., R. 15 W., by the Mission Hills Oil Co. in 1922, and abandoned as a dry hole. This well should have made a good test of this fold so that further drilling in this area is not advisable. Another well drilled to the north in sec. 32, T. 3 N., R. 15 W., also has been abandoned without satisfactory results.

No structural features particularly favorable for the accumulation of oil occur in the region east of the town of San Fernando and between the San Gabriel Mountains and the Verdugo Hills. South of Tujunga River there is a rather poorly developed anticline in the lower strata of the Modelo formation, which here consists largely of coarse sandstone and conglomerate. A well drilled by the Interstate Oil Co. in the NE. ¼ sec. 16, T. 2 N., R. 14 W., to a depth of about 2,000 feet failed to obtain any oil. When drilling was suspended in 1922 the conglomerate lying at the base of the Modelo formation was being penetrated. As this conglomerate rests directly upon the granite there is little hope that oil will be found either at this place or elsewhere on the south side of Tujunga River.

The San Fernando Oil Co. drilled a well more than 2,200 feet deep at the edge of the hills north of Tujunga River, in the ravine west of Lopez Canyon, in sec. 1, T. 2 N., R. 15 W. An oil sand crops out at the surface along the front of these hills, but the well started in strata lying below this sand. A heavy oil is reported to have been struck near the bottom, but the hole was not commercially productive. The structure here is not such as to produce any accumulation of oil, and it is doubtful whether further drilling would give better results. Although a well had previously been drilled a short distance to the north, it probably did not test the outcropping oil sands. An adequate test could be made by drilling through the Pico formation still farther to the north. A derrick has been erected for this purpose on the ridge between Lopez and Kagel canyons in sec. 31, T. 3 N., R. 14 W.

A shallow well drilled by the Sunland Oil Co. into an oil-soaked faulted vertical shale, near the center of sec. 2, T. 2 N., R. 14 W., failed to yield any oil. The structure in this territory is extremely poor for oil accumulation.

A well drilled north of Gold Creek in the faulted strip of Modelo strata along the San Gabriel fault is reported to have found oil showings. Further drilling in the region of Gold Creek and Little Tujunga Canyon near its head is to be discouraged, as the Modelo is so broken and its areal extent and thickness are so small that there is little chance, if any, of obtaining more than a show of oil.

SUMMARY.

Although the formation from which a large part of the oil in Ventura and Los Angeles counties originates is present in the Calabasas area, it is extremely doubtful whether this formation contains oil-bearing rocks here, owing to the lack of evidence from surface indications. Covering strata are also missing, so that any accumulation of oil would be improbable. Mainly for these reasons, and because a test well showed no oil sands, this area is not recommended as being favorable for oil. The Conejo field, at the western foot of Conejo Mountain, abandoned for a number of years but now operated, shows little promise of ever having a very large production. Three anticlines are present along the north side of San Fernando Valley, which in themselves appear to be conducive to the accumulation of oil, but tests on them have been unfavorable. The lack of suitable surface evidence of petroleum and certain unfavorable structural conditions suggest that oil in commercial quantity may be absent in the folds south of the Santa Susana fault.

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