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CHARLES D. WALCOTT, DIRECTOR

THE SANTA CLARA VALLEY, PUENTE HILLS AND LOS ANGELES OIL DISTRICTS

SOUTHERN CALIFORNIA

BY

GEORGE HOMANS ELDRIDGE

AND

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WASHINGTON

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THE PUENTE HILLS OIL DISTRICT, SOUTHERN CALIFORNIA, BY GEORGE H. ELDRIDGE.

THE LOS ANGELES OIL DISTRICT, SOUTHERN CALIFORNIA, BY RALPH ARNOLD.

ILLUSTRATIONS.

PREFACE.

Soon after Mr. Eldridge's lamented death, June 29, 1905, an examination was made of his unfinished reports on the oil fields of California to determine in what shape he left them. His field work had covered a period of approximately one year, from about July 1, 1901, to July 1, 1902. During this time he had examined all the principal oil districts from San Mateo County southward to the Santa Ana Mountains. He had planned to describe the oil fields of this entire area in one large monograph, and at the time of his death had practically completed the manuscript and accompanying geologic maps for the chapters on the Parkfield (Monterey County), Santa Clara Valley (Ventura and Los Angeles counties), and Puente Hills (Los Angeles and Orange counties) districts. Poor health for some time previous to his death precluded his doing more than this, and although there were copious notes relating to all the other districts none of these had been written up. The sad duty of preparing the nearly completed manuscript for publication and of utilizing the remaining notes for other reports was assigned to the writer.

In order to facilitate the publication of the chapters nearest completion it was deemed expedient to issue them one or more at a time as bulletins, instead of in a single monograph, as originally contemplated by Mr. Eldridge. This change in the method of publication necessitated some changes in the arrangement of the text and the treatment of the subject. In making these alterations, however, it has been the writer's sincere effort to modify as little as possible Mr. Eldridge's style of writing and manner of presentation.

The text and geologic maps of the Santa Clara Valley and Puente Hills reports are entirely the work of Mr. Eldridge, with the exception of some changes in the arrangement and some minor additions bringing them up to date. The choice and preparation of the illustrations and the preparation of the cross sections fell to the lot of the writer. The forbearance of the reader is besought for any inconsistencies or deficiencies in this bulletin, as they are doubtless largely due to the writer's inability to interpret and transcribe the ideas which Mr. Eldridge recorded in his notes.

RALPH ARNOLD.

JUNE 30, 1906.

THE SANTA CLARA VALLEY OIL DISTRICT, SOUTHERN CALIFORNIA.

By George Homans Eldridge.

INTRODUCTION.

This paper presents a brief description of the oil fields of the region adjacent to the Santa Clara Valley, in Ventura and Los Angeles counties, Cal. Owing to the somewhat limited time available for the field work it has been impossible to go into as much detail concerning certain of the fields as might be desirable. However, it is hoped that the data here brought together will be of assistance in the future development of the district. Figures of the characteristic or common fossils of the different formations of the district are given in Pls. XXV to XLI. The physical and chemical properties of the oil are treated on pages 203–218.

ACKNOWLEDGMENTS.

The writer wishes to extend his sincere thanks and acknowledgments to the officers and operators of the different oil companies in the district for their hearty cooperation and support. Without the data furnished by them the preparation of such a report as this would have been impossible.

TOPOGRAPHY.

The Santa Clara Valley of southern California is a structural depression modified by erosion. The heads of the valley lie in the San Gabriel Range and in the mountains to the north, which connect this range with other portions of the Coast Range and with the Sierras. After a westerly course of 75 miles the stream which drains the valley enters the Pacific a little south of the town of Ventura. The valley proper is given over to agriculture, but in the mountains on either side are many important oil fields.

The mountains north of the valley form the watershed between it and the Central Valley of California and also present a barrier to the Mohave Desert, which lies in the angle between the Sierras and the more southerly ranges of the State. These mountains are excessively rugged and represent the convergence of several ranges, which to the northwest maintain a conspicuous individuality. Pine Mountain, which is 7,488 feet in altitude, is their culminating point. The area thus occupied forms a part of the Santa Barbara Forest Reserve, recently set aside by the United States Government. The greater portion of it is accessible only by trail and is almost wholly uninhabited.

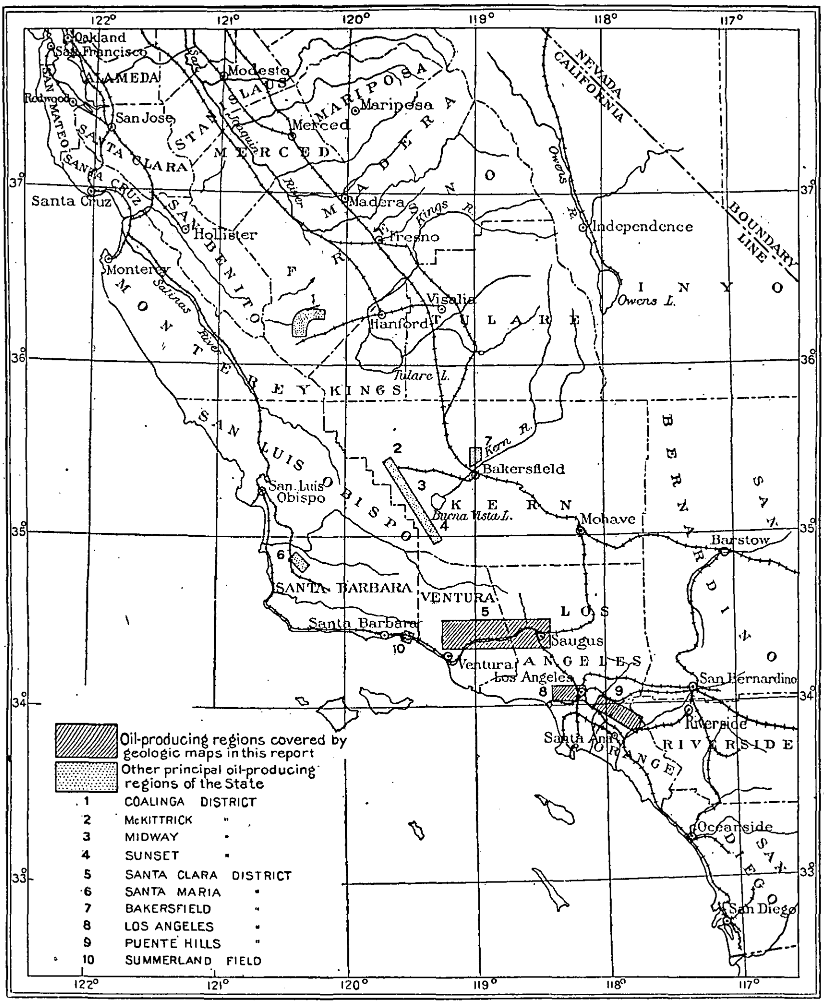
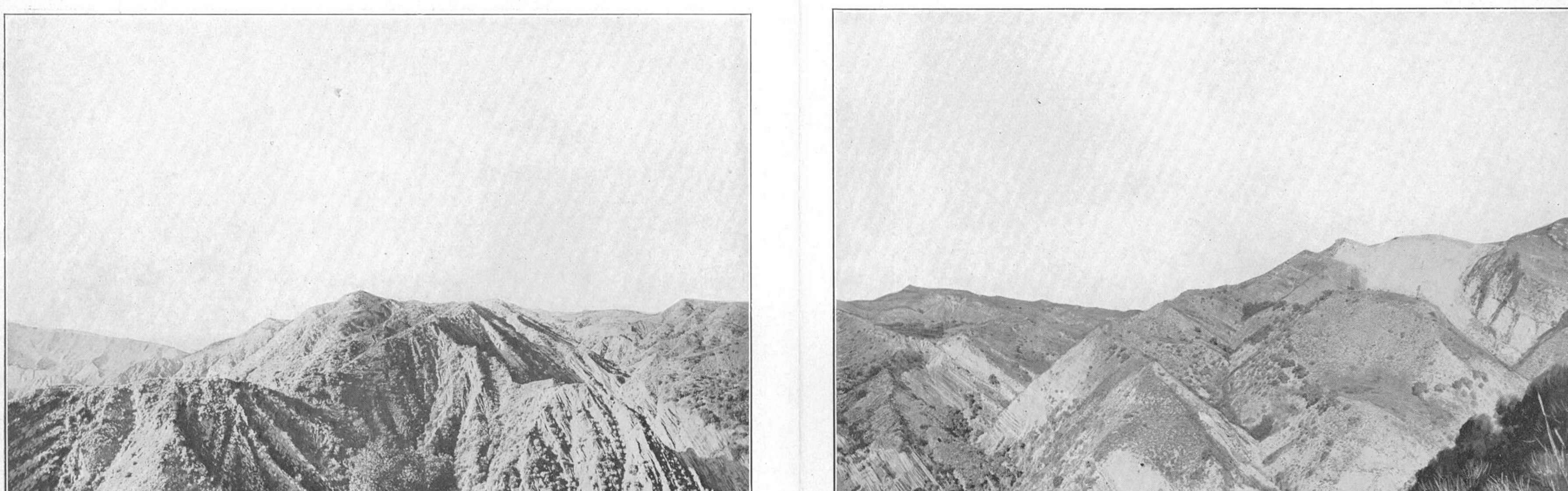


FIG. 1.—Index map of a portion of southern California, showing the location of the three districts described in this bulletin and of the other important producing districts of the State.

The San Gabriel Range, in which rise the southerly heads of Santa Clara River, equals in ruggedness and general altitude the mountains to the north. This range, with its western extension, the Santa Susana Mountains, separates the Santa Clara Valley from those of Los Angeles, Tujunga, and San Gabriel rivers, while still farther west Oak Ridge and South Mountain, in extension of the

A. PANORAMA ACROSS HOPPER CANYON TO VALLEY OF PIRU RIVER.

From Hopper Peak, Ventura County.



B. THE GREAT TOPATOPA ANTICLINE, SESPE OIL FIELD.

From hill above Los Angeles wells, Ventura County.

Santa Susana Mountains, lie between this valley and the minor depression of the Simi. The San Gabriel Range attains its maximum altitude at 10,080 feet in San Antonio Peak, in the eastern portion of the uplift. The highest peak in the Santa Susana Mountains reaches 3,756 feet. Oak Ridge and South Mountain rise to maximum elevations of 3,000 and 2,258 feet, respectively.

The Santa Clara receives its principal streams from the north. Named from east to west, these are: Castac, Piru, Sespe, and Santa Paula creeks. The courses of these streams are most tortuous, their loci having been determined in part by structure, in part by erosion. Their canyons are deep, sharply cut, and in many places cliff bound and inaccessible. In addition, there is a well-distributed and dense growth of chaparral. Sespe and Santa Paula creeks carry comparatively large amounts of water throughout their length. Piru Creek is a somewhat smaller stream, but is sufficient for the irrigation of the fertile lands which border its lower course to a width of a mile or more on either side. The Castac Valley is practically dry.

The Ojai Valley, an intermontane depression which evidently had its origin in a system of profound faults, but whose aspect has since been modified by erosion of the strata over the area of excessive disturbance, lies some distance north of the lower part of the Santa Clara Valley, yet from a geologic standpoint it is a part of the general area here considered. The trend of the valley is east and west; its length is about 12 miles, and its width from 2 to 3 miles. The drainage is now chiefly to the west, San Antonio Creek flowing through it and joining Ventura River, a stream of considerable size, which flows thence 10 miles to the south, entering the Pacific at the town of Ventura, not far from the mouth of the Santa Clara. At the eastern edge of Ojai Valley, however, a minimum of the drainage passes into Sisar Creek, which discharges into Santa Paula Creek. Midway of its length a low ridge divides the depression into two parts, known as the upper and lower valleys. The altitude of the upper valley ranges from 1,250 feet at its western extremity to 1,500 feet at its eastern; that of the lower valley from 750 to 1,000 feet. Ojai Valley is well watered from natural streams and wells. A few miles up Matilija Creek are noted hot springs that are reported to have remarkable healing powers.

North of Ojai Valley is the Topatopa Range, 7,000 feet in altitude; on the south is Sulphur Mountain, 2,750 feet. The mountainous country north of the valley can be reached only by trails, and although the distance across it to the San Joaquin Valley is but 36 miles, the region is one of the least accessible in the United States. Sulphur Mountain presents a steep northern face little indented with canyons; its southern slope, however, has been severely scarred by erosion, but is traversed by canyon roads. (See Pl. II.)

The centers of settlement in the Santa Clara Valley include Ventura, Santa Paula, Fillmore, Piru, Newhall, Camulos, and Saugus, their relative importance being in the order named.

The oil fields north of the Santa Clara Valley are developed on the open slopes in front of Mount San Cayetano and in the tributary canyons to a distance into the range of 5 to 10 miles. These fields include in succession from east to west, Piru, Modelo, Nigger, Hopper, Tar, Little and Big Sespe canyons, and the San Cayetano, Silver Thread, and Ojai fields. They follow in their development the line of the higher mountains. From Santa Paula Canyon westward, however, there is a line of wells in Adams, Salt Marsh, Wheeler, and Aliso canyons, along the south side of Sulphur Mountain, in strata younger than those carrying most of the wells in the fields just referred to. Prospecting is carried on west of Aliso Canyon, even as far as the valley of Ventura River, but no productive territory has yet been found in that area.

The productive wells south of the Santa Clara Valley are confined to the northern slopes of the Santa Susana Mountains and Oak Ridge, with the exception of a single well in the canyon of Placerita Creek, a stream which drains a portion of the northwestern slope of the San Gabriel Range. The field in which this well lies is the easternmost of those developed. Next westward is the Elsmere field, a mile or two southeast of Newhall; to the southwest of Newhall, in canyons descending from the Santa Susana Mountains, are, successively, the Rice, Wiley, Towsley, Dewitt, and Pico fields, the last noted in the past, as well as at present, for the lightness of its oil and the magnitude of its production. Along the northern face of Oak Ridge, 5 or 6 miles west of the Pico field, are those lying in Tapo, Eureka, and Torrey canyons; Wiley, Garberson, Shields, Grimes, and other canyons have also been prospected, but without much success, except in the case of Grimes Canyon, west of which no developments have thus far taken place.

The railway connection for these oil fields is the Coast division of the Southern Pacific, which unites with the San Joaquin Valley division at Saugus and passes thence southward to Los Angeles, distant 33 miles.

GEOLOGIC FORMATIONS.[a]

GENERAL STATEMENT.

The formations of the Santa Clara Valley include certain Pleistocene beds of which the precise horizon is not determined; a great series of conglomerates, sandstones, and arenaceous clays which were designated by Hamlin some years since as the Fernando formation

[a] See p. 143 for table of tentative correlations between the oil-bearing formations of southern California.

and which probably represent all of the Pliocene and overlap into both the Miocene and the Pleistocene; the Modelo formation, of sandstones and shales, which may prove to be the homologue of the Monterey; the Vaqueros formation, of shales, interbedded limestones, and sandstones; the Sespe formation, in the main a great body of brownish-red sandstones and conglomerates; the Topatopa formation, of quartzites, sandstones, and hard, more or less siliceous, and earthy shales; and an older basement of gneisses and granites, probably of Jurassic age. This series of formations appears to be conformable from the base of the Topatopa as far up as the base of the Fernando, where a distinct chronologic break is observable. The later Pleistocene, also, is unconformable with the beds below, resting here upon one formation, there upon another.

GRANITIC BASEMENT.

GENERAL CHARACTER AND DISTRIBUTION.

The oldest rocks in the territory under discussion are the gneisses and granites which underlie the Tertiary sediments east of Newhall. The gneisses are close grained, micaceous, conspicuously banded, and greatly contorted. In the region mentioned they strike approximately N. 70° W. and dip 50°–80° N. The underlying granitic rocks are mostly medium to fine-grained diorites, similar to those lying farther east which make up a large part of the San Gabriel Range. These and the other crystalline rocks found in the San Gabriels have been described by Arnold and Strong.[a] The granitic rocks are probably contemporaneous with those of the Sierra Nevada, which are of late Jurassic age. The most remarkable thing in connection with the gneisses east of Newhall is the occurrence in them of a very light oil, approaching a naphtha. Alternative hypotheses regarding the origin of this oil are given in the discussion of the geology of the Elsmere field (pp. 100–101).

TOPATOPA FORMATION.

GENERAL CHARACTER.

The Topatopa formation receives its designation from the name of the range of which it is the chief constituent. It is the lowest formation outcropping in the mountains north of the Santa Clara Valley. Its total thickness is unknown, but about 5,500 feet are exposed. This consists of excessively hard, submassive sandstones and quartzites, the latter of a greenish-gray color, clear or mottled with white, and shales, which differ from the quartzites in carrying an additional content of mica, in the fineness of their material, and consequently in

[a] Arnold, Ralph, and Strong, A.M., Some crystalline rocks of the San Gabriel Mountains, California: Bull. Geol. Soc. America, vol. 16, 1905, pp. 183-204.

their structure. The shales are of a slightly bluish hue, but discolor a rusty brown from the presence of iron or petroleum, or both. The mottlings of the quartzites, which are very characteristic, are usually about one-fourth inch in diameter, round or irregular in outline, and in many instances are as conspicuous as the greener, more homogeneous portion of the rock. The sandstones of the formation are usually light gray to white, and are only a little less hard and close textured than the quartzites. They carry numbers of *Ostrea*, the shells of which are usually black and 4 or 5 inches long by 3 or 4 inches across. It is difficult to obtain good specimens of these fossils, and their determinative value remains for the present unknown.

The quartzites and sandstones greatly predominate in the lower 2,000 feet of the formation as exposed, and the shales in the upper portion, but both types of rock intermingle to a considerable degree, imparting thus to the series as a whole a marked uniformity of appearance, which, with the persistency of its principal characteristics, is of especial value in identification. The formation contains toward the middle quartzites similar to those lower down.

The conspicuous features of this formation are a tendency to a broad concretionary structure in some of its members; the presence of smaller brown ferruginous sand concretions; the sparse distribution of fossil oysters and other very imperfect molluscan remains through a great portion of its thickness, more particularly in the shales; some evidences of woody tissue, and a frequent recurrence of what appear to be fucoids.

The upper part of the Topatopa formation on the lower slopes of the mountains on the north of the Ojai Valley consists of a succession of very ferruginous rusty-brown and gray sandstone and sandy shale, perhaps 2,500 feet thick in all. This facies of the Topatopa extends eastward as far as the Silver Thread field, adjoining the Ojai Valley on the east. The dip of the rusty beds at the mouth of Señor Canyon is southward, changing to northward at a point immediately within the low outer hills of the range. West of the canyon the northerly dip is maintained to a point far up the slopes. East of the canyon there are a number of flexures of greater or less severity, but of short extent. The strata are also bent at this point, the strike, which east of Sulphur Canyon is N. 60° to 70° W., west of the gorge becomes east and west, or even a little south of west, this direction being maintained to a point beyond Matilija Creek.

Cross-bedding is here and there observable. In the shaly zones there is a remarkable tendency to rapid variation in the thickness of the component layers; there also appears to be a certain amount of intraformational unconformity.

DISTRIBUTION.

The Topatopa formation occupies the heart of one of the greatest anticlines of southern California. The eastern limit of the formation is the eastern wall of Sespe Canyon. Westward it extends to a point far beyond the Ojai Valley—indeed, beyond Santa Barbara, a distance of at least 50 or 60 miles. Besides the area thus occupied there is possibly a small inlier in the heart of the Coldwater anticline (see p. 8), although the distance beneath the lower members of the Sespe formation is but slight. San Cayetano Mountain is also composed of this formation.

AGE.

Characteristic Eocene fossils have been obtained from the upper part of the Topatopa formation in the region north of the Silver Thread field. With the exception of the granite and gneisses previously described, no rocks older than the Topatopa are exposed in the Santa Clara district.

OCCURRENCE OF OIL.

The Topatopa formation is oil bearing at several horizons, and from it come seepages and sulphur springs. While these have been observed more particularly from the upper portion, they are also reported from the lowest beds exposed at the heart of the anticline.

SESPE FORMATION.

GENERAL CHARACTER.

The term Sespe has been employed[a] to designate a prominent and widely distributed mass of brownish-red sandstones and conglomerates, with minor layers of sandy and muddy shales, in all about 3,500 feet thick. With these are included 400 or 500 feet of white sandstone and greenish shale at the base and an equal amount of rust-colored calcareous sandstone at the top. The entire formation is exposed in a continuous section in the gorge of Sespe Creek near the entrance of Tar Creek and in the region which extends eastward between the waters of Tar and Little Sespe creeks. Throughout the formation the materials, whether fine or in the form of pebbles, are chiefly granitic. The coloring of the beds is in the main due to iron, but the pink feldspar adds to the effect.

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[a] Waits, W. L., Bull. California State Mining Bureau, No. 11, 1897, pp. 25–26.

LOWER ZONE.

Fig. 2 is a section of the lower 400 feet, which forms a persistent divisional zone between the Topatopa formation and the main mass of red beds. This part of the formation occurs at the mouth of a small tributary entering Sespe Creek from the slopes of Sulphur Peak at a point about a mile above the mouth of Tar Creek. It reappears 2 or 3 miles lower down Sespe Creek, in the heart of the Coldwater anticline. The distinguishing features of this zone are the whiteness of its sandstones, in contrast with the measures both above and below, and the delicate green and pink tints which pervade its clays and

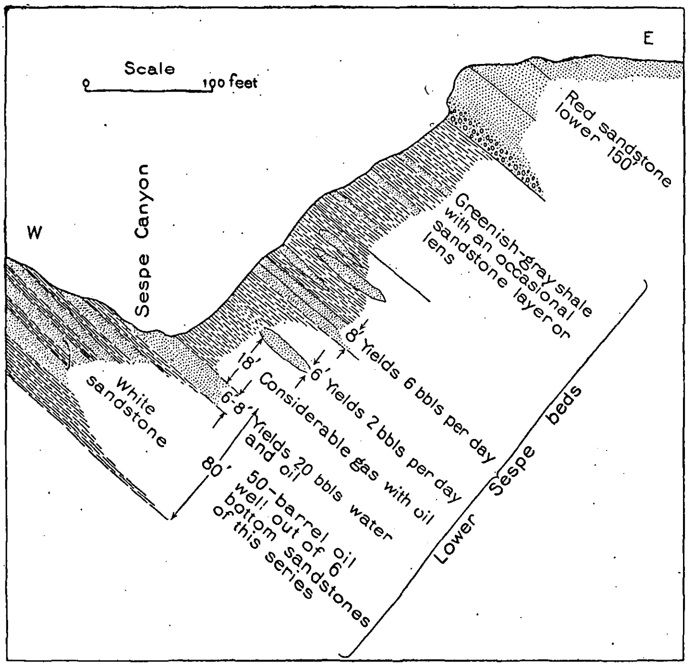

FIG. 2.—East-west section across Sespe Canyon above mouth of Tar Creek, showing detail of the lower portion of the Sespe formation, together with its oil-bearing sands.

shales. The heaviest of the sandstones is a bed about 80 feet thick at the base. The lower half of the zone has produced oil in commercial quantities.

RED BEDS.

GENERAL DESCRIPTION.

The beds of brownish-red color which constitute the mass of the Sespe formation and overlie the lower zone present at their base a band of coarse conglomerate from 40 to 100 feet thick. Above this is 300 or 400 feet of massive sandstone, with pebbles here and there. This is overlain by approximately 500 feet of heavy sandstone, with thin bodies of shale. The material of this sandstone is in many places coarse and gritty. Still higher are from 400 to 800 feet of sandstone and shale, the latter being somewhat more prominent than lower down in the formation. While the conglomerate is principally developed as indicated, layers of comparatively coarse pebbles are not infrequently encountered from the base to the summit of the red beds. There are, however, great masses of sandstone of uniform texture and color, capable, it may be remarked incidentally, of yielding a building stone of high grade. These beds as here described maintain their principal characteristics of color, texture, and composition wherever encountered in the Topatopa Range and its subordinate ridges. They occur in the type locality of the formation and form a conspicuous feature along the northern edge of the Ojai Valley and farther west, in the vicinity of Summerland and Santa Barbara.

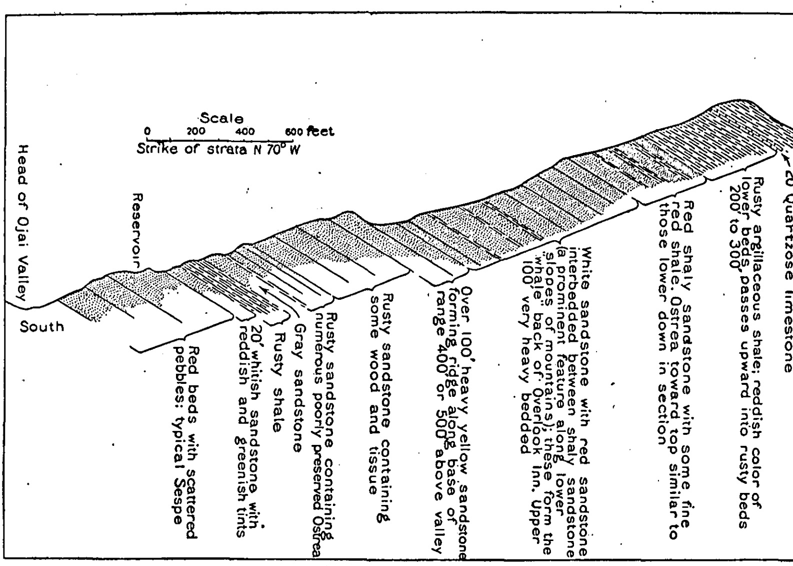

FIG. 3.—North-south section on north side of Lower Ojai Valley, showing lithologic variation in strata.

RED BEDS IN THE OJAI VALLEY.

The Sespe formation or what is believed to be its stratigraphic equivalent in the Ojai Valley consists of conglomerates, sandstones, and shales, bright red and white, the former color largely predominating. The red beds are not so unbroken, however, as in Sespe Canyon. On the contrary they are interrupted not only by certain white sandstones, but also by very considerable bodies of rusty sediments, which in some instances suggest a transition to the formation that is possibly the equivalent of the Topatopa. This lithologic variation is illustrated in the accompanying profile (fig. 3), which is taken from the lower slopes of the range bordering the Lower Ojai Valley on the north. The shales of the formation are not conspicuous, except in the region of Lion Canyon, where a thickness of between 50 and 100 feet in a single body is attained, the colors being rusty, gray, red, blue, and black.

RED BEDS SOUTH OF THE SANTA CLARA.

Certain evidence, which is as yet inconclusive, leads to the belief that south of Santa Clara River the Sespe formation is represented by a succession of gray and red-banded sandstones and coarse arenaceous clays that are conspicuous along the lower slopes of Oak Ridge. The rocks correspond in composition to those of Sespe Canyon. The red color is similar in both localities, and the overlying formation in both instances bears lower Miocene fossils. In the heart of the anticline which passes along the front of Oak Ridge a short distance above its base the Sespe consists of a massive rusty-yellow sandstone, bearing layers of small granitic pebbles. The sandstone in fresh fractures is locally brown, apparently from having once been impregnated with petroleum. Immediately overlying it are from 150 to 400 feet of banded bright-red and gray sandstones, argillaceous sands, and arenaceous clays. The transition is in some instances gradual, in others sharp and pronounced. The red and gray beds are also repeated beneath the rusty-yellow sandstone first described, as is evidenced in the wells of the Bardsdale Crude Oil Company, sunk adjacent to the axis of the anticline, a mile west of Grimes Canyon. Both red and gray beds are locally conglomeratic, the pebbles comprising clear quartz, red and blue quartzites, granite, chert, eruptives, and metamorphic rocks of several varieties. Small bodies of white limestone also occur here and there, interbedded in the formation.

OIL IN THE RED BEDS.

North of the Santa Clara oil has been produced in considerable quantity at a number of horizons in the red beds, and south of the river, in at least one locality, the suggested homologues have also yielded some oil.

UPPER ZONE.

Immediately overlying the body of red beds is about 500 feet of ferruginous, greenish-gray calcareous sandstone, in layers 8 to 10 feet thick, separated by thin bands of shale. Certain beds of the sandstone are so calcareous as to be almost sandy limestones. These are fossiliferous in many places, although no well-preserved forms were obtained. Oysters appear to predominate. The zone of sandstone thus defined is best seen in the ridge dividing Little Sespe Creek and its tributary, Fourfork Creek, from Tar Creek, and in the valley of the latter, where it appears as a conspicuous parting between the red beds below and the great series of Vaqueros shales above.

RELATION OF UPPER SESPE BEDS TO VAQUEROS SHALE.

No sharp lines of distinction separate the upper Sespe terrane from the underlying red beds or the overlying Vaqueros. On the contrary, there is a perceptible tendency for the terranes to shade one into another. Fossils of value have not yet been collected from this transitional zone. There is, therefore, some uncertainty as to whether the beds in question should be referred to the Eocene or the Miocene. The red beds proper are commonly regarded as of Eocene age. In Sespe Canyon fragments of grayish-yellow sandstone, coming either from some horizon unrecognized but well up in the red beds or from a horizon corresponding to that of the rusty beds just described, have been found bearing well-marked Eocene fossils, among which are the forms *Venericardia planicosta* Lamarck (Pl. XXV, fig. 1) and *Turritella uvasana* Conrad (Pl. XLI, figs. 2 and 3). Beds of a similar nature, with an abundance of Tejon (Eocene) fossils, also occur along the northern edge of the Silver Thread oil field, west of Santa Paula Canyon, overlying certain pink and gray sandstones that are believed, on lithologic grounds, to belong to the Sespe. The following species have been found at this locality. With one exception they were identified by the late J. G. Cooper.[a]

Sespe (Eocene) fossils from north side of Sisar Creek, west of Santa Paula Creek.

Anatina sp.
Cardium linteum Conrad.
Corbula n. sp.
Dentalium cooperi Gabb.
Leda gabbi Conrad.
Leda n. sp.
Meretrix californiana Conrad.
Nassa cretacea Gabb.
Neæra dolabriformis Gabb.
Nucula truncata Gabb.
Nucula solitaria Gabb.
Pecten calkinsi Arnold.
Pecten interradiatus Gabb.
Solen parallelus Gabb.
Spirocrypta pileum Gabb.
Tellina hoffmaniana Gabb.
Tellina longa Gabb.
Tellina parilis Gabb.
Thracia semiplanata Whiteaves.
Turbonilla n. sp.
Yoldia arata Whiteaves.
Yoldia nasuta Gabb.

It may be, therefore, that the rocks in question represent the uppermost member of the Eocene in the region of the Santa Clara and the mountains to the north. On the other hand, the resemblance of several of the beds of this transitional zone to others a little higher in horizon, that bear identified Oligocene or lower Miocene forms, is to be borne in mind. To determine satisfactorily the limits not only of this, but of all the other formations in the Santa Clara district, a large amount of field work will be required. The difficulty will be enhanced, too, by the highly disturbed condition of the rocks and the complicated structural relations which they bear one to another, unless distinctly characteristic fossils are found to correlate the beds of the

[a] Bull. California State Mining Bureau No. 11, 1897, pp. 84–85.

several localities. Tentatively, however, the line between the Sespe (Eocene) and the Vaqueros (lower Miocene) formations has been drawn at an indefinite horizon in the rusty beds described, at a point where the sandstone no longer predominates but is largely replaced by shale, yet below the lowermost lower Miocene fossils found.

OIL IN THE UPPER SESPE BEDS.

It is probable that a portion of the oil yielded by the Fourfork and Tar Creek wells has been drawn from the rusty series at the summit of the red beds or else from similar thinner beds in the lower part of the Vaqueros formation. It will be observed that the entire series of beds designated the Sespe shows a remarkable distribution of petroleum, in both its vertical and horizontal extent.

VAQUEROS FORMATION.

AGE AND GENERAL CHARACTER.

The formation designated Vaqueros, appears to be largely lower Miocene. The position of 3,000 feet of shale, such as make up the Vaqueros, below beds which are certainly well down in the Miocene, suggests the possibility that the lower part of the shale extends into the Oligocene. By a rough estimate the maximum thickness of the Vaqueros formation is between 2,000 and 3,000 feet, but the amount of sediment deposited evidently varied greatly from point to point. From the base upward the following more or less distinct zones are recognizable: Shales, purplish, rusty, and gray in color, purplish prevailing, perhaps 500 feet; a conspicuous zone of gray shale, 500 feet; a series of deep maroon, brown, and gray shales, approximately 700 feet; and an upper body of siliceous shale and limestone, gray, but weathering a pronounced yellow, 500 or 600 feet. The formation is therefore distinctly one of shale from top to bottom. Throughout its extent lenticular limestones occur, with a tendency to form continuous bands a foot or two thick. Much of the shale also is calcareous.

Through the lower half of the basal purplish zone are threaded thin layers of calcareous grits or gritty limestones. Where the quartz ingredient is sufficient, they resemble certain beds in the underlying rusty zone at the top of the Sespe formation. These beds are fossiliferous, and from them were gathered the following representative forms, determined by Ralph Arnold:

Fossils from Vaqueros formation.

TAR CREEK, BY TRAIL SIDE.

Modiolus sp.
Ostrea cf. idriaensis Gabb.
Pecten sespeensis Arnold (Pl. XXXIII, figs. 1, 1a, 2).
Turritella ineziana Conrad var. sespeensis Arnold (Pl. XLI, fig. 6).

IN TRIBUTARY ENTERING LITTLE SESPE CREEK AT FOOT-OF-THE-HILL WELLS.

Balanus concavus Bronn. (Pl. XXXII, figs. 5, 5a).
Pecten sespeensis var. hydei Arnold (Pl. XXXI, fig. 2).
Placunanomia sp.
Scutella fairbanksi Merriam (Pl. XXIX, fig. 3; Pl. XXX, fig. 3).

LITTLE SESPE CREEK, BELOW FOOT-OF-THE-HILL WELLS.

Balanus concavus Bronn. (Pl. XXXII, figs. 5, 5a).
Pecten sespeensis Arnold (type locality) (Pl. XXXIII, figs. 1, 1a, 2).
Trophon n. sp. (large).
Turritella ineziana Conrad var. sespeensis Arnold (Pl. XLI, fig. 6).

The limestones bearing these fossils are conspicuous in their persistency. One or another appears at intervals for several miles along the Tar Creek trail; again on upper Fourfork Creek, half a mile west of the upper wells; on Little Sespe Creek below the Foot-of-the-Hill wells; and in a tributary that enters Little Sespe Creek in the vicinity of the Foot-of-the-Hill wells. Besides the foregoing fossils, both shale and limestone, from base to summit of the formation, afford an abundance of foraminifera and fish integuments. The Vaqueros thus exhibits a degree of lithologic and paleontologic resemblance to the shale of the overlying Modelo formation. The stratigraphic position and unique fauna, however, determine the age of these beds, and the sharp line between them and the Modelo sandstones above indicates that the division between the two formations should be located at that plane.

About 30 feet below the contact of the gray and overlying maroon shale is a very persistent band of gray sandstone from 10 to 40 feet thick, the outcrop of which may be readily seen about the extensive amphitheater drained by Tar Creek.

The upper series, of calcareous and siliceous shales, is strikingly similar in appearance to the Modelo of adjacent localities; moreover, they abound in foraminiferal forms. Were the Modelo sandstone to disappear and the shales of the Vaqueros and upper Modelo to be brought in contact it would be impossible to distinguish a break of importance in the entire succession. It is suspected, indeed, that this has happened in the western face of Oat Mountain and in the ridge running southward, although with a thinning of the series as a whole.

VAQUEROS BEDS IN THE OJAI VALLEY.

The Vaqueros formation in the Ojai Valley is composed of rust-colored conglomerate, sandstone, and shale, together with interlaminated limestone. The conglomerates carry pebbles up to 2 inches in diameter of black chert, white quartzite, gray granite, and purple, green, and maroon eruptives. In places, also, there are pebbles that possibly may have been derived from some outcrop of the Franciscan formation not far distant. The matrix of the conglomerate is composed of the same materials as the pebbles.

The sandstone bears a striking resemblance to that in the lower portion of the Vaqueros formation in the vicinity of Tar Creek, without, however, the strong development that it has there.

The shale is argillaceous, fissile, and primarily of a blue-gray color, but this is modified to such an extent by the presence of iron that weathered surfaces and hill slopes are prevailingly rusty. Here and there faint tinges of red, pink, purple, and green are to be observed, shades that characterize the formation in the Tar Creek and Fourfork region.

The limestone beds of the formation vary from a few inches to 6 feet in thickness. They carry a large proportion of quartzose material and commonly show the presence of comminuted to more or less perfect oysters. Locally, also, they are found rich in other remains, notably pectens, turritellas, and barnacles, all of enormous size.

The following list of fossils, collected by the writer and identified by Ralph Arnold, indicates the general character of the fauna in these beds:

Fossils from the Vaqueros formation of the Ojai Valley.

SOUTH FORK AT HEAD OF LOWER VALLEY, ONE-FOURTH OF A MILE ABOVE OLD REFINERY.

Chione temblorensis Anderson (Pl. XXX, fig. 1).
Mytilus mathewsonii Gabb var. expansus Arnold (Pl. XXX, fig. 2).
Neverita sp. indet.
Pecten magnolia Conrad (Pl. XXVIII, fig. 1).
Pecten vaughani Arnold (Pl. XXXIII, figs. 3, 3*a*).
Tritonium, three sp.
Trophon n. sp. (large).
Turritella ineziana Conrad (Pl. XLI, fig. 5).

EAST END OF CREST OF RIDGE BETWEEN UPPER AND LOWER VALLEYS.

Balanus sp.
Chione sp.
Dentalium sp.
Leda sp.
Nassa sp.
Ostrea sp.
Pecten crassicardo Conrad (Pl. XXXI, fig. 1).
Pecten lompocensis Arnold (Pl. XXIX, fig. 1).
Phacoides sp. (flat).
Tritonium or Fusus sp.
Turritella cf. ineziana Conrad (young).

The precise area of outcrop of the supposed Vaqueros beds in the Ojai Valley has not been defined, but one of the principal exposures, which afforded the fossils above enumerated, occurs along Refinery Gulch on the south side of the upper portion of the Lower Ojai Valley. A second exposure is that in the locality of the section illustrated in fig. 3. The lithologic features of this section indicate the correlation of the red and white sandstones with the Sespe red beds and of the overlying fossiliferous rusty beds with the Vaqueros formation, the heavy body of rusty sandstones occurring at the base of the Vaqueros in the Tar Creek locality being possibly a variable factor from one point to another.

VAQUEROS FORMATION SOUTH OF THE SANTA CLARA.

South of the Santa Clara, along South Mountain, Oak Ridge, and the Santa Susana Mountains, is a body of shale, sandstone, conglomerate, and limestone, identified by their fossils with the Vaqueros, but at variance with that formation north of the Santa Clara in the accession of conglomerate and in the relative proportions of the other sediments. Sandstone, for instance, is far more abundant in the formation south of the Santa Clara than north of it. Moreover, the thickness of the beds is greatly reduced south of the river, a minimum of 400 or 500 feet appearing in Oak Ridge and South Mountain, increasing to about 1,000 feet in the Santa Susana Mountains.

The formation south of the Santa Clara, in its simplest form, consists of 300 or 400 feet of banded chocolate and gray argillaceous and arenaceous shales, sandstones, scattered limestone concretions, and more or less persistent mollusca-bearing calcareous grits, similar to the fossiliferous Vaqueros formation of the Tar Creek amphitheater. As a rule 50 to 100 feet of massive, coarse gray to yellow sandstone, also yielding lower Miocene remains, separate the formation from the red and gray banded beds below, and another very similar bed, 40 or 50 feet thick, carrying fossils of the same age, marks the summit of the terrane. This upper sandstone divides the underlying shale from 200 or 300 feet of other shale that is more siliceous and chalky and nearer the Monterey type.

Locally the shale of the Vaqueros formation south of the Santa Clara, in addition to its chocolate and gray colors, assumes faint green, blue, and red hues. Thin layers of white limestone appear here and there, some of which is highly crystalline, with almost the aspect of marble. The sandstone, particularly in the eastern half of the field, where it is better developed, carries spherical concretions resembling those of the lower Modelo stratum north of the Santa Clara. Besides the molluscan remains, casts and imprints of foraminifera are common in the calcareous and siliceous members from base to summit of the formation. Toward its top a yellow color is to be observed at many places, pervading alike both shale and sandstone.

The foregoing description of the Vaqueros south of Santa Clara River is more particularly applicable to that portion of the formation which lies west of Garberson Canyon. East of this region considerable modification occurs. In Wiley Canyon, for instance, the heavy sandstone that forms so conspicuous a feature immediately above the red and gray banded beds at the foot of the main range is doubtless the local representative not only of the sandstone bed farther west, but also of a considerable proportion of the chocolate and gray banded sands and clays that overlie that bed. The change in the composition of the beds is gradual and can be readily followed. The correlation of the sandstone is finally established by the presence of fossils. It carries pebbles of granitic and other débris up to 4 inches in diameter and concretions which, as already mentioned, closely resemble those of the lower Modelo sandstone north of the Santa Clara. The full thickness of the bed at Wiley Canyon can hardly be less than 600 feet and is perhaps even in excess of this. It is overlain by 100 or 200 feet of gray and brown arenaceous shales and sands, a remnant of the beds that are so characteristic of the formation farther west, and these are succeeded by approximately 200 feet of thin-bedded yellow sand and 100 feet of brown, gray, and white shale, which constitutes the uppermost member of the formation. The total thickness between the red and gray banded sandstone and shale of possible Eocene age and the siliceous shale of Monterey type capping the crest of the mountain is probably not less than 1,000 feet.

The beds cut by Tapo Canyon are broadly separable into the same formations as elsewhere in the Santa Susana Mountains, but their defining lines are more or less indistinct, and in some places it is not certain to which of the two principal formations the strata should be referred. There appears to be conformability, not to suggest transition, between the Miocene and Pliocene series at this point, although unconformability is the rule over the Coast Range territory. The younger series is, however, marked by conglomerates, while the older is more shaly and its sandstones are more thinly bedded. Here and there the older sandstones are concretionary. The shales are brown or chocolate colored, show a siliceous tendency, and increase in proportion to the sandstones as depth in the series is gained. In the ridge between the middle and east forks of Tapo Creek fully 400 or 500 feet of shale, with a minimum of sandstone, underlies the higher, more sandy members. Both shale and sandstone are locally bituminous, and from them come several oil seepages of importance. In this series the wells of Tapo Canyon have been sunk. The foregoing description of the older succession of strata in these canyons suggests correlation with the banded sands and chocolate-colored shale of Torrey and Wiley canyons and even in part with the Modelo north of the Santa Clara, though no fossils have been observed in either group of beds. In Tapo Canyon there is not less than 2,000 feet of the formation exposed, in Wiley Canyon the thickness is less than 1,000 feet, and farther west it is barely 500 feet.

In the region of Pico Canyon and to the southeast the beds mapped as Vaqueros consist of a great mass of thin-bedded shale overlain by brown shale, with some more or less important sandstone layers. Above these occur conglomerate, sandstone, and arenaceous clay, which are believed to belong to the Fernando formation, and are so mapped, although no sharp line of demarcation was discovered between the two formations.

The following fossils have been obtained from beds mapped as Vaqueros in the region south of Santa Clara River. Owing to the limited number of species represented the correlations are necessarily very broad. The identifications are by Ralph Arnold.

Fossils from Vaqueros formation south of Santa Clara River.

ELKIN'S RANCH, OAK RIDGE, EAST OF GRIMES CANYON.

Ostrea eldridgei Arnold (Pl. XXIX, figs. 2, 2a).
Turritella ineziana Conrad var. (Pl. XLI, fig. 4).

GULCH EAST OF WILEY CANYON.

Pecten (Hinnites) giganteus Gray (Pl. XXXII, fig. 1).
Turritella ineziana Conrad var. (Pl. XLI, fig. 4).

CHAFFEE CANYON.

Cardium n. sp.
Dosinia n. sp.
Ostrea sp. aff. titan Conrad.
Panopea generosa Gould var.
Phacoides sp.
Acmæa or Trochita sp.
Turritella cf. ineziana Conrad.

TORREY CANYON AND VICINITY.

Scutella fairbanksi Merriam (Pl. XXIX, fig. 3, and Pl. XXX, fig. 3).
Mytilus mathewsonii Gabb var. expansus Arnold (Pl. XXX, fig. 2).
Ostrea sp. aff. titan Conrad.
Pecten sespeensis var. hydei Arnold (Pl. XXXI, fig. 2).

MODELO FORMATION.

GENERAL CHARACTER.

The Modelo formation embraces at least two prominent bodies of sandstone and two of shale. The shale at many points bears a marked resemblance to that of the Monterey (middle Miocene), both from a lithologic and a paleontologic standpoint, and it may be that it is the correlative of that formation. The Modelo is distributed over a broad area north of the Santa Clara Valley and through folding and faulting its members are brought into most complex relationships. However, it is believed that the distinctions given below will serve as a satisfactory means of differentiation.

LOWER SANDSTONE.

The lowest member, a massive, heavy-bedded sandstone, rests directly and apparently conformably upon the Vaqueros shale. It varies in thickness from 200 or 300 feet to perhaps 1,500 or 2,000 feet. It is white to yellowish gray in color. Locally the sandstone is gritty, bearing also a dark-gray to black chert, and a few pebbles of another sandstone. It contains spherical and elliptical concretions from 1 foot to 5 feet in diameter, which are so prominent and so resistant to weathering as to form a conspicuous characteristic of the member, the more so because of the utter lack of such concretionary bodies in a second, otherwise similar sandstone that occurs higher up. The upper half of the sandstone is less concretionary than the lower and is also thinner bedded, the layers being separated by shale of a dark-drab color, which carry scattered gray limestone concretions that weather yellow. Traces of organic life are also visible. This member is usually stained dark with petroleum.

This lower sandstone early received the name Modelo, but the writer has thought it best to assign the name tentatively to the entire formation described in the opening lines of this section. The sandstone is best displayed in the bold escarpment east of Tar Creek and is also heavily developed in Hopper Canyon and at the head of Modelo Canyon. A large number of productive wells have been drilled in Modelo Canyon, the oil being doubtless derived from some of the lower horizons of the formation. Plate II, *A*, gives an idea of the appearance of this sandstone in the region north of the Modelo wells.

UPPER SANDSTONE.

The upper sandstone of the Modelo formation is but little less conspicuous than the lower, although its maximum thickness has been estimated at only 900 feet and in many places it is even less. It has the same mineral constitution as the lower bed, being composed of white, subangular quartz, with a trace of the salts of iron, which have colored it slightly yellowish. A considerable amount of dark chert is also present, and in one locality beautiful green and brown pebbles of siliceous shale were observed. The member is, however, nonconcretionary. It is also thinner bedded than the lower sandstone and for 100 feet at the base is not only comparatively micaceous, but is split by minor bodies of shale, the whole somewhat darker than the portion overlying, seemingly from the presence of dried petroleum. This portion weathers a peculiar bluish gray.

This sandstone is conspicuously developed in the region of Hopper Canyon, where it lies in a well-marked syncline that to the east is sharply compressed and, perhaps, faulted. South of this syncline the sandstone is involved in one or two other folds and finally, between Hopper and Nigger canyons, passes beneath the Santa Clara Valley.

SHALE IN THE MODELO.

The two sandstones described above are divided by a body of earthy shale, gray to brown, which bears limestone concretions weathering yellow and whose thickness has been variously estimated at 400 to 1,600 feet. Overlying the upper sandstone is a second body of shale, of uncertain thickness owing to the fact that in the region under discussion not only has erosion removed the sediments down to an undetermined horizon in the formation, but an unconformity also exists between this and the overlying formation. However, the thickness is variously estimated at between 200 and 1,500 feet, according to locality. This shale is indistinguishable from that separating the two Modelo sandstones already described. Both vary from a granular, siliceous type to one of an earthy and fissile character, more readily breaking down under the influence of weathering. The color of the lower bed is commonly light gray; that of the upper may be brown, gray, or yellowish. Both bodies carry calcareous layers and here and there lenticular limestone concretions that weather yellow. Were the upper sandstone to disappear the shales above and below would become a single mass, uniform in their general features, from top to bottom; were both sandstones to disappear it would be difficult to distinguish these rocks from the upper portion of the Vaqueros formation. They would be more readily differentiated from the lower portion of the Vaqueros, however, by the variety of color in the older beds and by the marked change to the rusty, calcereo-arenaceous grit at their base.

VARIATION IN COMPOSITION OF THE MODELO.

The foregoing paragraphs describe what appears to be the normal section of the Modelo formation, but the aspect varies somewhat from point to point, by reason of the subdivision of the sandstones and the changes in their relative porportion to the formation as a whole. At the head of Modelo Canyon, for instance, the outcropping portion of the lower sandstone appears to be split into two bodies, each 300 feet thick, by 60 to 100 feet of shale, and a similar division is shown by the logs of wells drilled in this canyon. What may prove to be the upper sandstone is separated from the lower by only about 200 feet of brown shale as compared with 400 to 1,600 feet in the normal section. The enormous development of the Modelo sandstones in the lofty divide separating Tar Creek from the drainage of Hopper Canyon and Piru Creek is also at variance with the average thickness of either of these members, and it may be that the shales are reduced to a minimum in this locality, resulting in a sandstone facies for this formation amounting to at least 2,000 feet.

South of Santa Clara River the Modelo formation is unrecognized, nor is it possible to find for it a proved correlative. Certain sandstones assigned here to the Vaqueros terrane carry concretions that closely resemble those in the lower Modelo sandstone, and the associated shale is also very much like the shales of the Modelo series north of the river. Yet these beds south of the Santa Clara contain fossils similar in a measure to those of the lower members of the Vaqueros in the Tar Creek, Little Sespe, and adjacent districts. This, with the diminished thickness south of the river, suggests a rapid and marked variation in conditions during the sedimentation of these mportant formations in the Santa Clara Valley.

All the shales of the Modelo formation, as well as those of the Vaqueros, carry at one horizon or another minute foraminiferal remains and fish integuments, similar in general appearance to those commonly present in the Monterey shale in other portions of California.

Many of the layers in the Miocene shales, whether older or younger, are flecked with particles of dried bitumen, indicating a general distribution of petroleum throughout the shales and suggesting that it may have been derived from the abundant organic life once present in them.

The lower Modelo sandstone also bears considerable bitumen in the region of Modelo Canyon, and it is said that in summer it yields numerous seepages of a comparatively light petroleum.

SUPPOSED MODELO BEDS IN THE OJAI VALLEY AND SULPHUR MOUNTAIN.

The supposed equivalent of the Modelo in the Ojai Valley and Sulphur Mountain is confined to beds similar to those which characterize the upper portion of the formation in the type locality; that is, it consists of shale, siliceous, chalky, or earthy, in color white, gray, or locally maroon, carrying the customary limestone concretions and interbedded here and there with sandstone of fine grain and a thickness up to 10 or 15 feet. In the shale are found the usual foraminiferal remains, abundant pieces of fish integument, and, it is reported, even bony fish skeletons. The soil formed by the disintegration of the formation is black. The extreme silicification that is so common a feature of the shale immediately at and below a mountain crest in other localities is repeated in Sulphur Mountain. The thickness of the formation in the region under discussion seems to be at least 1,500 feet.

CORRELATION OF THE UPPER SHALY PORTION OF THE MODELO WITH THE MONTEREY SHALE.

In the Santa Clara district the presence of the Monterey formation is uncertain, although the uppermost shale of the Modelo north of the river and the great mass of siliceous shale and "chalk rock" that so conspicuously caps the Santa Susana Mountains, Oak Ridge, and South Mountain, south of the river, may be a part of it. Only one fossil, the cast of a thin flat pecten, closely resembling *Pecten pedroanus* Trask (Pl. XXXVI, figs. 5, 6), has so far been found in these shales; this was obtained in the outcrop immediately east of the road in Sulphur Canyon, southwest of Bardsdale. This evidence, however, supports the suspected correlation, which otherwise is based on lithologic resemblances only. It might be well to say, furthermore, that the type locality of *Pecten peckhami* Gabb (Pl. XXXI, fig. 3) is the Ojai Valley (probably in the shale on the south side) and that this species is unusually abundant in the Monterey shale in most regions where the formation is known.

DIFFICULTIES OF CORRELATION BETWEEN NORTH AND SOUTH SIDES OF SANTA CLARA VALLEY.

The division of the great series of beds north of the Santa Clara into the Vaqueros and Modelo is made easy by the abrupt and marked change in the character of the sediments at the contact of the lower Modelo sandstone and the underlying shale. South of the river this division does not appear to hold, yet one or another of the characteristics of the Miocene, taken as a whole, north of the river reappears on the south side, suggesting that the beds on both sides of the valley from base to summit should be included in a single formation. The difficulty of correlation south of the river is greatly increased by the presence of sharp folds and faults. For example, in the normal succession the siliceous shale and the "chalk rock" unquestionably overlie beds of altogether different character, identified as the Vaqueros; yet at the east end of Oak Ridge and in the western portion of the Santa Susana Mountains an equally heavy body of siliceous shale appears to dip beneath similar shale that is believed to be of lower Miocene age. This unusual succession may be attributable to faulting, the siliceous shale being the younger. On the other hand, it may possibly be that the siliceous shale capping Oak Ridge corresponds to the mass of siliceous shale that occurs as the uppermost of the Vaqueros beds in their type locality. In this case the Modelo would be entirely wanting south of the river.

Another element in the difficulty of correlating the formations on opposite sides of Santa Clara River is the remarkable decrease in thickness toward the south. It would seem that the formations referred to have their type and maximum development north of the Santa Clara, and that south of the river the formations are thin, either through lack of material or through rapid changes in the attitude of the land, which resulted in intervals of nondeposition or even of erosion during the time the beds were being laid down.

BURNING OF THE SHALE.

The siliceous shale and "chalk rock" forming the crest of the mountains south of the Santa Clara have at many points been burned to a bright-red color. The fuel which supported such fires was perhaps the originally contained petroleum.

Opposed to this view, however, is the very considerable depth to which the shale has been altered to a brilliant-red lava-like rock; hence it may be inferred that spontaneous combustion alone has brought about the modification.

FERNANDO FORMATION.

GENERAL CHARACTER AND AGE.

The rocks that have received the name Fernando[a] consist of an enormous succession of conglomerates, sandstones, and arenaceous clays, largely of Pliocene age, developed over considerable portions of southern California. Fossils collected at many localities and at many horizons throughout the formation indicate that it extends from the upper Miocene (San Pablo formation of the general geologic column of the State) well up in the Pleistocene (San Pedro formation). It is possible to subdivide the formation locally on both lithologic and paleontologic grounds, but taken over a considerable extent of territory these divisions merge into one another both stratigraphically and geographically by insensible gradations. An unconformity usually marks both the base and the top of the formation, although in several localities in the Santa Clara region that at the base is difficult if not impossible to detect.

Along the sides of the Santa Susana Mountains and Oak Ridge and in the region east of Newhall the coarser beds of this formation are usually white, gray, or yellow, the clays bluish gray. The material of the conglomerate is principally granitic, but pebbles of the intermediate formations are occasionally found. In the limited region under survey no established succession of the different sediments was observed, although a broader field would doubtless reveal it. The unconformities are always to be reckoned with, and to them may be due in large measure the variations in the rocks that are in contact. Incidentally it may be observed that perhaps to them also may be due the fact that whereas south of the general fold out of which the several ranges are formed the Fernando is usually in contact with siliceous shale, north of the anticline, on the slopes of the Santa Susana Mountains, it is found resting directly upon beds that are of the Vaqueros facies.

[a] A term applied in unpublished maps by Homer Hamlin a number of years ago to the beds above the siliceous shale skirting the sides of the San Fernando Valley, Los Angeles County—the general equivalents of all the post-Modelo, pre-Saugus beds in the Santa Clara province.

In the vicinity of the Piru Valley the Fernando formation consists in ascending order of (1) a thick body of sandstone and conglomerate; (2) sandy shale and clay; and (3) heavy-bedded coarse conglomerate. These form the northern slope of the ridge north of Camulos, the distance of about 4,000 feet being equally divided among them. Overlying the upper conglomerate are several hundred feet of greenish-gray clay, and it is believed that this is succeeded in turn by 1,500 to 2,000 feet of alternating sandstone and conglomerate. If the succession is continued, clays then follow to the valley of the Santa Clara. In all, the formation is fully 5,000 or 6,000 feet thick in this vicinity, and if its thickness could be determined over the entire area that amount would doubtless be increased by many thousands of feet. The materials of the conglomerates include granite, shale derived from the Miocene, and a few eruptives.

North of the Santa Clara Valley, extending from the mouth of Sespe Canyon westward to the Pacific Ocean at Ventura, is another extensive area of the Fernando. The formation is best developed in the hills between Santa Clara River and Sulphur Mountain, where the succession consists of sandstones and conglomerates, underlain by a thick body of clay dirt-brown to gray in color. This clay is arenaceous and grades into sandstone both transverse to the strata and along the strike. In places even pebbly layers may be found in this part of the formation. Beneath the clay is another mass of heavy-bedded sandstone and conglomerate, separated by minor layers of clay, resembling that just described. If there are not faults in these beds—and none were detected—the thickness can hardly be less than 8,000 or 10,000 feet, about equally divided between the three varieties of sediments mentioned. Some of the lower sands are bituminous and their associated clays are brown or blue.

On the lower slopes of San Cayetano Mountain, making up a part of the area outlined in the preceding paragraph, is a mass of gray clay and shale, sandstone, and heavy gravel beds, all more or less hardened and resistant to weathering, which belong to the upper Fernando. The pebbles making up the gravel deposits are granite, quartsite, sandstone, limestone, and the harder shale all derived from the mountains of the Sespe region.

PALEONTOLOGY OF THE FERNANDO FORMATION.

At least three distinct faunas are recognizable in the Fernando, representing what are thought to be in a very general way the bottom, middle, and top of the formation. The oldest fauna was found in the area north and northeast of Camulos, and is, according to J. C. Merriam, the equivalent of the fauna of at least a part of the San Pablo formation. The middle fauna was found well developed in the region of Elsmere Canyon and Fernando Pass, and probably represents the typical fossiliferous portion of the Purisima and the lower part of the San Diego formation. The upper portion of the Fernando extends well up into the Pleistocene, as is attested by the fossils found at Barlow's ranch and on the south slopes of Mount San Cayetano; these have been correlated with the fauna contained in the San Pedro formation.

LOWER FERNANDO FAUNA.

The following species have been found in what is supposed to be the oldest portion of the Fernando, in the region north of Camulos:[a]

Fossils from the lower part of the Fernando formation, near Camulos.

[Those marked "a" are from the light-colored shale underlying the conglomerate on Santa Felicia Creek; "b," from conglomerate 5 miles northeast of Camulos; "c," from fine conglomerate and coarse sandstone 1 mile north of Camulos; "d," from coarse conglomerate 1 mile north of Camulos; "e," from conglomerate on the east side of Piru Creek, near the railroad bridge.]

Arca camuloensis Osmont (b, d) (Pl. XXXVII, figs. 1, 1a, 1b).
Bulloid n. sp. (c).
Callista subdiaphana Carpenter (c) (Pl. XXXIX, fig. 3).
Cancellaria n. sp. (b).
Cardium sp. (b).
Chlorostoma sp. (c).
Chrysodomus n. sp. (1) (b).
Chrysodomus n. sp. (2) (c, d).
Conus californicus Hinds (b, e).
Conus cast, sp. indet. (c).
Corbula n. sp. (c).
Dosinia ponderosa Gray? (c).
Echinarachnius, near excentricus Eschscholtz (a).
Fusus rugosus Trask (d).
Leda taphria Dall (b, c) (Pl. XXXVIII, fig. 5).
Lunatia lewisii Gould (c, d).
Macoma, near secta Conrad (a).
Macoma secta Conrad (b).
Mangilia sp., probably new (c).
Metis alta Conrad? (d).
Nassa californiana Conrad (b).
Nucula castrensis Hinds (d).
Nucula n. sp. (c, d).
Ostrea veatchii Gabb (d) (Pl. XXXIX, fig. 1).
Pachypoma n. sp. (a, b).
Pecten bellus Conrad (e) (Pl. XXXV, fig. 3).
Pecten cerrosensis Gabb (c, d) (Pl. XXXV, fig. 6).
Pecten merriami Arnold (a) (Pl. XXXVI, fig. 9).
Priene oregonensis Redfield var. angelensis Arnold (Pl. XL, fig. 11)
Phacoides sp., probably new (b).
Solen sicarius Gould (a).
Turritella n. sp. (b).
Yoldia scissurata Dall (c).

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[a] Collected by W. L. Watts; identified by J. C. Merriam; listed in Bull. California State Mining Bureau No. 19, 1900, pp. 220-222.

MIDDLE FERNANDO FAUNA.

The following species, found in Elsmere Canyon and the region of Fernando Pass, apparently represent a somewhat later fauna than that just described. The identifications are by Ralph Arnold.

Fossils from the middle of the Fernando formation, Elsmere Canyon.

Amiantis callosa Conrad (Pl. XXXIX, fig. 2).
Arca trilineata Conrad (Pl. XXXVIII, figs. 3, 4).
Callista subdiaphana Carpenter (Pl. XXXIX, fig. 3).
Cancellaria fernandoensis Arnold (Pl. XL, fig. 4).
Cardium quadrigenarium Conrad var. fernandoensis Arnold (Pl. XXXVIII, fig. 2).
Chione n. sp. (small).
Chrysodomus arnoldi Rivers.
Cryptomya californica Conrad.
Cypræa fernandoensis Arnold (Pl. XL, fig. 8).
Dolichotoma cf. carpenteriana Gabb.
Macoma indentata Carpenter.
Macoma sp.
Mactra cf. hemphilli Dall.
Modiolus rectus Conrad.
Monia macroschisma Dall.
Murex eldridgei Arnold (Pl. XL, fig. 12).
Mya truncata Linné.
Neptunea humerosa Gabb.
Neverita recluziana Petit (Pl. XXXVIII, fig. 6).
Olivella intorta Carpenter.
Panopea generosa Gould.
Pecten cf. caurinus Gould (Pl. XXXVI, fig. 1).
Pecten estrellanus Conrad var. catalinæ Arnold.
Pecten healeyi Arnold, 17 rib. var. (Pl. XXXIV, fig. 1).
Pecten cf. parmeleei Dall (Pl. XXXVI, fig. 7).
Phacoides acutilineatus Conrad.
Pisania fortis Carpenter var. angulata Arnold (Pl. XL, figs. 6 and 7).
Priene oregonensis Redfield, var. angelensis Arnold (Pl. XL, fig. 11).
Tapes tenerrima Carpenter.
Tellina idæ Dall (?).
Tritonium sp.
Trochita filosa Gabb (Pl. XL, figs. 2, 2a).
Turritella cooperi Carpenter, var. fernandoensis Arnold (Pl. XLI, fig. 13).

UPPER FERNANDO FAUNA.

Lists of species from three localities are given to show the characteristics of the fauna of the upper portion of the Fernando. The fossils in the first list may possibly be slightly older than those in the second, which in turn appear to be a little older than those in the third. The species from Barlow's ranch have been correlated with the fauna contained in the upper fossiliferous beds at San Pedro, which are well up in the Pleistocene.

Fossils from the upper part of the Fernando formation.

NORTHWEST OF SANTA PAULA.[a]

[Those followed by an "E" are from Goat Mountain, near the mouth of Adams Canyon; those followed by an "F" are from Santa Paula Creek, between Mupa schoolhouse and Sulphur Mountain.]

Astrodapsis whitneyi Conrad (F).
Astyris richthofeni Gabb (E).
Bittium aspersum Gabb (E).
Cardium corbis Conrad (E).
Cardium procerum Sowerby (F).
Chione mathewsoni Gabb (F).
Chione whitneyi Gabb (F).
Chorus belcheri Hinds (F).
Clidiophora punctata Conrad (E).
Crepidula princeps Conrad (E).
Cryptomya californica Conrad (E).
Dentalium semipolitum Broderip (F).
Echinarachnius excentricus Eschscholtz (F).
Galerus inornatus Gabb (F).
Glycymeris intermedia Broderip (F).
Hipponyx cranioides Carpenter (F).
Lacuna solidula Loven (E).
Lævicardium centifilosum Carpenter (F).
Lunatia lewisii Gould (E).
Macoma n. sp. (F).
Metis alta Conrad (E).
Mitra maura Swainson (E).
Modiolus rectus Conrad (E).
Monoceros lugubre Sowerby (F).
Murex monoceros Sowerby (F).
Nassa californiana Conrad (E).
Nassa perpinguis Hinds (E).
Nassa mendica var. cooperi Forbes (F).
Neptunea altispira Gabb (E).
Olivella intorta Carpenter (E).
Panopea generosa Gould (E).
Psephis tantilla Gould (E).
Semele n. sp. (E).
Solen rosaceus Carpenter (E, F).
Siliquaria edentula Gabb (F).
Spisula planulata Conrad (E).
Tellina idæ Dall (E).
Tresus nuttalli Conrad (E).
Triton gibbosus Broderip (E).
Turritella jewetti Carpenter (E) (Pl. XLI, fig. 15).
Turbonilla sp. (F).

SOUTHEASTERN FLANKS OF MOUNT SAN CAYETANO.[b]

Arca cf. labiata Sowerby.
Bittium cf. asperum Gabb.
Nassa perpinguis Hinds.
Calliostoma or Margarita sp.

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[a] Collected by W. L. Watts; identified by J. G. Cooper; listed in Bull. California State Mining Bureau, No. 11, 1897, pp. 81-83.

[b] Collected by the writer; identified by Ralph Arnold.

Cardium cf. quadrigenarium Conrad (?).
Crepidula cf. rugosa Nuttall.
Lacuna (?) sp.
Leda sp.
Macoma sp.
Modiolus (?).
Olivella sp.
Pholadidea cf. penita Conrad.
Psephis cf. lordi Carpenter.
Saxidomus gracilis Gould.
Siliqua patula Dixon (?).
Tapes staminea Conrad.
Tresus nuttalli Conrad (?).
Turritella cooperi Carpenter (Pl. XLI, fig. 14).
Yoldia (?) sp.

BARLOW'S RANCH, 3 MILES EAST OF VENTURA.[a]

Acmæa pelta Eschscholtz.
Actæon (Rictaxis) punctocœlata Carpenter.
Angulus buttoni Dall.
Anomia lampe Gray.
Balanus concavus Bronn.
Bittium asperum Gabb.
Cadulus fusiformis Sharp and Pilsbry.
Cancellaria tritonidea Gabb.
Chione succincta Valenciennes.
Chlorostoma funebrale A. Adams.
Chorus belcheri Hinds.
Columbella (Astyris) gausapata Gould.
Columbella (Astyris) gausapata, var. carinata Hinds.
Crepidula adunca Sowerby.
Cryptomya californica Conrad.
Cylichna alba Brown.
Dentalium hexagonum Sowerby.
Donax lævigata Deshayes.
Drillia hemphilli Stearns.
Drillia inermis Hinds.
Drillia inermis var. penicillata Carpenter.
Echinarachinius excentricus Eschscholtz.
Eulima micans Carpenter.
Eulima hastata Sowerby.
Lacuna compacta Carpenter.
Littorina scutulata Gould.
Macoma nasuta Conrad.
Mactra catilliformis Conrad.
Mangilia angulata Carpenter.
Modiolus fornicatus Carpenter.
Monoceros engonatum Conrad.
Nassa californianum Conrad.
Nassa fossata Gould.
Nassa mendica Gould.
Nassa perpinguis Hinds.

[a] Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Cal.: Mem. California Acad. Sci., vol. 3, 1902, p. 55.

Neverita recluziana Petit.
Neverita recluziana var. alta Dall.
Odostomia gouldii Carpenter.
Odostomia nuciformis var. avellana Carpenter.
Odostomia tenuis Carpenter.
Olivella biplicata Sowerby.
Olivella intorta Carpenter.
Olivella pedroana Conrad.
Pecten latiauritus var. monotimeris Conrad.
Saxidomus aratus Gould.
Scala crebricostata Carpenter.
Scala tincta Carpenter.
Tapes tenerrima Carpenter.
Terebra simplex Carpenter.
Tornatina culcitella Gould.
Tornatina harpa Dall.
Turritella cooperi Carpenter (Pl. XLI, fig. 14).
Turbonilla laminata Carpenter.
Turbonilla, four sp. (?).
Yoldia cooperi Gabb.

PLEISTOCENE DEPOSITS.

DEPOSITS IN THE VICINITY OF SAUGUS.

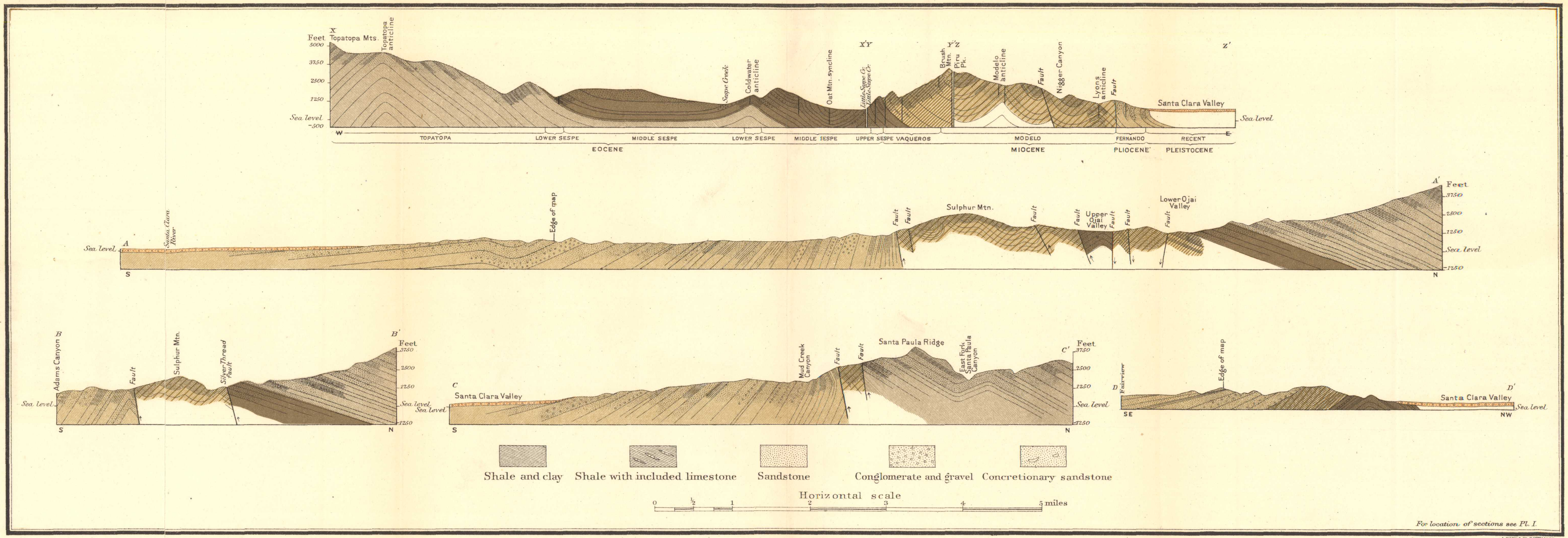
The low hills that border the broad, open valley of Santa Clara River in the vicinity of Saugus are covered by a prominent body of gravel, sand, and arenaceous clay, the gravel largely predominating. The coarser material is mostly composed of granite, derived, probably, from the San Gabriel Range. Traces of other rocks, however, are included with the granite, and the whole is loosely cemented together. The beds have a general dip of 2° to 10° toward the center of the valley. The thickness of the terrane is undetermined. Above the level of the valley perhaps 300 or 400 feet are exposed, but below the valley the extent of the formation is not known. These beds are probably of fresh-water origin and, though they have yielded no fossils whatever, their unconformable position on the Fernando suggests late Pleistocene as the time of their deposition.

DEPOSIT AT MOUTH OF SESPE CANYON.

At one point overlooking Sespe Creek there is a cut bluff showing bright-red sediments of apparently the same materials as those just described. The deposit was not examined in detail. It may prove to be a remnant of the Sespe formation or a portion of the Pleistocene that is composed of red material derived from the Sespe.

CONGLOMERATE OF LION CANYON.

In the vicinity of the Lion Canyon wells is a conglomerate that has not hitherto been recognized at any point in the Ojai Valley, nor, indeed, elsewhere in the ranges that border the Santa Clara. Its



GEOLOGIC STRUCTURE SECTIONS ACROSS MT. PINOS, TEJON, SANTA PAULA, AND CAMULOS QUADRANGLES, SOUTHERN CALIFORNIA leading feature is the contained bowlders of sandstone, differing but slightly in composition from the matrix or body of the rock itself. It appears only in the limited area between the Sespe and Modelo formations. A somewhat similar occurrence is found at the east end of the Upper Ojai Valley, where Sisar Creek leads out from it. The stratigraphic relations of this rock are uncertain, but its composition suggests that it may be the remnant of a Recent formation of bowlder sand which here and there skirts the Upper Ojai Valley, forming along its northern side, locally, extensive benches. In the region of the Lion Canyon wells the rock is impregnated with bitumen, and seepages spring from it. It is penetrated by the wells, but it is believed that they derive their oil from the underlying formation.

GENERAL STRUCTURE OF DISTRICT.

INTRODUCTORY STATEMENT.

It has been deemed expedient to divide the discussion of the structure of the region bordering the Santa Clara Valley into two sections. The first, embracing a brief exposition of the more important features, is included in the pages immediately following. The second, dealing with those details so essential for purposes of practical application, is subdivided, each portion being included in the description of the territory to which it refers. It may be well to call the reader's attention to the general sections on Pls. III and IV. These sections, together with the structural features depicted on the map (Pl. I, pocket), will doubtless more vividly portray the writer's interpretation of the structure than many chapters of descriptive text.

SANTA CLARA VALLEY.

The structure of the rocks underlying the Santa Clara Valley is perplexing. For several miles below Saugus the great body of younger conglomerate, sandstone, and clay of the Fernando formation passes diagonally across the bottom lands into the hills on either side, maintaining a strike of N. 50°-60° W. and a dip of 25°-50° NE. Within this area there is no apparent break in the regularity of the stratigraphic succession. From the mouth of Salt Creek westward, however, the hill formations become more and more folded, or even faulted, while the continuity of structure between the two sides of the valley is interrupted by a broad belt of river gravel. Lithologic similarity of both Miocene and Pliocene sediments at the several horizons adds still further to the difficulties attending a correct interpretation of the geologic conditions. The great mass of evidence suggests an enormous fault along the valley in the region north of South Mountain, the displacement dying out as it passes up the river. Final interpretation of the valley structure has, however, been reserved for a time when the general geology of the region shall be the primary object of investigation. The strip of enigmatical territory occupied by the valley therefore forms an obviously ideal line of division between the two more or less structurally distinct areas north and south of it, and advantage will be taken of this fact to discuss each of these areas separately.

REGION NORTH OF THE SANTA CLARA.

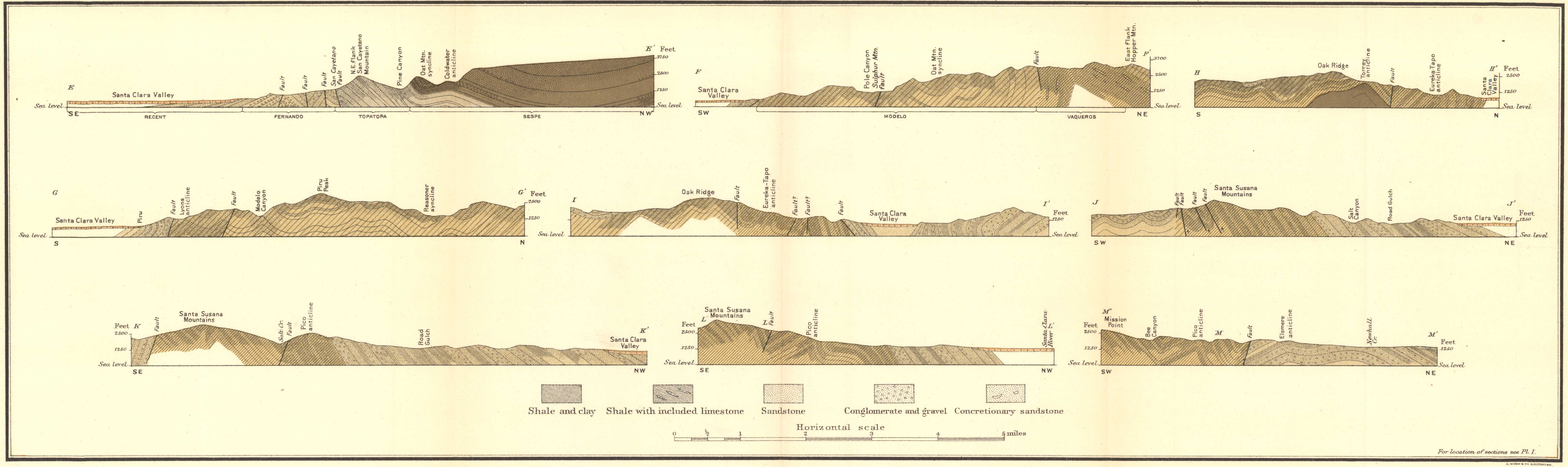
Of the great mountain system north of the Santa Clara Valley the southern member, the Topatopa Range, is alone involved in the geology of the developed oil fields. This range is 30 or 40 miles long; its trend is east and west; its structure is anticlinal, the axis passing a few miles north of the area mapped in Pls. I and V.

In the region of Sespe Creek the axis of the anticline lies beneath the crest of the range and is occupied by characteristic quartzites and slates to which has been assigned the name Topatopa formation. The anticline is symmetrical and is well displayed in the canyon walls. About the Topatopa formation bend in succession the Sespe, Vaqueros, Modelo, and Fernando beds, all strongly developed and forming conspicuous features of the landscape. Toward the east the point of the anticline broadens, the Modelo sandstone outcropping in a wide sweep about the axis and the youngest beds covering a still greater area in their arch. The west end of this great anticline has not been located, the consideration of its east end being sufficient for the purposes of the present report.

The northern side of the anticline is unexplored, and whether the prominent ridge of granite lying to the north is produced by faulting or is a part of a separate dynamic system is unknown.

The southern limb of the anticline presents an intricate succession of secondary folds and accompanying faults that extend from Ventura River and the Ojai Valley beyond Piru Creek. East of Santa Paula Creek the strata are strongly bowed to the south. At Sespe Creek the curvature is as pronounced in the opposite direction. Immediately west of Hopper Canyon the convex side of the bend is again to the south, while east of Piru Creek regularity of trend is once more approximately resumed. North and east of the Ojai Valley the south limb of the Topatopa anticline is overturned.

An examination of the map makes it obvious that faults are the dominant structural feature in the Ojai Valley, at the west end of the territory under discussion. No less than five fractures cross the region from east to west, divergent in trend from N. 60° W. at the north to S. 75° W. at the south. The result has been a succession of interfault blocks more or less limited in size, with considerable variation in the strata opposed. The faults originated nearly at a common center in the great fracture passing in front of San Cayetano Moun-



GEOLOGIC STRUCTURE SECTIONS ACROSS CAMULOS, SANTA SUSANA, AND FERNANDO QUADRANGLES, SOUTHERN CALIFORNIA tain. The northernmost fault lies between the rusty Vaqueros beds and the Modelo shale. South of this is the second fracture of the system, the block between them being composed of Modelo shale. Between the second and third faults, the latter passing immediately north of Lion Ridge, is a narrow block of rusty beds of the Vaqueros type. South of this is a comparatively broad zone of the Sespe formation, which in turn is separated from the Modelo shale, constituting Sulphur Mountain, by one of the most extensive faults of the region. South of Sulphur Mountain there is a fifth fault, marked by a line of seepages and oil wells. The evidence of faulting, however, must not be confused with the unconformity which exists between the Modelo and the Fernando. The shale of Sulphur Mountain is considerably crumpled, at least two marked anticlines (one of which is locally overturned) and the intervening syncline being present through nearly its whole length. The conglomerate, sand, and shale of the Fernando formation, south of their contact with the Modelo shale of Sulphur Mountain, maintain a southerly dip with marked persistency, at most varied only by minor and localized flexures.

The structural features west of Santa Paula Creek continue to the east for 4 or 5 miles, in front of Santa Paula Ridge and San Cayetano Mountain, but the faults terminate one by one or coalesce, until at the easterly apex of the region the disappearance of interfault blocks has brought the late Tertiaries into contact with the much earlier Topatopa formation, the great San Cayetano fault alone separating them.

In the Sespe district it is to be observed that the formations enter the Camulos quadrangle at its northern border from their passage around the east end of the axis of the Topatopa anticline, which lies between 1 and 2 miles to the north. Within the quadrangle crumpling begins near its northern border—at first gentle, then severe. The major features resulting from this movement are the Coldwater anticline, southeast of the broad table of red beds, and still farther south the syncline, whose eastern extension passes through the summit of Oat Mountain. South of the western part of this syncline is the great northward-dipping monocline of Topatopa beds on the north flank of Mount San Cayetano. Near the mouth of Sespe Canyon the beds are greatly disturbed by the close approach of the San Cayetano fault and the syncline just mentioned.

In the region east of Sespe Creek the more important of the subordinate or secondary folds include a partially overturned anticline southwest of Hopper Mountain; the Oat Mountain syncline, already referred to; an anticline that crosses lower Pole Canyon at its sharp turn from south to west, and another anticline a mile farther south. Each of these folds is a conspicuous feature of the geology from one or another point of view, but the syncline is perhaps the most marked, involving, as it does, the strata from the upper Modelo shale to the red beds of the Sespe. In addition to these, there are numerous local folds and one or two faults, each of which is of almost equal importance to the features first mentioned.

Both Hopper and Piru canyons, in the lower 10 miles, have been developed across the structure at points where the strata are extensively puckered, each canyon lying a little east of the axis of a sharp strike flexure. The western of the two axes presents a change in trend from N. 65°–70° W. to N. 50°–70° E. The easterly axis shows a reverse change from N. 60° E. through east-west to N. 80° W. Locally slight departures from the general trend are to be found. For instance, the Modelo anticline and the syncline immediately to its south have a direction approximately east and west, and a number of minor folds between 1 mile and 2 miles in length, particularly conspicuous on the east side of Hopper Canyon, lie diagonally to the general trend of the larger flexures. Between the individual folds of the several trends direct continuity has not been established, but there is a suggestion of this in several instances, notably in the Oat Mountain syncline, which apparently can be traced from Sespe Creek nearly to the Modelo district, and again in the Lyons anticline, which almost certainly passes directly from the Piru Valley to Hopper Canyon. In any event, the folds are unquestionably the associated crumples of a single affected zone that passes continuously, though with wavy trend, from the region of Mount San Cayetano to that of Piru Creek.

Pl. III, sec. X–Z′, illustrates the general occurrence of petroleum in the mountains north of the Santa Clara Valley. The section without being continuous nevertheless represents in nearly their true succession the formations that occupy this great area and portrays the structural features that prevail in most of the productive oil territories. The line of the section is laid down on the map (Pl. I). Besides being somewhat irregular it presents two important offsets that were necessary to the generalization of the conditions. One of these offsets (x′–y) occurs at Little Sespe Creek and is a mile in length; the other (y′-z) embraces the interval between Brush Mountain and Piru Peak, a distance of 5 miles. In both intervals, however, the break in the stratigraphic succession is reduced to a minimum.

The formations involved include the Topatopa formation; the Sespe formation, with its three divisions—base, middle, and top; the Vaqueros formation, with its several bands of varicolored clays; the Modelo sandstones and their accompanying shales, a portion of which at least may correspond to the Monterey, and the Fernando formation, which probably extends from the Miocene through the Pliocene and well up into the Pleistocene. Their distribution over the line of the section may be gathered from the illustration. There are, however, certain features which it may be well to consider somewhat at length, for the reason that they have a bearing on the occurrence of petroleum.

The Topatopa anticline, shown at the left of the section, involves rocks of the Topatopa formation, which are proved to be more or less petroliferous by the seepages that occur on their outcrops and by the actual dissemination of bituminous matter through certain of the beds. There are, however, no wells that penetrate the formation, and its possibilities are as yet unknown. At the base of the Sespe formation there is a layer of white sandstone which, in the gorge of Sespe Creek, has been found to yield an excellent supply of low-gravity petroleum. The well of the Union Consolidated Oil Company penetrates the strata in this vicinity to a depth of approximately 500 or 600 feet. The position of this well, on the regular slope of the main Topatopa anticline, is of especial importance from the clew it may afford as to the occurrence of oil at this horizon under like conditions in other localities.

A second feature of importance is the Coldwater anticline. The strata on the northern face of this arch are productive, the oil being derived from about the same horizon as that of the well just mentioned, 2½ miles to the northwest. The longitudinal extent of this anticline in an easterly direction was not determined by the writer, but in Boulder Creek, a little more than a mile to the east, a somewhat similar fold appears nearly in the line of the Coldwater flexure. It may be, however, but an offset of the latter or a mere crumple on its flanks. It is indicated in the section and is the locus of the Ivers wells. Although conspicuous in the field, when plotted it is of comparative insignificance. The oil found at this point may have no relation to the minor fold, but, on the other hand, the fractures resulting from such a fold may have afforded a special opportunity for the accumulation of the petroleum.

One of the few occurrences of oil observed in California near the axis of a syncline is that seen at the Kentuck wells, which are located in a hollow of the Sespe red beds half a mile north of Little Sespe Canyon. The most plausible explanation of this exceptional occurrence is that it is due to the effects of the Coldwater anticline, or possibly even of the greater Topatopa anticline, the negative effects of the local syncline being insufficient to overcome the influence of the greater folds.

A short distance south of this depression the red sandstone of the Sespe formation dips steeply near the point where the axes of the folds exhibit a general change in strike from northeast to southeast. The locality is one of marked crushing and its structure is most difficult to decipher. The offset of a mile in the section was made here, the strata being again taken up in regular succession in the vicinity of the

Foot-of-the-Hill wells. From this locality to the top of Brush Mountain the series of rocks from the upper members of the red sandstones of the Sespe through the rusty beds at their summit and the great mass of shale that makes up the Vaqueros formation is unbroken. Three oil-bearing horizons have been found within this range—one either at the summit of the red beds or the base of the rusty member of the Sespe; another perhaps in the purple clay of the Vaqueros formation, and a third in the upper, earthy, and siliceous portion of the Vaqueros, not far below the Modelo sandstone. The wells are to be regarded as located on the slope of the general Topatopa anticline, for a careful examination of the locality reveals only minor and very insignificant crumples in the general sweep of the beds in an easterly, northeasterly, and northerly curve about the axis of the main fold.

Brush Mountain is capped by the lower Modelo sandstone and a thin band of the overlying siliceous shale. The second offset in the general section occurs at this point. On Piru Peak very nearly the same formations are encountered, the only difference being a somewhat greater amount of the siliceous shale at the top of the series. The lower Modelo sandstone outcrops immediately beneath the shale and at the head of Modelo Canyon is affected by the Modelo anticline, which is one of the most conspicuous and perfect folds of this character to be found anywhere in the region under discussion. The sandstone here, however, appears to be at least several hundred feet thick—thicker, indeed, than on Brush Mountain, and yet by no means so extensively developed as about the head of Hopper Canyon, farther north. The succession of strata on the two sides of the anticline varies somewhat, but this is perhaps due to crumpling and faulting. The presence of a fault is indicated by the abnormal succession of beds encountered in crossing the outcrop of the formation. It is probable that at the line of this section the opposing beds for some distance from the surface belong to the shale between the upper and lower Modelo sandstones, but the exact amount of throw is indeterminable, first, because of the uniformity of the shale in appearance; second, because of the rapid variation in the thickness of the strata, and third, because of the crushing that has taken place adjacent to the fracture.

The Modelo anticline is one of the most productive folds north of the Santa Clara Valley. About midway of the folds are the wells of the Modelo Oil Company, attaining a maximum depth of about 1,800 feet, with oil at 1,400 or 1,500 feet and indications of oil at still greater depths below the surface. The wells are wholly in the Modelo sandstone, which in places is so free from shale and so solid as to stand without casing. The wells are drilled in strata that dip 60° or more on both sides of the anticline, at distances varying from less than 100 feet to 600 or 700 feet on each side of the axis. The wells of the Sunset Oil Company in Hopper Canyon, 1½ miles to the west, are also on this fold. They have produced some oil, but have not been operated with the same care as the wells of the Modelo Oil Company, and as a consequence much water occurs with the oil.

The Nigger anticline lies a mile and a quarter south of the Modelo fold, being separated from it by a syncline and the fault already described. The strata involved are the upper Modelo sandstone and the shales above and below. The productive wells on this anticline are in the easterly tributary of Nigger Canyon, a little south of the axis of the fold. They are 500 or 600 feet deep, the oil having been encountered at depths of 65 to 400 feet.

Half a mile south of the Nigger anticline is a sharp change in the rocks which represents the contact between the Modelo and the Fernando formations. The younger beds have a northerly dip, which represents either an overturn at the plane of unconformity or a fault—perhaps both. That an unconformity exists between the Fernando formation and the underlying beds is beyond doubt, and many strata are brought successively into contact on either side of the plane. From the point of the ridge separating Nigger Canyon from Piru Creek eastward for several miles beyond this stream there is a marked line of disturbance. A synclinal structure has been suspected, but careful examination indicates that this supposition may have been induced by the deceptive relations of the dips; in reality there is probably an anticline, with a very steeply inclined southern limb, which west of Piru Creek has possibly been the locus of a fault. At this point in the section, therefore, there may be a fault in proximity to a line of unconformity, much after the order of the unconformity and fault passing along the southern border of the Puente Hills from the region of the Santa Fe wells westward to Whittier. (See p. 111.) Doubtless the dip of the Fernando strata changes from northerly to southerly beneath the valley of the Santa Clara, but exposures along the bottom lands are wanting, and the relation of the formations north of the river to those south of it can only be conjectured.

REGION SOUTH OF THE SANTA CLARA.

The mountains bordering the Santa Clara Valley on the south represent the west end of one of the most important uplifts of southern California. The center of uplift, the San Gabriel Range, consists of granites and related rocks. Encircling these on the west are sedimentary beds of Tertiary age, which constitute, in the order named from east to west, the lower elevations of the Santa Susana Mountains, Oak Ridge, and South Mountain. The structure of this system of ridges is anticlinal and notwithstanding a degree of continuity between the formations north and south of the upper portion of the Santa Clara Valley the mountains south of the river preserve, on the whole, remarkable independence of structure. In the western half of the system the structure is comparatively simple, consisting of a main anticlinal fold affected by a few subordinate wrinkles. In the eastern portion, however, although the effect of the uplift has been the production of a single range crest, there are, nevertheless, three distinct folds of a more or less secondary nature, arranged en échelon and slightly diagonal in trend to the course assumed by the general ridge system. These folds may be designated the Torrey, Tapo, and Pico. A fourth, en échelon with the others and known as the Elsmere, is in reality the western terminus of the San Gabriel uplift itself. Although secondary to the dominant structure these folds are well developed and are of especial importance in that they have become the loci of several very productive oil fields. There are numerous minor crumples and, along the southeastern crest of Oak Ridge and the southwestern face of the Santa Susana Mountains, at least one fault of considerable throw.

OIL FIELDS NORTH OF THE SANTA CLARA.

The oil fields north of Santa Clara River involve an area having an east-west length of 35 miles and a width of 7 to 15 miles. For convenience of discussion, this area may be divided into the Ojai Valley, Sulphur Mountain, Silver Thread or Sisar Creek, Santa Paula Ridge, Sespe, Pole Canyon, and Hopper-Piru fields. (See Pl. V.)

OJAI VALLEY FIELDS.

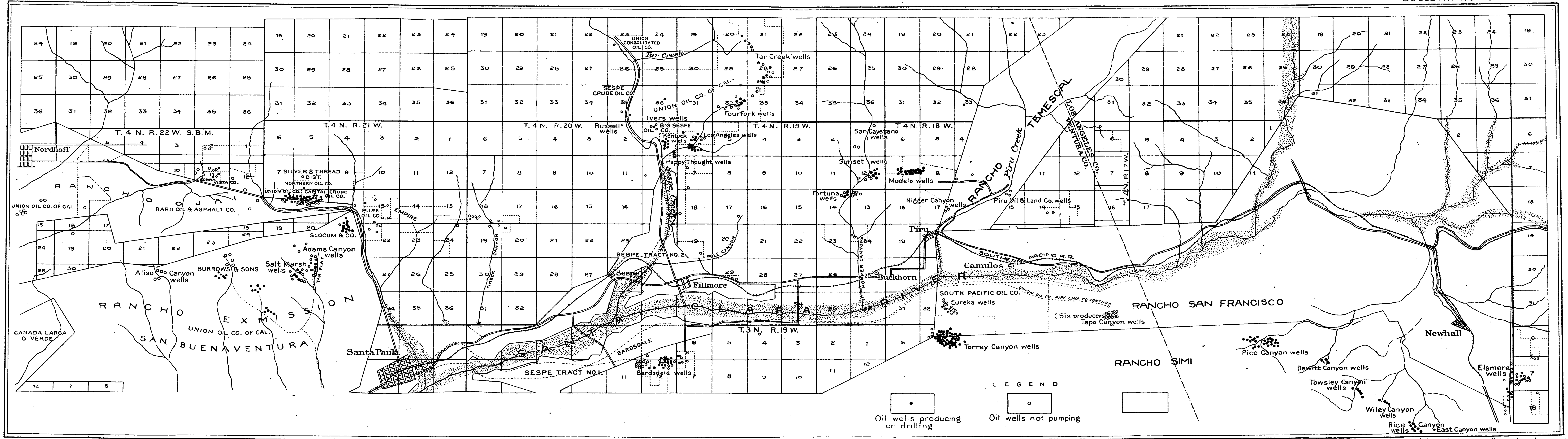
LOCATION.

The Ojai Valley fields comprise the region of the upper and lower valleys, lying between the Topatopa Range on the north and Sulphur Mountain on the south. Nordhoff, the only town within the district, lies about 15 miles north of Ventura, with which it is connected by a spur track of the Southern Pacific Company, and 12 miles northwest of Santa Paula.

STRUCTURE.

Pl. III, sec. A–A′ indicates in a very general manner the structural relations of the several formations exposed in this valley. The series of beds north of the Lower Ojai Valley is a part of the great overturned south flank of the anticline developed in the Topatopa Range. The overturning was accompanied by faulting. The delineation of the faults on the map (Pl. I) is highly generalized from the evidence afforded by soil coloring and isolated outcrops. They will be described in the order of their occurrence from north to south.

The succession of beds from the base of the Topatopa Range, or across Lower Ojai Valley, is perhaps without break. If so, there is an upper and a lower series of rusty beds separated by a broad belt,



Compiled from U.S. Geological Survey and California State Mining Bureau maps by W. L. Walker and Ralph Arnold

A. HOEN & CO. BALTIMORE, MD.

TOWNSHIP AND SECTION MAP OF THE SANTA CLARA VALLEY AND ADJACENT OIL FIELDS, CALIFORNIA

Oil well locations largely from original data, a small number however from California State Mining Bureau publications

Scale
0 1 2 3 4 5 miles

1906

between 1,000 and 2,000 feet thick, of red and white sandstones which seem to belong to the Sespe formation. Between the southerly belt of rusty beds, which are regarded as Vaqueros, and the Modelo shale, which constitutes Thompson Ridge, there is unquestionably a fault the throw of which can hardly be less than 2,000 feet. The Thompson Ridge fracture is more directly in line with the San Cayetano fault to the east than any of its associates and it may be responsible for the existence of both the Upper and Lower Ojai valleys. To the east it passes immediately south of the wells of the Bard and adjacent oil companies. Between the Lower Ojai Valley and Santa Paula Canyon the thickness of the red beds is greatly reduced, and to the south the rusty beds may almost entirely disappear, for in the Silver Thread district the outcrop of these two strata is less than 300 feet thick. From the trend of the formations north of the Lower Ojai and from lithologic similarities, it is inferred that the great development of rusty beds north of the Bard and Capital Crude wells is continuous with those of the Topatopa formation in the lower slopes of the Topatopa Range to the west. At this point these beds have furnished a fair collection of fossils, which are regarded as Eocene. In this connection it is worthy of notice that at the head of the Lower Ojai Valley the rusty beds south of the red beds carry fossils that were, with equal certainty, determined as lower Miocene.

The Modelo shale, forming Thompson Ridge, is severely crumpled and is probably an included fragment of siliceous shale. It disappears beneath the wash of the Lower Ojai Valley and has every evidence of wedging out a little west of the Silver Thread district.

South of this interfault block of Modelo there is a narrow band of rusty beds, which also wedge out to the east. These beds have every appearance of the Vaqueros formation and carry the same fossils as those north of the Modelo block. They border Thompson Ridge on the south and pass at once into the Lower Ojai Valley, where they disappear beneath the later wash. This block of rusty beds presents a variety of dips and strikes, and it is thought, therefore, to be simply an inclined fragment between the great faults of the region. The fracture separating it from the red beds bordering it on the south is recognized as passing the valley road at the head of the gorge between the Lower and Upper Ojai basins to the west, following the line of a short gulch to its junction with the general valley. It is probable that in this direction it has been the northern determinant of Lion Ridge. To the east the fault seems to pass in a direction about S. 80° E., merging finally with one or another of the greater fractures of the system.

It is interesting, also, to note the occurrence of a narrow strip of rusty beds included in the Modelo shale in the easterly portion of the crest of Thompson Ridge.

The red beds of the Sespe formation again become prominent in Lion Hill, which lies between the Lower Ojai and Lion Canyon to the south. This ridge is an anticline, the trend of its axis curving slightly from N. 87° W. at the west end to N. 70° E. at the east. The crown of the arch is but gently bowed. The flanks, however, show steeply inclined strata. Locally, a slight synclinal flexure appears. To the north the red beds pass beneath the wash of the Lower Ojai Valley; to the south they are succeeded by the Modelo shale of Sulphur Mountain, the line of division being practically coincident with the stream channel in Lion Canyon.

The Sespe formation of Lion Hill is doubtless another interfault block, more than ordinarily prominent, in the series that occupies the Ojai Valley. The apex of this block probably terminates within a mile of the Silver Thread district, the small body of red beds appearing in the latter region belonging to the greater mass of similar beds lying on the north side of the Ojai Valley. The Sespe formation in the block under discussion widens and becomes an important formation in the western portion of the Lower Ojai west of San Antonio Creek and Ventura River. On the north the red beds are in contact with the rusty beds in the minor interfault block already described, and, to the east of this block, with the projecting portion of the included fragment of the Modelo formation. On the south they are in contact with the Modelo shale throughout its whole length to San Antonio Creek. The minor interfault block of the Modelo in Thompson Ridge being disregarded, this Sespe block would appear to have been pushed up with reference to the formations north and south of it, particularly those on the north.

Along Lion Canyon and the south edge of the Upper Ojai Valley is another of the greater faults of the district. Like the others, however, it terminates near the common center in the vicinity of Santa Paula Canyon. Farther west it is probably of considerable extent, having been recognized, it is thought, at the canyon of Ventura River several miles below Nordhoff. In any event there is the same succession here that is encountered in the Ojai Valley.

Sulphur Mountain from one end to the other is composed of the Modelo shale, the strike of which corresponds with the trend of the ridge about N. 80° E. The dip is generally to the south. There are, however, local crumples of different degrees of importance, as, for instance, a possible anticline, indicated on the map (Pl. I) as passing along the lower slope of the mountain, and a second, the axis of which passes a little south of the well of the Langdell, Newmark & Roan Oil Company, a few hundred feet below the summit. Also, it is possible that faulting, as well as folding, has taken place within the confines of the mountain. Such folds and faults may be accountable for the lines of petroleum seepages on both the north and south sides of the ridge.

Sulphur Mountain itself is perhaps an interfault block, a possible fracture existing at the line of contact of the Modelo and Fernando formations south of the ridge, although the succession may be merely one of unconformity. The writer is inclined, however, to the view that a fault is present. The linear extent of the folds in Sulphur Mountain has not been determined. The east end of Sulphur Mountain presents a syncline at its crest, an anticline at its northern base coincident with the lower portion of Sisar Creek, and another anticline south of the mountain in the vicinity of the Adams Canyon oil wells.

There is an anticline south of the western portion of Sulphur Mountain showing in the road which descends from the summit to the upper part of the Cañada Larga. In the line of this anticline is a like fold at Ventura River, and it is possible that the two are continuous. Although the rocks involved in this fold belong mainly to the Modelo formation, gray and brown argillaceous shales and heavy sandstone, probably of the Fernando formation, lie immediately upon its southern flanks and locally may have become affected.

OIL WELLS.

The oil wells in the Ojai fields comprise those of the Union Oil Company on the Pirie ranch, at the west end of Lion Hill; two in Lion Canyon, about 1½ miles southeast of the Pirie wells; a couple drilled by Langdell, Newmark & Roan near the summit on the north slope of Sulphur Mountain, and a group along the northeastern side of the Upper Ojai, sunk by the Whidden-Double, Sobra Vista, and Santa Paula oil companies.

PIRIE RANCH WELLS.

Two groups of wells belonging to the Union Oil Company are located on the Pirie ranch south and southeast of Nordhoff, in the Lower Ojai Valley. The first group, consisting of three wells, is about a mile S. 25° E. of the town, on the west end of Lion Hill; the second group lies across a small valley, about three-fourths of a mile S. 70° W. of the first. All the wells penetrate the red beds of the Sespe formation, those of the first group being about 100 feet south of the axis of the Lion Hill anticline, and those of the second on the south limb of the same anticline, at least three-eighths of a mile south of its axis. At the time of the writer's visit the wells were abandoned and only one derrick was standing. It was learned, however, that black oil accompanied by considerable quantities of gas was struck in the wells of the first group, and that for a time they were pumped. Gas was heard rumbling in one of the holes and another contained water. No seepages were noticed in the locality of the wells.

Five wells constitute the second group, four close together and a fifth about one-fourth mile to the southwest. The deepest of the four is about 1,500 feet deep. A little oil was encountered at 30 feet and some also at about 400 feet; for a time considerable oil and water, mostly the latter, were pumped. In another well thick oil was struck at 100 feet and a lighter oil at 333 feet, thus indicating at least two oil-bearing strata for this locality. Much water was found in the westernmost well and it was abandoned before reaching the oil sands.

LION CANYON WELLS.

Two wells, now abandoned, were sunk in Lion Canyon about 2½ miles southeast of Nordhoff. They are situated in the brown shale of the Modelo formation, not far south of the fault separating the shale from the Sespe red beds of Lion Hill. The wells lie in line with what to the east is a faulted overturn, but which here may be only a simple anticline. Heavy oil stands in the eastern well at a depth of about 200 feet, while a lighter emulsion of oil and water rises to about the same level in the western well. Some of the oil which had been bailed out and was standing in a barrel had a gravity of about 16° B. It was black and ran quite freely, though stringing some.

LANGDELL, NEWMARK & ROAN WELLS.

The two abandoned wells of this company are located on the north slope of Sulphur Mountain, only a short distance below its crest and just west of the road leading up from the Upper Ojai Valley. The holes are sunk a little north of the anticlinal axis, which passes immediately north of the summit of the mountain, and penetrate the brown and gray shales of the Modelo formation. The higher well is located at the upper edge of a prominent oil seepage; it is said that a little light oil was struck at about 800 feet and that the well was abandoned in a white clayey shale at 1,000 feet. The lower well was sunk right in the seepage, but yielded nothing. The natural seepage of oil at the wells is claimed to be about a barrel a day.

WHIDDEN-DOUBLE WELLS.

The five wells of the Whidden-Double Oil Company are located in the Modelo shale fault block on the northern side of the head of the Upper Ojai Valley. The surface outcrops here show a slight northerly dip, while the well logs indicate a much steeper dip to the northeast for the oil sand. The structural relations in the vicinity are somewhat complex, but it seems likely that the wells are situated on the north flank of an anticline more or less complicated by minor folds. It is reported that the holes vary in depth from 132 to about 950 feet and that they yield oil of 8° to 15° gravity. The petroleum is black and in two of the wells is associated with more or less water. The deepest well is said to penetrate two sands, the lower of the two yielding the lighter oil. An interesting fact is that No. 3, one of the shallower wells, although having a greater initial production than No. 5, which was deeper, did not hold out nearly so well. The yield of the wells was never very great and they were finally abandoned in 1904.

SOBRA VISTA WELLS.

The Sobra Vista wells, three in number, are located at the head of the Upper Ojai Valley, immediately south of the Whidden-Double property. As indicated by the structure in the immediate vicinity, the wells are probably located on the north flank of the local anticline which is so well developed in the region of the Santa Paula group of

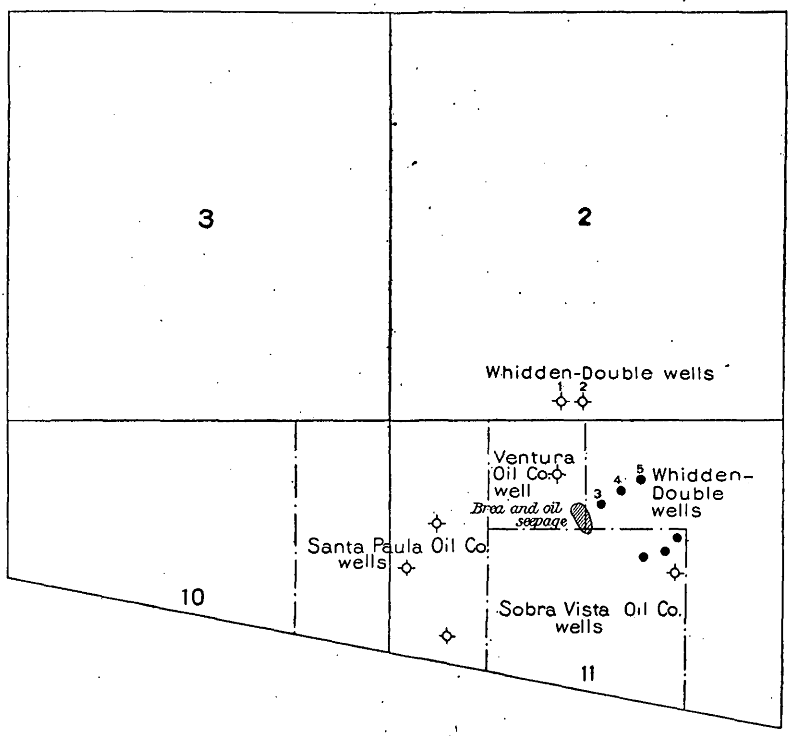


FIG. 4.—Sketch map showing location of wells and oil seepages in the northeast corner of the Upper Ojai Valley. Heavy black dots, wells abandoned since beginning of 1902; the other symbol, wells abandoned previous to 1902.

wells immediately to the west. The strata penetrated are the blue and gray shales of the Modelo formation, here containing interbedded sands from which, it is said, the wells derive their oil. In fact, the southernmost well of the group is located precisely on the line of strike of the sandstone which affords the heavy oil seepages on the Santa Paula property. The wells range in depth from about 375 to 740 feet and obtain their oil from two sands about 240 feet apart, the upper varying from 10 to 11 feet and the lower from 4 to 11 feet in thickness. It is said that an 11-foot stratum of black water sand was encountered between the oil sands in one of the wells, and that in another the drill was stopped in a deposit of tar too heavy to pump. The best well is reported to have started with a yield of 50 barrels per day, but this was reduced to about 13 barrels at the time of the writer's visit (1902), and still later is stated to have fallen off considerably more. The oil is black and heavy and is said to run 48 per cent of exceptionally pure (92 per cent) asphaltum.

SANTA PAULA WELLS.

Immediately west of the Sobra Vista group, at the head of the Upper Ojai Valley, are the two wells of the Santa Paula Oil Company. They penetrate the blue shale of the Modelo formation, which is here folded into a westward-plunging anticline. The wells derive their oil from interbedded sandstones, some of which yield seepages of heavy asphaltum. The northern well is farther down the dip and is the deeper of the two. It is reported that this yielded lighter oil than the southern well and that the latter struck oil similar to that encountered in one of the Sobra Vista wells, which was too heavy to pump.

SOUTHERN SULPHUR MOUNTAIN FIELD.

LOCATION.

The oil areas that have been developed along the southern base of Sulphur Mountain lie at the heads of Aliso, Wheeler, Salt Marsh, and Adams canyons and along the short gulch heading against Adams Canyon from the Santa Paula Valley. All are a short distance south of the northern boundary of what once constituted the San Buenaventura Mission. The general elevation of these areas is about 1,100 feet, Sulphur Mountain rising abruptly above to heights between 2,500 and 2,750 feet. The canyons are of easy grade and the intervening ridges are comparatively low.

GEOLOGY.

Two and perhaps three formations are involved in this field—Modelo shales; Fernando conglomerate, sandstone, and clay; and possibly certain remnants of the Pleistocene, consisting of coarse gravel and gritty sand.

The Modelo is confined to Sulphur Mountain and consists of blue and brown, finely laminated shale, which is either earthy or siliceous, here and there even slightly sandy, and thin beds of sandstone. The shale is the conspicuous feature, however, and is of the type variety. It carries the customary gray to yellow limestone concretions, which with the shale show an abundance of organic remains, foraminifera and fish integuments and their impressions. The browner variety of the shale is gypsiferous and carbonaceous.

Adjacent to the line of division between this shale and the succeeding formation there is in places a body of earthy shale, the general color of which is brown and through which are threaded thin-bedded sandstones from a few inches to a few feet in thickness. All in all, this shale somewhat resembles others of doubtful age that are encountered in the oil fields of the Santa Susana Mountains and is not unlike certain beds that underlie the more siliceous shale of the Modelo formation in the region of Hopper Canyon. The question regarding the beds referred to in the Santa Susana Mountains is whether the shale actually belongs to the Modelo or to a younger formation, although perhaps still of Miocene age. The same uncertainty holds for the shale of the Sulphur Mountain localities until detailed work shall have determined its proper reference. A possible characteristic that may prove to be of value in distinguishing this shale from those of the Modelo, the more finely laminated beds of which are of a like brown color, is the mud-like texture and consistency of the younger shales. The younger clays are, moreover, decidedly arenaceous, and are also commonly associated with sandstones.

The formation regarded as Fernando forms the mass of the hills between Santa Clara River and Sulphur Mountain, except, perhaps, a Pleistocene fringe along the immediate valley. Some of the lower sands are bituminous, this characteristic appearing to become more conspicuous as Sulphur Mountain is approached. The clays associated with the lower sands are brown or blue. The conglomerates of this series include pebbles of sandstone, quartz, granite, black chert, and siliceous shale, the last evidently derived from the Modelo and probably from Sulphur Mountain itself. The succession of beds here described is encountered also, though with some variation, in the Santa Paula Valley and in the several canyons to the west of Adams Canyon.

By reason of the uncertainty regarding the age of the brown shale referred to above it is evident that the line between the Fernando and the Modelo formation is indefinite. It is worthy of note in passing that there is a considerable difference in the gravity of the oils derived from the Modelo shales and the Fernando sands and gravels in this field, that from the Modelo being much the lighter.

Deposits of sand and coarse gravel occurring in the lower portion of Adams Canyon are doubtfully referred to the Pleistocene series. These have the appearance of being an outlier of the more prominent body of like sediments east of the Santa Paula Valley. The deposits have, however, received but passing attention and have little or no bearing on the geology of the Sulphur Mountain oil district.

STRUCTURE.

Secs. A–A′ and B–B′, Pl. III, show the probable structural relations of the different formations in the Sulphur Mountain region. The relation between the Modelo shale and the succeeding formation along the southern base of Sulphur Mountain is primarily that of unconformity, but faults are here and there suggested by the sharp contrast of the beds in contact and by the flexures that have particularly affected the strata in proximity to the line of the suspected fracture. The fault, if it exists, is in harmony with the other structural features of the region and is supplemental to those farther north already described. It is the southernmost component of the system radiating from the San Cayetano fracture a mile or two east of the Santa Paula Valley. In each of the canyons in the southern face of Sulphur Mountain evidences of the fracture are more or less distinct.

Of the flexures in the area under discussion the sharpest occur in the interfault block of the Modelo shale. The most conspicuous one occurs halfway up the face of Sulphur Mountain. It consists of a zone of severely crushed strata 100 to 200 feet broad.

A short distance south of the suspected fault, in the younger formation of clay, sandstone, and conglomerate that is possibly the Fernando, there may be here and there detected an anticlinal fold, its axis having the general strike of the formation, varying from N. 65° E. at the eastern terminus of the mountain to N. 80° E. farther west. The southern limb of the anticline extends beneath the foothills to the Santa Clara Valley, the dip varying from 45° to 80°, but usually approaching the lesser angle. The northern limb is steep, short, and truncated by the plane of the fault. This structure appears in several of the canyons and hill areas, but its continuity from point to point has not been established. Instead of an anticline it may be, perhaps, but a bending downward of the strata, a crumpling of the beds due to compression adjacent to the fracture. In Adams and Wheeler canyons the anticlinal feature is somewhat stronger, while in Aliso Canyon general crumpling seems to prevail. Farther west, however, in the region of Harmon Canyon, the anticline again appears; the northern limb is still short and terminates in a sharp reverse flexure, or perhaps at the fault, which marks the junction of a series of table-like benches with the main body of the mountain. The entire region north of this fault to the Topatopa Range is a succession of displaced blocks, crumpled in the manner just described. From the axis of this disturbance southward to the Santa Clara Valley the strata maintain their southerly dip with marked persistency, at most varying only by minor and localized flexures.

OIL WELLS.

The line of the suspected fault along the south side of Sulphur Mountain is marked in the several canyons by many strong seepages of petroleum, and in proximity to the fracture, in the northward dipping or more severely crumpled strata of the Fernando formation, most if not all of the wells of this general field are drilled. Those yielding the lighter oil, however, may penetrate to minor sands in the Modelo, or they may be peculiar to the brown shale of uncertain though perhaps Modelo age (p. 19). The heavier oil without doubt occurs in the Fernando formation.

The wells in the field under discussion have been drilled at the heads of Aliso, Wheeler, Salt Marsh, and Adams canyons and along the bottom of a short gulch east of Adams Canyon. But little new development was under way at the time of the investigation and it was difficult to obtain data relating to the occurrence of the petroleum. Furthermore, many of the wells were old and were abandoned, while the product of others was reduced to only 1 or 2 barrels a day. The initial flow of some of the wells appears to have been as high as 25 or even 50 barrels. The depth as a rule ranges between 150 and 500 feet, but here and there 1,800 or 2,000 feet is said to have been attained. An early mode of recovering the oil was by tunnels, many of which penetrate the shale of Sulphur Mountain. From these a small amount of oil still seeps, although several barrels a day have been obtained.

Two varieties of oil occur in this field—one black, with a gravity of 19° to 30° B.; the other green, with a gravity of 30° to 32° B. The lighter oil, as already stated, is believed to be associated with the shale doubtfully assigned to the Modelo formation. It occurs nearer the base of the mountain than the black and heavy oil. The comparatively shallow depth of certain of the wells yielding green oil and their location well up on the slopes of Sulphur Mountain suggest the possibility that the productive beds outcrop in the base of the mountain. None of the strata, however, so far as the writer could learn, showed any indication of containing petroleum.

The duration or life of the wells varies. Two years seems to be the maximum for the larger yields, but beyond this time the product dwindles to 1 or 2 barrels a day and then remains constant for an indefinite time. This constancy, coupled with the inexpensiveness of pumping, accounts for their still remaining in service. The earliest drilling reported in this field was done by Mr. Adams twenty-five years ago in Adams Canyon. This well and another in proximity, put down by the Union Oil Company, afforded a light oil, and a similar product was obtained by wells in Salt Marsh Canyon. Periodic attempts have been made to develop the source from which this supply was derived, but without success. Opinions differ as to the relations of the light oil to the Modelo shale. It is possible that this oil is derived from the strata adjacent to the shallow wells (about 200 feet deep) which are probably in the Modelo shale; but on the other hand, the beds are severely crushed and the oil may be derived from a considerable depth, rising through fissures in the shale. Of the wells in Salt Marsh Canyon, one yielding green oil is said to have produced an average of 60 barrels a day after the head had been pumped off. It is said also that in the Salt Marsh wells the horizon affording green oil is first struck, the black variety being 100 or 200 feet lower down. In Wheeler Canyon the conditions are reversed, the top oil having a gravity of 28° B. and the lower, 400 or 500 feet below, of 30° B.

The dip of the strata in the several productive areas of this field varies from 45° to 80° N. South of the axis of folding and crumpling—south of the productive line, therefore—the dip is usually less than 45° S., although here and there 80° may be attained.

SILVER THREAD OR SISAR CREEK FIELD.

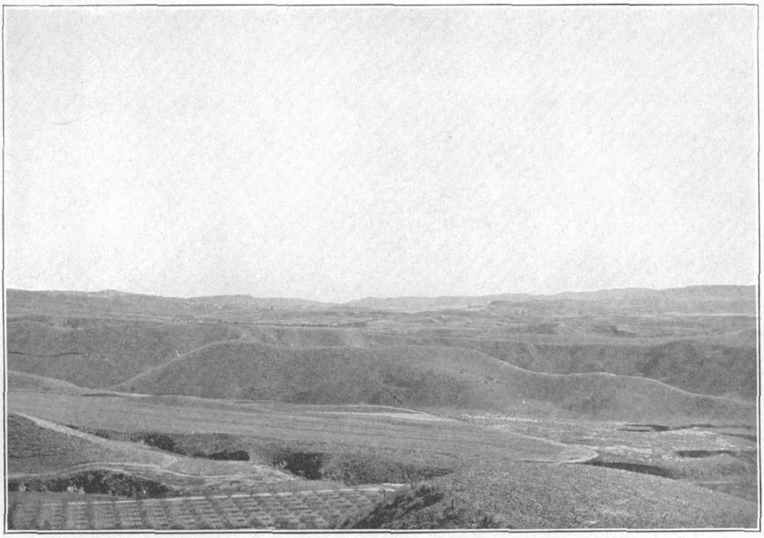
LOCATION.

The Silver Thread field is developed on the high ground immediately north of Sisar Creek, near its confluence with Santa Paula Creek, directly opposite the productive territory east of the latter stream. Pl. VI, *B*, shows its position in relation to the surrounding country.

STRUCTURE.

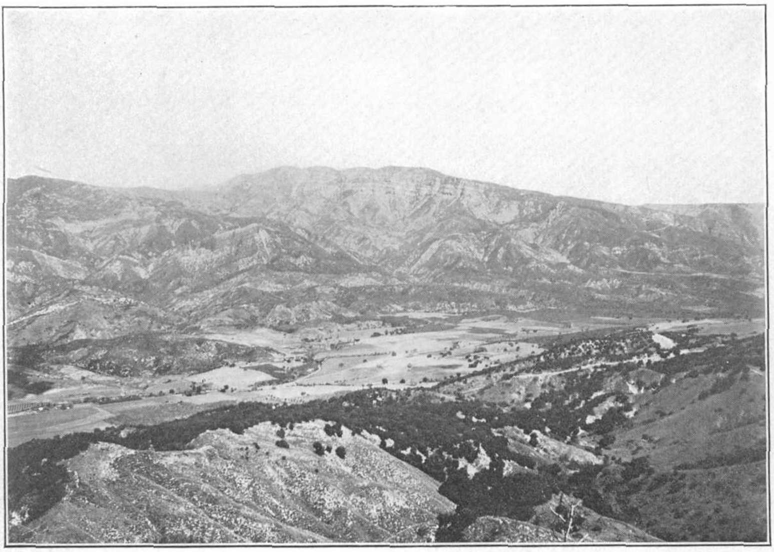
The field is included within the area of the great fault system extending from San Cayetano Mountain to the Ojai, and is therefore in structural relationship with the producing fields both west and east of it. It lies within a short distance of the point of convergence of the several faults that form so conspicuous a feature in the geology of this region. Pl. III, sec. B–B′, indicates the probable relations existing along this line through the field. The productive area lies in proximity to what is perhaps the principal fault of the Ojai system, which here passes along the steep slopes that form the northern walls of lower Sisar Canyon. The extent of the development is about a mile in length by 400 or 500 feet in width, the direction assumed by the wells being approximately S. 71° 45′ E., or about the trend of the line between the properties of the Bard Oil and Asphalt Company on the south and certain others on the north. The collars of the wells are but a short distance below the brow of the mesa that extends back to the main mass of the mountains on the north, being about 1,500 feet above sea level, or 500 feet above the bed of Santa Paula Canyon.

Only two or three formations outcrop in the Silver Thread field. The oldest of these, which occupies the northern portion of the belt, represents the upper part of the Topatopa and consists of a series of rusty conglomerate, sandstone, and shale, with interbedded quartz-



A. FLANKS OF OAK RIDGE AND SANTA SUSANNA MOUNTAINS, SHOWING POST-PLIOCENE PENEPLAIN.

From mouth of Sulphur Canyon; looking east.



B. THE UPPER OJAI VALLEY.

From crest of Sulphur Mountain, Ventura County ose limestones, which carry fossils that have been determined to be Eocene. These rusty beds are a part of the overturned south flank of the great anticline to the north, and pass directly beneath the great body of older Topatopa quartzite and shale that occupies the very heart of the range.

The red beds, probably belonging to the Sespe formation, are exposed in a narrow belt little more than 100 yards wide, along the upper portion of the face of the ridge north of Sisar Canyon. They outcrop south of the rusty beds, passing beneath them, however, with a northerly dip, as part of the overturned series. They consist of coarse sandstone, streaked red and white, and shale colored in like manner, as in the Sespe region. In the Silver Thread field, as well as in the Ojai Valley, there is, stratigraphically below the red beds, a conspicuous layer of white sandstone from 20 to 30 feet thick, which is locally bituminous and carries small lenticular bodies of green and purplish clay. Stratigraphically above the red beds in the Ojai Valley are rusty beds, but these are not exposed in the Silver Thread region.

South of the red beds is the Modelo shale, occupying the slopes of Sisar Canyon and Sulphur Mountain. The formation here has the typical appearance, consisting of earthy to siliceous shale, brown, gray, and white in color, more or less organic, impregnated with gypsum, sulphur, and bitumen, and carrying lenses of limestone that weather a bright yellow. This shale is thrust down against the formations already described by a displacement, which may be called the Silver Thread fault. This is probably the principal westerly branch of the San Cayetano break and may be the continuation of the principal fault of the Ojai Valley. If this connection is correct, the displacement amounts probably to several thousand feet. Immediately south of the fracture the beds are folded into an anticline, the axis of which is coincident with the lower part of Sisar Canyon. In Sulphur Mountain they lie in a syncline, the axis being coincident with the crest of the mountain. A little farther south there is a second anticline, beyond which, with the exception of minor flexures, the southerly dip of the strata is maintained to the valley of Santa Clara River.

In the bluffs of Santa Paula Canyon, at the base of the oil-yielding hills, there is immediately north of the anticlinal axis an outcrop of 200 or 300 feet of earthy, micaceo-quartzitic shale, chalky in color and bearing yellow to gray limestone concretions and thin beds of sandstone. This shale resembles the chalky Modelo shale in Hopper Canyon and is probably its equivalent. Immediately south of the anticlinal axis, at the mouth of Sisar Creek, the more siliceous shale sets in. It is possible, therefore, that some faulting has taken place along the crest of the fold, so that the series is not the same on both sides. On the other hand, it may be that the appearance of the shale of northerly dip has been altered by the crushing that it has undergone in proximity to the fault.

The Modelo shale of Sulphur Mountain and the valleys north and south is continued east of Santa Paula Canyon in the foothills of the Santa Paula Ridge and San Cayetano Mountain; finally, by the convergence of faults, wedging out between the Fernando sediments of the foothills and the Topatopa formation of the mountain.

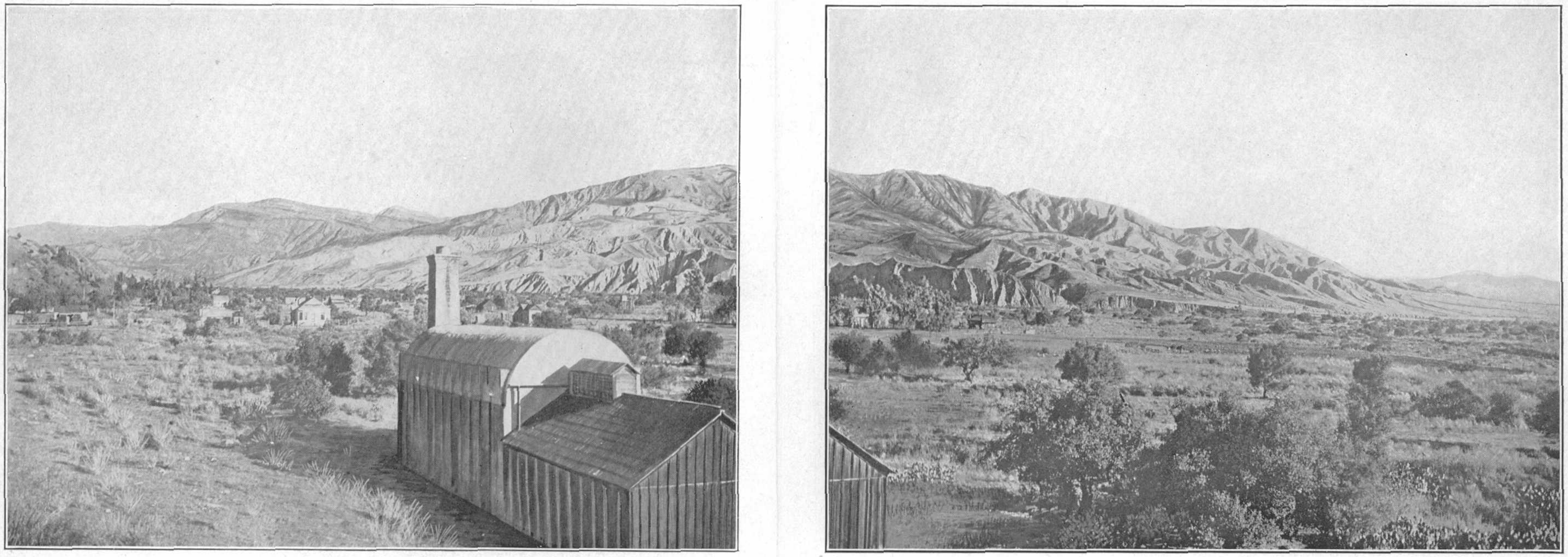
The general strike of the formations north of the Modelo is N. 65° W., the dip being 40°–70° N. Adjacent to the Silver Thread fault line the Modelo also strikes N. 65° W. parallel with the break, but along Sisar Creek the direction changes to nearly east and west, while south of Sulphur Mountain it is N. 60°–70° E. Immediately south of the main fracture the shale of this formation dips to the north, toward the plane of displacement, the axis of the adjacent anticline lying perhaps 200 or 300 yards farther south.

Although the prevailing dip near the Silver Thread fault is northward, the strata, nevertheless, present more or less irregularity of occurrence, the appearance suggesting a fragmental condition of the formations. This may readily be the case along a fracture of such proportions, the amount of displacement being hardly less than 5,000 or 6,000 feet.

OIL WELLS.

The oil wells of this district all lie immediately north of the Silver Thread fault, which separates the Modelo shale and the Sespe red beds. They pierce the red beds, and a few wells in their upper portions pass through the more southerly members of the older but overlying rusty beds that carry Eocene fossils. None of the wells is distant more than 200 or 300 feet from the plane of fracture, while one or two are especially close to it, appearing, indeed, to have been sunk in crushed rock of the Modelo formation; however, in view of the uncertainty as to the dip of the fault plane it may be that they pass at slight depth from the fragmental Modelo into the more solid strata of the older formations north of the fault.

The maximum depth attained is a little over 1,000 feet. The wells are all small, 12 barrels per day being the largest individual yield at the present time. The gravity of the oil varies somewhat from well to well, but the average is approximately 19° B. The color of the oil is green. The only flowing wells are those of the Ojai Company, which lie west of the others, with their collars at a considerably lower elevation; they are also very shallow and are, moreover, located directly in the line of seepage of the region.



A. SANTA PAULA CANYON, FROM SANTA PAULA, VENTURA COUNTY.

B. ELSMERE RIDGE AND OIL WELLS, NEAR NEWHALL, LOS ANGELES COUNTY.

FIELD SOUTH OF SANTA PAULA RIDGE.

LOCATION.

The productive oil territory immediately east of Santa Paula Canyon lies at the foot of the steep southern face of San Cayetano Mountain and is the eastward extension of the Ojai, Silver Thread, and Sulphur Mountain districts. The general configuration of the district is shown in Pl. VII, *A*, a panorama looking north from Santa Paula, in which this field appears along the face of San Cayetano Mountain on the right The sharply eroded ridges in the middle distance on the right are composed of the Fernando conglomerate, sandstone, and clay.

GEOLOGY AND STRUCTURE.

The great San Cayetano fault, along which the late Tertiaries are in contact with the Topatopa formation, lies at the base of the steeper portion of San Cayetano Mountain, at the upper edge of the lofty foot slopes, 2,000 feet above sea level. Along this line the oil-producing territory has been found, the area of yield widening somewhat with the appearance of other members of the fault system, in the direction of Santa Paula Creek. In this direction, too, the succession of strata and their relations become more and more complex.

The sediments involved in the productive region east of Santa Paula Creek include unmistakable Topatopa beds; a small wedge of the rusty Eocene sandstone, shale, and *Ostrea*-bearing limestone from the Silver Thread field; shale of the Modelo type, and a succession of sandstone, conglomerates, and blue, mud-like arenaceous clays, that have already been referred to as probably of Fernando (Pliocene) age. These last are the same as those occurring in Adams, Wheeler, and Aliso canyons and are also to be seen in strong outcrops crossing Santa Paula Creek from 3 miles above the town of Santa Paula to a point within a mile of Sisar Creek. The Modelo is identified by the siliceous character of its shales and by their organic life. As it is, however, in a locality in which the rocks are badly crushed and in which there is a rapid succession of interfault blocks, it is impossible to recognize its relations to adjacent beds.

A typical section (see Pl. III, sec. C–C′) of the field, directly across the strata from a point about 2 miles east of Santa Paula Creek, in the vicinity of the Hartford well, is as follows: On the north the typical Topatopa, succeeded across a fault plane by a siliceous shale typical of the Modelo. South of this is a large body of brown shale with limestone lenses, which under ordinary circumstances would be regarded as also a part of the Modelo, but which is less siliceous and more earthy than many of the Modelo beds. Still farther south are Fernando sandstone and conglomerate, which, with shale and clay, extend well out beneath the sloping foothills of the range. The strata in the fault zone and adjacent to it on the south have a northerly dip, varying from 80° in the sandstone and conglomerate just south of Bear Canyon and the well area to 50° in the well area itself and to 30° in the escarpment of Santa Paula Ridge and San Cayetano Mountain. The throw of the fault plane separating the Modelo and the Topatopa formations amounts, doubtless, to many thousand feet. A second fault probably exists in the interval between the Modelo siliceous shale and the Fernando sandstone and conglomerate south of Bear Canyon and at the head of Mud Gulch, the intervening brown shale, which is earthy and stained with bitumen, belonging, in the writer's belief, to the older formation. The strata south of the second fault are probably overturned, and only at a depth of 1,000 or 2,000 feet assume their regular dip to the south. This fault is probably the easterly extension of that existing along the southern base of Sulphur Mountain, since its trend and that of the adjacent strata is N. 65°–80° E., in conformity with the strikes in the latter region. The northern fault is doubtless the extension of the fault passing north of Sulphur Mountain, its trend and that of the lines of stratification adjacent being N. 65°–80° W. The extent of throw along the southern fault is undetermined and may vary from 500 to 1,500 feet. These two faults come together about 5 miles east of Santa Paula Creek, in the vicinity of the Empire wells, and east of this point only a single fracture is present.

OIL WELLS.

The wells of this field are confined chiefly to the brown shale and range in depth from a few hundred to nearly 2,000 feet. Sandy beds undoubtedly occur; but in the main the strata are blue, brown, and black shale, with occasional harder layers, known to the drillers as "hard shells." The oil is found in the coarser sediments. The Empire wells, in the eastern part of the field, show traces of the Fernando sandstone and conglomerate, from which, doubtless, they draw a portion of their oil, the remainder coming from the underlying Modelo formation. Some of the wells of this field are reported to have started at 200 barrels or more, the yield after a short time falling off until it is now between 5 and 20 barrels. The oil is light, its gravity being 35° B., and of greenish color, resembling in a measure that from the same formation in the Puente Hills.

The companies operating east of Santa Paula Creek are the O'Hara, the Chicago Crude, the Paxton Gold Bond, the Pure, the Hartford, the Cuniff, and the Empire.

SESPE FIELDS.

LOCATION.

The Sespe fields include that portion of the territory north of the Santa Clara Valley which lies adjacent to Sespe Creek in the lower 8 or 10 miles of its course, together with the area about Little Sespe, Fourfork, Tar, and Bear creeks and Pine and Coldwater canyons—all in the Sespe drainage system.

STRUCTURE.

In the Sespe district the formations begin to show crumpling, at first gentle, then severe, at the northern border of the Camulos quadrangle. The axis of the general fold lies just outside the quadrangle, while south of the fold is the edge of the broad table of Sespe red beds. (See Pl. III, sec. X-Z'.) In the country adjacent to the table of red beds on the south lies the axis of the Coldwater anticline, the lowest beds exposed being those at the base of the Sespe formation. The eastward extension of this anticline is somewhat uncertain, but it may prove to be continuous with or closely adjacent to the Ivers anticline, the axis of which is the seat of the Ivers oil wells. Both disappear in the folds at the gorge of Little Sespe Creek. South of the Coldwater anticline, confined to the narrow ridge between Coldwater and Pine canyons, is a sharply compressed syncline. This is nearly in line and may be continuous with the syncline that farther east passes through Oat Mountain and becomes one of the principal structural features of the region. In Pine Canyon, at the base of the ridge carrying the syncline above mentioned, the Topatopa formation reappears from beneath the Sespe beds and with northerly dip constitutes San Cayetano Mountain and Santa Paula Peak and the general mountain mass of which they are such conspicuous features. The structure of this mountain mass is monoclinal, developed, doubtless by faulting, from an overturned anticline whose arch could have been but little less than that of the main Topatopa fold farther north. The southern face of the monocline is a bold escarpment of 2,000 feet, in which the strata still show remnants of the arch. The displacement at this fault is probably 3,000 or 4,000 feet.

East of Sespe Creek the more important subordinate folds on the flanks of the main flexure include the Oat Mountain syncline, already referred to; an anticline that crosses lower Pole Canyon at the sharp turn from south to west; and another anticline, a mile farther south, that passes into the valley of Sespe Creek immediately below the entrance of Pole Canyon. Each of these folds is a conspicuous feature, but the syncline is perhaps the most marked, involving the strata from the Modelo to the red beds of the Sespe. In addition to these there are numerous local folds of but little less importance than those just mentioned. One or two of these local flexures are accompanied by faults, forming highly-crumpled zones.

The portion of Sespe Canyon lying above its confluence with Little Sespe Creek is the seat of marked disturbance. Apparently, there has been not only folding in conformity with the general east-west trend of the main anticline, but also a transverse buckling of the strata along strike lines that probably took place synchronously with the development of the principal folds. This buckling resulted in the sharp changes observed in the direction of structural lines and rendered still more complex the general folds and faults that affect the strata, especially in the angle between the main Sespe Creek and its tributary, Little Sespe Creek, and about the mouth of Sespe Canyon. In this region the regularity of the folds described in the preceding paragraphs has been almost completely destroyed, and the real structure is determined with difficulty.

The valley of Sespe Creek below the canyon is filled with Pleistocene deposits that conceal the older formations. East of the stream, in the lower slopes of Oat Mountain, there is a suggestion of the structure in the presence of *Ostrea*-bearing, rusty sandstone and shale, more or less calcareous, that closely resemble the rusty beds at the summit of the Sespe formation. These beds have a general N. 15° W. strike and an easterly dip. The strike becomes northwesterly toward the north, the beds evidently crossing the creek and uniting with those in the much-crumpled area immediately within the canyon mouth. To the south the rusty beds disappear beneath the overlying members of the Vaqueros formation, affording indications of a southerly dip beneath the valley. It is possible, however, that at this point there is a fault which has carried down the Modelo shale, bringing it into contact with the lower members of the Vaqueros formation and, perhaps, even with the rusty upper beds of the Sespe.

The strikes and dips here described suggest the east end of an anticline, most of which lies buried beneath the recent deposits of the Sespe and Santa Clara valleys. It is possible, too, that the trace of an anticlinal axis in the southern escarpment of San Cayetano Mountain, already referred to, may be a portion of the same flexure. In this case the San Cayetano fault may merge into this anticline on the east or it may die out in the much smaller fracture at the south end of Sespe Canyon, suggested in the preceding paragraph.

In the development of the earlier geologic features in the vicinity of the present Sespe Canyon there appears to have been formed, at the close of the Miocene, a structural bay, which was later filled with Pleistocene and, perhaps, Pliocene sediments. The uppermost Fernando or Pleistocene deposits are those which to-day are exposed in this locality. The lower Fernando is not exposed, but its outcrops cover considerable areas to the west and isolated areas also appear to the east, notably at the point of the foothills immediately east of Fillmore and in the vicinity of Piru. East of Piru the Fernando becomes the prevailing formation.

A stratigraphic feature that has considerable significance in connection with the geologic history of the Sespe region is the disappearance of the lower Modelo sandstone. In the area about the head of Hopper Canyon this terrane has an enormous development, its thickness amounting to at least 4,000 or 5,000 feet. Within the Sespe oil fields, however, its maximum is barely more than 1,000 feet and it disappears entirely in the slopes of Sespe Valley south of Oat Mountain. At other points within the confines of the oil fields it passes beneath the surface while still strongly developed, and its ultimate behavior is of course unknown.

The range south of Santa Clara River is seemingly a development independent of, though perhaps synchronous with, the mountains north of the river. There is, however, a degree of geologic relationship shown by the recurrence in the lower slopes of Oak Ridge of beds that from a paleontologic standpoint are undoubtedly the homologues of the lower portion of the lower Miocene which is encountered on Fourfork and Tar creeks. Below this paleontologic horizon in other portions of Oak Ridge, particularly to the west, still lower measures are exposed, consisting of brightly banded red and gray sandstone and sandy clay and heavier cross-bedded and somewhat conglomeratic rusty sandstone. This series is in general appearance very different from the Sespe beds north of the Santa Clara, yet in some of the details there is considerable resemblance. It would seem, therefore, that the horizons mentioned are repeated in the two localities, but with a certain differentiation of sediment and a reduced thickness to the south. Suggestions of such reduction are found even north of the Santa Clara in the westerly slope of Oat Mountain, where the Vaqueros and Modelo formations are perceptibly thinner than in their type localities.

The foregoing description of structure about Sespe Canyon is the result of a reconnaissance made with reference to the mode of occurrence of petroleum in the several localities in which it has been found. Detailed work, careful examination of individual strata for their fossil contents, and the tracing of the several horizons should lead to a much clearer understanding of the complexities that exist and might even alter the present exposition of some of the features. In the main, however, it is believed that the view presented is correct, and so far as it bears on the occurrence of petroleum it may be accepted.

OIL WELLS.

The wells in the Sespe district may be grouped as follows: Those of the Union Consolidated Oil Company in Sespe Canyon, at the base of Sulphur Peak; those in the vicinity of Devilsgate, a narrow gorge of the Sespe 2 or 3 miles below the Union wells; the Ivers wells, still lower in the canyon; the Kentuck wells, also in Sespe Canyon just above the mouth of Little Sespe Creek; the Happy Thought wells, on the south bank of Little Sespe Creek near its mouth; the Foot-of-the-Hill wells, on Little Sespe Creek a mile above its confluence with the main stream: the Fourfork wells, on an upper branch of Little Sespe Creek 2 or 3 miles above the Foot-of-the-Hill wells, and the wells on Tar Creek.

UNION CONSOLIDATED WELLS.

The territory being developed by the Union Consolidated Oil Company lies on the north flank of the main Topatopa anticline. At the time of the writer's visit the company had but a single productive well, located at the sharp bend of Sespe Creek opposite a minor tributary descending from Sulphur Peak and entering the main stream a mile above the mouth of Tar Creek. The purpose of this well was to tap the white sandstone at the base of the Sespe formation, a sandstone that here gives forth a considerable seepage of oil. The gravity of the oil of this well is about 11° B. A second well was about to be drilled by the same company half a mile farther up the canyon, starting in the upper part of the Topatopa formation. It is probable that the intention was to obtain a yield from some of the petroliferous sandstones in the upper part of the Topatopa, seepages from which occur in the river bed a few hundred yards above the location of the well.

REGION OF DEVILSGATE.

The oil wells in the vicinity of Devilsgate are located a short distance above the narrows of the Sespe gorge, close to the axis of the Coldwater anticline. The major part of this anticline lies west of Sespe Creek, the strata in the arch of the fold having been sufficiently crushed to determine the position of Coldwater Canyon. The general trend of the axis is N. 70° E., with an easterly pitch in the vicinity of Sespe Creek. About the end of this anticline the wells of the Russell Company have been drilled. The western limit of the anticline is not known, but it extends well toward the summit of the divide between the Sespe and Santa Paula drainage systems, and may perhaps continue into the upper canyons of the east fork of the Santa Paula. The territory that has been proved to be productive along this fold is at present confined to its most accessible point, Sespe Canyon. The possibilities for the remaining length of the anticline are yet to be determined.

The heart of the Coldwater anticline is occupied by the lower division of variegated strata at the base of the Sespe formation. The arch is well exposed in the canyon walls east of the Sespe channel, where practically the same succession of beds is to be seen as in the region of the Union Consolidated Oil Company's wells 2 or 3 miles farther up the canyon, at the base of Sulphur Peak. The lower members of the formation, however, are not exposed. The arch is comparatively symmetrical, and the wells lie on both sides of the axis and also of Sespe Creek. They penetrate strata lying below the division of greenish-gray shale in the upper part of this member of the Sespe, and it is reported that oil is derived from the white sandstone at the base of the formation, and possibly also from certain strata in the upper part of the Topatopa formation. The source of the oil is, therefore, supposedly the same as in the wells of the Union Consolidated Oil Company. The wells, five in number, yield a black oil of heavy gravity. One of the wells is said to have produced 40 barrels of heavy oil per day and to have yielded enough gas to run a 30-horsepower boiler. Considerable water rises with the oil, but of course is easily separated in the settling tanks. No shipments of oil have as yet been made from this field, the entire product being consumed in the operations of drilling.

IVERS WELLS.

The Ivers wells, located in Sespe Canyon a short distance below Devilsgate, are drilled on and near the axis of a local anticline in the red sandstone lying about midway of the Sespe formation (see fig. 5).

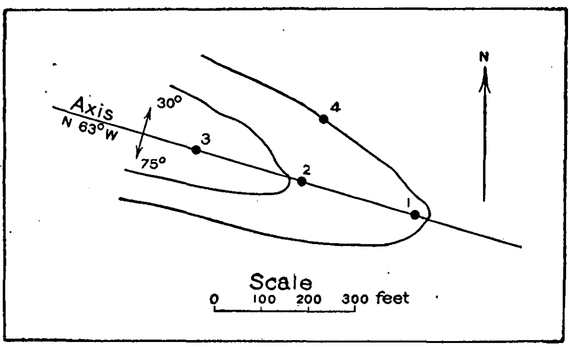


FIG. 5.—Sketch map showing location of Ivers wells with relation to anticlinal axis in the Sespe red beds. Heavy dots, wells productive in 1902. Figures indicate numbers of wells. Lines show outcrop of beds around nose of anticline.

The anticline has a trend of N. 65° W. with an easterly pitch. A transverse section of the anticline indicates a dip of about 75° on the south limb and 30° on the north limb. The particular horizon affording oil is possibly well toward the bottom of the red beds, and is at least 600 feet lower than that from which the oil of the Kentuck wells, one-half or three-fourths of a mile to the south, is derived.

The westward extent of the Ivers anticline was not determined, nor are its relations to the other folds of the region known. Its general trend would carry it toward the mouth of Coldwater Canyon. The change in direction exhibited by the numerous folds in this region suggests that the Ivers anticline may be continuous with the Coldwater anticline, the main curvature taking place at some point between the two groups of wells, probably on the slope toward Coldwater Canyon. On the other hand, the Ivers anticline may be merely a local crumple, one of the many that were evidently formed in this region.

The Ivers wells are four in number, the oldest having been drilled about fifteen years. The early production of this well is said to have been about 20 barrels per day, but the four wells together at the time of the writer's visit were not producing over 11 barrels. It may be added, however, that the condition of the wells was not conducive to their maximum possibilities, for they are cleaned only at long intervals. The oil is black and is said to vary slightly in gravity from well to well, the average being about 17° B. The depth of the wells is reported as between 800 and 1,000 feet.

Incidentally it was learned that the cost of production for the four wells in 1902 was only about $3 per day, including $2.50 wages paid a pumper. Eleven barrels of oil per day at 50 cents yielded $5.50, indicating a profit of $2.50 per day, or about $75 per month.

Concerning the extension of the productive area westward along this fold there is, of course, a question. Seepages, however, are reported for its entire length, or well down the slope on the east side of Sespe Canyon above Devilsgate.

KENTUCK WELLS.

The Kentuck wells, in Sespe Canyon, just above the mouth of Little Sespe Creek, are unique from the standpoint of their structural location, for they lie along or in proximity to the axis of a syncline, which is, moreover, one of the most prominent in the fields north of Santa Clara River. It must be said, however, that the region is one of exceedingly sharp compression, and it may be due to this that local channels and reservoirs conducive to the accumulation of oil have been formed under what might ordinarily be construed as unfavorable structural conditions. Throughout the Coast Range are many instances of oil having been obtained from wells drilled in highly crumpled strata.

The syncline in which the Kentuck wells are located is traceable eastward through the summit of Oat Mountain and across Pole Canyon to Hopper Canyon, where it perhaps unites with another syncline of northeasterly trend, the curvature marking the change in direction which is characteristic of all the successive folds encountered from north to south along this gorge. To the west evidences of the syncline are to be found almost to Devilsgate, and it is possible that in this direction the fold is continuous, though in a curved line, with that occupying the ridge between Coldwater and Pine canyons. The pitch of the axis of this syncline is toward the east, the strata becoming successively higher as distance in this direction is gained. This fold is the most prominent lying between the main Topatopa anticline and the series of folds which pass across the outer hills of this mountain mass.

On account of the unusual structural position of the Kentuck wells a sketch of their location with reference to the axis of the syncline is given in fig. 6. Although they are identified with the synclinal structure it might be said that those on either side of the axis are on the corresponding slope of the adjacent anticline, and perhaps

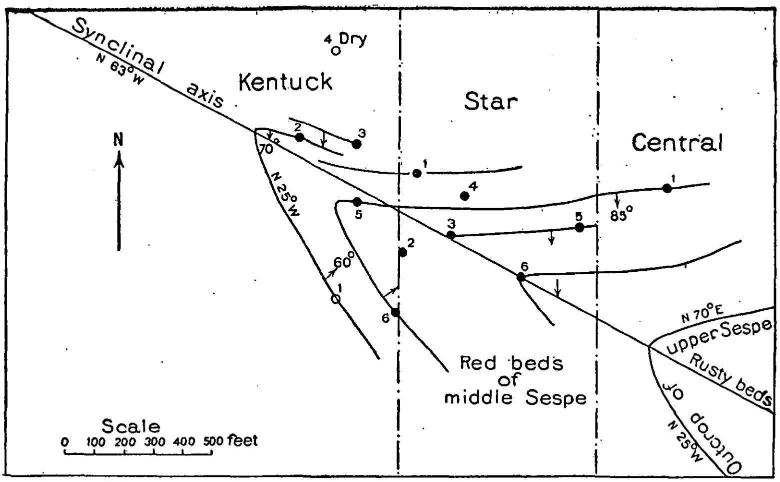


FIG. 6.—Sketch map showing location of Kentuck group of wells in syncline in Sespe red beds. Heavy dots, productive wells; circles, dry wells. Lines indicate outcrops around syncline. Figures refer to numbers of wells or to dip of strata.

this is the true way in which to regard them. Although the syncline is a prominent fold, it is, nevertheless, like the adjacent Ivers, Coldwater, and other anticlines, subordinate to the great anticline of the Topatopa Range, and the effect of the local structure may be lost in the general position which it occupies on the flanks of the far broader fold. It seems to the writer to be only in some such way as this that the presence of oil here and elsewhere along the axes of minor folds and even faults in this region can be accounted for. Incidentally, it is worthy of note that along portions of its length this syncline, as well as the adjacent folds, is so compressed that the plane of its axis is thrown past the vertical, the strata on both sides dipping to the north. In the immediate vicinity of the Kentuck wells, however, this overthrow has not taken place.

The horizons from which the Kentuck wells draw their oil are about midway of the Sespe formation. The logs of the wells show that the strata penetrated are sandstone, with minor layers of shale, all of a reddish color. The depth of the wells varies from 600 or 700 feet to nearly 1,500 feet, and they pass through several zones that furnish oil in commercial amounts. The more productive body of rock, however, is encountered in the lower half of the drill holes. The oil is of a dark green to black color, and its gravity is said to be about 30° B. In January, 1906, only seven wells of this group were pumping, four on the Kentuck property and three on the Star. No. 4 Star was abandoned, because of the oil giving out and water coming in.

HAPPY THOUGHT WELLS.

The Happy Thought Oil Company's wells are located in the SE. ¼ sec. 1, T. 4 N., R. 20 W., on the south side of Little Sespe Creek, immediately east of its confluence with the main stream. The wells are drilled in the steeply dipping beds on the south side of the syncline from which the Kentuck wells derive their oil. In the Happy Thought territory, however, this syncline plunges rapidly toward the southeast, so that, considered from one point of view, the wells penetrate strata dipping southeastward from a hypothetical anticlinal axis somewhere to the northwest, possibly the Topatopa axis. The wells start just below the brown sandstone at the top of the Sespe red beds, the oil, it is said, being derived from several layers of soft sandy shale between harder impervious beds. On account of the steep dip of the rocks and their alternating hard and soft composition, drilling on this property is reported to be difficult.

The company now has three wells down and is drilling a fourth. The wells are less than 1,000 feet in depth, the oil being encountered at about 500 feet. The production is good at the start, and although falling off after a while, soon reaches a normal rate that is about the average of the other wells in this region. The oil is brown and the gravity about 27° B. A 2-inch pipe line connects the Happy Thought property with storage tanks at Brownstone, 3½ miles distant, whence the oil is shipped by rail to San Francisco.

FOOT-OF-THE-HILL OR LOS ANGELES WELLS.

The Foot-of-the-Hill or Los Angeles wells, eight in number, are located on Little Sespe Creek about a mile above its entrance into the main stream. They are the westernmost wells in the southward sweep of the strata after their passage around the broad east end of the general Topatopa anticline. They are also adjacent to, yet in strata not involved in, the zone of highly crushed rocks that form so conspicuous a feature at the confluence of Little Sespe and

Sespe creeks. They are, therefore, to be compared with the Fourfork and Tar Creek wells rather than with the Kentuck, Ivers, and other wells farther west. Drilling was started in the upper, rusty division of the Sespe formation, but the source of the oil is either in the lowermost strata of this division or in the uppermost of the red beds. The wells are from 800 to 1,600 feet in depth, and their oil-bearing zones constitute the fourth general horizon at which oil has been found in the Sespe formation. Their source of supply is below that of the Fourfork wells, which is, therefore, a fifth horizon in this great series of red beds and their associated strata.

While the foregoing statement doubtless covers the general conditions of the occurrence of oil in this vicinity, the fact that the wells

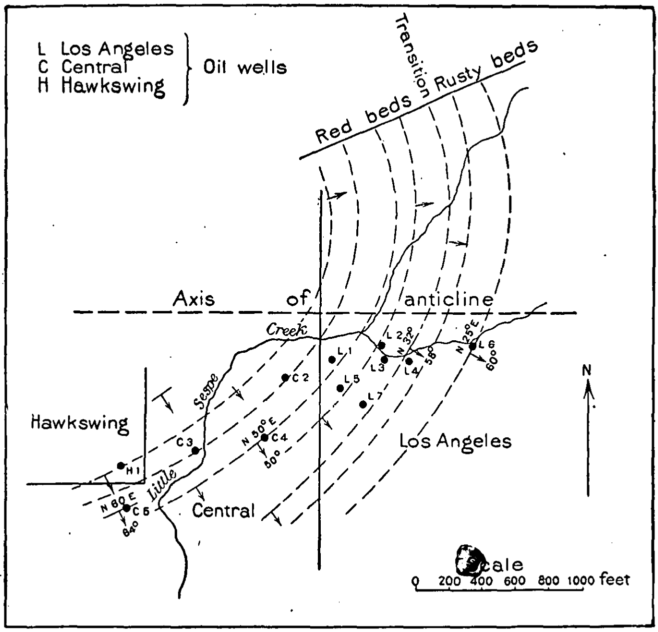


FIG. 7.—Sketch map of Foot-of-the-Hill oil wells, showing location with relation to Little Sespe Creek and the geologic formations. Heavy dots, wells productive in 1902. Broken lines indicate outcrops around nose of anticline. Figures are numbers of wells or dip of strata.

are in line with a minor anticlinal flexure which appears in the summit of the ridge to the east must be kept in mind. It is to be observed also that their position is at a point where the strike of the beds changes rather abruptly from northerly to westerly; they are also in one of the inner concentric belts of strata which are involved in the general Topatopa anticline; thus it may be that the conditions are almost analogous to those of an anticline. In conditions somewhat similar to this many productive wells of the Coast Range fields have been found. Fig. 7 is illustrative of these conditions. The relative positions of the wells are closely approximated, although the results are not those of an actual survey.

At the time of the writer's visit to the locality in 1902 it was impossible to learn the precise depth of the several wells or whether the source of the oil was the same in all. The position of certain wells on strata following the inner curve, and of others on higher strata following an outer curve, taken in conjunction with the actual difference in elevation of about 300 feet, would indicate that possibly the oil zone is of considerable breadth and thickness.

FOURFORK WELLS.

The Fourfork wells, 15 in number, are located along one of the main branches of Fourfork Creek, a tributary of Little Sespe Creek.

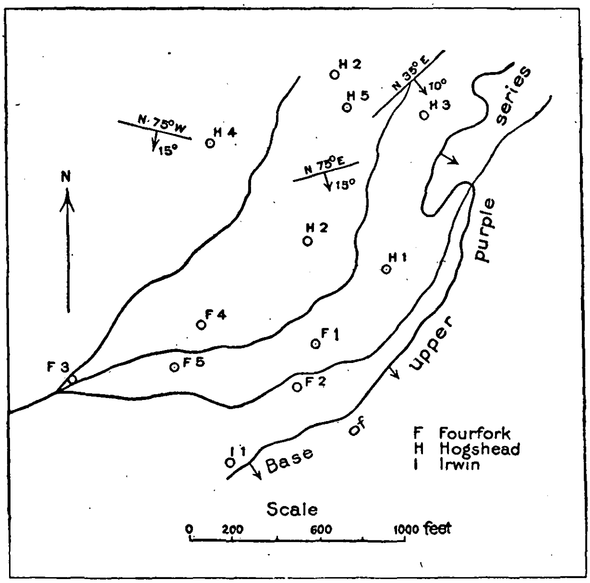


FIG. 8.—Sketch map showing location of the Fourfork group of wells on Fourfork Creek with relation to the base of the upper purple beds. Circles, wells productive in 1902. Figures indicate numbers of wells or dip of strata.

They are but a little west of the divide between this stream and Tar Creek. The altitude of their collars varies from about 2,200 to 2,700 feet above sea level. Their depth is between 1,200 and 1,800 feet, in rocks which strike in general about N. 50° E. and dip 35°-45° SE. The strike is, however, but a part of the broad curve which is assumed by the strata in their passage about the east end of the Topatopa anticline. Stratigraphy and structure are both regular in the vicinity of the wells, a complete absence of the minor flexures which form so common a feature in other portions of the adjacent mountains being noteworthy. It will be recalled that the succession of strata in this vicinity, from the base upward, is the red beds and rusty beds, both regarded as Sespe; the purple shale, gray shale, and upper purple or maroon measures (Vaqueros); the siliceous shale (Modelo), and the Modelo sandstone. The wells penetrate the lower third of the series, starting at horizons in or near the top of the lower purple shale and reaching perhaps the lower part of the rusty, calcareous sandstone which constitutes the upper division of the Sespe formation. It may be even that the upper part of the red beds is reached, red sand having been encountered in the bottom of some of the holes. Fig. 8 indicates the general disposition of these wells. Their production has been comparatively large, 200 barrels a day being the record of several at the start. Within a year, however, most of them decreased to about 60 barrels, and at the present time few yield more than 20 to 30 barrels a day and many much less. The gravity of the oil is about 32° B.—the same as that of the Tar Creek wells.

The feature of especial interest in regard to the Fourfork wells is their altitude, coupled with the fact that they derive their oil from the same general zone, although from a somewhat different horizon, as the Tar Creek wells to the east and those of the Foot-of-the-Hill district to the west. This indicates an undulation of the oil table or the altitude at which the oil stands in the same bed.

TAR CREEK WELLS.

The Tar Creek wells are located in the southwestern portion of the Tar Creek amphitheater, which is drained by several tributaries flowing directly into this stream, including one of its principal branches known as Bear Creek. The wells number between 20 and 30, but are now mostly abandoned, their yield having fallen to but 3 or 4 barrels a day. Originally 100 to 200 barrels was the production. Like the wells of the Fourfork region, these also are distributed along the curve of the strata as they bend about the axis of the Topatopa anticline. The local strike varies, however, slightly on either side of N. 10° E., and the dip is generally between 25° and 30° SE. The strata penetrated are apparently somewhat higher than those of the Fourfork region, and these are, therefore, the highest wells thus far considered in the Sespe region. One at least starts near the top of the gray shale about midway of the Vaqueros formation; the others start somewhat lower; a few wells, the shallowest of the group, start at a comparatively short distance above the rusty beds of the upper division of the Sespe formation. Oil appears to be obtained at depths between 230 and 1,700 feet below the surface, in the lower portion of the Vaqueros formation or the rusty beds in the upper portion of the Sespe. There is evidence, however, that many oil-bearing horizons were passed in the younger beds overlying these members. The presence of oil in these younger beds is undoubtedly due to the occurrence of fine sands or other porous materials, which are distributed through the series and which form the reservoirs for the collection of oil from the more shaly members. The logs of some of the wells indicate that a considerable amount of sand had been penetrated by the drill, but it is probable that the strata are sandy shale of fine grain rather than distinct sandstone. Occasionally red sand has been reported from some of the wells at depths less than 1,000 feet, but it is probable that this is the purple or reddish shale constituting the lower part of the Vaqueros formation.

In the field it was thought that a slight local undulation of the beds could be detected in their broad sweep about the axis of the general Topatopa anticline. A like occurrence was suspected in the Fourfork district. Slight as these are, they should not be disregarded in an attempt to collect facts bearing on the conditions under which the oil of the Coast Range is found.

The yield of these wells is very irregular and the accumulation of oil is readily pumped off. It is reported by the man in charge of the wells that they are affected by rain, the yield increasing materially after a heavy fall.

POLE CANYON.

LOCATION.

Pole Canyon, although but 2 miles from Sespe Creek, lies wholly beyond the area of disturbed rocks that are so well developed at the entrance to the gorge of the Sespe. Although no productive wells have yet been drilled in this territory it is deemed advisable to include here a short discussion of its structure, as it connects two productive areas and may at some future time be found on careful prospecting to be itself an oil-producing region.

GEOLOGY AND STRUCTURE.

Pl. II, sec. F–F′, is illustrative of the conditions along the lines F–F′ of the general map (Pl. I) which are practically those prevailing along Pole Canyon. At the north end of the section, on the eastern flank of Hopper Mountain, the southern and western edge of an extensive outcrop of Modelo sandstone is seen. South of this outcrop is a narrow belt of Vaqueros shale which is locally crumpled into an asymmetric anticline. South of the Vaqueros area the Modelo formation reappears, turned past the vertical at the crest of the ridge east of Pole Canyon, but quickly regaining its southerly dip in the slopes below. At the lower edge of the outcrop there is some confusion in the succession of strata and in the dips and it is believed that a slight displacement has taken place in addition to an overthrow. The overthrow is best observed in the upper Modelo sandstone, which outcrops in a continuous half circle, the axis of the fold pitching about 45° SE. In this sandstone also is well shown the principal syncline of the region, which may be designated the Oat Mountain syncline, its western extremity lying in that mountain. Except for sharp anticlinal crumples near its northern and southern edges, this syncline is comparatively symmetrical, the outcropping stratum in the trough of the fold being the uppermost shale of the Modelo formation. Immediately south of the southern anticlinal crumple is a second fault, designated the Sulphur Mountain fault, its trend being N. 60° W., the direction of its hade doubtful, though perhaps to the south, the downthrow to the south, and the maximum displacement probably more than 1,000 feet. This fracture is traceable diagonally across Sulphur Mountain to the bottom of the Santa Clara Valley; it is also in direct line with certain sharp crumples in Chaffee Canyon, south of the valley, to which, therefore, it may be structurally related. To the west the fault passes into the ridge running south from Oat Mountain, perhaps continuing to Sespe Canyon and merging with the San Cayetano fracture. Over this portion of its course, however, its identification is next to impossible, for the strata are but a succession of shales which may be either Vaqueros, Modelo, or both. These shales are of great thickness and extend southward in unbroken outcrop to the Santa Clara Valley, only a narrow fringe of overlying Pliocene separating them from the bottom lands for a mile or two along their front. The shales display a number of minor folds, but their predominant dip is northward. Just before passing beneath the Pliocene, however, this seems to change to southward, more or less in conformity with that of the younger rocks. Across the Santa Clara Valley, but at a distance of nearly 2 miles, the probable upper members of the Sespe and lower members of the Vaqueros appear, but the intervening structure is unknown.

In a broad way the folds along the section just described appear to divide themselves into three major and half a dozen or more minor folds. The major folds include the anticlines at the north and south ends of the section and the intervening syncline; the minor folds the crumples on the sides of the syncline. Of the major folds the syncline extends farthest toward the area of confused structure at the mouth of Sespe Canyon, perhaps being involved in it; the northern anticline apparently disappears on the southeasterly slope of the general Topatopa fold; while the anticline at the south is lost beneath the recent deposits of the Sespe and Santa Clara valleys.

East of the line of the section both major and minor folds in the main continue to the center of curvature a mile west of Hopper Canyon, where the strata bend from a northwesterly to a northeasterly trend. Indeed, the folds seem in places to bend in like manner or at least to pass into others of northeasterly trend, similarly developed farther east.

HOPPER-PIRU FIELDS.

LOCATION.

The district discussed in this section embraces the territory contiguous to Hopper and Nigger canyons, the lower portion of Piru Creek, and its tributaries Modelo, Blanchard, Lime, and Reasoner canyons on the west and Santa Felicia and Holser canyons on the east. The topography, especially about Hopper Canyon, is very rugged, but considerable portions of the district are accessible over the roads which follow the canyons. Piru, at the mouth of Piru Creek, is the only town of importance in the district.

STRUCTURE.

WEST OF PIRU CREEK.

Within the drainage area of Hopper Canyon the structure varies so abruptly that to indicate it completely would require cross sections every quarter or half mile; a general idea of it may, however, be gained by the examination of sec. G–G′, Pl. IV, which represents a north-south section through Piru Peak.

The Hopper Canyon section proper reveals at its north end a short, though pronounced anticline of northeasterly trend, with a narrow core of Vaqueros beds exposed at its center and the Modelo sandstone arching over and about its end a short distance to the east. In the Piru Peak section this anticline is probably represented by the slight pucker near the north end. Near the middle of the section is the sharply compressed Modelo anticline, showing in massive beds of the lower Modelo sandstone. Between this anticline and that first mentioned are several sharp puckers, the most pronounced being that on the syncline which passes south of Piru Peak. For this portion of the section the thickness of the Modelo sandstone is estimated at about 3,000 feet.

The Modelo anticline is one of the most conspicuous of the secondary folds in the field. The arch shows to best advantage at the head of Modelo Canyon, where the lower Modelo sandstone on either side is sharply compressed. The dips are between 60° and 80°, but the southern limb of the fold is perhaps a little steeper than the northern limb. The anticline may be traced westward to Hopper Canyon, beyond which it either disappears or merges with one or another of the folds that occur in the Vaqueros shale. Eastward the fold is traceable to Piru Creek, where it seems to disappear, unless it should by a sharp curve merge with the Holser anticline, half a mile to the south. In the lower portion of Modelo Canyon the upper sandstone of the formation, together with the underlying shale, shows marked crumpling, the crest of the fold being carried past the vertical. The succession of strata on the two sides of this fold does not appear to be exactly the same, the relative proportion of sandstone and shale being somewhat at variance. This probably is due to concealed faults a short distance south of the axis.

The Modelo anticline is the seat of two important fields of oil. One is developed close to and on either side of the axis of the fold, along the upper course of Modelo Canyon and at the divide between this canyon and the drainage flowing to the west; the other is developed by the Sunset wells near stream level in Hopper Canyon. Other portions of the anticline are as yet undeveloped, but there is no evidence to show that such areas do not contain oil, and it seems probable that search by the drill would be rewarded.

South of the Modelo anticline are two successive synclines separated by a fault. These appear both on the general section (Pl. III) and on sec. G–G′ (Pl. IV). The rocks involved are the lower and upper Modelo sandstones and the intermediate and overlying shales. The evidence of the fault lies in the irregularity of outcrop at the head of the south fork of Modelo Canyon, in the succession of strata in Lyons Peak and farther west, and in the fractured condition of the beds overlooking Hopper Canyon. As exposed at the surface, the fault seems to be confined to the shale between the two Modelo sandstones. It is difficult to estimate the amount of throw that may have taken place, but it is at least 500 feet at the point of maximum development and perhaps much greater. To the east the fractured condition of the rocks continues for at least half the length of Modelo Canyon but here possibly the fault dies out on the southern limb of an exceedingly sharp fold that appears in a prominent knoll just north of the gorge, directly in line with the axis of the Modelo anticline. The effects of the fold doubtless extend as far east as Piru Creek, possibly beyond. The western terminus of the fault is uncertain. South of the fault the upper Modelo sandstone appears to have been folded into a sharp syncline.

Less than half a mile south of the syncline just mentioned lies the Lyons anticline, which is the third important anticline of the region and which crosses the lower portion of Nigger Canyon. The arch is well shown in the divide immediately east of the Lyons wells in the upper Modelo sandstone and the shales immediately above and below. The shale is more conspicuous in the heart of the anticline to the west, while the sandstone may be seen on the slopes toward Piru Valley, curving about the underlying bed. The trend of this anticline is approximately N. 80° E. from Nigger Canyon eastward and S. 65° W. from half a mile west of Nigger Canyon westward. This curve conforms to that of the other folds both to the north and to the south. To the east the Lyons anticline was not recognized with certainty beyond Piru Creek. Its trend is toward the Holser anticline, south of the Holser Canyon, but whether the Lyons or the Modelo anticline is continuous with the Holser is undetermined. In general, there is great confusion of strikes and dips in the slopes of the hills west of Piru Creek for the lower 2 or 3 miles of the valley, and without further details it is impossible to affirm whether or not any of the folds are continuous with other folds that appear to the east of the stream. In the Hopper Canyon section the Lyons anticline shows conspicuously in the middle Modelo shale. It is probable also that a fault has developed along the axis of the fold in this locality, the beds to the south having been carried downward several hundred feet. The maximum displacement appears to be along the east-west lateral entering Hopper Canyon from the east half a mile above its mouth. The fracture seems to have resulted from the excessive local development of the anticline into an overturned or reversed fold. The attendant displacement accounts for the discrepancy in the distances of the Modelo sandstone from the apparent axis of the fold on one side and the other, in the line of the Hopper Canyon section. West of Hopper Canyon the fault is marked by a zone of highly contorted and fractured strata, having a width of about 400 feet. The direction assumed by the fault would carry it directly against the Sulphur Mountain fracture a mile farther west at an angle of 60°.

A short distance south of the Lyons anticline the Modelo formation is unconformably succeeded by heavy conglomerates and sandstones of the Fernando formation. Near the contact east of Hopper Canyon the dip of the younger strata is southward. East of Nigger Canyon, however, the Fernando beds are overturned, with a steep northerly dip, but this probably changes to southerly as the beds pass beneath the Santa Clara Valley. From this point the line of unconformity between the Fernando and Modelo formations passes, with a curvilinear trend, northward above the mouth of Holser Canyon, remaining east of Piru Creek.

At the line of the general section (Z–Z′, Pl. III) the Fernando formation is narrow of outcrop and highly inclined, but otherwise simple of structure. A short distance to the east, however, it is folded, and the folds become more pronounced and extensive across Piru Creek, developing into an anticline of considerable proportions, with several minor crumples near by on either side.

The Fernando and underlying beds pass beneath the Santa Clara Valley, but although the distance across the valley is less than 2 miles the Modelo formation has apparently disappeared on the south side, the principal formation in the hills being the Vaqueros, with Fernando rocks here and there resting against it above the valley level. This occurrence suggests possible faulting along the valley, with overlap of the Fernando on the older Miocene beds.

The fold next north of the Modelo anticline is the syncline that passes south of Piru Peak. It may be seen both on the west side of the divide and east of the peak in the upper portions of Blanchard Canyon. The crumpling is slight and the dip on either side of the axis comparatively gentle.

North of this syncline is another anticline of importance, the axis of which passes east and west across Lime Canyon. The heart of this fold is occupied by the lower Modelo sandstone, which is here exposed over an area of 3 or 4 square miles. It is surrounded by the overlying shale, which in the divide north from Piru Peak forms scarcely more than a thin film. To the east across Piru Creek the shale is succeeded by the upper Modelo sandstone, and this in turn by the still higher siliceous shale at the top of the Modelo; finally the heavy mass of the Fernando sediments sets in, arching about and over the eastward-pitching axis of the fold.

The northernmost fold along this section within the Camulos quadrangle, with the exception of one or two minor crumples, is the Reasoner syncline, the axis of which occupies Reasoner Canyon. This flexure disappears, however, in the divide at the head of the creek, where the heavy lower Modelo sandstone lies in a broad arch about the axis of the Topatopa anticline. To the east the syncline continues for an undetermined distance beyond Piru Creek, being conspicuous in the Fernando conglomerate and sandstone in the hills between Santa Felicia and Devil canyons. Both slopes of the syncline are gentle, the dip generally being less than 40°; but there are areas in which this is somewhat increased by local crumpling.

The northernmost of the folds described in the preceding paragraphs and others beyond the confines of the Camulos quadrangle all fade into or are developed as minor crumples on the general easterly slope of the main Topatopa anticline.

Within the region here described the three prominent anticlines, the Hopper, the Modelo, and the Lyons, have proved oil bearing, the Modelo being the most productive, perhaps on account of its greatest development; the Lyons less so, and the Hopper the least. On the Hopper fold, however, there is at the present time but a single well of low yield.

STRUCTURE EAST OF PIRU CREEK.

The region east of Piru Creek presents a number of approximately east-west folds, some of which, particularly the more northerly, are continuations of those lying west of the stream already described, while others farther south are apparently restricted almost wholly to the area east of Piru Creek, only their extreme points extending westward across the stream. Of the latter, the Holser anticline is the most conspicuous. The axis of this fold lies in the hills a little south of

Holser Canyon. Its trend is slightly north of west. It extends westward across the Piru Valley, perhaps connecting with the Modelo or the Lyons anticline, or with both. To the east it was recognized in the high knoll near the Ventura-Los Angeles county line, beyond which observations in detail were not carried. The surficial formation affected by this anticline is the Fernando, consisting of conglomerate, sandstone, and clay. Along its axis the coarser strata have at various places been impregnated with petroleum, and near one of these, in Ramona Canyon, the Ramona Oil Company is drilling a well, the depth at the time of the writer's visit being about 1,000 feet, but only the slightest traces of oil have been found. North of Holser Canyon is an abandoned dry well, known as the Crown King.

Between the Holser and Lime Canyon anticlines there is undoubtedly a syncline, but the details were not worked out for the region east of Piru Creek. To the south the Holser anticline occupies the space quite to the Santa Clara Valley, but on this limb of the fold (see Pl. IV, sec. I–I′), on the southern face of the outer ridge, a short distance below its crest, is developed a sharp pucker, by which the beds in the lower half of the ridge are turned past the vertical, having a northerly dip.

OIL WELLS.

The oil wells of the Hopper-Piru district comprise the San Cayetano, Sunset, Fortuna, Nigger Canyon, Modelo Canyon, Piru Oil and Land Company, and Holser Canyon wells. All but the last two groups are situated west of Piru Creek.

SAN CAYETANO WELLS.

The San Cayetano wells, three in number, lie near the forks of Hopper Canyon about 3½ miles in a direct line above its mouth and constitute the uppermost development in this gorge. They are drilled in the upper portion of the Vaqueros shale, the northernmost well starting but a short distance below the lower Modelo sandstone. The maximum depth is 600 feet. In one or another of them, however, oil has been found almost from the grass roots down in streaks of sandstone of variable thickness that are interbedded in the shale. With the oil has been found considerable water and gas. These wells lie in a region of great disturbance, which is attributable, perhaps, to the proximity of an anticlinal axis, in the first place, and to a sharp bend in the strata from a northwesterly to a northeasterly direction in the second place. This latter feature is repeated at the Sunset and Fortuna wells farther down the canyon. It may be reasonable to infer that while each of these three oil-bearing localities is that of an anticline, the curvature of the strata as a feature in the great Topatopa system of folds may also have acted favorably on the yield of petroleum in this region, the center of curvature in this case being construed as a part of the axis of an anticline. Such an occurrence has been encountered at a number of points in the oil fields of the Coast Range.

The anticline on which the San Cayetano wells are located has a northeasterly trend from a point a little southwest of the wells to the divide between Hopper and Reasoner canyons. The length of the fold is, therefore, about 2 miles. Except for these wells the anticline is unprospected, but there is no reason for the choice of one location over another. As the territory develops it will be interesting to note the success of drilling to the northeast of the present field. That the anticlines of this region may yield oil in more than one locality is evidenced by the Modelo anticline, which carries the very productive territory of the Modelo wells and also that of the Sunset Oil Company.

The yield of the San Cayetano wells is but 4 or 5 barrels of 14° gravity oil, but it is thought that this will increase as drilling is carried deeper.

SUNSET WELLS.

The Sunset wells, 11 in all, are located on the east side of Hopper Canyon, a short distance above the entrance of a lateral gorge that heads against Modelo Canyon. They penetrate the Modelo sandstone, which occurs also in the wells of the Modelo Oil Company to the east. The dip of the beds is about 45° N.—that is, the wells have been drilled on the northern flank of an anticline the axis of which has a general N. 80° W. strike. Apparently the anticline is the same as the Modelo, although the connection between the two has not been traced. The area covered by the Sunset wells is somewhat less than a half mile east and west by 500 to 600 feet north and south.

The depth of the wells is generally less than 600 feet. The production is between 3 and 15 barrels per day, with a variable and in several wells excessive amount of water. It is thought that the production might be considerably increased by cleaning the wells. The oil is run into a common tank, and the gravity there obtained by the writer was 16.4° B. An initial yield as great as 75 barrels was obtained from certain of the wells several years ago. In January, 1906, only five of the wells were being pumped.

The Sunset wells afford another case of production in a region of highly crumpled strata and a rapid succession of flexures.

FORTUNA WELLS.

The wells of the Buckhorn Oil and Transportation Company are, perhaps, best designated by their early name, Fortuna. The territory is the farthest south of the productive areas in Hopper Canyon, lying about 2 miles north of the town of Buckhorn.

This also is a group of wells that has been developed along the axis of one of the minor anticlines. (See Pl. VIII, *B*.) The fold has an apparent length of barely 1 mile, and it is in the midst of a series of closely spaced flexures. The strike of the anticlinal axis is N. 50° E., and the wells are distributed along the axis in almost a direct line. Fourteen holes have been drilled to a maximum depth of about 1,000 feet. The rocks penetrated are the siliceous and earthy shales that lie between the lower and upper Modelo sandstones. In one or two instances, however, the lower portion of the upper sandstone, which consists of alternating thin sandstone and shale beds, has been perforated. This horizon is the highest that is productive in the Hopper Canyon district. The Sunset wells draw from strata near the base of the Modelo formation, while the San Cayetano wells receive their supply from the upper members of the

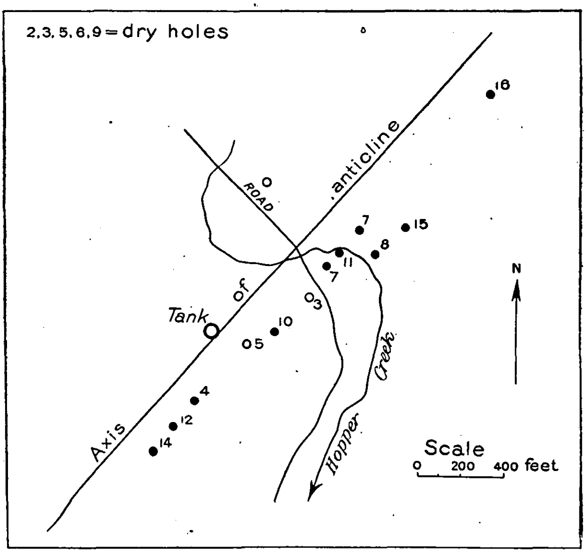
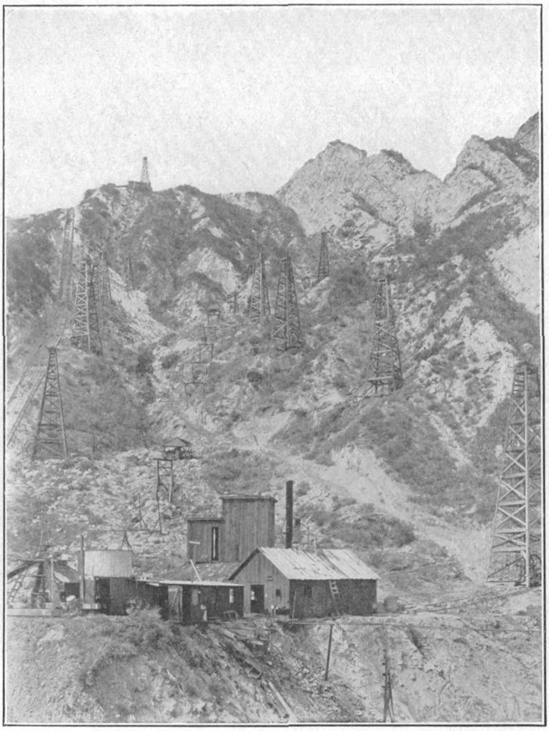


FIG. 9.—Sketch map showing location of Fortuna wells with relation to the anticlinal axis. Heavy dots, productive wells; small circles, abandoned wells. Figures indicate numbers of wells. (See Pl. VIII, *B*.)

Vaqueros formation, which in turn are higher than any of the productive horizons in the Tar Creek and other districts already considered.

The maximum yield of any one of the Fortuna wells as reported is 75 barrels per day, but it is now generally less than 10 barrels. The gravity of the oil is about 14° B. Much water is pumped with the oil, being separated in tanks at the wells. The oil is pumped to storage tanks on the line of railway about 2 miles distant.

The accompanying sketch (fig. 9) illustrates the general distribution of the wells with respect to Hopper Creek and the axis of the anticline.



A. MODELO WELLS, MODELO CANYON, VENTURA COUNTY.

B. FORTUNA WELLS, HOPPER CANYON, VENTURA COUNTY.

NIGGER CANYON WELLS.

The three wells in Nigger Canyon are owned by L. H. Lyon, of Los Angeles. They are located at the head of the southern of the two east forks of the canyon and start in strata which are close to the line of division between the upper Modelo sandstone and the underlying shale—that is, they penetrate a zone which is practically the same as that from which the Fortuna wells obtain their oil. Their depth is approximately 1,000 feet. Oil springs occur in the immediate vicinity and may have determined the selection of this territory for drilling. The wells are close to the axis of a prominent anticline, which is perhaps one of the leading secondary folds north of Santa Clara River. This fold has an apparent length of about 5 miles, but no wells except these have been drilled upon it. Its trend in general is about N. 80° E., but varies somewhat from point to point. Toward the east, in the direction of Piru Valley, this fold has the appearance of passing into the Modelo anticline or one of its minor crumples. To the west it is traceable beyond Hopper Canyon, where it becomes more or less obscure in the great body of shale which separates the two principal Modelo sandstones and where it comes into close proximity with one of the important northwest-southeast folds that extend from this point westward to Sespe Canyon. Of the Nigger Canyon wells, Nos. 1 and 3 are a short distance south and No. 2 is immediately north of the axis of the anticline, which at this point trends N. 83° W. These wells are from a year to three and a half years old. Nos. 1 and 3 yield each 5 to 8 barrels per day, but No. 2 was flooded with water, which has prevented its being in service. It is reported that in No. 3, at a depth of 65 feet, a body of asphalt was encountered, which drilled with difficulty. It was hard at the top and of the consistency of maltha at the bottom, and is supposed to have filled a fissure in the shale. The oil was found at intervals from a depth of 10 feet to the bottom of the wells. Gas occurs in small amounts, and water to the extent of about one-third of the oil has been encountered.

MODELO CANYON WELLS.

The structural feature of chief interest in Modelo Canyon is an anticline in which the lower Modelo sandstone is sharply folded as diagrammatically represented in Pl. III, sec. X–Z′ and Pl. IV, sec. G–G′. The general aspect of the locality is shown in Pl. VIII, *A*. A second feature of minor importance is the succession of crushed folds, with faults, at the head of the south fork of the canyon, one-fourth to one-half mile south of the anticline.

The Modelo anticline has already been referred to, notably in the general description of the geology of the region between Hopper and

Piru creeks. Nowhere, however, is the fold more perfectly and symmetrically developed than at the head of Modelo Canyon, nor is the lower Modelo sandstone anywhere more typically represented than in this region. The exact horizon of the sandstone that outcrops at the divide between the east and west drainage is probably in the lower half of the sandstone member, but owing to the steepness of the dip on both limbs of the anticline, amounting to 70° or 80°, it is questionable if the wells have penetrated to the base of the formation, although a depth of 1,500 feet has been attained.

The length of the Modelo anticline is somewhat uncertain; to the west, beyond Hopper Canyon, it may pass into one of the folds of that region, while to the east it may prove to be continuous with the anticline that lies immediately south of Holser Canyon. The Modelo wells are located about the middle of this fold and on either side of its axis. This is one of the few instances in the Coast Range where oil wells have been developed midway of a fold or in such close proximity to its axis. It may be worthy of note that the Modelo anticline lies but a short distance north of a line of sharp crushing and folding, thus repeating a relationship between the productive anticlines and faults that has been established in several of the California fields, notably those of the Puente Hills. The developed area of this district is thus far confined to the lower Modelo sandstone, but the structure is continued eastward into the overlying shale and the upper sandstone.

The relative positions of the wells along this anticlinal fold in Modelo Canyon, considered with the depths at which oil is obtained, are of interest; for instance, between the lowest and the highest well there is a difference in altitude of nearly 800 feet; between well No. 18, the lowest, and No. 19, at an elevation slightly below the highest well, there is a distance of perhaps 700 feet; in No. 18, with a depth of 1,090 feet, the lowest oil occurred at 930 feet; in No. 19 the lowest oil was found at 805 feet, at the bottom of the well. This would indicate a curve of the oil table, which corresponds somewhat with the slope of the present surface along the anticline.

The general trend of the axis of the Modelo anticline is but 3° or 4° north of west, although in approaching Hopper Canyon and the valley of Piru Creek the direction becomes N. 80° W.

The wells of the Modelo Oil Company number 24. One is drilled directly in the divide between Modelo and Hopper canyons, two a short distance west of this divide, and the remainder east of the divide for half a mile down Modelo Canyon. The accompanying three logs from the records of the company have been selected to show the composition of the Modelo sandstone. Well No. 14 lies near the middle of the group, No. 24 is about 500 feet west of the divide, and No. 18 is the easternmost well in the proved area.

Logs of wells of the Modelo Oil Company. Modelo Canyon and vicinity.

WELL NO. 14.

	Thickness.	Depth.
	Feet.	*Feet.*
White sand	190	190
Oil sand (oil)	210	400
White sand	60	460
Oil sand (oil)	70	530
White sand	70	600
Oil sand (oil)	35	635
White sand	75	710
Oil sand (oil)	70	780
Water sand	40	820
Oil sand (oil)	50	870
Water sand	10	880

WELL NO. 24.

Sand rock	115	115
Adobe	5	120
Clay	25	145
White sand	10	155
Adobe	15	170
Sand rock	10	180
White sand	315	495
Sand and adobe	45	540
Adobe	5	545
Oil sand	50	595
Water sand	25	620
Sand and adobe	70	695
Oil sand (oil)	10	705
Sand rock	50	755
Sand and bowlders	120	875
Hard sand	20	895
Water sand	60	955
White sand	15	970
Oil sand (oil)	42	1,012
Hard sand	23	1,035
Sand and adobe	75	1,110
Oil sand (oil)	35	1,145

WELL NO. 18.

Blue sand	121	121
Gray sand (oil at 160 feet)	39	160
Black shale	25	185
White sand	45	220
Black shale	30	250
White sand (water at 290 feet)	45	295
Black shale (water at 316 feet)	35	330
White sand	50	380
Clay	28	408
White sand (gas and water at 495 feet)	132	540
Clay	20	560
White sand (oil at 870 feet)	310	870
Gray sand	35	905
Shale and sand (oil at 923 feet)	25	930
Asphaltic sand	5	935
Gray sand	65	1,000
Water sand (oil at 1,030 feet)	30	1,030
Clay	43	1,073
Water sand	17	1,090

The figures in the first column of the above log represent the distances for which each individual stratum was encountered. As the dip of the beds is between 65° and 80°, these amounts are far in excess of the actual thickness of the respective beds.

From the log of well No. 18 it seems probable that the thickness of the productive sands at the several horizons is slight.

The logs are given in the vernacular of the driller. It is probable however, that adobe and clay are one and the same, except that the former is perhaps somewhat more tenacious than the latter. Shale is distinguished from clay by being less sticky and more inclined to come up in minute slivers. The sands are distinguished by colors, but this feature is not significant. The water sands are those in which water has been encountered in drilling, and it is to be observed that they are in alternation with the oil sands, the two being in places adjacent; in places separated by a clay parting. Mr. Sperry, manager of the Modelo Oil Company, believes that at least a thin stratum of shale between such sands is the rule. It is difficult to explain the alternation of water and oil sands if consideration is given to the supposed transmigration of the oil from its seat of origin in the shales into the sandstones, which serve as reservoirs. It has been suggested that this alternating occurrence may be accounted for by considering each pair of layers—the oil above and the water below—as occupying an isolated channel or reservoir, the segregation having taken place after their entrance into the containing strata on account of the difference in specific gravity of the two fluids. Nearly all the wells periodically pump more or less water with the oil, at times in the proportion of 3 barrels of water to 1 barrel of oil, at other times in equal amount. The continuity of sands bearing water and oil need not be regarded as indicating that the two are mixed in their natural occurrence, but only that both flow into the well from the same bed, the oil perhaps resting upon the water in the reservoir.

The bowlders referred to in the log of well No. 24, between the depths of 755 and 875 feet, are unquestionably the concretions that characterize the lower Modelo sandstone.

The yield of the Modelo wells is between 5 and 15 barrels per day, and Mr. Sperry states that since 1897 there has been no perceptible decrease in the amount. Of course for the first few days the yield was considerably in excess of these figures. The oil is black and its gravity ranges between 25° and 32° B., with perhaps 28° as an average. The wide variation in gravity of the oil from these wells is a feature that is difficult to explain.

Strong seepages are found along the canyon in the débris that fills the bottom. The sandstone in the arch of the anticline also is dark, with bitumen contents, especially on the northern side of the axis.

WELLS OF THE PIRU OIL AND LAND COMPANY.

The productive wells of the Piru Oil and Land Company are located in the valley of Piru Creek, about 2 miles northeast of Piru. At present two wells yield oil and one water. They penetrate conglomerate and sandstone, with some clay, which are believed from their fossils to be the Fernando formation. The general dip of the strata is from

45° to 60° or 70° S. and the strike varies slightly on either side of east and west. The particular horizon in the Fernando is somewhat uncertain, by reason of the proximity of the wells to what appears to be a line of unconformity between this formation and the older Modelo beds. It is, however, undoubtedly well up in the Fernando, if the section across the hills in front of the wells and directly north of Camulos is to be taken as a criterion.

The structural position of the wells is also somewhat in doubt, for no anticline is encountered along the creek for the distance of a mile. On the other hand, there is within half a mile south of the wells a marked east-west disturbance, which has at one point the appearance of a syncline, at another of an overturn of the beds adjacent to a sharp crumple, and at still another of a fault. About half a mile northwest of the wells is the anticline, near the axis of which the Nigger Canyon wells are situated. It is possible that the effect of this anticline extends as far distant from its axis as this group of wells. They are from 300 to 600 feet deep, and undoubtedly their oil is derived from the conglomerate and sandstone of the Fernando, a horizon higher than any other yielding oil north of Santa Clara River.

The production of these wells is but a barrel or two daily of what is said to be 15° gravity oil. The oil is black and thick, and much water is pumped with it, separation being effected in tanks.

Several other wells have been drilled on the property of the Piru Oil and Land Company lying along Piru Creek, extending from the mouth nearly to Reasoner Canyon. These ventures, however, have not been crowned with success.

WELLS OF HOLSER CANYON.

Less than half a mile south of Holser Canyon is one of the more prominent anticlines that have affected the Fernando formation east of Piru Creek. The continuation of this anticline to the west was not determined, but from its position and trend it may pass into the Modelo fold; on the other hand, like so many other folds in this region, it may spring from the system west of Piru Creek, but maintain an independent position east of the stream.

Two wells, the Ramona and New Camulos, are located a little south of the axis of this anticline, in tributaries of Holser Canyon, and north of the canyon, between half a mile and a mile north of the axis, is the Crown King. None of these wells has yet found oil. The rocks of Holser Canyon are conglomerate and sandstone, with local beds of argillaceous shale. Some of the sandstone shows the presence of a considerable amount of bitumen throughout its mass and it is probable that drilling operations are conducted here on this account.

OIL FIELDS SOUTH OF THE SANTA CLARA.

GENERAL STATEMENT.

The oil fields south of Santa Clara River involve an area having an east-west length of 29 miles and a width of from one-half mile to 4 miles. For convenience of discussion the territory is divided into four fields, which lie at varying intervals along the front of Oak Ridge and the Santa Susana Mountains, none being yet developed on the slopes of South Mountain. Enumerated from west to east they are the Bardsdale and the Torrey-Eureka-Tapo fields, on the north flank of Oak Ridge; the Pico field, comprising Pico, Dewitt, Towsley, Wiley, Rice, and East canyons, along the Santa Susana Mountains; and the Elsmere field, containing the Elsmere and Placerita wells, on the spurs of the San Gabriel Range. (See Pl. V, p. 36.)

The fields are developed along the axes of the Oak Ridge, Torrey, Eureka-Tapo, Pico, and Elsmere anticlines. The Placerita wells are quite independent of the others and are located on the northward-dipping schists of the San Gabriel Range. The formations involved are the Sespe (Eocene); Vaqueros (lower Miocene); and Fernando (largely Pliocene). All of these are productive. In addition the schists of the San Gabriel Range afford some oil.

BARDSDALE FIELD.

LOCATION.

The Bardsdale field, as here described, includes South Mountain and Oak Ridge as far east as the vicinity of Chaffee Canyon. As all of the proved oil territory in the field lies north of the crest of the range the detailed descriptions will deal largely with the northern slopes.

GEOLOGY AND STRUCTURE.

The South Mountain-Oak Ridge anticline extends the entire length of the two ridges from which it receives its name. The axis is well down on the northwest slope of the mountains, in most places at a distance of less than half a mile from the edge of the Santa Clara Valley and locally but a few rods away. At the west the axis disappears beneath the valley filling a few miles from the end of South Mountain, leaving the extremity of this ridge wholly on the southern limb of the fold. At the east the anticline terminates abruptly against the northwest-southeast system of folds that sets in at Chaffee Canyon and continues thence eastward to Fernando Pass.

The trend of the anticlinal axis varies in sweeping curves between N. 65° E. and east and west, displaying a certain degree of parallelism with the nearer strikes and with at least one structural curve—that on the southern slope of San Cayetano Mountain, north of the Santa Clara Valley. While, therefore, the South Mountain-Oak Ridge-Santa Susana uplift is undoubtedly an independent unit of structure, its development was very probably synchronous with the mountain building to the north. Transversely the fold is unsymmetrical at nearly all points, the southern limb having much the gentler dip and the strata on this side of the axis showing less severity of crumpling than those on the north side. The axis of the anticline is also undulatory, the high points being midway of the length of South Mountain and of Oak Ridge.

A transverse section of the anticline at Sulphur Canyon, which practically marks the division of South Mountain from Oak Ridge, shows between 1,000 and 2,000 feet of conglomerate, sandstone, and shale that are probably Fernando, and at least 500 or 600 feet of chalk rock and siliceous shale which have been described as of the Modelo type, but concerning the proper stratigraphic reference of which some doubt has been expressed. The shale and "chalk rock" occur in the axis of the fold, while the conglomerate and its associated strata rest unconformably upon its southern flank, forming the higher portions of the ridges and extending far into the Simi Valley. On the northern flank the Fernando beds do not appear, the underlying shale extending to the Santa Clara Valley. The anticline is somewhat contracted in the region of Sulphur Canyon, and no beds older than those of Modelo type outcrop. A short distance to the east and west, however, the fold broadens perceptibly and lower formations are successively exposed.

In South Mountain the lowermost beds are red and gray banded sandstone and clay, which are tentatively regarded as the partial correlative of the Sespe beds north of the Santa Clara, and hence of Eocene age. The formation is here especially conspicuous for its brilliancy of coloring and the sharp contrasts therein. At least 500 feet of strata are exposed opposite Santa Paula, but the formation occupies the heart of the anticline and its total thickness may be much greater. Overlying these are other heavy sandstone and shale, resembling in general aspect certain phases of the chocolate-colored and gray-banded beds of the Vaqueros formation farther east and bearing fossils similar to those of the Vaqueros. Still higher are siliceous shale and "chalk rock" of the Modelo type, bearing not only the customary limestones of that formation, but also several beds of fine-grained, gray sandstone. The "chalk rock" is somewhat more conspicuous in South Mountain than farther east. The formation as a whole, however, shows the same general characteristics as in Oak Ridge, even to the red, lava-like appearance, the probable result of the burning of its petroleum content. The shale, with its brilliant colors, forms the crest of South Mountain, and extends for a considerable distance down its western slope. It is succeeded by the Fernando formation.

Minor crumples appear in South Mountain, but in the main the direction of dip is to the south, northerly dips being confined practically to the northern side of the anticline along the edge of the Santa Clara Valley.

East of Sulphur Canyon the anticline rapidly opens, and at Grimes Canyon (see Pl. III, sec. D–D′) it attains its greatest development. Here are exposed, in consequence, lower rocks than elsewhere—the deep-yellow sandstone that has been described as the possible correlative of the rusty beds in the upper portion of the Sespe formation north of Santa Clara River. It is overlain by red and gray banded beds, except on the north, where the valley has been eroded through these beds and into the older strata below. The yellow sandstone is also underlain by red and gray beds, as shown by the logs of the wells of the Bardsdale Crude Oil Company. Whether or not the heavy mass of red sandstone and conglomerate which constitutes the greater part of the Sespe formation north of the Santa Clara is present here at still greater depths is undetermined. The formations throughout give evidences of marked change within comparatively short distances, and it may be that the red beds of the Sespe have practically disappeared.

Overlying the red and gray beds are rocks which have been identified by their fossils as a portion of the Vaqueros formation, consisting of conspicuous and persistent sandstone at the base and summit, and chocolate-colored and gray arenaceous shale, with occasional bands of limestone between. They bend down over the anticline between Garberson and Wiley canyons, and west of a point a little west of the mouth of Shields Canyon are adjacent to the Santa Clara Valley. At Wiley Canyon the axis of the anticline presents a small core of the underlying red and gray beds. The outer body of the Vaqueros displays a slight syncline, a flexure that is the beginning, perhaps, of the more highly disturbed conditions that exist but a short distance farther east. A secondary anticline also occurs well up the slope of the mountain between Shields and Garberson canyons, with a length of slightly over a mile.

The Vaqueros is easily confused with the Fernando formation, as the sandstone and conglomerate of the two formations bear considerable resemblance. It is probable, however, that the Fernando does not appear west of Torrey Canyon, but from that point eastward it grows in importance to the east end of the Santa Susana Mountains, where it is very prominent.

Siliceous shale and "chalk rock" of the Modelo type overlie the Vaqueros and form the crest of Oak Ridge for nearly its entire length.

Although in South Mountain this formation appears to contain minor divisions of sandstone, these seem to be wanting in Oak Ridge. On the southern slope of the ridge, above the shale and unconformable with it, are the Fernando conglomerate, sandstone, and clay. These for the most part lie well down the slope of the mountain, but here and there reach the crest.

OIL WELLS.

UNION AND BARDSDALE CRUDE WELLS.

A single oil field has been developed in the South Mountain-Oak Ridge anticline. It lies opposite Bardsdale, extending along the axis of the fold from Grimes Canyon westward for a mile and a half. Two companies are operating—the Union Oil Company and the Bardsdale Crude Oil Company. The territory of the former is adjacent to Grimes Canyon; that of the latter is the westward extension of the field. The wells of these companies are sunk in the rusty-yellow conglomeratic sandstone described as the lowermost formation of this district and possibly of Eocene age. The wells are located along the highest portion of the anticline, the elevation of any particular bed diminishing in both directions along the axis of the fold. The records of the wells indicate that oil is found in the rusty sandstone and in the underlying red and gray sandy beds at depths of 300 to 815 feet. The total depth of the wells varies from 500 to 1,000 feet. The oil is black and its gravity is reported as ranging from 23° to 32° B., the average being about 30°. In one instance an oil of about 17° B. was encountered. Occasionally water is pumped with the oil, but this is exceptional where a good landing stratum is obtained for the casing. Such a stratum is usually found among the red bands of the beds underlying the rusty sands. These, being generally more argillaceous than the gray bands, afford a more nearly water-tight bed. The wells of the Union Oil Company have been steady producers for a number of years, the decrease reported to the writer being but slight. These wells yield a large quantity of gas, which is used entirely for fuel. Of the total number of wells the Union Oil Company pumps about fifteen, the Bardsdale seven. The foreman of the Union Company remarks that if the gas be retained in one of the two strings pumped by them the wells of the other have an increased product, and that if the gas is not taken from the wells the pressure in them becomes so great as to hold the oil back. Numerous devices have been used for drawing out the oil, one of them being the ordinary steam ejector.

At several other points in the Oak Ridge anticline wells have been drilled, but without success. This may be due in part to insufficient depth and in part to their location beyond the oil zone. In Garberson Canyon, for instance, a well has been drilled to a depth of over

1,800 feet, producing nothing but water. In Shields Canyon, however, west of Garberson, a trace of oil was found at 500 feet, the total depth of the well being 850 feet. The gravity of this oil is said to have been 29.5° B., but much water was encountered with it.

TORREY-EUREKA-TAPO FIELDS.

LOCATION.

The district discussed in the following paragraph embraces Oak Ridge east of Chaffee Canyon and the western portion of the Santa Susana Mountains as far east as the head of Tapo Canyon. Within it are three productive areas—those of Torrey, Eureka, and Tapo canyons.

GEOLOGY AND STRUCTURE.

As will be gathered from the description of the geology of the Bardsdale district, there is a marked regularity in the stratigraphic succession of the formations and in the anticline into which they have been thrown from the west end of South Mountain to Chaffee Canyon. Here, however, the regularity ends. The region between Chaffee and Tapo canyons shows a highly complicated geologic structure, and there is great confusion in the stratigraphic succession, resulting from the presence of folds and faults and the difficulty of distinguishing between formations, owing to a lack of distinctive characteristics in the beds and to changes in the relative proportions of the coarse and fine sediments from point to point.

The first break in the regularity that exists to the west appears in a small gulch at the foot of Oak Ridge immediately west of Chaffee Canyon. At this point the end of what for convenience may be termed the Chaffee syncline appears in "chalk rock," siliceous shale, and limestone that are believed to be of the same formation as similar rocks which form so great a portion of the summit of Oak Ridge, having been brought into this position, almost at the edge of the valley, by arching over the axis of the Oak Ridge-South Mountain anticline. The general trend of this syncline is about S. 30° E., the dip on either side averaging perhaps 35°, although steepening sharply as the axis is approached. The syncline increases in prominence as it crosses the drainage of Chaffee Canyon, and at the summit of the ridge at its head becomes a conspicuous feature in the crest line. The details of this syncline have not been gathered in full, but apparently the heavy fossiliferous sandstone which outcrops in bold escarpments in Wiley Canyon plunges beneath the axis to reappear on the northeast side in the ridge that separates Chaffee and Torrey canyons. The conditions observed in Chaffee Canyon suggest that only the lower beds of the siliceous shale and "chalk rock" are involved in the fold, although at the southeast end of the syncline, on the southern slope of Oak Ridge, a considerably greater thickness has been folded in.

The direction of the Chaffee syncline is at variance with that of every other fold that has been observed in the ranges south of Santa Clara River. Moreover, it lies between two systems of folds, either of which might be said to terminate against it. One of these systems includes the anticline traceable from Wiley Canyon westward to the end of South Mountain; the other is that passing from the region of Torrey Canyon in a S. 65° E. direction to the west end of the Santa Susana Mountains. It is worthy of note, too, that the position of the Chaffee syncline is nearly in direct line with the principal fault in the hills north of the Santa Clara.

In the region of Torrey and Eureka canyons the geology is extremely complicated, but the general facts appear to be as follows: The formations exposed include 150 or 200 feet of red and gray banded sandstone and arenaceous clay of the Sespe, about 600 feet of fossiliferous sandstone and chocolate-colored and gray sandstone and shale of the Vaqueros, perhaps 400 feet of siliceous shale and chalk rock of Modelo type, and a great body of heavy-bedded sandstone and conglomerate, in some of which have been found fossils identifying them as the Fernando (Pliocene). These formations are shown in a section of Oak Ridge across the Torrey field—the oldest beds at the heart of an anticline at the northern edge of the productive area, the youngest on the southern slope of the ridge and again at its northern base, the siliceous shale and "chalk rock" at the mountain crest, and the Vaqueros on the upper and lower middle slopes of the northern front.

The structural lines of the Torrey field have a trend approximating N. 65° W., contrasting in this respect with those of Oak Ridge to the west and in harmony with those to the east, the dividing line between the two systems being the Chaffee syncline, already described.

The principal fold of the Torrey field (see Pl. IV, sec. H–H′) is an anticline that crosses the ridge between Torrey and Smith canyons at the summit of the easterly grade leading to the developed territory. This anticline has not been traced eastward to the edge of the Torrey basin, but directly in line with it at this point is a similar fold, which is probably its continuation. To the west the anticline crosses Torrey Canyon, being particularly conspicuous in its lower slopes, becoming less so in the ridge between Torrey and Chaffee canyons, and disappearing to a mere trace in the lower portion of Chaffee Canyon as it approaches the Chaffee syncline. The trend of this anticline, which may be designated the Torrey, is N. 65° W. The inclination of the strata on either limb varies from point to point, but in general may be taken at about 35°. Southward from the axis the dip is comparatively regular to a point beneath the summit of Oak Ridge. To the north, however, the dip continues but a short distance when it gives way to a southerly dip, the syncline thus formed being hardly less conspicuous than the anticline itself.

The formations exposed in the Torrey anticline include, at the axis, a small outcrop of red and gray banded beds, believed to be the Sespe formation; overlying these is the principal formation of the field, heavy sandstone and chocolate-colored and gray-banded shales, which, by their fossils, have been identified as lower Miocene (Vaqueros), nearly 1,000 feet thick; succeeding these, on the south the siliceous shale of the Modelo, which forms the crest of Oak Ridge opposite the Torrey field, and on the north—the siliceous member apparently being wanting—the heavy sandstone and conglomerate that are regarded as the Fernando. The Fernando is, however, of small extent in this vicinity, becoming prominent in the region of Tapo Canyon and attaining its maximum development several miles farther east, opposite Pico Canyon and beyond.

A second anticline in the Torrey field lies in the lower slopes of the hills and is probably the west end of that believed to exist along the channel of Eureka Canyon, this, in turn, being continuous with the main Tapo anticline farther east. This fold may be seen to advantage in the west wall of Torrey Canyon, midway between its mouth and the forks half a mile up. East of this the flexure is not quite so pronounced and is, therefore, not so readily and perhaps not so correctly defined. Between Eureka and Torrey canyons the axis of the fold pitches to the west, while the strike of the beds is generally north and south. There is considerable doubt concerning the structure and the succession of the strata in Eureka Canyon. At first glance the regularity appears to be unbroken from the crest of Oak Ridge to the outer face of the lowermost foothills, the entire cross section, except at the summit of the ridge, presenting a southerly dip. From the region of Tapo Canyon, however, the main anticline may be traced with only slight irregularities to the divide between the Tapo drainage and that of Eureka Canyon, but at this point there is a sharp change in the position of the strata, as if the anticline had been severely compressed and the plane of its axis had been pushed northward with a dip of perhaps 60° to 90° to the south. (See Pl. IV, sec. I–I′.) In the higher portions of Eureka Ridge, a short distance north of this anticline, there is a syncline of secondary importance, which also has probably suffered strong compression. The resultant position assumed by the beds thus influenced by the compound flexure described is one of southerly dip, with local obliteration of the axes of both folds, and an apparent continuous succession of strata from base to summit of the mountain. It is evident, however, that if this should prove to be the correct structure there is a duplication of beds in the cross section referred to. At the mouth of Eureka Canyon there is an exposure of Fernando conglomerate and sandstone, bearing fossils identifying them with the beds of Packard Hill, near Santa Barbara. Their dip is vertical, the change from the southerly dip of the older strata immediately south being somewhat abrupt. This is probably due to unconformity rather than to a structural break. The Eureka-Tapo anticline appears to be coextensive with the Torrey, a mile to the south. Neither has been traced from one end to the other, as delineated on the map (Pl. I), but by reason of the alignment of several folds observed independently it is thought that all are parts of a single crumple. As in the case of the Torrey anticline, productive territory has been developed in proximity to the axis of the Eureka-Tapo fold, the western field being that near the mouth of Eureka Canyon, the eastern including several branches of Tapo Canyon.

Between the two anticlines thus described is a syncline which has not been traced through from west to east, but which is supposed to be continuous, as represented on the map. It may be seen on both sides of Torrey Canyon, but in the eastern wall of Smith Canyon the fold, which is so pronounced to the west, is considerably obscured, perhaps by faulting along its axis. A sharp disturbance of the strata is recognizable in a vertical cliff of shale and sandstone directly across Smith Canyon from the easterly grade to the Torrey wells. In the line of the syncline, also, there is a similar flexure near the summit of Oak Ridge, and this in turn is in line with the Tapo syncline, a flexure a few hundred yards south of the main anticline in Tapo Canyon.

There are other folds of minor importance in this region, here and there, sharp or even developed into faults of small extent. The larger folds that have been described converge near the mouth of Chaffee Canyon as they approach the Chaffee syncline.

The formation chiefly involved in the flexures of the Torrey-Eureka region is that of Vaqueros age. To the south in the higher portion of Oak Ridge the siliceous shale of Modelo type is also involved in a minor degree. On the southern slope of the main ridge, near the Torrey road, the general dip, aside from numerous minor crumples, is northward, and a short distance north of the outcrop of the Fernando formation a sandstone suggesting one of the Vaqueros beds occurs in a position not at all out of harmony with the general structure. The actual correlation of this bed, however, remains undetermined and it has not been indicated on the map. North of the Vaqueros area, at the foot of Oak Ridge, is the Fernando, which also is involved in the general folding that has taken place.

It is possible that faults occur within the area of the folds referred to in the foregoing paragraphs. The greatest disturbance appears to have been in the line of the syncline separating the Torrey and

Eureka-Tapo anticlines, in the eastern rim of the Torrey amphitheater, the facts pointing to an elevation of the strata north of a possible plane of fracture.

The Tapo anticline is traceable for 3 or 4 miles across the northern spurs of the easterly portion of Oak Ridge, its axis lying from one-half to two-thirds the distance from base to summit. The general trend of the fold is about N. 70° W., the dip of the strata on either side of the axis varying between 75° and 85°. The heart of the anticline is occupied by a mass of brown shale and interbedded concretionary sandstone. These are believed to be the equivalents of the banded chocolate-colored and gray sandstones and shales in the vicinity of Wiley Canyon and farther west, and, if such is the case, are of Vaqueros age. On the other hand, the concretionary phase of the sandstone resembles the lower Modelo formation north of the Santa Clara, but no fossils have been found to decide the point. Many of the sandstones of Tapo Canyon are highly bituminous, and along the crest of the flexure in the several forks occur seepages of petroleum of considerable size. In the main canyon, either on the axis or slightly to the south of it, is a gas well, but its depth and the horizon from which gas is derived are unknown.

The Tapo anticline appears to die out toward the east in a mass of crushed strata at the head of the westernmost branch of Salt Creek on Santa Susana Mountain. In a westerly direction the geologic conditions are somewhat uncertain, but in the ridge separating West Tapo and Eureka canyons the axis has the appearance of bending rather sharply to the north. On the other hand, as already suggested, the geology of Eureka Canyon and the adjacent slopes is very complicated, and for a definite conclusion concerning the relations of the thousands of feet of very similar beds additional field work is necessary. The position of the Tapo anticline is but tentatively indicated on the map (Pl. I).

Between 100 and 200 yards south of the Tapo anticline is a syncline which is pronounced in the region of the main forks of Tapo Canyon, but which west of this disappears in the general crumpling on the higher slopes in front of Oak Ridge. In an easterly direction its axis approaches that of the anticline, and both are apparently lost in a common mass of crumpled strata at the end of the Santa Susana Mountains.

The zone of excessive crumpling, embracing the Torrey and Tapo anticlines and their associated synclines, passes from Oak Ridge into the west end of the Santa Susana Mountains, in part also crossing the crest of the range at the low point opposite the head of Tapo Canyon. In the region thus indicated the disposition and succession of the strata are very anomalous, and from a topographic standpoint there is a distinct offset in the alignment of the two ranges, the west end of the Santa Susana lying a little farther north than the east end of Oak Ridge. The topographic relation of the mountain ridges may be due to the development en échelon of successive anticlines, but the anomalies of stratigraphy suggest the presence of a strike fault a little south of the Tapo syncline. For instance, in the northern slope of Oak Ridge between the Eureka and Tapo drainages, the apparent succession of beds is quite the reverse of the normal. Both the siliceous shale of the Modelo and the chocolate-colored shale and sandstone of the Vaqueros maintain a northerly dip, and the inference is that the latter are the younger. It is probable, however, that along the line indicated there has been displacement, the strata south of the fracture plane having been depressed, though to what extent is yet undetermined. This would agree with the explanation already suggested of the positions assumed by beds about the head of Smith Canyon. South of the Santa Susana Mountains the line of the fault is marked by great complexity of strata, it being impossible to recognize horizons and, in consequence, the relations of the beds. The fault plane from Tapo Canyon eastward appears to lie somewhat diagonal to the general trend of the formations; the area of siliceous shale, a prominent feature to the west, is diminished almost to disappearance, and the difficulty of correctly interpreting the structure is even further enhanced by the approach of the line of unconformity between the Vaqueros and Modelo beds and the Fernando formation. The Vaqueros beds are, however, chiefly involved in the crushing south of the range crest. The breadth of the zone of severely crushed and folded strata is hardly less than a mile, while its continuity can be traced for a distance of at least 10 miles.

The axis of a somewhat prominent anticline, trending a little south of east, passes through the knoll at the southeastern extremity of Oak Ridge, about three-fourths of a mile north of the parallel 34° 20′ N. and 2 miles west of the meridian 118° 40′ W. The eastern half of the fold involves the Fernando formation, but the western half lies almost wholly within the area of siliceous shale, though not far from the northern edge of the Fernando. The general trend of the axis is more nearly east and west than the direction assumed by the zone of crumpling. These two features therefore diverge toward the west, the zone of crushing and fracture turning to the north of Oak Ridge, the anticline passing to the south.

In addition to the foregoing, there are many other minor crumples of greater or less breadth and linear extent, particularly within the area of siliceous shale. All have a general direction of S. 70°–85° E., but their continuity has not been traced out.

The formation in the middle fork of Tapo Canyon from which oil is derived is a succession of sandstone and shale. The sandstone is generally thin bedded, and its proportion to the shale diminishes toward the base of the series. Concretions, some of them comparatively large and rounded, characterize certain horizons. The shale is for the most part earthy or sandy, but through it may be traced bands of harder and in some places even siliceous rock. Limestone concretions are also sparingly present. Both shale and sandstone have been more or less impregnated with petroleum, as well as with iron and salts of other minerals. Along the axis of the anticline, wherever crushing has been particularly severe, occur important seepages of petroleum.

Overlying the thin-bedded sandstone and shale, with comparatively sharp passage from the one to the other, is heavy-bedded sandstone divided by minor layers of sandy shale. The sandstone is gray to yellow in color, although yellow appears to characterize more generally the lower beds. The sand is coarse and locally gritty or even pebble bearing. Well up in the mass conglomerate appears, becoming in the outer ridges of the Santa Susana Mountains, a conspicuous feature in the geology. The sandstone and shale in the lower 1,000 feet of this younger formation have been impregnated in varying degree with petroleum, and from some of them come seepages, indicating considerable richness. From one or another member of this group of beds is derived the oil in the producing wells of Tapo Canyon.

Conformability appears to exist throughout the succession of strata above described, from the lowest, encountered in the heart of the anticline, to the highest, observed at the outer edge of the range. It is difficult, therefore, to recognize any true basis on which to segregate the beds into distinct formations, yet in a broad way they are separable into a mass of conglomerate and associated heavy-bedded sandstone and shale which bear a distinct resemblance to the Fernando of other localities in the Santa Clara district on the one hand, and thin-bedded sandstone and shale of a siliceous character, which closely resemble the banded chocolate-colored and gray shale and sandstone farther west in Oak Ridge and the Modelo in the range north of the Santa Clara on the other. For the sake of mapping, the dividing line has been taken at the lower horizon of the heavier conglomerate in the main Tapo Canyon, a quarter to half a mile above its mouth, occurring somewhat farther up on the streams to the east and somewhat lower down on those to the west.

OIL WELLS.

The oil wells in the territory just described comprise, in order from west to east, the Torrey, Eureka, and Tapo groups, each being designated by the canyon in which they are drilled.

TORREY WELLS.

The productive territory of the Torrey anticline, forming what is known as the Torrey field, embraces an area of about 1 square mile, the length being twice the breadth and lying with the strike of the rocks, which gradually bend from N. 65° W., the direction prevailing on the side of the flexure, to northwest, north northwest, and north as the strata round its end. The axis of the anticline passes close to the northern edge of the field, the wells, with a few exceptions, having been drilled in the strata of gentler dip, 30° to 40°, south of the axis. In all there are between 50 and 60 wells, aligned in seven or eight concentric arcs, in accordance with the curves assumed by the outcropping strata. The wells nearer the axis penetrate the red and gray banded argillaceous sandstone that has been correlated with a portion of the Sespe formation, while those more distant are perhaps entirely confined to the sandstone and shale of the Vaqueros.

It is said to be usually impossible in this field to identify horizons in one well with those in another, even though the two locations are adjacent. The oil sands also vary in thickness from a few feet to 150, and even the thicker beds, it is reported, can not be identified from well to well. It is, however, the opinion of the writer that considerable order might be worked out with the aid of carefully prepared cross sections.

The oil has a gravity of 30° to 35° B. and resembles that derived from the same formation north of the Santa Clara, especially that from the region of Fourfork and Tar creeks. The depth of the wells varies from 600 to 2,000 feet, the deeper wells being those farther away from the axis of the fold. North of the Torrey anticline the productive territory is apparently confined to the east end of the field where the distance from the syncline immediately north and from the fracture possibly accompanying it is greatest.

Concerning the extent of the Torrey field beyond the present developed area, it may be said with some degree of assurance that to the west and north it is likely to be limited by structural conditions to nearly the existing lines. In the other directions no prediction can be made.

EUREKA WELLS.

The wells of Eureka Canyon are located in its lower reaches, most of them being grouped at the sharp turn half a mile above its mouth. The geology of the immediate region is somewhat doubtful, but if the structure is that of a highly compressed compound fold, as suggested on page 82, the locus of the wells is not far from its anticlinal axis; moreover, the developed territory is in the vicinity of a prominent curve in the stratification planes, the axis having been pushed somewhat northward between Eureka and Torrey canyons. The wells penetrate the Vaqueros sandstone, conglomerate, and shale, but whether any of the beds are duplicated it is impossible to determine. Such duplication may have taken place, but it has had practically no effect on the productiveness of the territory. The wells are located a little over a mile north northeast of the Torrey group, the geology of the two fields being quite distinct.

Twenty-one wells were in operation or drilling at the time of the writer's visit. They vary in depth from 600 to 1,200 feet, and the strata passed through, according to the logs, embrace sand, arenaceous shale, dark, adobe-like clay, and the usual "hard shells" of the drillers. The character of the beds varies every 50 to 125 feet in depth, but sandstone predominates. Oil sand, so-called, appears to be encountered at depths of 540 to 620 feet. Water is found both in the upper parts of the wells and beneath the lowermost oil sand recorded. Well No. 20, of the group at the turn of the canyon, is the only one in which pebbles are reported. These are, perhaps, a local development of one of the more prominent sandstones that lie near either the summit or the base of the Vaqueros beds. Usually but a single oil sand shows in a well, and it is the opinion of the superintendent that the producing horizon is the same throughout the field.

The gravity of the oil averages, it is said, 24° B., but in some instances rises to 26°. This difference, as compared with the Torrey oil, is inexplicable, for both are believed to be derived from the same formation. Their horizons, however, may be different, and in the Eureka field the sediments appear to be coarser, while the strata are far more fractured, if the interpretation of the geology here given is correct. The latter feature would tend to permit the easier escape of the lighter hydrocarbons, leaving behind the heavier oils, which now constitute the product.

The yield has been from 1 to 40 barrels per day. The field has, however, never been one of large production, but from the records the wells appear to have maintained their supply with remarkable uniformity. The log of one of these wells is appended:

Log of well in Eureka Canyon.

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy shale and "adobe"	50	50
Gravel, with water	25	75
Dark, black "adobe"	265	340
Arenaceous shale	135	475
Soft sand	50	525
Blue, caving shale, with thin sands interlaminated, becoming solid at 580 feet	35	570
"Hard shell," this marking the top of the oil sand, according to the driller's statement. At this point, also, water is shut off	15	585
Oil sand	10	595
Water sand with gravel distributed through it (abundance of water, no oil)	245	840
Soft, blue sandy shale	160	1,000
Coarse gravel (water)	127	1,127

No evidence of the red and gray banded series of probable Eocene age has been found in any of the holes in this field.

TAPO WELLS.

Wells have been drilled in the main fork of Tapo Canyon and also in each branch of a westerly tributary. Those at present producing lie along the east fork of this tributary. They are four in number, although from their designation, Nos. 12 to 15 inclusive, it is to be inferred that several others have been in existence in earlier days. Indeed, one or two of these old wells still contain a slight amount of oil. The producing wells are sunk in northward-dipping sandstone and shale a mile north of the axis of the Tapo anticline. They yield at present from 5 to 40 barrels of oil per day. The gravity is 20° to 24° B., the 20° oil being produced by the well highest up in the canyon and lowest as to the strata penetrated. These wells are about 200 feet apart and range in depth from 460 to 1,200 feet. The oil sand is encountered at 235, 465, 940, and 865 feet, from the well farthest up the creek to that lowest down, respectively. The wells lowest on the dip are the greatest producers. The dip of the measures is from 50° to 60°, and it is impossible to say that a single bed produces oil for the entire field, although this is suggested by the increasing depths of the wells in the direction of the dip. More or less water is pumped with the oil, and it is the opinion of the superintendent that the two are mined and come from the same bed. The amount of water, however, is slight, the proportion being given as 1 of water to 40 of oil. Inasmuch as water-bearing sands overlie the oil sands it may be that a leak occurs which would account for its presence with the oil. Water was also found beneath the oil sand in the well farthest up the gulch and has been encountered in some of the wells now abandoned. All the wells yield gas, the deeper the well the greater the quantity.

The whole of the lower half of the Vaqueros strata exposed in Tapo Canyon shows a greater or less impregnation with petroleum. No unusual amount appears to have been assembled in proximity to the axis of the main anticline, and it may be that the productive territory is a particularly rich portion of the series of beds which, from some cause or other, has held its oil better than the great mass of the beds in the region. From the surface no reason can be seen for the enrichment of one portion of the formation over another portion, and except for strong seepages in proximity to the wells one locality might as readily have been chosen for development as another.

The logs of the Tapo wells show a succession of blue clay, brown shale, gray sandstone, fine to coarse, and in one instance a trace of conglomerate. The thicknesses of these several materials, which are constantly repeated, vary from 5 to 200 or more feet, the average being, perhaps, between 20 and 75 feet.

PICO FIELDS.

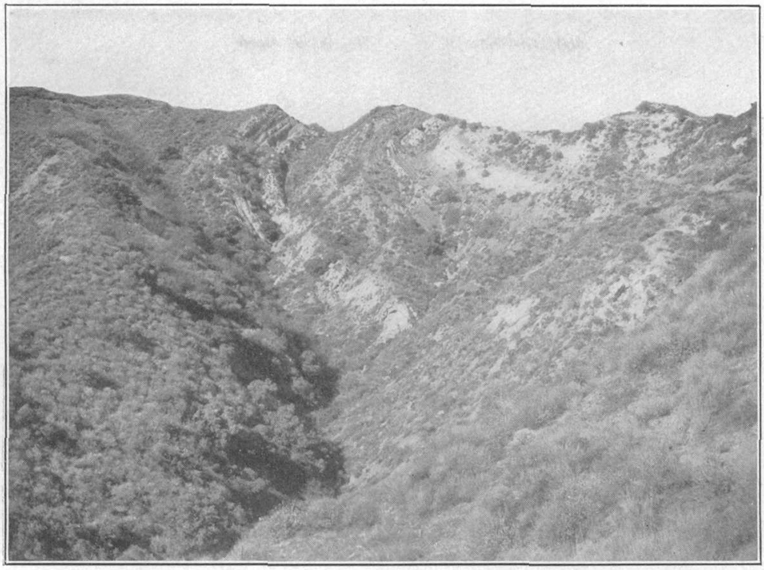
LOCATION.

The Pico district, the western part of what is popularly known as the "Newhall district," comprises the region of the Santa Susana Mountains from Tapo Canyon to Fernando Pass. The Newhall district is divided into the Pico and Elsmere districts for the purpose of this discussion, the geologic conditions in the two subdistricts being quite different.

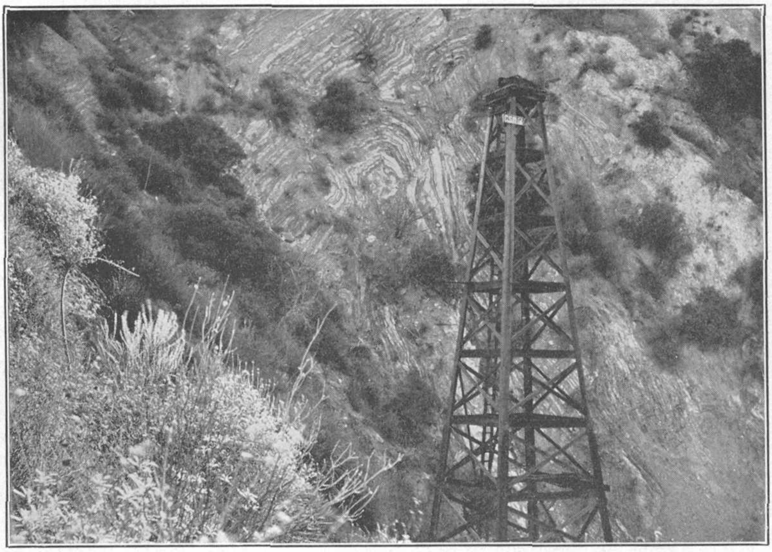
GEOLOGY AND STRUCTURE.

In the body of the Santa Susana Mountains there are many flexures in the siliceous shale of the Modelo and in the shale and heavy sandstone of the Vaqueros. Certain of these flexures along the northern front of the range have become of primary economic importance from the development of rich oil-bearing territory adjacent to their axes. With these alone the following pages have to do. (See Pl. IV, secs. J–J′, K–K′, L″–L–L′, and M″–M–M′.)

Chief among such folds is one which may be designated the Pico anticline. This extends for perhaps 10 miles along the northern front of the range. Its trend is N. 60° W. and the strata on the southern limb dip 25° to 30°, on the northern limb 50° to 70°. At the west the anticline originates in the divide between the waters of Pico and Salt canyons. The east end passes out of the range a mile or so south of Fernando Pass, the actual terminus being apparently in the foothills of the San Gabriel Range, or in the valley edge immediately adjacent. The axis of the anticline may be seen in any of the canyons of the Santa Susana Mountains draining to the Santa Clara. (See Pl. IX, *B*.) Its trend is somewhat irregular, though in its entirety the fold maintains the direction given very closely. In the hills between Dewitt and Pico canyons a minor fold of the same nature branches off to the north, but this in few places amounts to more than a pronounced pucker in the beds affected by it. The Pico anticline is traceable at least to Wiley Canyon, and perhaps even to the forks of Rice and Gavin canyons. South of the main fold is a syncline which parallels it for its entire length. This originates at the west at about the same point as the anticline, in a mass of highly crumpled strata in the divide between Pico and Salt canyons. After a divergent course of 2 or 3 miles the anticline and syncline lie parallel with each other to the San Fernando Valley. At certain points along the syncline, as, for instance, at the head of Pico Canyon, there is some evidence that faulting has taken place immediately to the south, the strata south of the fault plane being downthrown and the plane itself inclined at an angle of 50° to 70°. The evidence, however, was not followed up,



A. OVERTURN IN VAQUEROS FORMATION, WEST SIDE OF PICO CANYON, LOS ANGELES COUNTY.



B. PICO ANTICLINE, PICO CANYON, LOS ANGELES COUNTY.

and on the map (Pl. I) the syncline is in the main given as unbroken. The similarity between this fold and the Tapo anticline is worthy of remark. In each case there is a principal anticlinal fold, with a parallel syncline on the south, and faults and a highly crushed zone in one instance and perhaps also in the other still farther south. The position of the Pico anticline is en échelon with that of the Tapo to the west and also with that of the Elsmere to the east, all being somewhat diagonal in trend to the general direction assumed by the ranges.

The strata involved in the folds described above and underlying the adjacent regions include a heavy deposit, presumably of lake beds, in the low hills about the junction of Santa Clara River and its tributary, Newhall Creek; conglomerate, sandstone, and clay of the Fernando, of a horizon possibly somewhat younger than that of the Fernando beds that lie immediately east of the mouth of Piru Creek; and a succession of brown and chocolate-colored shale, comparatively thin interbedded sandstone, and local conglomerate, which will doubtless prove to be of lower Miocene (Vaqueros) age, of the same horizon as the beds of similar nature in the region of Torrey and Tapo canyons and in the northern front of Oak Ridge farther west. The assumption that the beds last mentioned are lower Miocene is, in the absence of fossils, based on their lithologic resemblance to those of other localities in which determinative forms occur, on the presence of organic siliceous shale here and there in the beds of chocolate-brown color and of more earthy character, and on the occurrence of concretionary bodies, round to elliptical, in the sandstone of the formation. The shale and sandstone regarded as Vaqueros are confined to the heart of the anticline and to the regions adjacent which are affected by the subordinate folds in connection therewith. They occupy the entire front of the range to their line of union with the Fernando beds near the base.

The Fernando formation displays marked regularity of strike and dip, and from any of the high points within the range may be seen arching about the foothills from the vicinity of Newhall across Pico Canyon to the mouth of Salt Creek, bending in its trend from N. 50° W. to N. 75° W. A conspicuous feature of this formation is a great mass of bluish-gray clay that occurs a short distance above its base. It is particularly strong of outcrop in Road Gulch, perhaps on account of the gentle dip and wide erosion of this portion of the formation. The conglomerate which overlies this clay is heavily developed in beds from 50 to 300 feet thick.

The line between the Fernando formation and the beds regarded as Vaqueros is placed at the horizon of the uppermost brown or chocolate-colored shale. Conglomerate extends below this horizon, but not of the importance attained by those above. The manner of its occurrence is somewhat perplexing, for it is interspersed among the chocolate-colored shale and does not show the individuality of the two zones of heavy conglomerate that lie at the base and summit of this formation in the region of Wiley and other canyons to the west. Unconformity between the two formations probably exists, although angular discrepancies were not detected at any point in the Pico region. The absence, however, of the heavy mass of siliceous shale between the Vaqueros and the Fernando beds along the lower northern slopes of the Santa Susana Mountains is noteworthy. South of the Oak Ridge-South Mountain anticline, in the lofty upper escarpments, this shale attains a thickness of 300 to 500 feet and separates the Vaqueros from the Fernando conglomerate and sandstone on the southern slopes of the mountains. The absence of the siliceous shale in one locality and its presence in the other, notwithstanding the short interval between the two, suggest unconformity between the Fernando and the underlying beds. Moreover, there are several areas over which distinct unconformity is observable.

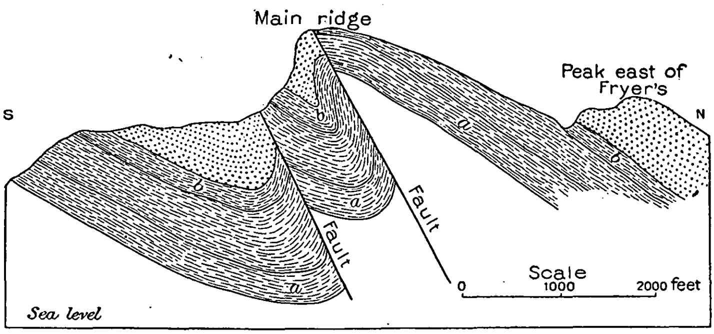


FIG. 10.—Section through Fryers Peak east of Fryer's ranch. Dots represent sandstone; fine lines, shale; a, b, beds of shale.

The Pico anticline has proved one of the most productive folds in the Santa Clara Valley. It exhibits marked regularity; the fold maintains a comparatively uniform elevation from west to east for nearly its entire length, and the beds involved are of uniform texture and uniformly disposed with reference to one another and to the axis of the fold. The inference seems natural, therefore, that such conditions would be favorable to the extended field that has been developed.

The northern slope of the Santa Susana Mountains presents considerable regularity in the succession of beds from the crest nearly to the line of the Pico oil field, but to the south of the crest, especially in the area opposite the Salt Creek drainage and the more easterly tributaries of the Tapo, there is a conspicuous crumpling in a zone half a mile wide, trending N. 70° W. The most severe crushing is to be seen immediately beneath the summit of the range, where in the chocolate-colored shale and its accompanying sandstone of the Vaqueros two or three anticlines, with their intervening synclines, occur in close succession; indeed, surface conditions suggest faulting similar to that shown in fig. 10. Within this zone or possibly slightly south of it is a dry well, the depth of which is unknown to the writer. The linear extent of the zone is unknown, but disturbance of the strata may be detected as far as the divide between the Simi and San Fernando valleys, and this series of fractures may prove continuous with the great fault suggested by the Whitney survey as south of at least the eastern half of the Santa Susana Range.

It is very evident that there is a pronounced unconformity between the Fernando conglomerate, sandstone, and clay and the older formations of Miocene, Eocene, and Cretaceous age south of the Santa Susana Mountains. The line dividing the Fernando from the older formations is, however, indicated only in a general way on the map, for the region was not studied with a view to geologic detail, being somewhat beyond the areas of developed oil fields.

PRODUCTIVE FIELDS OF THE PICO DISTRICT.

The productive fields of tne Santa Susana Mountains, enumerated from west to east, include those of Pico, Dewitt, Towsley, Wiley, Rice, and East canyons, all on the northern slope. With the exception of those in Dewitt Canyon, which are apparently on a secondary crumple, all are ranged along the main Pico anticline, some to the north, others to the south of the axis. The anticline apparently maintains a uniform elevation except at the extremities, where it pitches east and west, respectively. This uniformity of level may account for the fact that the anticline has been found productive for so large a proportion of its length. This is in marked contrast to the development along the Oak Ridge anticline, the axis of which is decidedly undulating and which has been proved productive only at its point of maximum elevation opposite the town of Bardsdale. Doubtless many other factors enter into the explanation of the relative productiveness of the two anticlines, but the conditions above mentioned are to be considered in any attempt to account for it.

Only a single formation, the Vaqueros, is present in the productive oil fields of the Santa Susana Mountains. Its correlation is based on lithologic similarity to recognized lower Miocene beds of other localities, no fossils having yet been found in it in this district. The strata include a large proportion of brown argillaceous and arenaceous shale, much interbedded sandstone, and considerable conglomerate. Brown and white bands, a feature characteristic of this formation from Chaffee Canyon westward, are far less conspicuous in front of the Santa Susana Mountains, but conglomerate has a much greater development. As elsewhere, the shale includes at short intervals thin strata of a siliceous nature and limestones that are more or less concretionary. The sandstones and sandy shales are also concretionary, and here and there a bed may be found which bears a striking resemblance, except for thickness, to the lower Modelo sandstone north of the Santa Clara. The entire series has been more or less impregnated with bitumen, to which is probably due, in a large degree at least, its brown color. Except for local variation in the materials composing these beds, there is considerable regularity in their appearance as a whole, and the general succession is comparatively well maintained from one end of the region to the other. The local irregularities in composition, however, render it next to impossible to correlate the logs of wells a mile or more apart along the anticline. The dips are steep in many places, yet the crushing that is found in the region of Tapo and Torrey canyons is here wanting.

OIL WELLS.

PICO CANYON WELLS.

The wells of Pico Canyon, which belong to the Pacific Coast Oil Company, are located not far from the west end of the Pico anticline, which terminates in the divide between Pico and Salt canyons. In the western half of the productive territory the axis of the fold has a distinct pitch to the west. Between 40 and 50 wells have been drilled in the field, some more productive than others, but nearly all yielding at least a few barrels of oil. With the exception of three at the upper forks of the canyon, all are on the northern limb of the anticline, not far distant from the axis. They are sunk not only in the canyon, but even on the summits of the sharp knobs on either side of the gorge, the lowest and highest having a difference in elevation of 700 feet. The depth of the wells varies from 600 to 3,000 feet. The logs were not ascessible to the writer, but the superintendent stated that no two holes showed the same succession of beds and that it was impossible to distinguish horizons as between wells. It is also stated that there is no clearly defined horizon at which oil occurs. As an instance, it is reported that of three wells nearly in line of strike, in beds of approximately the same amount of dip, and within a distance of but a few hundred feet, one afforded a certain oil at a depth of 1,600 feet, another a like oil at 1,200 feet, while the third, midway between the other two, was 1,900 feet deep and showed not a trace of oil. The superintendent under whose direction the wells had been drilled suggests the possibility that the oil passes from one horizon to another; this is not contrary to one or two observed occurrences, where beds impregnated with asphalt, originally petroleum, have been exposed. Of the many wells in this canyon the three south of the anticlinal axis are said not to be so productive as those on the north, yet other factors may enter into this difference besides the mere positions of the wells. The general strike of the beds in the Pico field is about N. 55°–60° W. The dip north of the axis is about 55°, south of the axis 65°, though locally on each side it is 80°.

The average production of the wells at the present time is from 12 to 25 barrels, although a few yield but 1 to 5 barrels. At the start some wells produced as high as 80 barrels, gradually dropping to the steady average maintained at the present day. The oil is green in color and its gravity 38° to 40° B. It occurs in sandstone, conglomerate, and shale, but apparently the texture of the bed is without influence on the oil. The age of this field, or the life of its oldest well, is about twenty-eight years.

DE WITT CANYON WELLS.

The wells of Dewitt Canyon are but three in number. It is reported that although they afford a slight amount of oil, the yield has never warranted operating. The well in the main canyon is located immediately south of the axis of what is apparently a secondary fold thrown off to the north from the Pico anticline, midway between the Pico field and Dewitt Canyon. The other two wells were not visited by the writer, but probably lie somewhat to the north of the axis of this fold. The formation penetrated is principally the brown shale of the Vaqueros. The strike of the axis of the branch anticline is more nearly east and west than that of the main fold to the south. The beds south of the axis dip 40°, and those north of the axis 45° to overturned. The well in the main canyon is said to have produced 1 barrel of black oil a day, of a gravity of 20° B.

The subordinate anticline on which the Dewitt wells are located may be traced eastward as far as Wiley Canyon, but no further developments have taken place along it, and its appearance is in many places that of a mere crumple rather than of a well-formed fold.

TOWSLEY CANYON WELLS.

In Towsley Canyon 6 or 7 wells have been drilled, all but 1 being near the axis of the Pico anticline. Three of the wells lie on the southern slope of the fold, the remainder on the northern slope. The strike of the beds is about N. 55° W. The northerly dip varies from 25° to 65°, the southerly from 25° to vertical and overturned. The wells near the axis of the fold yield oil, water, and gas, the 3 north of the axis producing somewhat in excess of those south of it; all, however, are small. One well, at a distance of about half a mile south of the axis, is dry. Seepages of oil occur on the axis on both sides of the canyon. The strata in the heart of the anticline are brown shale interbedded with siliceous shale and carrying hard yellow silico-calcareous beds more or less in the form of concretions. The gravity of the oil in this canyon is 26° B.

WILEY CANYON WELLS.

The wells of Wiley Canyon lie 200 or 300 feet south of the anticlinal axis. The Pacific Coast Oil Company drilled 13 wells in this canyon ranging from 600 to 1,626 feet in depth[a]. Only 3, however, were found productive. The gravity of the oil is reported to be 30° B. At the time of the writer's visit to the locality the Wiley Canyon wells were idle.

RICE CANYON WELLS.

The producing wells of Rice Canyon include 2 of the Pacific Coast Oil Company and 6 belonging to W. P. Rice. The Pacific Coast wells are in the bottom of the canyon, the Rice wells on the hill to the east. All are in brown shale bearing gray-yellow concretions of limestone. These wells lie on the south limb of the Pico anticline, comparatively near the axis. The dip on this side is 22° to 35°, on the north side 25° to 75°. The crest of the anticline over an area 100 yards wide is considerably crumpled. The Rice wells vary in depth from 825 to 1,600 feet. They yield gas, oil, and water. In No. 5, the deepest well at the time of the writer's visit, oil sands are reported at 800 and 1,550 feet. The yield of the wells is small.

Farther up Rice Canyon, one-half mile above the sharp turn from east to north, is the Newhall well, 1,500 feet deep, but without oil. The strike of the beds is here N. 65° W. and the dip 60° S. The well is only about 100 feet north of the axis of the Pico syncline, which lies parallel with the anticline at a distance of half a mile. The strata penetrated by this well are sandstone, with some shale. The horizon is considerably higher than that of the Rice wells.

EAST CANYON WELLS.

There are only a few wells in East Canyon, and but little information is available concerning them. Of the two observed by the writer, one is about 400 feet south of the axis of the Pico anticline, in heavy brown shale; the other about an equal distance north, in strata much the same. The southern well is known as the Bradshaw and is said to have yielded a small amount of black oil. The one north of the axis is reported dry.

ELSMERE FIELD.

LOCATION.

The Elsmere field comprises that portion of the Newhall district lying east of Newhall Creek and extending as far east as Los Pinetos Canyon. The productive territory is confined to the northwest end of the San Gabriel Range, which terminates at Fernando Pass and Newhall Creek.

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[a] Watts, W. L., Oil and gas yielding formations of California: Bull. California State Mining Bureau No. 19, 1900, p. 69.

GEOLOGY AND STRUCTURE.

At Fernando Pass, the low point between the Santa Susana and San Gabriel mountains, there is a break in geologic continuity. The Elsmere anticline, described below, forms another step in the en échelon development exhibited by the Torrey, Tapo, and Pico anticlines farther west. The Elsmere fold, however, is hardly more than a secondary flexure of gentle curvature on the western flank of the San Gabriel Range.

The formations involved in the Elsmere field include a vast body of granite and schist, probably of Jurassic age; chocolate-colored shale, sandstone, and minor beds of conglomerate bearing characteristic fossils of the Vaqueros formation; the Fernando (Pliocene) conglomerate, sandstone, and clay; and certain Pleistocene gravel, sand, and clay, already mentioned in the description of the Pico anticline, that occupy what appears to have been an old lake basin coincident with the present valley of the Santa Clara in the vicinity of Newhall and Saugus.

The granite and schist occupy the heart of the San Gabriel Range; the other formations, except the lake beds, encircle its west end. Although the San Gabriel Range is probably the result of faulting there is in the encircling Tertiary rocks at least one anticlinal flexure, the Elsmere. This anticline has been developed in somewhat unsymmetrical form, the axis lying well toward the southern side of the fold. (See Pl. IV, sec. M″–M–M′.) The elevation of the strata north of the axis is maintained by minor flexures, until at a distance of a mile or more the beds drop beneath the level of the lower hills and pass to the east, with a N. 70° E. strike and a dip of 25°–30° N. The syncline separating the Elsmere anticline from the Pico fold is suggested in the curves of the strata in the creek southwest of Newhall and in one or two minor crumples in the Fernando formation higher in the hills. In the Vaqueros beds on the Santa Susana side there are two folds having a general trend of N. 60°–70° W. One is the eastern terminus of the Pico anticline and the other of the syncline to the south. These folds do not appear east of the Southern Pacific Railroad, their trend carrying them at this point into the San Fernando Valley, beneath the level of which the anticline sinks. The Fernando formation, lying between the two bodies of Vaqueros east of the railroad, maintains a southwesterly to southerly dip, except immediately north of the axis of the Elsmere anticline, in proximity to the more northerly body of Vaqueros. The relations of the Fernando to the underlying strata are extremely irregular and the details of the unconformity have not been worked out. About the northern base of the San Gabriel Range, however, east of the railroad, this unconformity is readily discernible.

It is particularly marked in the varying beds upon which the Fernando rocks rest, showing that the earlier beds of this formation were deposited across the upturned edges of the Vaqueros.

The source of oil in the Elsmere anticline is in part, doubtless, from the sandstone and conglomerate immediately overlying the Vaqueros, but the numerous wells in Elsmere Canyon draw their supplies from Vaqueros strata.

OIL WELLS.

The Elsmere oil field is developed in the broad sweep of the strata about the west end of the Elsmere anticline. The companies operating, named in order from south to north, include the Enterprise, Zenith, Eureka Crude, Pearl, Santa Ana, and Pacific Coast. The Pacific Coast wells are confined chiefly to the slopes and bottom of Elsmere Canyon, although a few are ranged along the crest and western face of Elsmere Ridge. The Santa Ana Company has three wells high up on the north point of this ridge, while the wells of the other companies are ranged along a tributary of Newhall Creek, west of Elsmere Ridge, in proximity to the Los Angeles wagon road. Roughly, the wells are ranged concentrically about the anticline, the Enterprise, Pearl, and Zenith lying farthest out and to the west, the wells of Elsmere Ridge in a circle somewhat within these, and those of the Pacific Coast Oil Company in Elsmere Canyon nearest the heart of the fold. In addition to the above Nettleton & Kellerman have a group of three wells a little farther north and the New Century and Freeman & Nelson oil companies a few wells in Placerita Canyon, 5 miles east of Newhall. The well of the California Oil Company, high up on the slopes of the San Gabriel Range, is said to penetrate a few feet of still older beds of the Vaqueros and then to pass into granite.

ENTERPRISE, PEARL, AND ZENITH WELLS.

The Enterprise well and one of the Pearl Oil Company near by, both but a few feet south of the axis of the anticline, are said to be between 800 and 1,000 feet deep and to have failed to find oil. The Zenith Company, one-half mile north, has two wells which penetrate yellow sand of considerable stability; running sand, soft, blue, and bearing cobbles; blue shale or adobe, as it is called by the drillers; and at the bottom of the wells, 600 to 630 feet below the surface, other sands, together with a few "hard shells." The supply is derived from the lowermost sands of these wells, beneath about 230 to 270 feet of "adobe." The production of the wells was at first 15 barrels per day, but is now 10 barrels. The gravity of the oil is 19° B.

Two other wells of the Pearl Oil Company, adjacent to the Zenith wells, have a depth of 665 and 720 feet. The deeper is as yet unfinished. Adobe is reported in it from 370 feet down. In the other well an oil sand was encountered at 570 feet, but not until 600 feet was reached did the yield become sufficient to justify pumping. In this well sand and cobbles are reported nearly all the way down, although it is probable that in the lower portion some adobe or clay was encountered. It is almost certain that the adobe reported in this locality is but a clay body of considerable extent held in the sandstone and conglomerate. It may, however, correspond in a measure to the great body of blue clay observed in Pico Canyon between the lowest conglomerate of the Fernando formation and those next higher. Other wells were in process of drilling by these companies, but were unfinished at the time of the writer's visit.

ELSMERE RIDGE WELLS.

The depth of the wells on the crest of Elsmere Ridge (see Pl. VII, *B*) is said to be approximately 1,000 feet, but the information is somewhat indefinite. They are sunk in heavy sandstone and conglomerate which strike with the crest of the ridge, north and south, and dip 25° W. The source of the oil is probably near the base of the Fernando beds, and the production is not heavy. The gravity of the oil is reported as about 14° B.

ELSMERE CANYON WELLS.

Of the 15 wells in Elsmere Canyon, which belong to the Pacific Coast Oil Company, but little was learned. Seven were said to be productive, yielding from 7 to 75 barrels a day. They are reported to range from 400 to nearly 1,000 feet in depth. Soon after the writer's visit (1902) the company abandoned its property in this field.

NETTLETON & KELLERMAN, WELLS.

In the shallow gulch immediately north of Elsmere Canyon, perhaps a mile distant from the Elsmere wells, is a group of three wells owned by Nettleton & Kellerman. Two of these are unproductive, the other yields 10 barrels per day, deriving its supply from a depth of 1,100 feet. The gravity of the oil is 20° B. The strike of the measures is here N. 70° E. and the dip 23° N. The source of the oil is probably one of the lower members of the Fernando formation.

WELL SOUTH OF RIDGE CREST.

On the southern slope of the San Gabriel Range, about a mile east-southeast of Fernando Pass, is a well drilled near a brea deposit. It is abandoned and its history was not investigated. It is located on the outcrop of the Fernando formation, but if any considerable depth was reached it may have passed into Vaqueros beds.

PLACERITA CANYON WELLS.

Perhaps the most remarkable of all the oil fields of California is an area of insignificant size in Placerita Canyon, 5 miles east of Newhall. The oil here is almost a naphtha, and its gravity is said to be above 50°. The yield is very slight. The remarkable feature in connection with the oil is its occurrence in crystalline schist which overlies the San Gabriel granite and which is in turn overlain at no great distance from the wells by rocks that are believed to be of the Fernando formation. Oil was discovered in shafting for gold.

The schist in which the oil occurs is micaceous and granitic, conspicuously banded, and greatly contorted. It strikes approximately N. 70° W. and dips 50°-80° N. The accompanying diagram (fig. 11) indicates the position of the wells. There are six in all, the three on the north belonging to the New Century Company and those on the south to Freeman & Nelson. The New Century wells are nearer the Fernando sandstone and conglomerate, which approach within a few feet. It is said that one of these wells spouted high and that another barely flowed. The deepest well of the six is the southernmost of the Freeman & Nelson group, which attained a depth of 1,030 feet. Oil is reported in this well at 410, 613, and 682 feet. It is said to yield 5 or 6 barrels per day, with 30 or 40 barrels of water to each barrel of oil.

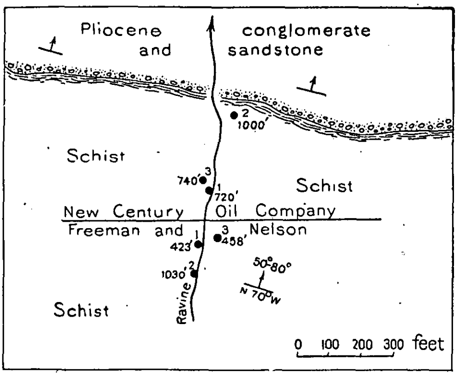


FIG. 11.—Sketch map showing location of Placerita Canyon wells, 5 miles east of Newhall. Heavy dots, wells. Figures indicate numbers and depths of wells.

In a tributary of Placerita Canyon, three-fourths of a mile east of the wells described above and in the same schist, is the Pioneer well, 1,100 feet deep. It struck oil, but the yield could not be learned. The granite lies about three-fourths of a mile south of this well.

The presence of oil under conditions similar to those that exist here is perhaps unknown in any other part of the world. It occurs from 400 to 1,000 feet beneath the surface in a steeply dipping and close-textured crystalline schist. That a reservoir, even though small, exists in such rocks must be due, it would seem, to the fracturing of the schist, the natural result of the severe contortion to which it has been subjected. If the oil originated in the schist, or rather in the sediments from which the schist was metamorphosed, it is beyond comprehension that it should have remained in them under the tremendous pressure and heat to which the strata have unquestionably been subjected. Indeed, it seems to be an impossibility that such can be the history of its development. Moreover, the gravity of the oil, between 50° and 60° B., is equally enigmatical. Even if it was originally a high-gravity oil, the lighter hydrocarbons would have been the first to be 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 paraffin residue. It may be that the oil is of later origin or, in any event, that it was for a time stored in another reservoir, perhaps of Vaqueros age, possibly even of Fernando age. It is possible that from such a reservoir the light oil, already from some cause separated from the heavy oil, may have found its way between the two formations and penetrated the crystalline rocks through one of their fractured zones.

Bull. 309—07——8

THE PUENTE HILLS OIL DISTRICT, SOUTHERN CALIFORNIA.

By George Homans Eldridge.

INTRODUCTION.

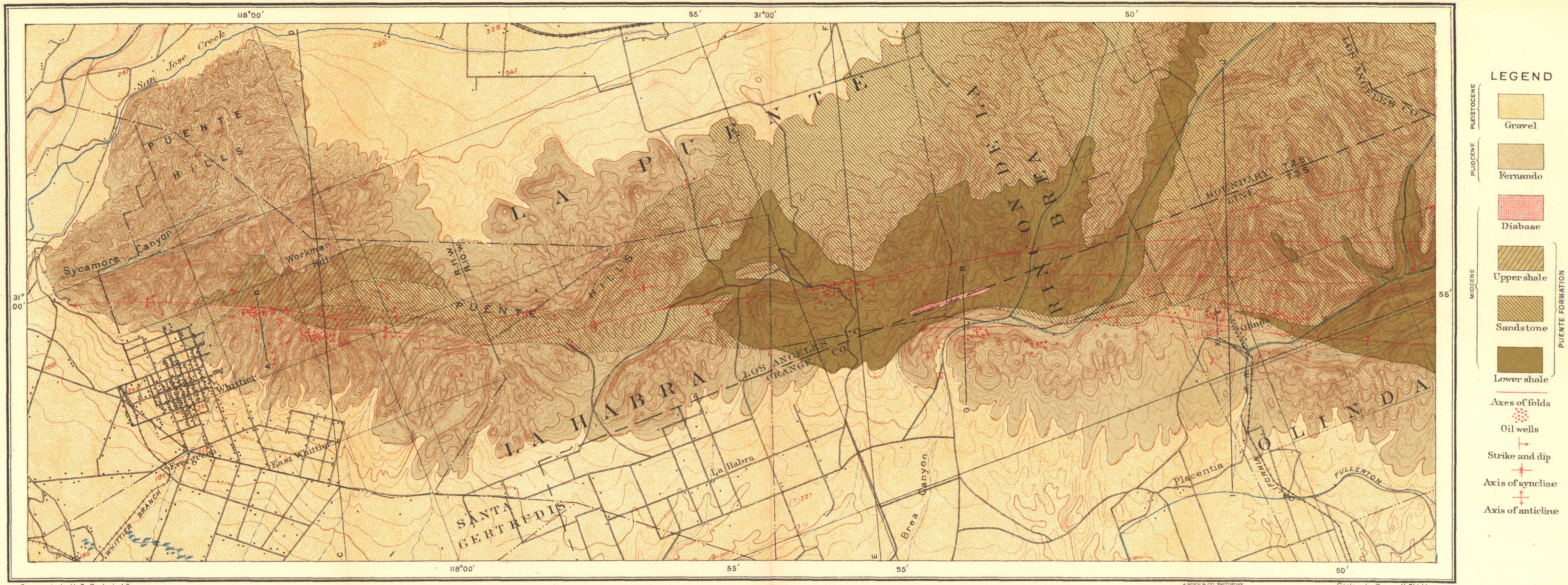
In the following report it is proposed to describe briefly the geology and structure of the Puente Hills, especial attention being given to those features which appear to have a bearing on the occurrence of petroleum in the different fields of the district. The reader is referred to Mr. Arnold's report on the Los Angeles district (pp. 138–142) for information concerning the previous knowledge of the region and for a bibliography of publications relating to it.

ACKNOWLEDGMENTS.

Acknowledgments are due to the various oil companies and their managers in the different fields for assistance in various ways and for information given by them during the course of the work. Thanks are due more particularly to Mr. Fred T. Perris, manager of the Santa Fe Railway oil properties; to Mr. E. A. Bacon, of the Murphy Oil Company; to Messrs. Graham and Loftus, of the Graham-Loftus Oil Company; to Mr. R. N. Bulla, of the Central Oil Company, and to Mr. Dan Murphy, of the Brea Canyon Oil Company. Uniform courtesy has been shown by those in control of the different properties in this district, all, without an exception, furnishing any information requested.

LOCATION AND TOPOGRAPHY.

The Puente Hills, along the southern face of which has been developed one of California's most productive oil territories, are situated in the southwest corner of the State, beginning at a point about 12 miles slightly south of east of Los Angeles and extending in a general east-southeasterly direction for 22 miles to Santa Ana River. They cover an area, roughly, of about 140 square miles. The western and northern parts of the hills lie in Los Angeles County; the southeastern part is divided between San Bernardino County on the north and Orange County on the south. They are situated but 35 miles from San Pedro, the principal deep-water harbor of southern California.



Topography by U. S. Geological Survey.

Geology by George H. Eldridge–1902

A. HOEN & CO. BALTIMORE

GEOLOGIC MAP OF THE OIL FIELDS OF THE PUENTE HILLS, CALIFORNIA

Scale $\frac{1}{62500}$

miles

kilometers

Contour interval 20 feet.
Datum is mean sea level

1906.

The Puente Hills are the northwestern extension of the Santa Ana Mountains, from which, however, they are now separated by the deep canyon of Santa Ana River, with a fault, perhaps, as an interruption to the present continuity of structure. The general trend of the hills is west-northwest. Their highest point, 1,780 feet, is San Juan Hill, on the boundary line between San Bernardino and Orange counties. In the eastern half of the hills numerous peaks reach elevations between 1,200 and 1,400 feet, but in the western half this altitude is exceptional. The base of the hills lies about 400 feet above sea level. For 3 or 4 miles to the south an altitude of 200 or 300 feet is maintained, the southern edge of this area being defined by a low ridge that lies parallel with the hills from the region of Placentia to a point opposite Whittier. South of this the elevation drops to less than 150 feet, decreasing gradually to the sea.

The region of the Puente Hills is dry, all the streams being intermittent. The canyons are deeply cut and in places present considerable ruggedness of aspect. Nearly all are the result of erosion, although the loci of some of the erosion valleys were doubtless determined by the folding to which the strata had been subjected. Narrow, perpendicular-sided channels characterize the bottoms of many of the canyons, especially those cutting through shale. In many places, however, the higher slopes are gentle and the hill summits rounded and grassed.

GEOLOGY.

FORMATIONS.[a]

The formations involved in the geology of the Puente Hills include the Puente formation, largely sandstone and shale, of Miocene age and the equivalent of at least a part of the Modelo formation, and possibly including some of the Vaqueros; some diabase post-Puente, probably contemporaneous with similar rocks found throughout the Coast Range as far north as San Francisco; clay, sandstone, and conglomerate of the Fernando formation, largely Pliocene in age; and superficial Pleistocene deposits of sand and gravel. (See Pl. X.) The Puente formation has been divided on lithologic grounds into a lower shale, a sandstone, and an upper shale.

LOWER PUENTE SHALE.[b]

The lowest rocks exposed in the Puente Hills, which will be called the lower Puente shale or simply lower shale, embrace at least 2,000 feet of shale, in the main earthy, but with minor members of a sili-

[a] A table giving the formations of the Santa Clara Valley, Los Angeles, and Puente Hills districts, together with their probable correlatives of the standard Tertiary formations of California, is given on p. 143.

[b] It was not the intention of the authors to apply specific names to the divisions of the Puente, but to treat them as unnamed parts of that formation.

ceous nature, the whole gray or brown from the presence of iron and bitumen. Thin, fine-grained sandstones are interbedded with the shale from top to bottom and lenticles of gray limestone weathering yellow also occur. All in all, the formation bears close resemblance to the Monterey and certain portions of the Modelo. The only evidence of life thus far discovered consists of foraminifera and diatoms, so common in the Miocene of the Pacific coast. These occur in both shale and limestone. The shale is exposed in the heart of the hills with varying prominence; its outcrop is especially strong from Brea Canyon westward and in the southeastern portion of the hills. To judge by the sequence of beds in other parts of southern California, this shale is probably underlain by a mass of coarse sandstone.

PUENTE SANDSTONE.

Overlying the shale is a moderately coarse gray to yellow heavy-bedded sandstone, separated by minor bands of organic siliceous shale. Spherical and lenticular concretions, consisting of the same material as the mass of the rock, characterize the sandstone. The lower portion of the sandstone is more thinly bedded than the upper, and the intercalated shale is more earthy, suggesting a transition to the underlying member. This feature is especially conspicuous along lower Soquel Canyon. The thickness of the sandstone varies from perhaps less than 300 feet in the western portion of the hills to possibly over 1,000 feet in the eastern portion, where it lies in a gently undulating position, and its areal extent is very great. The sandstone is wanting in outcrop along the southern face of the hills opposite the wells of the Puente Oil Company.

UPPER PUENTE SHALE.

Overlying the Puente sandstone is a variable thickness of earthy, siliceous, and chalk-like shale, with a few beds of fine yellow ferruginous sandstone and minor quartzo-calcareous concretions. This portion of the formation will be called the upper Puente shale, or upper shale. The thickness is uncertain, but in the region of the Olinda field it appears to be considerably less than it is believed to be in the western portion of the hills. Nowhere, perhaps, is it more than 300 or 400 feet in outcrop. However, the overlying formation rests upon it unconformably, and for this reason it is impossible to estimate its full original thickness. In doubtful structural positions only has it been suspected of having a development of over 100 feet. The most important instance of this kind is on the eastern border of the Whittier field, where the crest of the hills shows the following section from north to south: In the axis, shale that is believed to be the lower division of the Puente; at the southern edge of the crest, sandstone that is identified as Puente, 200 or 300 feet in all; and on the southern face of the ridge, other shale, also of the Monterey type, bearing the fossil *Pecten pedroanus*, and succeeded across a fault plane by the next younger (Fernando) formation. The uppermost two beds have a northerly dip; the inclination of the Puente sandstone is exceedingly steep, with a dip here north and there south, and a consequent uncertainty as to which of these directions is the normal. The shale in the heart of the hills is crushed and crumpled. Were it not for this extensive crumpling and the attendant faulting the sequence given above might be regarded as normal; yet an alternative is possible, namely, that the suspected uppermost shale, with its northerly dip, occupying the southern face of the ridge adjacent to the fault line, may be instead the lower member and pass beneath the highly inclined Puente sandstone at the crest of the ridge, the two together being faulted down against the lower shale farther north, or that it may, by a sharp reversal of its dip, again return to the surface in a compressed and broken synclinal fold.

CORRELATION OF THE PUENTE FORMATION WITH THE MONTEREY.

The resemblance of both lower and upper divisions of shale, if such there be, to the Monterey, as it is known in other parts of the Coast Range, may warrant their correlation, the Puente sandstone to be regarded as an intercalated member. Yet, before finally accepting this view, it is well to recall the marked lithologic similarity of portions of the lower division of the Puente formation to certain strata in the Santa Clara Valley and elsewhere in the Coast Range that have been determined by their fossils to be lower Miocene and possibly Oligocene—lower than the Monterey. From geologic conditions to the south of the Puente Hills in the Santa Ana Range, however, the writer is inclined to consider the entire succession of beds described above as the local equivalent of the Monterey. The only fossil thus far obtained from the Puente shales is *Pecten pedroanus* Trask (see Pl. XXXVI, figs. 5 and 6), a form which is found both in the Miocene and lower Pliocene. A nearly related form, *Pecten peckhami* Gabb (Pl. XXXI, fig. 3), is a characteristic species of the Monterey (middle Miocene).

POST-PUENTE DIABASE.

A dike of diabase nearly a mile long and varying in width up to an eighth of a mile breaks through the Puente sandstone and shale along the southern slope of the hills north of the mouth of Brea Canyon. The exposed portions of the rock are so much weathered that good specimens could not be obtained. The altered material is grayish in color and shows the light-colored, lath-shaped feldspar crystals very distinctly in the specimens examined. The outcrop of this rock in the face of the ridge north of the road connecting the Puente and Brea Canyon fields has the peculiar irregular contour which enables one to distinguish it at a glance from the adjacent sedimentaries. Farther east the weathering of the diabase has stained the soil a peculiar reddish-brown color characteristic of the diabase areas throughout the Coast Range. The age of this diabase is approximately the same as that of similar diabase found in the Santa Monica Mountains in a like stratigraphic position—that is, it is post-Puente and pre-Fernando and belongs in the upper Miocene of the time scale.

FERNANDO FORMATION.

The youngest of the Tertiary formations in the Puente Hills is a succession of gray to yellow quartzose and granitic conglomerate and sandstone, together with interbedded arenaceous shale and clay, in all at least 1,500 or 2,000 feet. Occasionally a trace of eruptive débris, derived perhaps from the ranges to the north, is found with the other constituents, and locally a concretionary tendency may be observed. At one or two points, also—notably on the crest of Brea Ridge south of the Union Oil Company's wells and on the main ridge north of the wells of this company in La Habra Canyon—the formation appears to carry a few inclusions of siliceous shale and calcareous concretions. The conglomerate, sandstone, and clay are fossiliferous, the forms indicating an identity of the beds with the Fernando of the Santa Clara Valley district. A feature characteristic of this formation is the ready disintegration of its sandy shale, which under heavy traffic becomes an extremely annoying dust. This formation flanks the Puente Hills on the north, south, and west sides. It also covers a large area in the Coyote Hills, 3 miles south of La Habra Canyon, and here some exposures of its sandstone show a deep rusty or crimson color.

The following fossils, some of which are characteristic of this horizon, have been found in the Fernando beds, mostly in the vicinity of Olinda and Brea Canyon (see Pl. XXXIV to XLI):

Fossils from the Fernando beds of the Puente Hills.

[Species marked with an asterisk (*) are still living; those with a dagger (†) are supposed to be characteristic of this horizon.]

GASTEROPODA (UNIVALVES).

* Astyris (cf.) gausapata Gould.
*Bulla (cf.) punctulata A. Adams.
*Calliostoma (cf.) costatum Martyn.
†Cancellaria (sp. like San Diego well form).
*Conus (cf.) californicus Conrad.
*Crepidula (cf.) rugosa Nuttall.
*Dentalium neohexagonum Sharp and Pilsbry.
Dentalium (n. sp. like Miocene form).
*Fissuridea murina Carpenter (Pl. XL, figs. 3, 3a).
Fusus cf. barbarensis Trask.
*Nassa fossata Gould.
*Nassa perpinguis Hinds.
*Neverita recluziana Petit (Pl. XXXVIII, fig. 6).
†Priene oregonensis Redfield, var. angelensis Arnold (Pl. XL, fig. 11).
†Trochita costellata Conrad (Pl. XXXII, fig. 3).
*Trophon multicostatus Carpenter.
*Turritella cooperi Carpenter (Pl. XLI, fig. 14).

PELECYPODA (BIVALVES).

*Arca multicostata Sowerby (?) (Pl. XXXVIII, fig. 1).
Arca trilineata Conrad (Pl. XXXVIII, figs. 3, 3a, 4).
*Cardium (cf.) corbis Conrad.
*Cardium quadrigenarium Conrad, var. fernandoensis Arnold (Pl. XXXVIII, fig. 2).
*Chione (cf.) fluctifraga Sowerby.
*Leda taphria Dall (Pl. XXXVIII, fig. 5).
*Metis (cf.) alta Conrad.
*Modiolus (cf.) rectus Conrad.
†Ostrea veatchii Gabb (Pl. XXXIX, fig. 1).
†Pecten ashleyi Arnold (Pl. XXXIV, fig. 2).
†Pecten auburyi Arnold (Pl. XXXV, fig. 7).
*Pecten hastatus Sowerby.
†Pecten nutteri Arnold.
†Pecten oweni Arnold.
†Pecten wattsi Arnold (Pl. XXXV, fig. 1).
*Phacoides acutilineatus Conrad.
*Phacoides californicus Conrad.
*Phacoides nuttallii Conrad.
*Phacoides richthofeni Gabb.
Siliqua edentula Gabb.
*Solen sicarius Gould.

PLEISTOCENE.

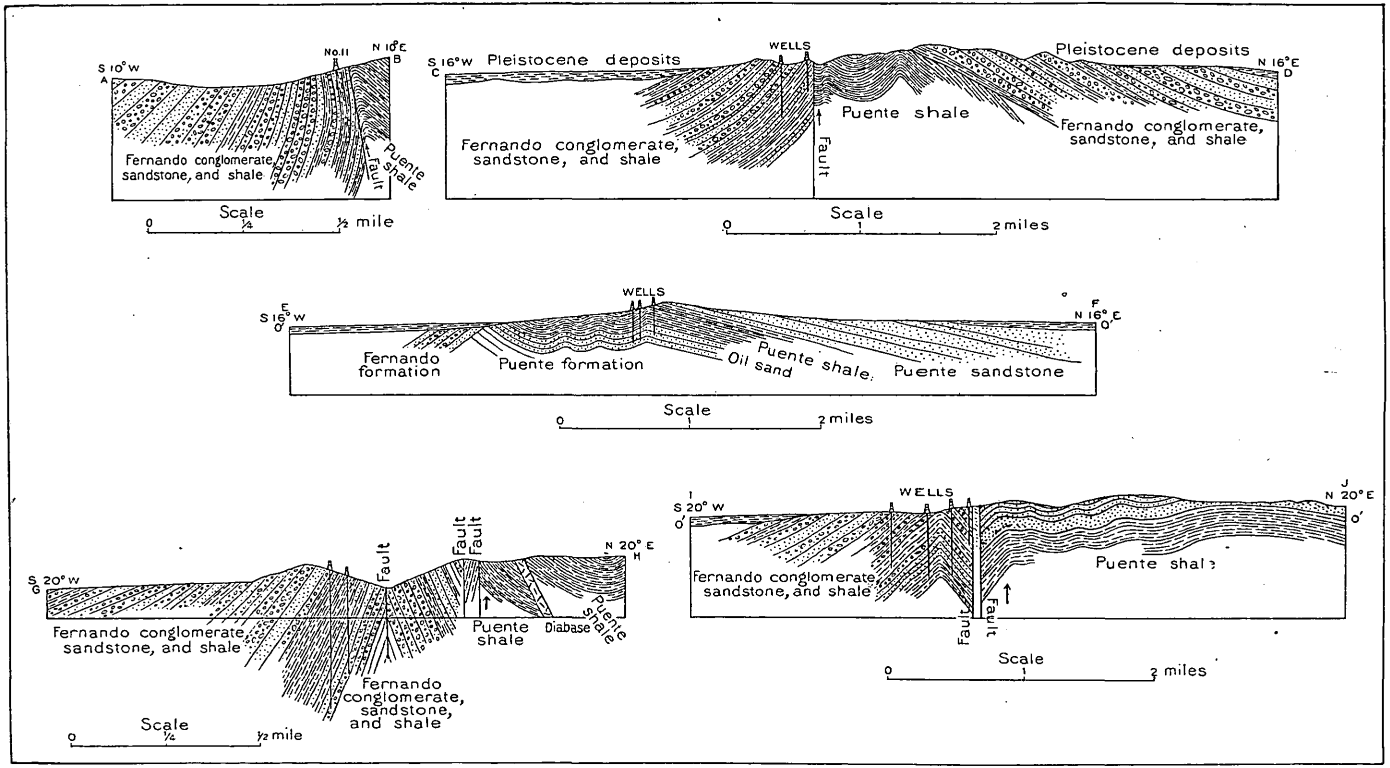
Alluvial gravel, sand, and clay of one or more periods of deposition underlie the valleys adjacent to the Puente Hills.

STRUCTURE.

GENERAL STRUCTURAL RELATIONS OF THE FIELDS.

The structure of the Puente Hills is that of an anticline, contracted in the western part, expanded in the eastern. The main axis of the flexure is not everywhere easy of recognition, owing to the prominence of some of the nearly parallel secondary folds that exist throughout the length and breadth of the hills, but the line laid down on the map (in the eastern half of the hills—the northern branch) approximately indicates the axis of the anticline. The general trend of the Puente fold is N. 65° W., varying but a few degrees in either direction. Besides the main and parallel or slightly divergent secondary folds, there are several flexures, with a trend approximately northeast and southwest. These are particularly developed on the northern slope of the main anticline in the eastern half of the hills. The most important is the broad, gentle arch occupying the region of the forks of Brea Canyon, and to this is due, in considerable degree, the areal expansion of the Puente Hills in their eastern part. The eastern rim of the hills presents several complications of strike and dip, doubtless more or less connected in structure with the Santa Ana Range to the south. (See Pl. XI.)

The south side of the Puente Hills is devoid of folds other than those secondary to and parallel with the main anticline. On this side of the hills, however, the force which produced the anticline has most severely manifested itself, the folds being sharp and numerous and the strata badly crushed. Indeed, the data at hand suggest the possibility of a fault of considerable magnitude, extending from the extreme west end of the hills nearly or quite to Santa Ana River. The amount of throw is indeterminable, but local displacements of several hundred feet are indicated by the relation of the beds. The continuity of the fault, considered as a single fracture, is not established. On the contrary, it is probable that within the zone of maximum disturbance there are a number of fractures, more or less connected, it may be, yet throughout a part of their course apparently distinct—in fact, a zone of faults instead of a single uninterrupted break. The chief evidences of faulting are the continuity of a zone of marked crumpling, the overturned and crushed condition of the beds at many points, variation in the succession of beds adjacent to the line of suspected fracture, and a divergence between trend of break and strike of strata, particularly well defined in the Whittier field. On the other hand, the line of possible fractures is at no point far distant from the contact between the Fernando and the Puente formations, and it is well known that throughout the Coast Range there is a conspicuous unconformity at this horizon. Without doubt the unconformity is



GEOLOGIC SECTIONS ACROSS THE OIL FIELDS OF PUENTE HILLS DISTRICT.

A–B, C–D, Whittier field; E–F, Puente field; G–H, La Brea Canyon field; I–J, Olinda field.

present in this field, and it is probable, too, that the younger sediments, as has been found the case with their equivalents elsewhere, were laid down upon the already upturned and partially eroded beds of the older formation. This would account for many of the irregularities noted along the length of the disturbed belt, but the broken condition of the beds on either side of the line of suspected fracture and the steeply inclined, in many places overturned, dip of the Fernando sediments in proximity thereto indicate a combined effect of faulting and unconformity for the zone in question. The conditions are almost a repetition of those in the McKittrick district, in the San Joaquin Valley, along the eastern base of the Coast Range. The oil fields of the Puente Hills have been developed in the zone of sharp crumpling and in proximity both to the trace of the possible fault and to the line of unconformity; the important wells of the McKittrick district have been drilled along the fracture and adjacent to the unconformity there existing. A guide to development has been the numerous seepages that occur along the belt of severely disturbed strata; but these have not always proved reliable indications of a large accumulation of oil.

COYOTE HILLS ANTICLINE.

The low east-west ridge known as the Coyote Hills, 3 or 4 miles south of the Puente Hills, is an anticline which flanks and is in a general way parallel with the Puente fold and was probably developed synchronously with it. The exposed strata in the west end of the Coyote Hills are the Fernando conglomerate and sandstone, but no data were obtained indicating how thick they are at this locality or at what depth the underlying Puente shale and sandstone lie. No seepages have been found in these hills, but toward their west end, 3 or 4 miles south of Whittier, is a large gas well. It is probable that oil also exists in the crest of this anticline, but at what depth and in what quantities only future development will show. Some of the most productive wells, however, are located in regions where the structure is similar to that of this ridge.

GEOLOGIC RELATIONS OF OIL-BEARING STRATA.

The distribution of the surrounding mountain masses and the position of the Puente Hills in relation thereto do not appear to have influenced the accumulation of oil. On the contrary, the significant factors appear to be the anticline, the sharply disturbed zone along its southern side, the fault that seems to be located within this zone, and the unconformity between the Fernando and the Puente formations. Finally, all the foregoing conditions would be unavailing had not the formation of petroleum taken place somewhere within the succession of beds in the close vicinity of the hills.

All the sedimentary formations in the Puente Hills, at one horizon or another, carry petroleum or its asphaltic residue. In the region developed by the Puente Oil Company, near the center of the productive belt, oil is derived from sandy strata low down in the lower division of the Puente shale. The Puente sandstone is bituminous at several points, particularly along the eastern crest of the hills, although as yet it affords no oil. The upper shale, also unproductive, nevertheless carries a small content of disseminated oil. The Fernando formation has proved extremely rich in several localities. The presence of oil at the horizons mentioned is not, however, an argument for their productiveness at all points. The factors of structure and of the original occurrence or formation of petroleum are always to be considered.

While it is evident that severe disturbance of the strata has been the chief determinant of the presence and development of the succession of oil fields along the southern face of the Puente Hills, such occurrences as that of the Chino field, on the eastern crest of the hills, 5 miles southwest of the town of Chino, are evidences of the possibilities, under right conditions, in the regions of subordinate folds. As yet, however, prospecting of the secondary and lateral anticlines has been but slight.

OIL FIELDS.

The developed oil fields of the Puente Hills include the Whittier, immediately east of Whittier; the La Habra, on La Habra ranch, 3 miles southeast of the Whittier field; the Puente, on the summit of the ridge in its most contracted portion; the Brea Canyon, 1½ miles southeast of the Puente field; the Olinda, on Olinda ranch, 7 miles northeast of Fullerton, and the Chino, about 5 miles southwest of Chino. The last-mentioned field, although within the general anticline of the Puente Hills, is independent of the other petroleum-producing areas, which lie at intervals along the belt of highly disturbed strata on the south side of the hills. (Pl. XII.)

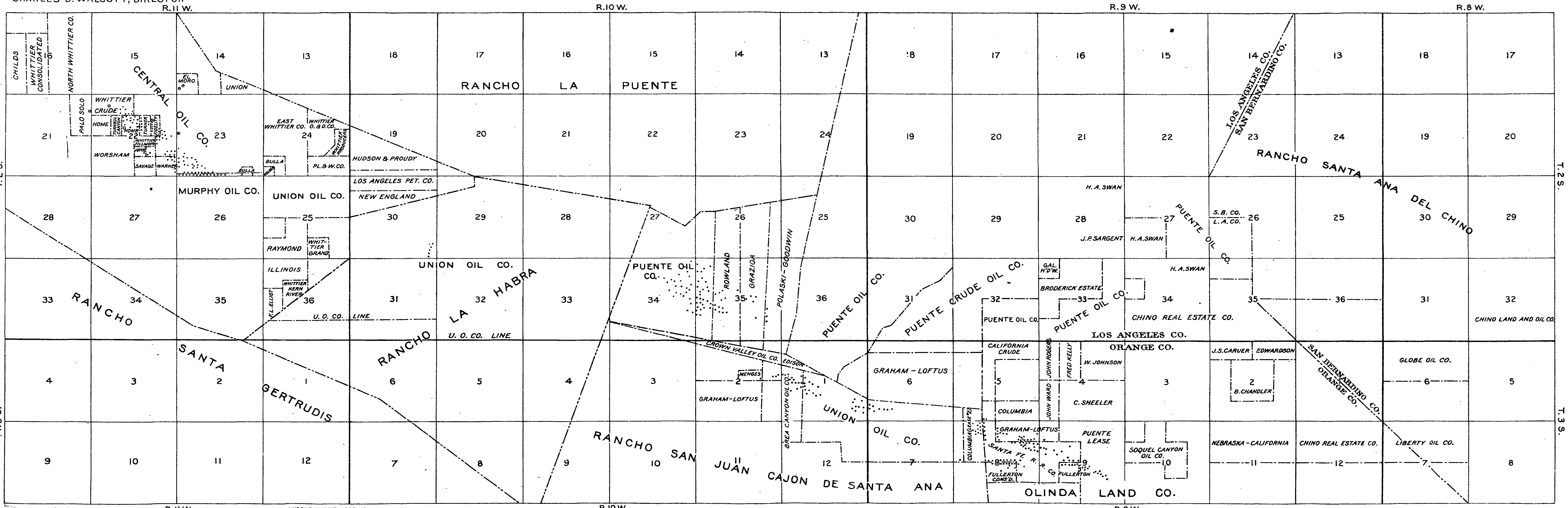
WHITTIER FIELD.

LOCATION.

The producing territory of the Whittier oil field lies on the southern slope of the Puente Hills, beginning within a mile of the town of Whittier and extending in a S. 65° E. direction about 2½ miles.

GEOLOGY.

The field is developed along the south side of the well-defined Puente fault zone, in southward-dipping conglomerate, sandstone, and argillaceous beds of the Fernando formation, which successively abut against different members in the siliceous and other shales of



Compiled from various sources by Ralph Arnold

Well locations largely from oil companies' maps

TOWNSHIP AND SECTION MAP OF THE PUENTE HILLS OIL DISTRICT, SOUTHERN CALIFORNIA

Scale

0 1 2 3 miles

1906

the Puente that lie with varied dip on the north of the fault. The line of producing wells trends N. 65° W., in marked divergence with the strike of the formations, which varies but little on either side of an east-west line. The wells, in other words, follow the trend of the fault rather than the strike of the beds, and in the Fernando formation the oil horizons vary with the strata that are brought into contact with the shale across the fracture plane. In the eastern portion of the field, for example, the petroleum is in beds considerably higher than in the western portion. An apparent exception to this tendency of well development to follow the fault plane exists in the long parallel strings of Murphy and Central wells that lie on either side of an east-west property line, a little north of the south line of sec. 23, T. 2 S., R. 11 W. (See Pl. XIII, *A*.) These wells closely follow the strike of the formation, with which, however, the property line, the determining factor in their location, happens to be nearly coincident.

North of the plane of separation of the Fernando and Puente formations the wells drilled in the Puente beds have been, with a few unimportant and slight exceptions, total failures. It would seem, therefore, that for this field the productive belt is in the Fernando formation adjacent to the plane of fracture or of unconformity. The width of this belt is uncertain, but is at least between a quarter and half a mile, and the oil is found at greater depths in proportion as it is distant from the line of fracture. The strata affording oil in the Whittier field are members of the Fernando formation and consist of coarse gray to yellow-brown conglomerate, heavy-bedded sandstone, and pulverulent argillaceous sand that shades locally into distinctly arenaceous clay. Here and there the clay has been hardened by the presence of lime, and in some of the sandstone also there are hard quartzo-calcareous concretions, such as have been observed in this formation at other points in the hills. Locally, also, the sandstone shows the presence of more or less dry bitumen, which imparts to the rock a brown color. The exact position of these beds in the formation as a whole is unknown, by reason of faulting, because of the unconformity which exists between the Fernando and the underlying formations, and from the fact that as yet the various divisions have not been identified and correlated by their fossil contents. Furthermore, there is an apparent variation in composition along the strike of the formation. The relative position of the beds in the eastern and western portions of the productive tract may, however, be traced with comparative precision by reference to strike lines which vary but little from east and west; a heavy conglomerate, for instance, which lies a quarter of a mile south of the Murphy and Central wells in the eastern part of the field is found fully half or three-fourths of a mile south of the Home wells in the western part. Other conglomerates that in the vicinity of the Home wells outcrop in close proximity to the fault line may be those cut at considerable depth in the Murphy and Central group.

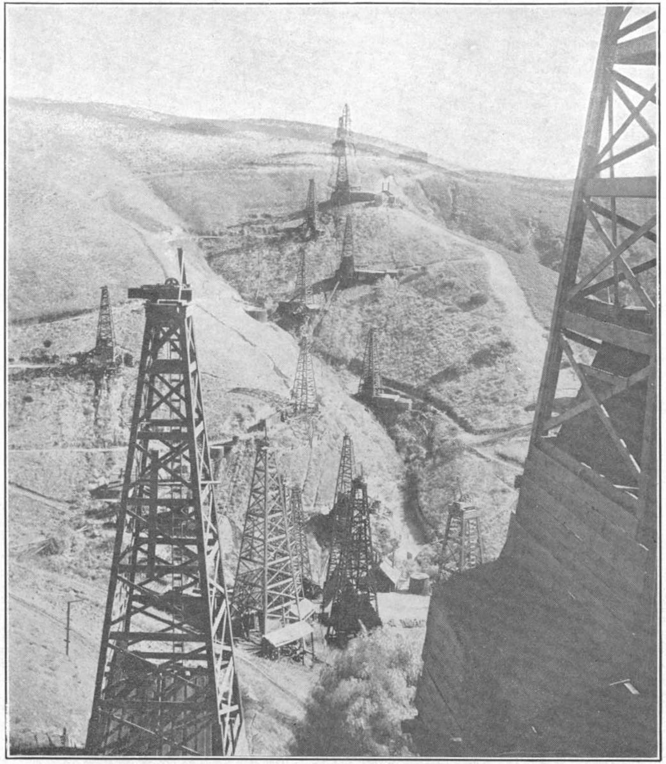
The Puente shale north of the fault line is in part siliceous, in part earthy, and in places it is brown from the presence of bitumen as well as of iron. In many of the layers may be found traces of the low organisms, foraminifera, etc., which are usually present in the Miocene formations, especially the Monterey. Limestone concretions also occur. Whether the shale outcropping adjacent to the fault belongs above the Puente sandstone or below was not positively determined. All three divisions of the formation perhaps occur at one point or another in the field, but the contorted and faulted condition of the beds requires the utmost detail of study for their successful correlation, and this the present reconnaissance did not permit. It is sufficient for the immediate purposes of this report that the Miocene shale (Puente) has been identified in faulted or unconformable contact with the oil-bearing members of the Fernando.

The number of oil-bearing horizons in the Fernando formation adjacent to the fault line and the fact that they are in contact with the bituminous shale of the Puente suggest a passage of the oil from the older formation into the various members of the younger, the fault having been not only a disturbing element affecting the positions of the strata, but also, perhaps, the means of affording a channel for the transfer of the fluid from the entire thickness of Puente shale to the several horizons of the Fernando. The fault plane, in fact, here seems to have performed in an enhanced degree the same function as the plane of unconformity between the two formations, so conspicuous an element in many of the oil fields of California. The younger formation of open, porous sandstone and conglomerate lies in contact with the bitumen-bearing shales of the Puente; in the one instance by faulting, in the other by deposition. In both instances the receptive strata of the younger formation, which happen to lie against or upon the older beds, have become impregnated with the bitumen capable of removal through wells.

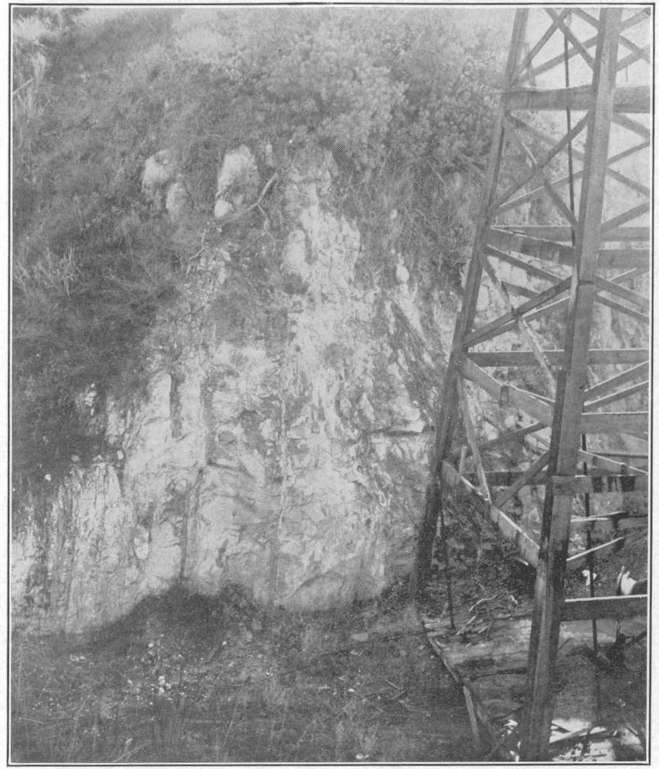
That the surficial relation between the Fernando and the Puente beds is one of faulting rather than simple unconformity is argued from the irregularities of strike and dip of the various strata, but beneath the surface the unconformity which exists at the base of the upper Miocene at almost every point in the Coast Range is undoubtedly also present.

STRUCTURE.

The nature of the Puente fault zone is exhibited in a complex of fractures observable a few hundred feet north and northwest of the principal group of Central wells. It consists of two principal breaks.



A



B

WHITTIER OIL FIELD, LOS ANGELES COUNTY.

A, Wells along property line of Central Oil Company and Murphy Oil Company, looking east; *B*, Productive well in vertical strata.

The southern, in the eastern half of the field, receives at an acute angle the axis of an anticlinal fold, which in the region of the Chandler wells is conspicuously developed in the Fernando formation to the south of all recognized fault planes. The northern break is traceable but a short distance to the east; but in alignment with it, a mile distant, is a sharp crumple in Puente strata. West of the Murphy-Central region the fault zone resulting from the union of the fractures thus described passes immediately north of the productive wells of the Fidelity, Turner, and Home companies and thence toward the west end of the hills. The block between the two faults just mentioned involves both the Fernando and Puente formations. The foregoing details derive their chief interest from their possible bearing on the occurrence and yield of petroleum in the region discussed.

Toward the west end of the Whittier field, especially in the vicinity of the Home Oil Company's wells, the Fernando beds appear to be slightly overturned. (See Pl. XI, sec. A–B.) North of the fault line, in a little ravine north of Home well No. 11, the Puente shale inclines to the north at an angle of about 25°, while immediately adjacent to the fracture it dips southward at a steep angle. The Fernando beds next to the fault are approximately perpendicular, but a little farther south, in fact as far as Home well No. 7, they dip to the north at angles varying from 75° to 90°. (See Pl. XIII, *B*.) A short distance south of well No. 7, however, the dip changes to 75° or 80° S. in rather coarse conglomerates, while the inclination of the alternating bands of sandstone and conglomerate from this latter point southward to the edge of the hills gradually becomes less.

The conditions in the vicinity of the East Whittier and Bulla wells, near the west edge of sec. 24, T. 2 S., R. 11 W., have already been referred to on page 111, under the heading "Geology." (See Pl. XI, sec. C–D.) A short distance south of the crest of the hills, in the region of the Bulla wells, the strata show sharp compression, together with a distinct break in stratigraphic continuity, Fernando conglomerate abutting against Puente shale, both dipping north. The relationship between the formations appears to mark the locus of a fault in this region. The line of division is, moreover, in the direct trend of the suspected fracture as recognized farther west. North of the fracture the Puente shale and sandstone lie in somewhat confused relationship; it is possible that a second fault parallels the main fracture, or it may be that the strata are folded into a sharply compressed syncline.

OIL WELLS.

The wells of the Whittier field draw their supply wholly from the members of the Fernando formation. They range in depth from about 800 feet close to the fault line to nearly 2,500 feet at a distance from the break, the width of the productive zone as at present developed varying from an eighth to a quarter of a mile. The sandy members of the formation, rather than those of clayey consistency, yield the petroleum, although in some instances the material is comparatively fine, while in others it is coarse and even conglomeratic. The gravity of the oil varies from 16° to 23° B., the higher grade being reported from greater depths, although, perhaps, from younger beds. It is to be remarked also that some of the shallow wells are the older and that their condition is now far from satisfactory, water having in many instances found its way into oil-bearing strata, with the consequent effects of oxygenation and the transmission of more or less impurities. The daily production of the wells is said to vary from 2 barrels in the oldest to 300 in the newest and deepest.

Among other groups of wells within what may be regarded as the confines of the Whittier field are the Chandler, a group of four wells 1 mile southeast of the Murphy and Central wells. These were about the first drilled in the Whittier field, but are now abandoned. Their location was probably determined by an oil seepage from the sandstone and conglomerate. They were, however, primitive in equipment and shallow and afforded but a light yield of heavy oil. At this point the Fernando formation lies in an anticline secondary and parallel to the main fold in the hills. The beds south of the axis dip from 45° to 70°, and those north of the axis, with steeper dip, apparently abut against the Puente fault, being in contact with the Puente shale forming the central and higher portion of the hills. This shale also pitches to the north immediately adjacent to the fracture, a position that may be either normal or overturned, the latter occurring at many places within the zone of severe crumpling along the southern face of the Puente Hills. The Chandler wells are located a little south of the axis of the secondary anticline referred to above.

One or two wells have also been drilled in the same general region as the Chandler group, but in the Puente shale north of the fracture. As in the case of other wells in this formation in the territory adjacent to the Whittier field, the results were negative. The fact, however, that the Puente shales or their included sandstone locally carry oil is evident from the field developed by the Puente Oil Company, but no law governing this relationship has been discovered. In case the oil is not originally contained in the formation, its presence is probably due to the porportion of sandy members—a factor widely variable from point to point.

At the summit of the Puente Hills, about 1½ miles north of Whittier, near the east edge of sec. 16, T. 2 S., R. 11 W., the North Whittier Oil Company has drilled two wells on the north limb of the main

Puente anticline, within a mile or two of the west end of the fold. The wells are sunk in Fernando conglomerate and sandstone, which have a regular dip. They were not a marked success and no more have been drilled in the immediate vicinity, although at depths between 900 and 1,500 feet oil-bearing strata affording a small yield were encountered. These wells are of especial interest, since they are among the first to be exploited in the younger formation on the north limb of the anticline. Faults of importance have not been observed in this locality. From surface indications the position of the North Whittier wells seems to be somewhat analogous to that of other wells in such productive fields as Coalinga, Midway, and Sunset, where petroleum occurs in formations having remarkable evenness of dip, strike, and succession.

The productive wells of the Whittier field embrace those of the Home, Turnbull Canyon, Turner, Fidelity, Strong, Central, Warner, and Murphy oil companies. Other companies have drilled at various points in the field, but thus far without success. In general, the wells immediately south of the fracture have been found productive; those to the north unproductive. (Pl. XIV, *B*.)

LA HABRA CANYON FIELD.

LOCATION.

The region of La Habra Canyon occupies the heart of the Puente Hills, midway between the Whittier and Puente fields. It has an east-west length of about 3 miles, the productive territory being near the west end.

GEOLOGY.

The geologic relations between this and the fields on either side have not been fully established, but in a broad sense the three are similar, the principal differences consisting in the details of folding, their position within the general anticline, and the strata pierced. The formations of the region include the upper and lower members of the Puente formation, together with the intervening sandstone, and the Fernando conglomerate, sandstone, and clay. Exposures of the lower shale are limited to the center of the general anticline in the eastern part of the area; the Puente sandstone outcrops in the middle, a trace of the upper shale overlying, while the Fernando formation almost closes over and around the older beds at the west end. West of this the conglomerate again gives way to outcrops of the Puente, which in the Whittier field occupies a large proportion of the ridge crest.

STRUCTURE.

The older formations in the heart of the area lie in anticlinal position, the flanks of the fold showing sharp local crumplings, with possibly a continuation of the faults that occur in the fields to the east and west. The prevailing strike is N. 70°–80° W. The position of the Puente fracture, if it be present (or of its alternative, the line of unconformity) is considerably nearer the axis of the general anticline than at points to the east, a few hundred feet only separating the two if, indeed, they are not locally coincident. As in other fields, there is here also a marked divergence between the trend of folds and the course assumed by the line of maximum disturbance. Along this line the development of oil territory has taken place. In the vicinity of the Union and New England wells, at the west end of the district, the strata show marked crumpling, with some evidence of faulting, although this is north of what appears to be the main anticline as traced from the east. The locality is one of especial confusion, owing to the compressed condition of the folds, to the proximity of the horizon of unconformity between the Fernando and older beds, and to the crushing that the rocks have undergone.

Of the several flexures present the most important appears to be that which passes directly north of the Union wells, in apparent continuation of the princpal anticline of the hills to the east. It lies considerably south of the point of greatest disturbance in the field, which is apparently in the immediate region of the New England wells. Farther west it possibly merges with the fold which appears south of the fault zone at the east end of the Whittier district. North of this fold are others, both anticlines and synclines, in one of which are the New England wells and an isolated well of the Union Oil Company. The rocks along the axis of this fold show severe crushing, with indications of considerable displacement.

At the head of the east fork of La Habra Canyon the structure again shows marked complexity. Sharp crumples, even faults, exist. The most conspicuous displacement is between the hills on either side of the road over the divide. The unconformity also is very marked, the line between the Fernando conglomerate and the siliceous shale of the Puente sweeping in a broad curve to the southern base of the hills and passing thence to the entrance to Walnut Canyon and the hills separating this from the entrance to Brea Canyon. Whether faults exist along this line is uncertain. North of the more conspicuous fracture the lower body of shale, beyond an interval of sharp minor folds, assumes a northerly dip, which is maintained by the succeeding formations to the northern limit of the hills. South of the fracture the shale, together with a small fragment of Puente sandstone, appears to lie in a sharp syncline, which is succeeded by an anticline, but there is much confusion in the details of structure, and these have not been determined. The changes in structure so frequently encountered in the Puente Hills are well exemplified in the present locality. Within a quarter to half a mile to the east the folds are less complicated, but the flexures continue to the Puente oil field, with faults, doubtless, in considerable number, but difficult of detection in the homogeneous shale.

The La Habra locality is noteworthy also in that the line of faulting and unconformity traceable westward from the Olinda and Brea Canyon fields here approaches the system of successive folds that characterizes the region of the Puente Oil Company's wells. Farther west the relations of these folds are even more intimate, and the zone of disturbance carrying them is greatly contracted.

OIL WELLS.

The only wells of the La Habra district are those of the Union and New England oil companies. They lie in two groups; the Sansinena wells, belonging to the Union Company, are situated in the gulch bottom a little south of the axis of what to the east is probably the main anticline; the other group is on the crest of the ridge, half a mile to the northwest, in highly disturbed strata close to the axis of one of the subordinate folds. The production of these wells is not large and the oil is comparatively heavy. A maximum depth of nearly 2,000 feet has been attained, although most of the wells are said to be much shallower. Oil is reported to the depth of 1,850 feet. The formations in the deeper wells embrace 300 or 400 feet of Fernando conglomerate at the top, followed by shale and sandstone below, in part, perhaps, of the Fernando, in part older.

PUENTE FIELD.

LOCATION.

The Puente oil field lies along the crest of the Puente Hills and of the general anticline forming them. It is about 1½ miles northwest of the mouth of Brea Canyon and 3 miles east-southeast of the developed territory of La Habra Canyon. The productive area is approximately 1¼ miles long by one-eighth mile wide, the length corresponding with the general strike of the beds (N. 70° W.).

GEOLOGY.

The formation underlying the region of the Puente field is the lower Puente shale, which, as shown by the well logs, is here largely interstratified with beds of fine sand varying in thickness from a few inches up to 100 feet or more; an unbroken thickness of 100 feet is, however, exceptional. Oil occurs at intervals from a depth of less than 300 feet to nearly 2,000 feet. The shale lies at the very heart of the Puente anticline and is, therefore, except in one or two places, not only the oldest body of rock exposed northwest of Santa Ana River, but the lowest formation in which oil has been found in the general region of the Puente Hills.

Flanking the shale on the north is the Puente sandstone, which is overlain by a thin body of the upper shale, and this in turn at the periphery of the hills by the Fernando conglomerate and associated beds. The dip from the crest of the ridge northward is to the north with marked regularity. South of the crest, opposite the developed territory, the shale extends to the valley level, the younger formations lying buried beneath the more recent wash. The dip on the south side of the ridge, especially in the eastern half of the field, is variable, indicating a rapid succession of synclines and anticlines, each lower as the edge of the prairie is approached. Opposite the western half of the field the folds are less pronounced and the prevailing dip on the lower slope of the hills is northward, changing to southward higher up.

Opposite the Puente oil field, for a distance of 2 or 3 miles along the southern base of the hills, the Fernando formation is wanting in outcrop, this being the only break in its continuity from a point near the Santa Ana to San Gabriel River. The ridges which usually mark the outcrop of the Fernando are also wanting, having been carried away, doubtless, by erosion at the time when the Pacific washed the base of the hills. It may be due to this that the Puente sandstone lying buried with the younger formation beneath the terrace gravels of the valley is also lacking along this same stretch of country. On the other hand, the disappearance of the Fernando and Puente sandstone may be by faulting, which is known to have disturbed the structural relations both to the east and to the west. North of the hills the strike of the Fernando and underlying formations changes from its normal direction of N. 65°–70° W. to nearly northeast. The Fernando passes from the flanks of the hills to the valley of San Jose Creek, while the Puente sandstone and the underlying shale enter into those subordinate folds of northeasterly trend which characterize the northern side of the hills from this point eastward.

STRUCTURE.

Without a detailed survey it is impossible to delineate the individual flexures of the Puente field. They are many in number, parallel with one another, of varying length and amplitude, and some are but slightly less important than the main anticline itself. There is no doubt, however, that the axis of the principal fold is here nearly coincident with the crest of the ridge, and the oil territory has been developed chiefly in proximity to this axis on either side. (See Pl. XI, sec. E–F.) From the Puente field eastward oil development has followed the line of the suspected fault and unconformity, although the main anticline has been but slightly prospected. Wells north of the line referred to, however, have been generally unsuccessful. The axis of the anticline has a gentle westerly pitch, which is maintained, except for modification by faulting, to a point beyond the New England Oil Company's wells.

Whether faulting has taken place in the immediate region of the wells is undetermined. It is suggested, however, both by the sharp crumpling which the beds have undergone and by the fact that the line of development is directly in the trend of the fault which has been recognized at the head of the east fork of La Habra Canyon. The locus of the main Puente fracture (or of its alternative, the unconformity) lies at the southern base of the hills and is traceable eastward to the Brea Canyon district and westward to the head of La Habra Canyon. The lack of confirmatory evidence to the contrary and the irregularity in the trend of the interformational line argue rather for unconformity than for faulting, although the possibility of the latter must be admitted. A feature of the field is the convergence of the axes of several folds that farther east are of considerable prominence.

OIL WELLS.

The wells of the Puente oil field are those of the Puente Oil Company, which now penetrate the lower shale of the Puente formation to a depth of nearly 2,000 feet, although for years 800 or 900 feet was the maximum. Oil is drawn from many layers of sand of varying thickness, some of the lower being especially productive and others affording but a minimum yield. The depth of 2,000 feet attained by the drill, together with the amount of erosion that must have taken place from the arch of the fold, indicates that this division of the Puente is at least 2,500 feet thick, the thickness of the entire formation being still undetermined.

The wells of the Puente Oil Company are among the oldest in California, dating back to the year 1885. Their production until recently has never been large, but has been maintained with marked constancy. Some of the newer wells have yielded 100 to 200 barrels of oil a day; but, as in the case of all other fields, this amount has decreased as the pressure has diminished and the territory has become drained. During 1905 but a few of the wells in this field were being pumped, and these only to avoid flooding. The oil is of an olive-green to black color by reflected light and varies in gravity from 22° to 35° B.

BREA CANYON FIELD.

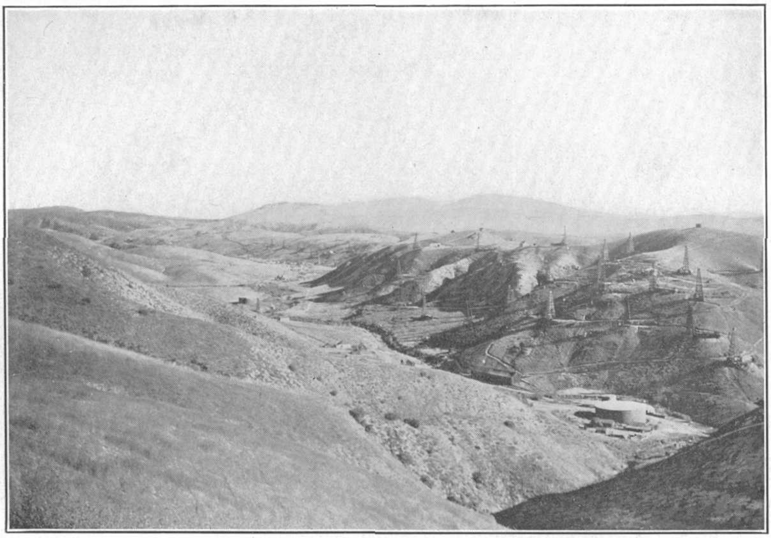
LOCATION.

Brea Canyon finds exit from the Puente hills 5 miles north-northeast of Fullerton in the vicinity of one of the most important oil districts in the territory. Below the forks the canyon assumes the trend of the main Puente anticline and lies close to the zone of maximum disturbance. At a point where the beds have been locally crushed it cuts directly through the outer terrane of the hills and passes into the valley. (See Pl. XIV, *A*.)

GEOLOGY.

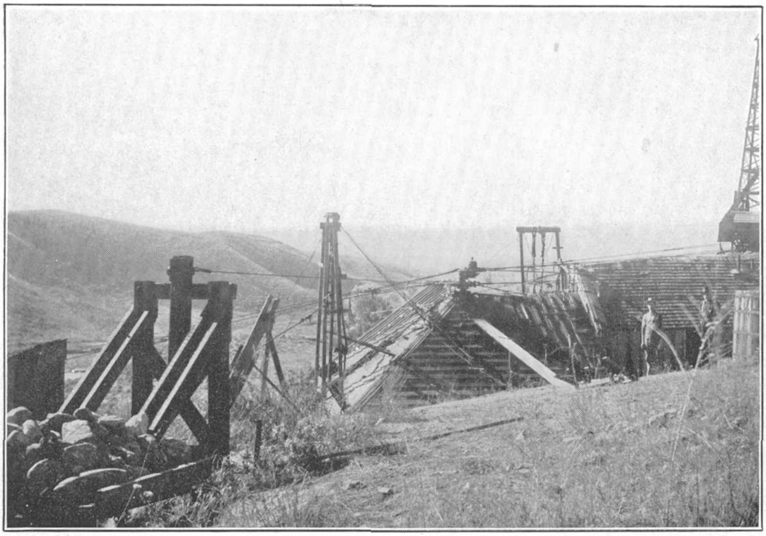
The Brea Canyon oil field is developed in the zone of highly disturbed strata along the lower canyon in a general N. 65°–70° W. direction. The formations include the Fernando conglomerate, sandstone, and arenaceous clay, the upper shale of the Puente, the Puente sandstone, here limited in area, and the lower division of the Puente, with its shale, interbedded sandstone, and lenticular masses of limestone.

The Fernando formation is well exposed along the lower portion of Brea Canyon. The higher and outer members consist of bright gray and yellow conglomerate, sandstone, and arenaceous clay. Within and lower in the series conglomerate becomes somewhat less conspicuous and traces of bitumen begin to appear. This feature is especially noticeable at the entrance to the canyon proper. Here also the sandstone, with a few pebbles, shows the concretionary structure observable elsewhere in the hills, but the formation is not on this account to be confounded with the Puente sandstone, for otherwise there are marked lithologic differences, and in addition to these the fossils of the younger beds are especially abundant and characteristic. The conglomerate of the Fernando formation enters largely into the composition of Brea Ridge, extending eastward far beyond the region of the Santa Fe wells. Westward it may be traced to its disappearance beneath the valley opposite the Puente oil field. Still lower in the series and occupying the inner or northern slope of Brea Ridge are several bands of petroliferous sandstone that display a few concretions and here and there a pebble mass and are interbedded with arenaceous clay. Two of the sandstone bands are particularly conspicuous, one well down on the north face of the ridge, the other north of the ridge near the creek channel. It is possible that these may lie at the same horizon, but that they are duplicated by faulting, the valley of the creek being coincident with a line of marked local disturbance. These beds carry fossils of lower Pliocene age. (See list, p. 107.) In the hill north of Brea Canyon there is a further succession of beds of clay, sandstone, and conglomerate, one or two of the conglomerate beds



A. LA BREA CANYON FIELD, ORANGE COUNTY.

Looking southeast.



B. CHARACTERISTIC PUMPING PLANT, WHITTIER FIELD, LOS ANGELES COUNTY.

being particularly persistent. Midway between the base and summit of the hill there is a calcareous pebbly layer, which is also fossiliferous, yielding a lower Pliocene fauna. The beds forming the lower slope north of the stream, although perhaps not a repetition of the beds south of the canyon, are unquestionably of the same formation.

A small body of limestone a few feet across, together with a little shale similar to the Puente material, was observed in the Fernando of Brea Ridge. A similar occurrence was noted near the Union wells in the La Habra district. Both are unusual and inexplicable.

Opposite the entrance to Brea Canyon the Fernando formation is succeeded on the north by shale, thin-bedded sandstone, and calcareous concretions characteristic of the lower divison of the Puente in this region. A narrow dike of diabase extending in an east-west direction for nearly a mile intrudes these Puente beds a short distance north of Brea Canyon. The shale and sandstone are directly traceable into those which occupy the heart of the general anticline 2 miles to the west, in the region of the Puente Oil Company's wells. They are overlain by the Puente sandstone in the eastern half of this field, and at the divide between Brea Canyon and the drainage of the Olinda field the upper shale in turn appears, in contact with the Fernando. In the western half of the field the sandstone and the overlying shale are wanting, having been carried beneath the surface, possibly by the Puente fault, which may here pass along the northern slope of the canyon. Notwithstanding, however, the evidences of faulting in the severe crushing which the strata have undergone, it is also possible that the unconformity admittedly existing between the Fernando and the older formations may prove to be accountable for the variation in the succession of strata, the younger members of the earlier formation having been uplifted and removed prior to the deposition of the later conglomerate and associated sediments. East of the east fork of Brea Canyon the Puente sandstone regains its prominence, and from this locality almost to the valley of the Santa Ana and the lowlands about Chino it is the most conspicuous formation of the hills.

STRUCTURE.

The structure about lower Brea Canyon is difficult to read, but from what has already been said the inference may be drawn that it is probably in direct general continuation with that both to the east and west; that is, the sharp folds, faults, and unconformity existing in the hills of the Santa Fe region extend along the northern slopes of the canyon, passing thence across the spur immediately west of its mouth to the edge of the prairie opposite the Puente oil field. The formations north of the fault line, or of the line of unconformity, show the usual variety of flexures, the shale being especially crumpled, the Puente sandstone less so. Syncline and anticline appear with a few secondary faults, parallel to the main fracture. An instance of the minor faults is to be found in the face of the ridge between the east and west forks of Brea Canyon, where Puente sandstone lies vertically against slightly undulating beds of the lower division of the Puente shale, indicating the dragging-down of the younger horizon in connection with the sharp fold from which the chief displacement has been developed. Toward the crest of the hills is the main axis of the general anticline, the fold being here somewhat modified by the radiate flexure passing to the northeast between the forks of Brea Canyon.

The position assumed by the Fernando beds south of the Puente fault is of the greatest interest from a structural standpoint. The dip of the conglomerate and sandstone north of the canyon, opposite the wells of the Brea Canyon and Menges oil companies, is 50°–90° N. (See Pl. XI, sec. G–H.) There appears to be a considerable difference in the succession as well as in the composition of the beds on the two sides of the gorge, yet in the uncertainties of lithology their correlation can not be denied as possible. A doubt exists as to whether the strata immediately south of the supposed fault lie in an anticline, as in similar positions at several points along the hills, or whether the conglomerate, sandstone, and arenaceous clay have been overturned by dragging against the fracture plane in their downward displacement. At one or two points there is some evidence of the latter condition; at others there is equal evidence of an anticline; elsewhere all is confused. If the anticline exists, its axis lies near the stream channel in the lower portion of the canyon, gradually passing into the slopes of Brea Ridge toward the east, to become continuous or but slightly en échelon with that of the anticline south of the fault in the Olinda field. The line of seepages in the bottom of Brea Canyon may mark such an axis and may possibly indicate a fracture developed along the crest of the fold. The most satisfactory evidence of an anticline aside from the unconnected northerly and southerly dips along the canyon exists about the head of the small lateral gulch in which the Menges wells are situated, the Fernando formation here showing the arch of a gentle fold, which, though lying close to the Puente fault, may prove continuous with the anticline suspected as coincident with the lower portion of Brea Canyon—its westernmost extension in fact. Moreover, it may be due to the near approach of anticlinal axis and fault—perhaps to the merging of one into the other—that the exterior ridges of the hills disappear to the west, the fracture alone passing thence along the base of the ridge opposite the wells of the Puente Oil Company. On the other hand, near the suggested fault line north of the Menges and Brea Canyon oil territory there is marked confusion of the strata, and the region is not without evidence of a simple overturn adjacent to the line of displacement. If this be the case, the line of seepages along the bottom of Brea Canyon marks the line of greatest crushing in the Fernando, except directly against the fault plane. Whether anticline or overturn, however, the general conditions bearing on the occurrence of the oil must be practically the same. The composition of the Fernando is repeated in a constant succession of conglomerates, sandstones, and clays to the bottom of the series, and crushing, equal under a fold of either description, must have produced equivalent effects of texture and structure. The prime factors in the field are the Puente fault, the crushing attendant on its development, and the contact of Fernando and Puente beds.

OIL WELLS.

The companies operating in the Brea Canyon field are the Brea Canyon, the Union, and the Menges. Other companies have drilled wells, but thus far without success The wells of the Brea Canyon Oil Company occupy a small area on the northern slope of Brea Ridge adjacent to the mouth of the canyon, their number being 21. To the east, also on the northern slope of the ridge, is the area drilled by the Union Oil Company, 32 wells being distributed along the strike of the beds for a distance of 1½ miles. The Menges Oil Company's property adjoins that of the Brea Canyon Company on the west, lying just west of the mouth of Brea Canyon. This company has two wells.

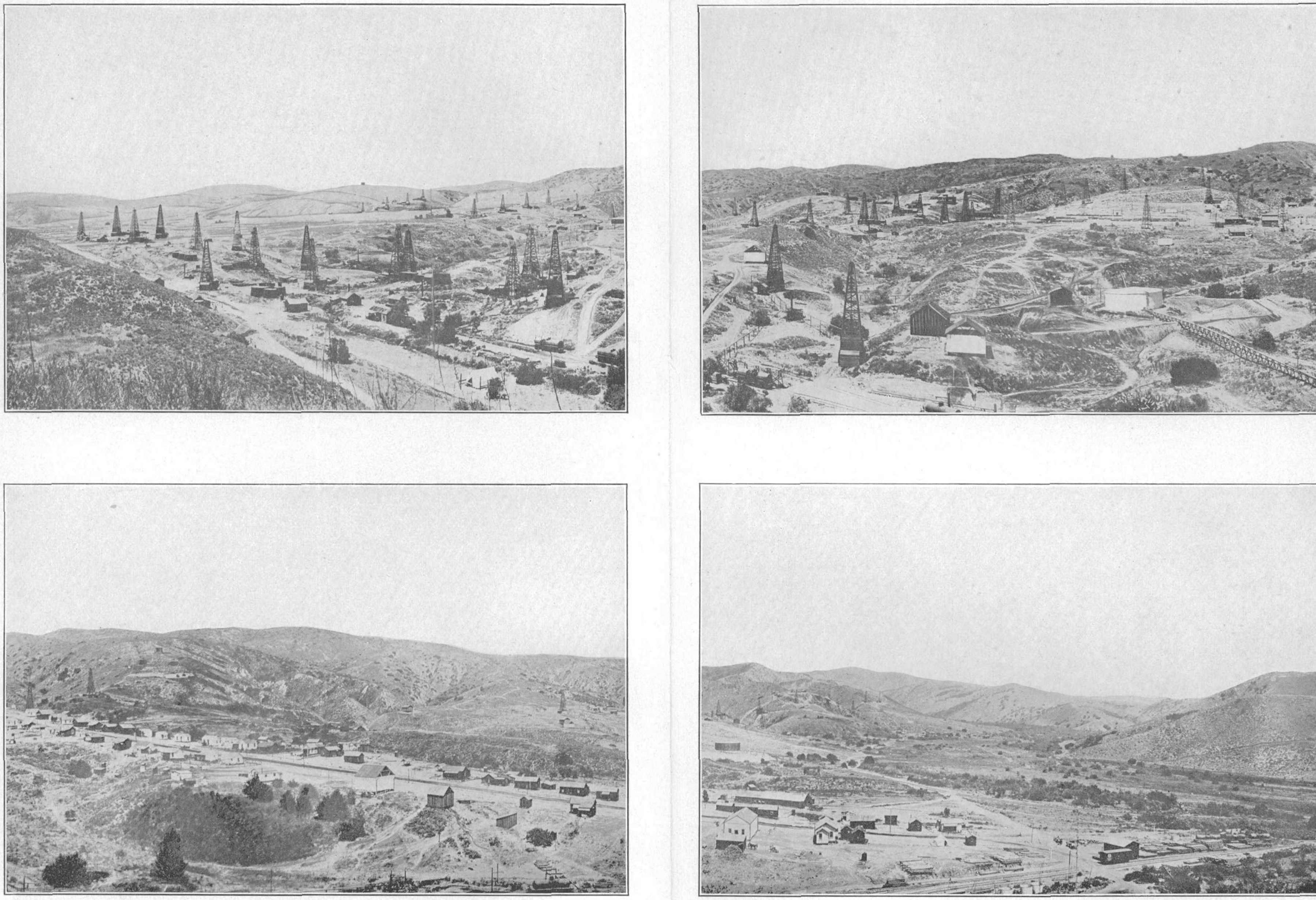
The wells of the Brea Canyon Oil Company are sunk in the conglomerate and sandstone of the Fernando formation, which strike N. 70° W. and dip about 50° S., both with considerable regularity. The strata cut are exposed, in part at least, in the northern slope of Brea Ridge and along the stream bottom, and include the bitumen-bearing sandstone referred to on a preceding page. It is impossible, however, to affirm that these horizons have furnished even a portion of the oil yielded, so at variance are the records of the wells when compared one with another and with surface exposures. It may be that owing to the crushing that has taken place adjacent to the fault and its possible extension to the region of the wells oil has filtered from the beds originally containing it into others until there has been a general diffusion of the fluid through the more porous strata along channels that for some reason have more readily permitted migration. In marked contrast, however, to the fine wells of this company on the south side of the canyon are those on the north side, where in strata far more disturbed little or no success has been attained.

The wells of the Brea Canyon Oil Company vary in depth from 600 to nearly 2,000 feet, in production from 12 to perhaps 1,000 barrels per day, in the gravity of their oil from 18° to 26° B. The heavier oil is said to come from the upper sands, the lighter from the lower. The product of the wells is run to a common tank with a resultant gravity of between 21° and 22° B.

The westerly wells of the Union Oil Company adjoin on the east those of the Brea Canyon Company, and the territory in which they are drilled, except for a slight undulation of the strike from a few degrees north of west to an equal amount north of east, is stratigraphically and structurally similar so far as surface exposures indicate. A marked difference in the productiveness of the two areas has been revealed by development, however, the many conditions in depth familiar to all students of oil occurrence probably being sufficiently variant in the two areas to cause the widely differing results obtained. It is unsafe as a general rule to predicate the success of a proposed group of wells upon that of a group already drilled, and, on the other hand, it is equally difficult to offer a tenable reason for the superior yield of one area over another, the conditions available for observation in the two being practically the same. Where there is a noticeable variation in surface conditions between two localities there is likely to be an equal variation in underground conditions, and it would not be unreasonable to expect a marked difference in the results of drilling. In illustration of this may be compared the eastern part of the Union Oil Company's tract in Brea Canyon and the western part already referred to. In the eastern part the strata show a distinct bowing to the south, and, moreover, the area is in proximity to a complex of folds that are traceable from the Olinda field. The conditions in the western part are more regular, the beds dipping rather uniformly toward the south. While in the light of experience it would be impossible to predict whether the eastern area would be more or less productive than that a mile to the west, it would be a fair inference that there would be a material difference in the yield of the two, and such a difference has been found by exploitation.

The territory of the Menges Oil Company, which adjoins that of the Brea Canyon Company on the west, is structurally at variance with both productive tracts described above and has so far yielded smaller wells. The general horizon at which oil is obtained by the Menges and the Brea Canyon companies is the same, but between the two tracts, strongly developed at the sharp bend in the canyon, is a compound flexure involving the oil-bearing strata, in part at least, of both properties. The flexure is as local as it is sharp, and disappears within a short distance of the stream. In the Menges tract, however, the strata are more disturbed than in that of the Brea Canyon Company, showing local and abrupt variations in both strike and dip, at one or two points with distinct overturns having a northerly dip.

The foregoing discussion has been carried to considerable length at this point because of the typical example afforded by the Brea Can-



PANORAMA OF OLINDA OIL FIELD.

From Olinda Ridge, Orange County, looking west to east.

yon field of the varying conditions attendant on the occurrence of petroleum within a comparatively small area. This field illustrates, also, the impossibility of offering a definite opinion regarding the probable productiveness of a particular territory, an opinion frequently asked of the geologist by all interested in the petroleum industry.

OLINDA FIELD.

LOCATION.

The Olinda oil field lies 6 miles northeast of Fullerton, just within the southern edge of the Puente Hills, near the entrance to Soquel Canyon. It is connected with the main line of the Atchison, Topeka and Santa Fe Railway by a branch from Richfields, 4 miles south. As developed, the field extends along the strike of the measures, N. 65°–70° W., about a mile and a half, the breath of the oil-bearing zone varying from one-eighth to one-third of a mile. The field is supplied with water from wells a mile or two out in the valley. In the immediate vicinity of the productive area the principal features of topography include the main mass of hills, an exterior ridge which borders Telegraph Canyon on the south and extends for a mile beyond the entrance to Soquel Canyon, and an inner valley separating the hills from the exterior ridge. Development has taken place in this valley and on the lower slope of the main mass of the hills to the north. (See Pl. XV.)

GEOLOGY.

The formations involved in the Olinda field embrace the upper and lower Puente shales, the Puente sandstone, and the Fernando conglomerate, sandstone, and arenaceous clay. The lower Puente shale, the homologue of that in the Puente oil field, is exposed principally to the east of the developed territory, along Soquel and Carbonne canyons, entering but slightly into the higher portions of the ridges. The Puente sandstone is confined entirely to the main body of the hills, extending north and east from the edge of the field for many miles and forming the cap rock on all the higher portions as far as the Chino divide. The upper shale is not well developed, and it is questionable whether it is present at some places in more than a trace. The Fernando formation constitutes the mass of the ridge south of Telegraph Canyon, the point of the ridge between Telegraph and Soquel Canyons, the hills west of the entrance to Soquel Canyon, and the low bench lands between the latter and Brea Ridge, at the west end of the field. It finally enters Brea Ridge and passes westward to the Brea Canyon field. It also underlies a considerable portion of the interior valley. These formations all extend to the region of Santa Ana River.

STRUCTURE.

The Olinda oil fields lie on the southern limb of the general anticline of the Puente Hills. The prevailing dip of the strata is, therefore, to the southwest, but an opposite dip is encountered at many places by reason of subordinate folds developed on the flanks of the principal flexure. The axis of the main fold, which trends N. 65°–70° W., lies somewhat less than a mile north of the oil belt, those of the lesser folds traversing the intervening space.

The northern edge of the oil belt, which is closely coincident with the base of the main body of the hills, is the locus of an extremely sharp fold that has many of the attendant features of a fault. In immediate proximity to it, also, is a trace of the contact between the Fernando and older formations, but whether this is a plane of faulting or of unconformity it is difficult to say. Perhaps the conditions are the combined results of the two, for the evidence for each at one point or another seems almost conclusive. The formations which are in contact are the Puente sandstone and the shales beneath and above on the north, and the conglomerate, sandstone, and clay of the Fernando formation on the south.

The zone of disturbed strata is traceable westward directly into Brea Canyon and eastward across the point of the ridge between Soquel and Telegraph canyons well into the hills south of the latter. It is marked in numerous places by heavy seepages of oil, which, however, appear to be from the Fernando rather than from the older beds. Beyond Telegraph Canyon the examination was not conducted in detail, but it is a significant fact that in the vicinity of Santa Ana Canyon, directly in the line of maximum crushing in the Olinda field, is another area of disturbance found by Mr. Homer Hamlin in a hurried inspection of the geologic conditions there existing.

The evidence for a fault in the Olinda field consists in an irregular succession of beds, a zone of crushed strata for 200 or 300 feet on either side of the interformational line, sharp flexures with local downward curve of the Puente beds on the north of the suggested plane of displacement and upward bend of the Fernando on the south, and the high inclination of both formations. These features also attest to the development of the fracture subsequent to the deposition of the Fernando, although prior to this period faulting might have taken place along a line practically coincident with the later displacement. In fact, there is ample proof in the hills area that the rocks of the Puente had been considerably folded before the Fernando formation was laid down upon them, and it may be that they were faulted as well.

The suggestion of unconformity is borne out by divergence in dip and strike and by the presence in the Fernando of materials unmistakably derived from the older beds. It is, moreover, in harmony with observations throughout a large portion of the Coast Range. The fact that in the Olinda field, therefore, the Fernando formation lies at one point against the lower shale of the Puente formation, at another against the upper shale, and at still another in contact with the Puente sandstone, may be attributed to unconformity, to faulting, or to both. As already mentioned, the writer inclines to the belief that both of these causes have contributed their part in the development of the existing conditions.

The principal features of structure in the Olinda field will now be taken up in somewhat greater detail. In the eastern third of the field, from the vicinity of the gulch containing Santa Fe wells Nos. 21, 32, 36, and 38, eastward to the Columbia ground and Soquel and Telegraph canyons, there appear to be two divergent lines of structure, the southern line marking the trace of the main fault, or of its alternative plane of unconformity between the Fernando and the older beds, maintaining the general trend of N. 65°—70° W., and passing across the lower portion of Telegraph Canyon; the northern, a line of severe crushing, extending more directly eastward or even a little north of east and following the gorge of Soquel Canyon. The northern line is confined wholly to the Puente formation. The combined effect of faulting and folding, together with the divergence in strike noted, has brought to the surface, north of the divisional line between Puente and Fernando, beds gradually lower in horizon toward the east, the prevailing dip being 25°-60° N. As the divergence increases additional crumples, some of them extremely sharp, appear in the Puente beds.

Immediately north of the northern of the two divergent lines referred to above and close to the northern line of wells is located the axis of the general syncline that is so persistent and conspicuous a feature along the northern border of the Olinda field. Its trend is N. 65° W. and it is especially prominent in the Puente sandstone. This syncline is of especial interest near the center of sec. 9, where are clustered several wells of the Santa Fe, Fullerton Consolidated, and Columbia (Puente lease No. 1) oil companies. At this point there is considerable uncertainty regarding the stratigraphic horizon, both from the crumpled condition of the beds and from the lack of distinguishing characteristics. The Puente sandstone appears a short distance north of the wells, dipping to the south, but about the wells the strata dip northward and have more the nature of arenaceous, granular, and muddy shale, with traces of the siliceous variety, in one instance faintly organic. On the whole the formation bears considerable resemblance to that underlying the Puente sandstone along the lower slopes of Soquel Canyon east of the Columbia wells (lease No. 1), and yet it is not unlike certain members of the Fernando. The writer is inclined to place the beds in the Puente and to regard the area as lying within a zone of especial disturbance that is manifest along both the main fracture and its northern branch, in all probability in an inter-fault block. The syncline is traceable in strike from north of east through north to north of west, and in a dip correspondingly variable from north to west and then to south around the east end of the trough, this being especially manifest in the heavier sandstones at the point occupied by the Fullerton wells, which lie close to the synclinal axis or a short distance off on its southern limb. Evidences of the syncline continue eastward to the bottoms of Soquel Creek in a constant repetition of the structural features of the Columbia ground (lease No. 1), a westerly dip along the axial line locally as high as 45° being especially noticeable. Beyond Soquel Canyon the identity of the syncline is lost.

Most of the Columbia wells (lease No. 1) are located on the south side of the synclinal trough; some, however, are close to the axis, while two or three of excellent yield appear to be in strata that dip to the south or are intensely crushed. One of the deeper wells in which, up to the time of the investigation, no oil had been found penetrates at the collar the organic shale of the Puente. The others, which start in heavy sandstone, probably of the Puente formation, are highly productive.

The easterly wells of the Santa Fe and those of the Fullerton and Columbia oil companies appear thus to have been drilled in the Puente formation, in ground whose structure is somewhat uncertain. Most of them lie a little south of the line of maximum crumpling. It may be inferred, therefore, that the horizon of their oils is approximately that of the oils of the Puente Oil Company's wells 5 miles farther west. Moreover, the logs of the wells indicate the presence in depth of shale similar to that of the Puente oil field, whereas in other portions of the Sante Fe area the strata are of the more open and porous nature characteristic of the Fernando. This similarity of strata penetrated in the Puente field and the east end of the Olinda field accounts for the similarity of the oils of the two localities. The gravity varies between 23° and 35° B., the oil of the Olinda field being somewhat the lighter.

Typical Puente shale with steep dip is exposed a few feet east of the Columbia camp (lease No. 1), several hundred feet south of the eastern wells of this company. The outcrop is in line with others of the same nature up Soquel Canyon, and it is probably continuous with them, the Fernando having here crossed to Telegraph Canyon. Loose shale fragments are also found over a considerable area in the same general region south of the wells.

Along the middle portion of the field, in the eastern half of the Graham-Loftus tract, the strata occupying the face of the hills north of the wells but south of the syncline, extending from the region described in the foregoing paragraph, include yellow and gray concretionary sandstone of the Puente type, with the associated siliceous shale and a succession of sandstone and arenaceous shale, also yellow and gray but apparently devoid of concretions and of the minor organic forms that characterize the Puente. There appear to be two formations in juxtaposition—one undoubtedly Puente, the other closely resembling the Fernando. Their relations suggest the locus of the Puente fault, a view strengthened by the sharp disturbance affecting the strata in the adjacent gulches. The strike of both formations is the same, about N. 70° W. The fault plane, on the whole, is believed to pass a short distance south of the northernmost of the Graham-Loftus wells, No. 17, but north of the others in this vicinity. With the exception mentioned, therefore, all the wells in this part of the field have apparently been drilled in the Fernando formation, and this view is borne out by the fact that conglomerate is encountered at various depths in the wells of both the Santa Fe and the Graham-Loftus companies. The position of these wells is believed to be on the northern limb of the subordinate anticline south of the fault.

Outcrops of conglomerate and siliceous shale about 125 feet northwest of the Santa Fe No. 12 well may be regarded as locating the position of the main Puente fracture for this part of the field. The strike of the conglomerate ranges from N. 85° W. to east and west; the dip 35°–40° N. The shale, as usual, shows large crumples for a considerable distance from the fault. The westernmost well of the Santa Fe Company, No. 37, is close to the line of rupture, possibly a little to the north of it.

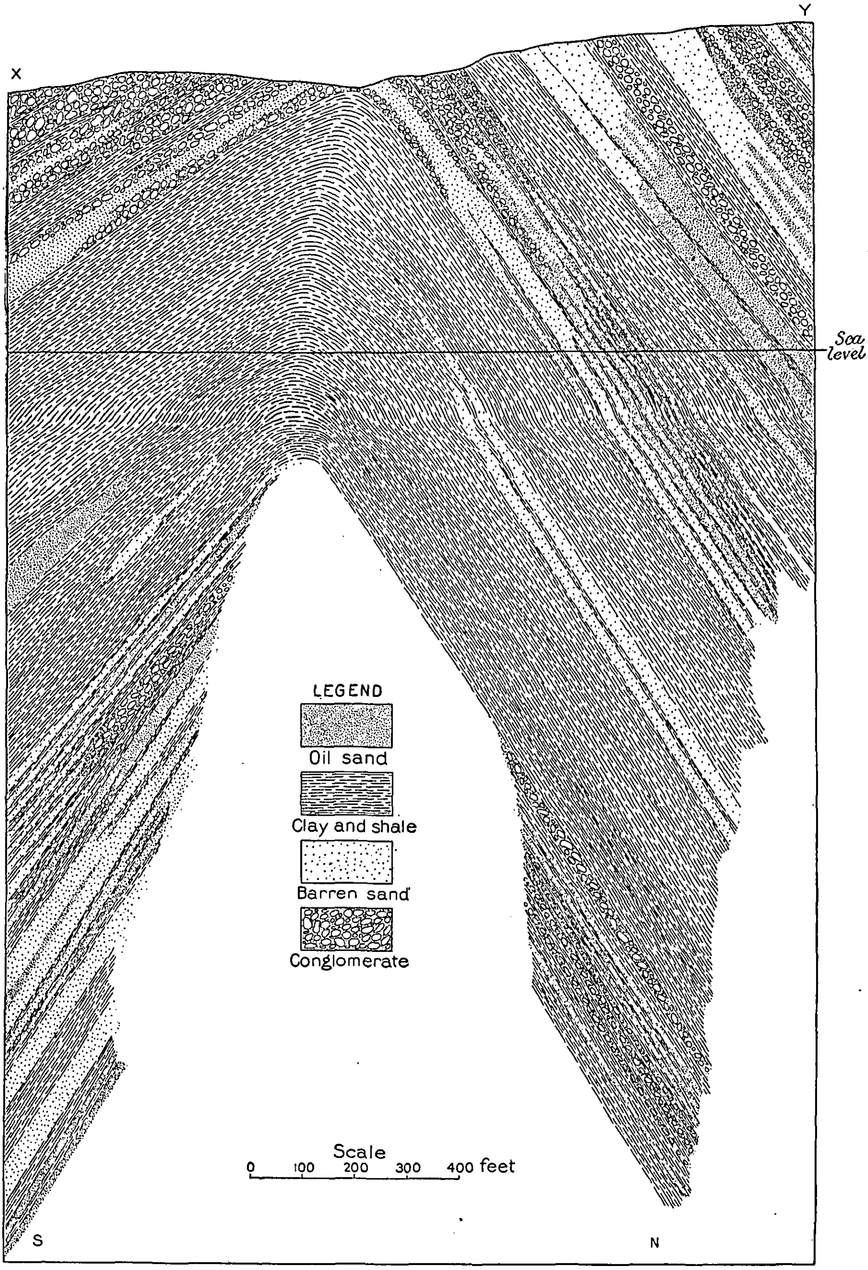
The structure just described continues with some variation, not only to the west end of the field, but into Brea Canyon and the territory north and south. The locus of the fault as it crosses the divide between the Olinda and Brea valleys is obscure, but it is not far from the point of least elevation. North of this point heavy beds of Puente sandstone lie in vertical or overturned position, bending, however, to a southerly dip of 20° or less as they pass to the summits of the hills above. South of the divide and for a mile or more along the southern slope of the ridge north of Brea Canyon the siliceous shale of the Puente outcrops. Although this shale is in natural sequence with the Puente sandstone on the north, it is believed that, on account of irregularities in adjacent areas, the two beds are separated by the Puente fault, or at least by a subordinate fracture. In Brea Canyon the syncline that in the Olinda field lies immediately north of the fault disappears, although other flexures in considerable number, among them a syncline of some importance, may be observed along the slope of the hills to the west.

In the region of the Santa Fe wells the details of structure for the area along the interior valley underlain by the Fernando conglomerate, in which much of the development has taken place, are somewhat obscure. In a general way, however, it is evident that east of the western group of Columbia wells (lease No. 2) the strata are deflected from their general strike of N. 65°–70° W. to N. 45° W. in the vicinity of the southwestern Santa Fe wells, thence bending to S. 70° E. and passing onward into the ridge south of Telegraph Canyon. A trace of a similar and concentric deflection, with marked local folds, exists also in the rocks of the older formation northeast of the Fernando area, in the hill slopes north of the Santa Fe village, and the flat to the east. The explanation may be that compression took place after faulting, affecting the strata in a like manner on both sides of the general fracture. Still, this occurrence may be a coincidence rather than one of direct relationship in the movements of the beds.

Again, the Fernando formation, though of comparatively steep southerly dip in the exterior ridges of the field, assumes a much lower angle of inclination farther north in the interior valley region, with an actual northerly dip, as evidenced by the logs of the wells of the Graham-Loftus and Columbia oil companies, near the line of the fault or of maximum folds. (See Pl. XI, sec. I–J, and Pl. XVI.) In other words, there is apparently, through at least the western half of Olinda Valley, an anticline whose axis coincides with that of the valley, trending about N. 65° W.

The anticline is clearly traceable in the eastern face of Brea Ridge, the axis passing through the southern group of wells of the Columbia Oil Company (lease No. 2), or probably a short distance to the south of all these wells. Evidences of the fold also appear in the structural lines that cross the crest of the ridge diagonally in Union ground, a mile west of the Columbia wells (lease No. 2), and in some of the gulches that cut the northern face of the ridge in the same vicinity. The strikes and dips vary according to the position of the beds in the fold. It is possible that the anticline continues westward to the Brea Canyon field, being identical with the fold suggested along the line of seepages in the bottom of the valley. Some irregularity is displayed in the disposition of the strata along the eastern third of Brea Ridge, the Fernando formation being confined to the southern limb of the anticline, though crossing to the north of the axis in the region of the Columbia wells (lease No. 2), and possibly farther west, in the ridge between the forks of Brea Canyon.

How far to the east the anticline extends is undetermined. It does not appear in the Fernando at the point of the ridge between Soquel and Telegraph canyons, although the Puente beds here have the opposite or northerly dip and half a mile up Telegraph Canyon show distinct evidences of a fold. It may be that the anticline continues



DETAILED GEOLOGIC SECTION THROUGH OLINDA OIL FIELD.

through to this point, the Fernando, however, no longer bending over the crown of the arch.

The direction which the eastward extension of the Olinda field may take is somewhat problematic. The development in Columbia ground (lease No. 1) follows the northern fracture, or at least the line of excessive disturbance passing up Soquel Canyon to the entrance of Carbonne Canyon; the surface conditions prevailing in the western half of the productive territory, however, continue across to Telegraph Canyon, except that the Fernando conglomerate is in contact with lower members of the Puente than to the west. Apparently the beds are somewhat transitional in their nature, gray micaceous sandstone and shale lying beneath the Puente sandstone, the precise horizon varying from point to point. The structure of the lower beds is very complicated. In the northern face of the ridge between Telegraph and Soquel canyons the rather heavy gray and yellow gritty sandstone dips to the north, while the associated brown argillaceous shale, only 150 feet distant, has a southward inclination. The strike of both is N. 65° E. In the southern face of the ridge the principal dip of the older rocks is 45°–80° N., although half a mile up Telegraph Canyon the beds of the same character begin to show a southerly dip, which is maintained well into the hills to the south. The conglomerate south of these beds strikes N. 65° W., nearly parallel with the axis of the anticline referred to above; it dips 80°–45° S., according to the distance from the fault line. It rests upon older beds that dip in some places to the north, in others to the south, the northward-dipping rocks lying near the mouth of Telegraph Canyon. The similarity of the conditions in Telegraph Canyon and in the western half of the Olinda field is thus obvious, and while there are slight differences it would, nevertheless, seem reasonable, from surface conditions, to expect equal chances for obtaining petroleum along the line of the fault or unconformity in the two localities. However, wells at some distance from this line, in the Fernando beds on the ridge south of the interior valley, have not yet proved successful.

In the discussion of the relations of Fernando to Puente in the region of Telegraph Canyon the question of faulting or unconformity arises with the same force as elsewhere. The conditions are explicable on the basis of an unconformity, the upheaval and erosion of the older rocks prior to the deposition of the Fernando being presupposed; they may also be explained by faulting, or they may be due to the two causes combined.

OIL WELLS.

The oil wells of the Olinda field number over 100, and except a few, chiefly along the outer ridge, all have been of wonderful productiveness, yields of 700 to 1,000 barrels of oil per day having been reached. The maximum depth attained is 3,000 feet. The wells are ranged along two lines, the northern group following the zone of greatest disturbance, together with the fault, and the southern following the land line which separates the properties of the Santa Fe and Fullerton Consolidated oil companies and having no connection whatever with the structure.

The oils of the Olinda field vary in gravity from 12° to 35° B., the heaviest being found at the west end of the field in members of the Fernando, those of 18° to 20° B. in the southwestern part, also in the Fernando, and those between 23° and 35° B. in the eastern half of the productive area in various horizons of the Puente.

CHINO FIELD.

The Chino oil field occupies a small area on the crest of the divide between Soquel Canyon and the Chino Valley, 5 miles southwest of the town of Chino. It is located on what appears to be one of the northeast-southwest flexures that radiate from the main Puente anticline. The wells, four in number, are drilled in the axis of the flexure and on either side. They pierce the Puente sandstone and underlying shale, but the details of their logs were unavailable at the time of the writer's visit. Aside from their commercial value, they are of especial interest as suggesting the possibilities of at least some of the subordinate folds in the hills.

CONCLUSIONS CONCERNING FUTURE DEVELOPMENT.

Whether petroleum will be obtained north of the line of maximum disturbance in the Puente fault zone, in rocks adjacent thereto, is questionable. Thus far wells in this position have been unsuccessful. A reservoir of coarse sand or other open-textured rock is filled with oil at the expense of the finer strata in which it may prove to have been but temporarily stored, or in some of which it may have even originated. Under conditions such as have been described, it may be inferred that in the region of the fault, along the southern face of the Puente Hills, the oil has been drawn from the beds north of the fracture zone into the more crushed and hence more open and porous strata of the same age south of it, and also into the still more receptive reservoir of coarse sediments presented in the Fernando formation. How great an area north of the fault may have thus been drained it is impossible to say.

An argument in favor of productiveness of the Puente formation away from the zone of faults is presented by the Puente Oil Company's wells, which are drilled in an anticline in the lower division of this formation. Similar evidence is also offered by the wells of the Chino Oil Company, which penetrate the Puente, including the sandstone, on a fold subordinate to the main Puente anticline, yet not far from its axis. That the lower Puente shale in these hills is generally oil bearing in some degree is recognized, that the Puente sandstone is also impregnated with bitumen is evident, but that the shale and the associated sandstone are everywhere impregnated to such an extent as to render them of economic value, under structural conditions that would be regarded as favorable, is improbable.

PETROLEUM OF THE PUENTE HILLS DISTRICT.[a]

YIELD AND GRAVITY OF OIL IN DIFFERENT FIELDS.

The yield of the individual productive wells in the Puente Hills varies from 1 to over 1,000 barrels per day, those in the Puente field giving the lowest averages and those in the Brea Canyon field the highest. The wells of the Whittier field produce oil varying from 14° to 24° B., the yield of the individual wells running from 2 or 3 barrels to nearly 175 barrels per day (in one well), although it is said that one or two wells went as high as 400 barrels at the start. The gravity of the Puente field oil runs from 28° to 34° B., but the average yield of the wells is lower than in any other part of the district, and none of the wells have gone much over 100 barrels per day, even in their prime. In contrast with the low production and high-grade oil of the Puente field is the high production and medium-gravity oil of the adjacent Brea Canyon field. The gravity here ranges from 18° to 26° B., while some of the wells yield as high as 1,000 barrels per day. Several flowing wells have been struck in this territory, one at least, it is said, gushing with a pressure of more than 250 pounds to the square inch. The Olinda field furnishes both high and low grade oil, the high grade, with a maximum of 35° B., coming from wells in the northeastern part of the field yielding from 2 or 3 to 150 barrels per day, and the low grade, with a range of 18° to 20° B., coming from wells in the west end. Six "gushers" have been developed at Olinda, one of which is said to have flowed at the rate of 20,000 barrels per day for a short time. One of the flowing wells on the Santa Fe property is now (October, 1905) flowing under a pressure of 100 pounds to the square inch.

FACTORS IN YIELD OF WELLS.

The factors governing the yield of oil wells, aside from the natural conditions—porosity of rock, pressure, etc.—are usually those connected with the manipulation of the wells, such as size of casing, loss of tools, caving in of casing, or accidents of one kind or another. Sometimes, however, the condition of the oil market has a most potent influence on the production by causing the partial or total shutting off of the wells; this has been the cause of a decline in the production of several groups in the Puente Hills district during 1905.

[a] For a discussion of the physical and chemical properties of the oil of the Puente Hills, see pp. 210-217.

The yield of most wells becomes less with the lapse of time. This decline is generally more marked during the first few months of the well's life than later, when the conditions governing the flow appear to become more stable. Pl. XVII, giving the average daily yield by months of a group of wells in the Puente Hills district, illustrates graphically the common variations in the yield. The minor fluctuations in the curves are usually traceable to the sanding up or cleaning out of the wells or to other local causes.

ASSOCIATED HYDROCARBONS.

Brea and gas are the only hydrocarbons associated with the oil in the formations of the Puente Hills district. Brea (sand or soil impregnated with oil from seepages, the volatile substances having evaporated) is found in all of the fields. The largest deposits in the district are in Brea Canyon, on the south slope of which are considerable areas covered by the material. No practical use has been made of it except locally for road dressing.

Nearly all the wells in the territory under discussion yield more or less gas, especially in the earlier stages of their existence. In some localities the gas contains a considerable percentage of hydrogen sulphide, to judge by the odor encountered in the vicinity of certain wells; in others the gas is of such a quality as to be used profitably both in the generation of power by gas engines and for domestic purposes. Among the companies making use of the gas derived from their wells are the Santa Fe, in the Olinda field, and the Murphy, in the Whittier field. The Santa Fe Company is said to use gas entirely for all purposes requiring the generation of heat and light on its property. Some years ago a well yielding gas under strong pressure was struck south of Whittier, in the western extension of the Coyote Hills anticline. This well never furnished any oil, and as the gas gave out the hole was abandoned.

STORAGE AND TRANSPORTATION.

With the exception of the oil in the Olinda field, much of which is stored in open earthen reservoirs, most of the oil of the Puente Hills district is stored in circular metal tanks. These tanks are usually covered, and vary in capacity from 5-barrel settling tanks to storage tanks holding about 55,000 barrels. The tankage of the Whittier field is something over 200,000 barrels; that of the Puente field, including the Chino refinery, over 100,000 barrels; that of Brea Canyon approximately 85,000 barrels, and that of the Olinda field possibly 200,000 barrels. In addition to this, the Union Oil Company has a storage capacity of about 150,000 barrels at Norwalk, the center of its pipe-line system, and of 37,500 barrels at San Pedro, its shipping point by boat.

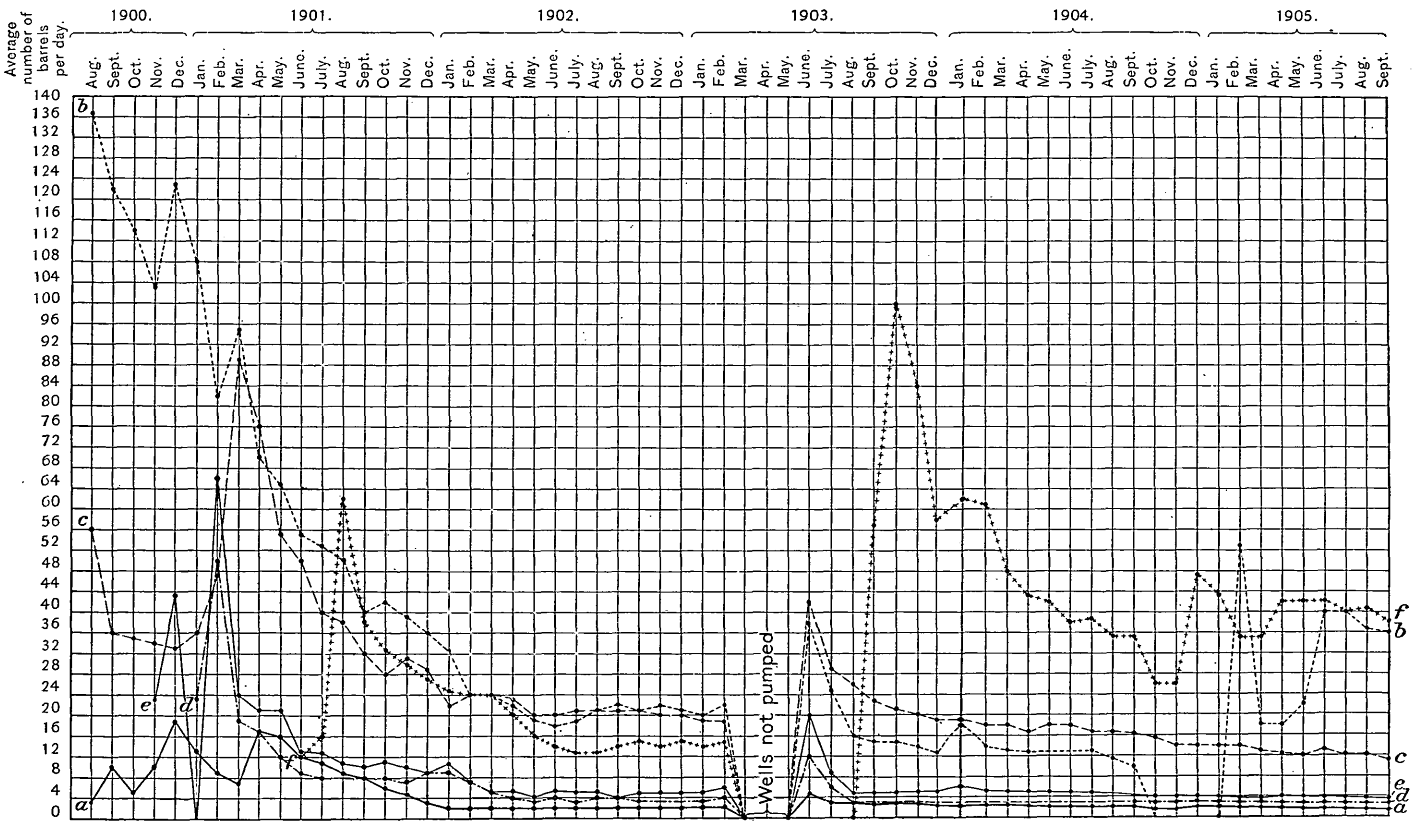


CHART OF VARIATIONS IN AVERAGE DAILY YIELD OF SIX WELLS IN THE PUENTE (MIOCENE) SHALE AND SANDSTONE TERRITORY (REGION OF LIGHT, OR 32° TO 34° OIL), PUENTE HILLS OIL DISTRICT, CALIFORNIA.

The Union Oil Company owns all the longer pipe lines in the district, with the exception of the 13-mile 3-inch line of the Puente Oil Company from its property to its refinery in Chino and the 3-inch line of the Murphy and 4-inch line of the Central oil companies from their wells in the Whittier field to Los Nietos, 3 miles farther west. The Union lines comprise 17 miles of 5-inch pipe from San Pedro to Norwalk; 15 miles of 4-inch (some 5-inch also) from Norwalk to Los Angeles; 12 miles of 4-inch from Norwalk to Brea Canyon; 3 miles of 4-inch from Brea Canyon to Olinda, and 4 miles of 4-inch from Whittier to a junction with the Norwalk-Brea Canyon line.

The oil is shipped from Olinda and Los Nietos over the Atchison, Topeka and Santa Fe Railway, and the Southern Pacific Company has connections at Whittier and Los Nietos and also at the Puente Company's refinery at Chino. The Union Oil Company is the only one shipping oil by water from this district, its loading point being San Pedro, which, as already mentioned, is connected by pipe line with Norwalk and thence with all the fields of the Puente Hills.

UTILIZATION OF THE OIL.

Much the larger part of the oil produced in the Puente Hills is used in southern California. Some of the product, however, is exported and shipments have been made to Alaska, Washington, Oregon, Arizona, New Mexico, the Hawaiian Islands, and even to Chile. In Alaska the oil is used principally for the development of power for mining purposes, while in Washington it is coming into direct competition with the local coal, which it is supplanting for purposes of gas production and as a fuel. The chief uses for oil in Arizona and New Mexico at present are in connection with mining. In the Hawaiian Islands the oil is used principally for fuel in the refining of sugar and for the development of power needed in the irrigation systems on the great plantations. In southern California it is used for the following purposes, named in the order of the amount consumed: Fuel, illuminants, the direct development of power in gas engines, oiling roads, and lubricants.

A new use for oil that has been developed during the past five years is for the purpose of road dressing. California is virtually without rain for two-thirds of the year, and as a result the subject of dusty highways is one of paramount importance. It has been found by experiment that the heavy oils not only settle the dust but, if properly applied to the road, produce a springy surface which closely approaches that of asphalt paving. The usual method of application is to scratch or break up the surface of the road to the depth of an inch or more, sprinkle on the oil by means of certain mechanical devices, and finally spread a thin coating of sand over the whole.

This soon becomes packed and the volatile constituents of the oil evaporate, leaving a dustless, springy surface of asphalt, soil, and sand. Several municipalities use the oil process entirely for their city streets and hundreds of miles of country roads in southern California are treated in a similar manner. A recent judicial ruling which holds that the principle of road oiling is not patentable has greatly stimulated this use for the heavy oils.[a]

PRODUCTION.

The gross production of petroleum in the Puente Hills district from 1899 to 1904, inclusive, was 8,241,081 barrels, as follows:

Production of oil in Puente Hills district, 1899–1905.

	Barrels.		Barrels.
1899	217,599	1903	2,545,318
1900	511,550	1904	2,328,064
1901	909,588	1905	2,007,021
1902	1,728,962		

These figures were compiled from data furnished by the officers of all the producing companies. Previous to 1899 the oil produced in this district came almost entirely from the Puente field.

PRICES.

The Union Oil Company has furnished the following table, showing the average price per barrel paid for crude oil (average gravity 18°–19° B.) at the wells in the Puente Hills district:

Average price per barrel, in cents, paid for crude oil at the wells, Puente Hills district.

	1901.	1902.	1903.	1904.	1905.
January		80	49	60	44
February			53	56	53
March		80	53	57	54
April			44	57	48
May			50	58	43
June			51	56	45
July		35–40	55	59	43
August			54	57	42
September		35–40	55	59	41
October			56	56	
November		40	55	55	
December		40	63	55	
Average for year	80	60	53	57	46

[a] For a detailed description of the road-oiling process see Prutzman, Paul W., Production and use of petroleum in California: Bull. California State Mining Bureau No. 32, 1904.

OIL COMPANIES IN PUENTE HILLS DISTRICT.

The following list gives the names of the companies that have put down wells in the different fields of the Puente Hills district, with the number of wells drilled by each. Those marked with an * are not operating.

Companies and number of wells in Puente Hills district, 1905.

Name of company.	Field.	Number of wells.
Brea Canyon	Brea Canyon	20
Buena Vista*	Puente	1
Bulla*	Whittier	3
Central of Los Angeles	do	46
Chandler (now Murphy)*	do	3
Chino Land and Oil*	Chino	4
Columbia Oil Producing (lease No. 2)	Olinda	12
East Whittier*	Whittier	2
Fidelity	do	9
Fullerton	Olinda	12
Fullerton Consolidated	do	16
Golden Gate*	La Habra	1
Graham-Loftus	Olinda	18
Hardison*	do	1
Holden*	Whittier	1
Home	do	18
Iowa*	Olinda	1
Joyce*	Whittier	1
Los Angeles Petroleum*	La Habra	1
Menges	Brea Canyon	2
Murphy	Whittier	21
New England*	La Habra	3
North Whittier*	Whittier	2
Olinda Crude*	Olinda	5
Palo Alto	Whittier	(?)
Palo Solo*	do	1
Pasadena	(?)	(?)
Price*	Whittier	1
Puente	Puente	65
Puente (Columbia lease No. 1)	Olinda	28
Santa Fe Ry	do	49
Strong*	Whittier	3
Turnbull Canyon	do	1
Turner	do	8
Union	Brea Canyon	30
Union (Sansinena)*	La Habra	9
Warner	Whittier	8
Whittier Consolidated*	do	2
Whittier Crude	do	9
Whittier-Filmore	do	2
Whittier Grand*	do	1
Whittier Oil and Development*	do	1
Whittier Producers*	do	1

THE LOS ANGELES OIL DISTRICT, SOUTHERN CALIFORNIA.

By Ralph Arnold.

INTRODUCTION.

During the summer of 1902 Mr. George H. Eldridge spent about two weeks in the vicinity of Los Angeles collecting data concerning the geology and oil production of the region, but owing to poor health for a long time previous to his death in 1905 he had done little toward working this information into a report. Since Mr. Eldridge's visit the city field has been considerably modified by the abandonment of many wells and the present state of development of the Salt Lake field has been brought about. It has therefore been necessary to make a new and more detailed examination of the same region in order to prepare a suitable report.

ACKNOWLEDGMENTS.

The writer wishes to fully acknowledge the value of Mr. Eldridge's notes, which have been freely used and which have contributed largely to whatever of value there may be in the following pages. Acknowledgments are due also to the various oil companies and their managers, as well as to individual drillers in the district, for assistance in various ways and for information given by them during the course of the work. Thanks are due more particularly to Mr. E. J. Eginton, superintendent of the Clark Oil Company; to Mr. A. F. Gilmore, of the Gilmore Oil Company; and to Mr. W. W. Orcutt, geologist of the Union Oil Company.

PREVIOUS KNOWLEDGE OF THE REGION.

After the researches of William P. Blake and Thomas Antisell, geologists accompanying the Pacific Railroad exploring expeditions, who visited southern California in 1853 and 1855, respectively, and of J. D. Whitney, State geologist, who went over portions of the same territory in the early sixties, no important geologic investigations in the region of Los Angeles or in the southern California oil fields in general were carried on until 1894, when W. L. Watts began a study of the petroleum deposits for the California State mining bureau.

Blake was the pioneer geologist in this region and his observations[a] are wonderfully accurate in view of the difficulties under which he and his associates worked. The part of his report relating to the southern California oil fields is that describing the region of the route traveled by his party, from San Francisquito Pass, north of Saugus, southward through Fernando Pass to Los Angeles and thence eastward to San Bernardino. He describes the east end of the Santa Susana Mountains, mentions Tertiary fossils found in Fernando Pass, and speaks of the eruptive rock (basalt) which outcrops in Cahuenga Pass. About 5 miles northwest of Los Angeles he found some "light-colored shales, thinly stratified, and charged with bitumen, which formed black and brown seams between the layers,"[b] and correlated them with the Miocene shale found in the vicinity of Monterey. Blake's only observations bearing directly on the oil question refer to the bitumen which he noticed exuding from the light-colored shale, and are as follows:[c]

> These places are known as tar springs, or pitch springs, and some of them form large ponds or lakes. One of the springs was passed on our way to the city, and was near the outcrop of bituminous shale in the banks of the creek already described. This spring was nothing more than an overflow of the bitumen from a small aperture in the ground, around which it had spread on all sides, so that it covered a circular space about 30 feet in diameter. The accumulated bitumen had hardened by exposure and its outer portions were mingled with sand, so that it was not easy to determine its precise limits. It formed a smooth hard surface like a pavement, but toward the center it was quite soft and semifluid, like melted pitch. The central portion of the overflow was higher than its margin; and it was evident that all the hard portion had risen in a fluid state and by the heat of the sun had been gradually spread out over the surface; at the same time being constantly exposed to dust, it had become so thoroughly incorporated with it that the compound had all the consistency of an artificial mixture. Tufts of "salt grass" were growing in some of the hollows and crevices of the outer portions of the hardened bitumen.

During the winter of 1854–55 an exploring party under the direction of Lieut. John G. Parke, accompanied by Dr. Thomas Antisell, geologist, examined the Santa Susana and Santa Monica ranges and the region adjacent to them as far east as San Bernardino. The results of this examination are set forth in Parke's report,[c] one chapter dealing with the geology of the two and another with the plains of San Fernando, Los Angeles, and San Bernardino. By far the most interesting chapter bearing on the oil question in Antisell's report is that on "Bituminous effusions," which gives a brief summary of all the then known bitumen deposits in the State. The following notes concerning the Los Angeles region are copied from this chapter:[d]

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[a] Pacific Railroad Report, vol. 5, pt. 2, 1856, pp. 65–88.
[b] Op. cit., p. 76.
[c] Pacific Railroad Report., vol. 7, pt. 2, 1857, pp. 75–86.
[d] Op. cit., pp. 112–113.

Deposits of Los Angeles Valley.— . . . The asphalt is protruded through these strata near its contact with the argillite, forming distinct wells or springs, which overflow. The land where they lie is owned by Captain Dryden,[a] who at the time of the visit was sinking a pumping apparatus for hoisting up the bitumen, which is very liquid at this locality, where it forms a small pond a fourth of a mile in circumference, thinner in the center than at the edges. Like the other varieties, it readily dries and forms a solid pavement some yards around the edge of the wells. A large quantity is occasionally raised and sold at the rate of 40 gallons for $5—$1 for 8 gallons. It is in some demand for flooring and roofing. The quantity drawn at present seems to have no effect in diminishing the supply, but as intervals of rest occur, owing to the limited demand, it is difficult to say what continuous supply could be derived from this source. Mr. Trask, in his report (Doc. No. California, session 1855), calculates the amount of asphaltum in the counties of Santa Barbara and Los Angeles as not less than 4,000 tons. As he only mentions two localities, that near the village of Santa Barbara and this at the pueblo Los Angeles, it is presumed he reckons these as the only sources of his estimate. He does not state what the data of the calculations are. The actual quantity already poured out on the Santa Barbara shore is vastly greater than at Los Angeles—perhaps 6,000 tons would be an underestimate for Santa Barbara, but as a source of asphaltum it is extinct, while that at Los Angeles is actively pouring out, although the accumulated overflow is much smaller. As a locality of asphaltum available for the present time, Santa Barbara is preeminent; as a source for future wants, Los Angeles is preferable. By following the line of upheaval on these hills and making borings in the sandstone strata, the bitumen might be reached, and thus other sources than the natural well might be drawn upon. Doctor Trask values the asphaltum delivered in San Francisco at $16 per ton, but this is an excessive valuation according to the price at the well or according to the calculations of freight from Santa Barbara northward. Allowing the value to be $7 per ton, and in Los Angeles Valley about 2,500 tons to be at present available, the actual present wealth of the valley in bitumen would be $17,500. This, of course, does not take into account the future supply.

In addition to the descriptive matter Antisell gives a geologic section across the Santa Monica and Santa Susana ranges and another from San Pedro through Los Angeles to San Fernando.[b]

J. D. Whitney, State geologist from 1860 to 1874, describes the region from the San Fernando Valley north to the Bay of Monterey,[c] and in the same chapter enters into a discussion of the probabilities of finding oil in the Tertiary rocks of the Coast Range. He also severely arraigns the promotors of "wild-cat" oil companies, which, at the time of writing the report (1865), were preying on the credulous public. Another chapter is devoted to the geology of the Santa Monica and San Gabriel ranges and the vicinity of Los Angeles. The following are Whitney's notes concerning the brea deposits in what is now the Salt Lake field:[d]

About 7 miles due west of Los Angeles is the most important of the numerous tar springs seen in this vicinity. It is from here that most of the asphaltum used in the town is obtained. Over a space of 15 or 20 acres the bituminous material (which, when seen by us, in the winter, had exactly the consistency and color of tar) was oozing

[a] The "old Dryden well" is located about three-eighths mile north-northwest of Westlake Park.
[b] Pacific Railroad Rept., vol. 7, pt. 2, 1857, Pl. V, figs. 2, 3.
[c] Geol. Survey California, Geology, vol. 1, 1865, pp. 108-166.
[d] Op. cit., pp. 174-175.

out of the ground at numerous points. It hardens on exposure to the air and becomes mixed with sand and dust blown into it, and is then known as "brea." The holes through which the bitumen comes to the surface are not large, few being more than 3 or 4 inches in diameter. On removing the tarry substance from the holes, by repeatedly inserting a stick, the empty cavity was very slowly filled up again. At one place there was a pit several yards square and 6 or 8 feet deep, from which the tar had been taken, but it was filled with water at the time of our visit in consequence of late heavy rains. The brea is used almost exclusively for covering roofs at Los Angeles, selling (in 1861) at the springs for $1 per barrel, the purchaser collecting it himself, which is done by digging a pit 2 or 3 feet deep by the side of one of the holes from which the tar is issuing and letting it fill up. A very large amount of the hardened asphaltum, mixed with sand and the bones of cattle and birds, which have become entangled in it, lies scattered over the plain. Before 1860 the experiment of shipping it to San Francisco for the purpose of distilling burning oil from it had been tried, without success, at least in a pecuniary point of view.

A report on the geology of a portion of southern California, by Jules Marcou;[a] a paper on the petroleum, asphaltum, and natural gas of California, by W. A. Goodyear,[b] and a paper on the origin, composition, etc., of California petroleum, by F. Salathè,[c] complete the list of more or less important papers bearing on the geology and oil industry of the region about Los Angeles up to 1897.

In 1897 W. L. Watts issued the first[d] of his two reports largely devoted to the Los Angeles and adjacent oil districts. In this report he gives a brief outline of the geology of the territory discussed; lists and logs of productive, test, and abandoned wells, and notes on miscellaneous subjects, such as fossils of the oil-bearing formations, production, uses, and chemical and physical properties of the oil, refineries, drilling machinery, etc. Watts's second report,[e] although covering the California oil districts in general, is still largely given over to the fields of Los Angeles, Ventura, and Orange counties. Chapters are devoted to a discussion of the structural conditions pertaining to the occurrence and distribution of petroleum in California, the uses and chemical and physical characters of the oil, etc., and in addition there are brief reports on the fossils of the oil-yielding formations by J. C. Merriam, on the Humboldt County oil fields by F. M. Anderson, and on the oil-yielding formations of San Luis Obispo and Monterey counties by H. W. Fairbanks.

A paper by G. H. Eldridge,[f] in the Contributions to Economic Geology for 1902, is of interest not only on account of its comprehensive though short description of the individual fields, but also because it

[a] Ann. Rept. U. S. Geog. Surv. W. 100th Mer., 1876, Appendix H 1, pp. 158-172.

[b] Seventh Ann. Rept. Califorina State Mineralogist, 1888, pp. 63-114.

[c] Thirteenth Ann. Rept. California State Mineralogist, 1896, pp. 656-661.

[d] Oil and gas yielding formations of Los Angeles, Ventura, and Santa Barbara counties: Bull. California State Mining Bureau No. 11, 1897, pp. x+94, 35 figs.

[e] Oil and gas yielding formations of California: Bull. California State Mining Bureau No. 19, 1900, pp. 236, 26 text figs., 35 half tones, 13 maps.

[f] The petroleum fields of California: Bull. U. S. Geol. Survey No 213, 1903, pp. 306-321.

alone contains in epitomized form a number of the conclusions of this eminent authority regarding the California fields as a whole. A brief description of the Salt Lake field is given by the writer [a] in Contributions to Economic Geology for 1905.

A most useful bulletin relating to the technical and commercial phase of the oil question by Paul W. Prutzman [b] gives maps and other brief data in regard to the principal oil districts, together with detailed information concerning the character of the oil and its uses for fuel, for oiling roads, etc.

A short bibliography of the principal papers relating to the geology and technology of the Los Angeles and adjacent oil districts and to the oil industry of California is given on pages 199–202 of this report.

LOCATION AND TOPOGRAPHY.

The Los Angeles district, comprising the productive oil fields immediately north and west of the city, is located from 15 to 20 miles from the coast in the central part of southern California. Three transcontinental railroads—the Southern Pacific, the Atchison, Topeka and Santa Fe, and the San Pedro, Los Angeles and Salt Lake—pass through it, and steamers touch at Port Los Angeles, Redondo, and San Pedro, its ports of entry.

The city of Los Angeles occupies an area of about 15 square miles, the greater portion lying west of Los Angeles River at its debouchment from the low hills, which to the west pass gradually into the Santa Monica Range and to the east and north into the San Rafael Hills and Verdugo Mountains. To the southeast are the Raphetto Hills, which with the Puente Hills farther southeast constitute the connecting link between the Santa Monica and Santa Ana ranges. The Elysian Park hills north of the city trend northeast and southwest. Their southwestern slope is gentle and extends into the great Los Angeles-Santa Monica plain. Their northeastern slope is abrupt and parallels Los Angeles River. Northwest of the Elysian Park hills is the eastern extension of the Santa Monica Mountains, somewhat isolated from the main range by Cahuenga Pass, which trends northwestward from Hollywood, a suburb of Los Angeles. The mountainous area east of Cahuenga Pass is cut into sharp ridges and deep canyons and culminates in Cahuenga Peak at an elevation of 1,825 feet.

[a] The Salt Lake oil field, near Los Angeles, Cal.: Bull. U. S. Geol. Survey No. 285, 1906, pp. 224-226, fig. 9.

[b] Production and uses of petroleum in California: Bull. California State Mining Bureau No. 32, 1904, pp. 230, 64 figs.

North of the Santa Monica Range lies the San Fernando Valley, separating this range from the Santa Susana Mountains on the north. South of the Santa Monica Range and the Elysian Park hills is the broad Los Angeles-Santa Monica plain, which slopes gently southward to the Inglewood hills, southwest of Los Angeles. A physiographic feature which appears to reflect in a general way the underlying structure—and if so may be important in determining the location of the productive territory—is the gentle declivity extending from the middle of the Salt Lake field northwestward toward Sherman.

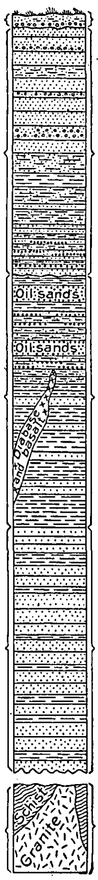
GEOLOGIC FORMATIONS.

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

Period.	System.	Series.	Standard California section.	Santa Clara valley.	Los Angeles.	Puente Hills.
Cenozoic.	Quaternary.	Recent.	Alluvium.	Alluvium.	Alluvium.	Alluvium.
		Pleistocene.	San Pedro.	Sand and gravel.	Sand and gravel.	Sand and gravel.
			—Unconformity—	—Unconformity—	—Unconformity—	—Unconformity—
	Tertiary.	Pliocene.	Merced.	Fernando.	Fernando.	Fernando.
			Purisima.			
		Miocene.	San Pablo.			
			—Unconformity—	—Unconformity—	—Unconformity—	—Unconformity—
					Diabase intrusion.	Diabase intrusion
			Monterey.	Modelo. {Shale. Upper sandstone. Lower sandstone.}	Puente. {Upper shale. Sandstone. Lower shale.} (?)	Puente. {Upper shale. Sandstone. Lower shale.} (?)
			Vaqueros.	Vaqueros.		
		Oligocene	San Lorenzo.	Sespe. {Upper. Red beds. Lower.}		
			—Unconformity—			
		Eocene.	Tejon. Martinez.	Topatopa.		
			—Unconformity?—	(?)		
Mesozoic.	Cretaceous.		Chico. Horsetown. Knoxville.			
			—Unconformity—	—Unconformity—	—Unconformity—	
	Jurassic.		Granitic rocks of the Sierra Nevada.	Granitic rocks of the San Gabriel Range.	Granitic rocks of the Santa Monica Range.	
					Black schist.	

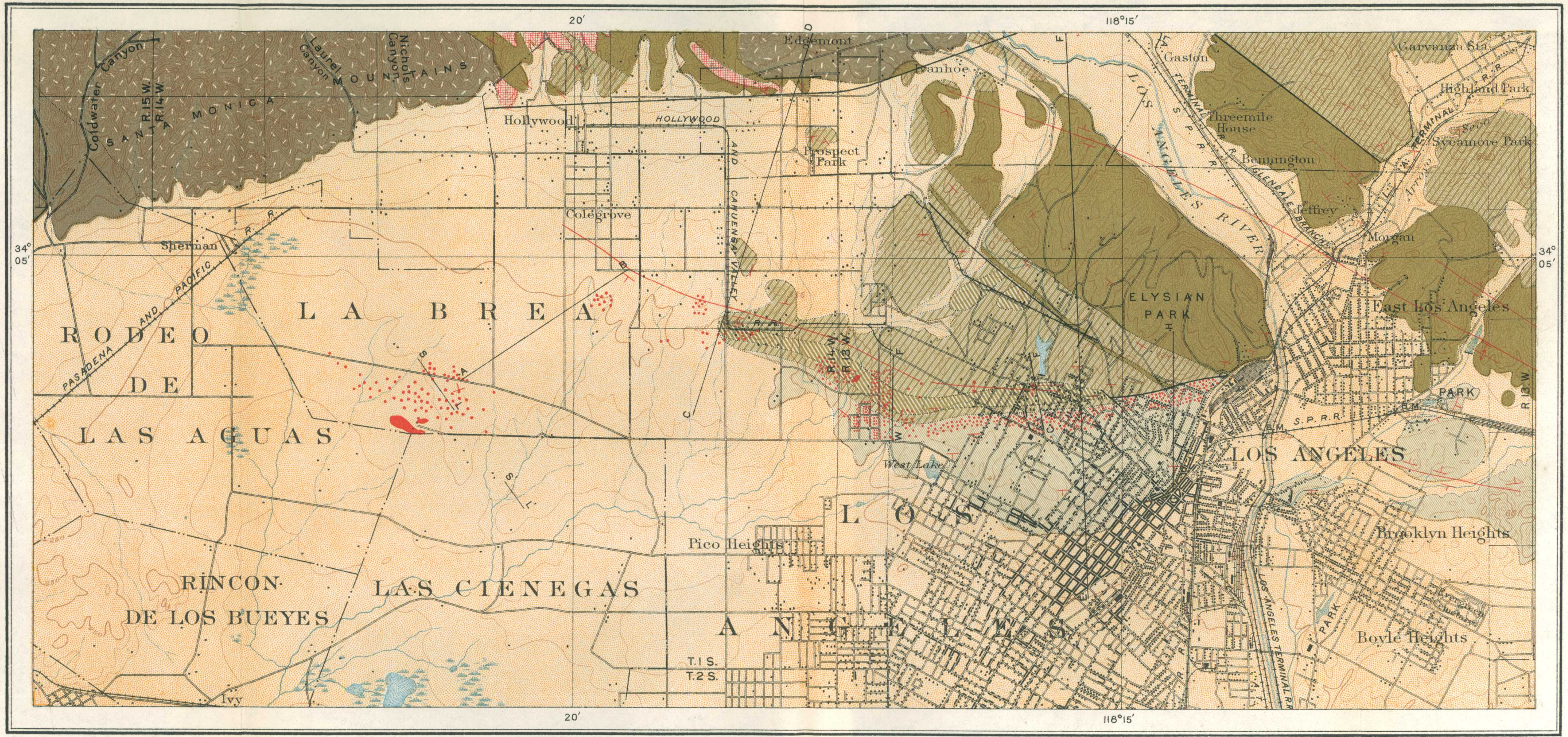
GENERAL STATEMENT.

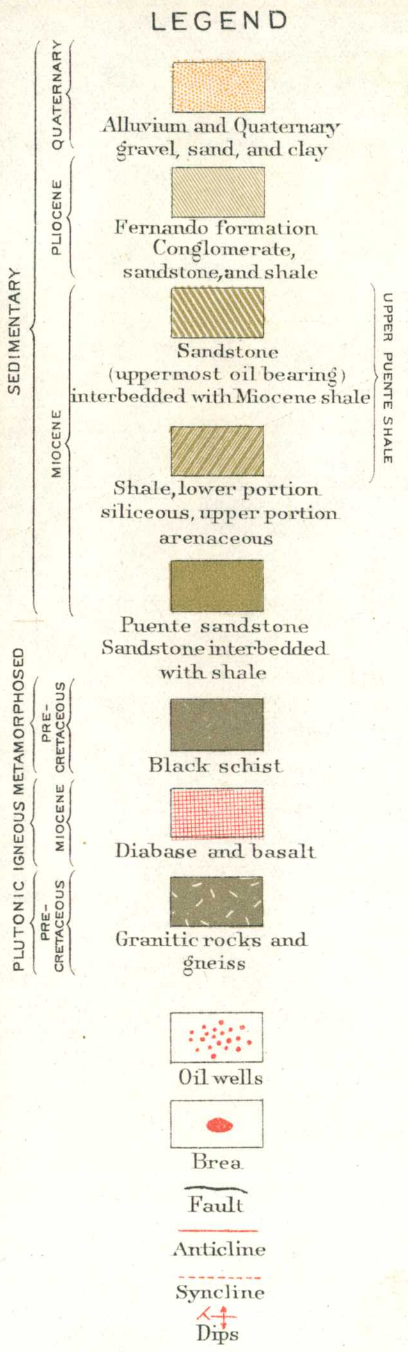
The formations involved in the geology of the region about Los Angeles consist of (*a*) black micaceous schist; (*b*) a granitic series embracing diorite, gneiss, and other crystalline rocks; (*c*) more than 2,000 feet of Puente sandstone of lower Miocene age; (*d*) about 2,000 feet of upper Puente shale and soft, thin-bedded sandstone, also of Miocene age, (*e*) basalt and diabase intruding the previous formations, but older than the following: (*f*) 2,000 feet or more of soft, thin and thick bedded sandstone, thin-bedded shale, and heavy-bedded conglomerate of the Fernando formation, largely of Pliocene age, and (*g*) a capping of Pleistocene gravels and sands of variable thicknesses. (See fig. 12.)



	Feet.	
Quaternary	100+	Alluvium and roughly bedded gravel, sand, and clay.
Pliocene	2,000+	Upper portion thick-bedded soft sandstone with a few layers of conglomerate and thin-bedded sandy shale. Lower portion, largely thin-bedded soft clayey sandstone and sandy shale, somewhat petroliferous near the Miocene contact.
		Probable unconformity, beds of both formations having approximately the same dip.
Middle (and possibly upper) Miocene.	2,000±	Upper half, thin-bedded sandstone and sandy shale, with some hard siliceous members and one or two bands of coarse sandstone, which usually carry oil. Lower half, alternating bands of thin-bedded siliceous shale and coarse sandstone. This and all older formations intruded by diabase and basalt.
Lower Miocene	2,000+	Coarse, heavy-bedded brown arkose sandstone interbedded with minor quantities of argillaceous and siliceous shale, the shale being relatively more abundant toward the top and bottom of the formation. Total thickness unknown.
Pre-Cretaceous		Basement complex of diorite and other granitic rocks and gneiss, associated with an extensive dark-colored micaceous schist.

Fig. 12.—Generalized geologic section for the immediate vicinity of the Los Angeles oil fields.





Topography by U. S. Geological Survey, 1894.

A. HOEN & CO. BALTIMORE.

Geology by Ralph Arnold, 1905.
For sections see Pl. XX and figs. 13, 14, and 17

GEOLOGIC MAP OF THE REGION OF THE LOS ANGELES OIL FIELDS, CALIFORNIA

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 miles

1 ½ 0 1 2 3 kilometers

Contour interval 50 feet.
Datum is mean sea level.
1906.

BLACK SCHIST.

Black micaceous schist with a general northwesterly dip outcrops on the flanks of the Santa Monica Mountains about a mile northwest of Sherman and extends in a westerly direction along the south slope of the range for at least 15 miles. This schist is black to dark reddish brown in color, in some cases resembling certain hematite ores, and usually shows a very characteristic luster, due to the faces of the minute component mica flakes. Little is known concerning the age of these rocks except that they are older than the granite which bounds them on the east. It is certain, however, that they are pre-Cretaceous and very probable that they are Jurassic.

GRANITE.

A large part of the Santa Monica Mountains from the vicinity of Coldwater Canyon eastward to Los Angeles River is made up of granitic rocks similar in all respects to and probably contemporaneous with the granitic rocks which form the Verdugo hills, the northern part of the San Rafael hills, and the major part of the great San Gabriel Range to the north and east of the Santa Monica Mountains. In the region about Edgemont, northeast of Hollywood, the rock appears to be a fine-grained biotite granite, showing considerable quartz in hand specimens, although weathering precludes any exact determination of the composition. Biotite and hornblende granite, with some closely associated brown micaceous schist, appears to make up the larger portion of the crystalline area from Cahuenga Pass westward to Coldwater Canyon. With the possible exception of the western contact, which is probably one of deposition, the rock of the Edgemont area appears to be separated from the adjacent formation by fault planes, although the exact nature of the shale-granite contact north of Ivanhoe was not determined. The granite is younger than the black schist and is certainly pre-Cretaceous and probably late Jurassic in age.

PUENTE SANDSTONE.[a]

GENERAL CHARACTER.

The oldest Tertiary rocks so far discovered in the Los Angeles area consist of a heavy-bedded sandstone which overlies the pre-Cretaceous granite and schist on the flanks of the Santa Monica Mountains and makes up the bulk of the Elysian Park hills and the hills on the northeastern side of Los Angeles River from Gaston southeastward to the hills east of Eastlake Park. The lower part of the formation is somewhat argillaceous and may correspond to

[a] See note regarding divisions of Puente formation on p. 103.

the lower Puente shale or to a portion of the Vaqueros formation, but the larger part is doubtless contemporaneous with the Puente sandstone of the Puente hills district. The best exposures of the Puente sandstone in the region about Los Angeles are in the Elysian Park hills, which are developed on the southern limb of a great anticline. (See Pl. XXI, *B*.) The formation as here developed consists of at least 2,000 feet of heavy-bedded, coarse-gray to rusty-arkose sandstone, interbedded at irregular intervals with dark-colored earthy and siliceous shale. The sandstone beds vary in thickness from 1 to 12 feet. Some are uniformly hard throughout, while others are concretionary, the concretions usually being elliptical in shape and in some cases coarser grained than the surrounding rock. As a rule, however, the sandstone is soft and falls an easy prey to weathering agents, being much less resistant than the interbedded shale. This differential weathering is well exemplified in certain ridges in Elysian Park, which cut transversely across alternate layers of the steeply dipping sandstone and shale, the latter forming prominent knobs at its outcrops along the top of the ridge. Jointing is well developed in the sandstone in certain localities, notably at the south end of Elysian Park, where hardening along the cracks of three different systems forms a kind of block structure. This is common in similar sandstones at many places throughout the Coast Range. In the region west of Edgemont and also along the flanks of the Santa Monica Mountains west of Sherman the basal beds of the Puente consist of conglomerate and sandstone, with appreciable amounts of interbedded gray to drab shale. The pebbles and cobbles in the conglomerate consist of granite rocks, diorite porphyry, quartzite, etc., some attaining a diameter of 3 feet. In the region of the basalt intrusions and flows about Cahuenga Pass the sandstone appears to have been slightly baked, and is harder, more jointed, and darker colored than in the Elysian Park hills. It may also represent a somewhat lower horizon than the Elysian Park rock.

FOSSILS.

The Puente sandstone has yielded fossils in several localities in this region. In a street cut in Pasadena on the west side of Raymond Hill, about 2 miles northeast of the corner of the area shown in the accompanying map (Pl. XVIII) was found the following fauna:

Puente fossils from Raymond Hill, Pasadena, Cal.

Arca cf. montereyana Osmont.
Chione n. sp.? (small, with prominent concentric frills).
Leda cf. taphria Dall (Pl. XXXVIII, fig. 5).
Panopea generosa Gould.
Phacoides cf. acutilineatus Conrad.
Thracia n. sp.

Yoldia n. sp.
Agasoma barkerianum Cooper.
Natica or Neverita sp.
Turritella cf. variata Conrad (Pl. XLI, figs. 10, 11, 12).

Another fossiliferous locality is at Laughlins Hill, one-half mile southwest of Edgemont, where the following species were obtained:

Puente fossils from Laughlins Hill, north of Los Angeles, Cal.

Cardium sp. (large; sharp ribbed).
Pecten crassicardo Conrad (Pl. XXXI, fig. 1).
Phacoides cf. childreni.
Phacoides richthofeni Gabb.
Neverita callosa Gabb (Pl. XXXI, figs. 4, 4a).
Trophon sp.

The following fauna, characteristic of the lower Miocene throughout the southern San Joaquin Valley and as far south as the Santa Ana Mountains, is found at the head of Topanga Canyon, about 3 miles south of Calabasas, at the west end of the San Fernando Valley:

Puente fossils from 3 miles south of Calabasas, Los Angeles County, Cal.

PELECYPODA.

Callista (Amiantis) diabloensis Anderson.
Cardium sp. (sharp ribs).
Cardium sp. (square ribs).
Chione temblorensis Anderson (Pl. XXX, figs, 1, 1a).
Dosinia ponderosa Gray (Pl. XXXIII, fig. 4).
Glycymeris sp. (large).
Macoma cf. nasuta Conrad.
Mytilus mathewsonii Gabb var. expansus Arnold (Pl. XXX, fig. 2).
Ostrea titan Conrad (Pl. XXVII, fig. 2; Pl. XXXII, fig. 2).
Pecten bowersi Arnold (Pl. XXVII, fig. 1).
Pecten cf. miguelensis Arnold.
Phacoides richthofeni Gabb (Pl. XXXII, fig. 4).
Venus pertenuis Gabb.

GASTEROPODA.

Agasoma cf. kernianum Cooper.
Bittium sp.
Calliostoma sp.
Cancellaria cf. condoni Anderson (Pl. XXVII, fig. 9).
Cerithium topangensis Arnold (Pl. XXVII, figs. 7, 8).
Chlorostoma (Omphalius) dalli Arnold (Pl. XXVII, figs. 4, 4a, 4b, 5, 6, 6a).
Cylichna sp.
Dolichotoma keepi Arnold (Pl. XXXIII, fig. 5).
Drillia sp.
Fusus sp.
Macron merriami Arnold (Pl. XXVIII, figs. 4, 4a).
Neverita callosa Conrad (Pl. XXXI, figs. 4, 4a).
Ocinebra topangensis Arnold (Pl. XXX, fig. 4).
Purpura edmondi Arnold (Pl. XXVII, figs. 3, 3a).
Sigaretus perrini Arnold (Pl. XXVIII, fig. 5).

Trochita costellata Conrad (Pl. XXXII, fig. 3).
Trochita cf. inornata Gabb.
Trophon sp.
Turbo topangensis Arnold (Pl. XXVIII, fig. 6).
Turritella ocoyana Conrad (Pl. XLI, figs. 7, 8, 9).
Turritella variata Conrad (Pl. XLI, figs. 10, 11, 12).

The above fossils indicate that the beds in which they occur are of lower Miocene age and probably equivalent in general to the Vaqueros sandstone of central California.

UPPER PUENTE SHALE.

GENERAL CHARACTER.

Above the massive-bedded Puente sandstone and grading into it is a mass of strata at least 2,000 feet thick, in which shale beds of one sort or another largely predominate. No sharp line of demarcation separates this shale from the sandstone beneath, but as a whole they are radically unlike. The two members are differentiated on the map (Pl. XVIII) along a line which, it is thought, marks the boundary between the preponderance of the sandstone facies on the one hand and the preponderance of the shale on the other. The shale in the region north of Los Angeles may be roughly divided into two approximately equal parts, the lower 1,000 feet consisting of broad bands of thinly laminated white to gray shale interbedded with similar bands of more or less thick-bedded, coarse yellowish to brown sandstone, and the upper 1,000 feet or more being characterized by thin-bedded sandy and clayey shale and thin to medium bedded sandstone. At the top of the shale series is a band of thin-bedded hard white siliceous shale, interstratified with 2 to 4 inch layers of brown sandstone. The top of this band is used in mapping as the arbitrary line between the Puente formation and the overlying Fernando (Pliocene) sandstone.

Most of the shale in the lower part of the member, and also many of the shale beds interstratified with the Puente sandstone, are of the hard white siliceous variety characteristic of the Monterey shale in the Coast Range. This shale splits easily along the bedding planes into thin, sharp-cornered plates. Fragments of these scales or plates, which are very resistant to weathering, are often found scattered over the ground and thus indicate the presence of the beds over areas in which outcrops may be rare. Abundant minute organic remains are usually found in the siliceous layers, but no recognizable molluscan forms have so far been obtained from them in this region. In the territory northeast of Los Angeles the structure is complex and an exact determination of the position of the shale is impossible; but it is probable that most of it belongs to the upper part of the Puente formation. In the vicinity of Sycamore Park the rock consists of at least 400 to 500 feet of very dark colored, highly carbonceous, thinly laminated gypsiferous shale, showing traces of sulphur on the weathered surfaces. Associated with this is dark-brown sandy shale, interstratified with yellowish limy layers containing gray to yellowish calcareous elliptical concretions as much as 5 feet in length. Thin-bedded white chalky shale containing numerous fish remains is also found a little to the southwest of Sycamore Park. In the region about the mouth of Cahuenga Pass, where the shale is intruded by diabase, it is much contorted and fractured, gray to discolored blue gray and rusty brown in color, in places gypsiferous, and much of it tending to concretionary structure.

The upper 1,000 feet or more of the upper Puente shale consists principally of soft, thin-bedded clayey to sandy shale, varying in color from gray through light yellow to rusty brown and locally, where oil bearing, to bright tints of yellow and pink. A peculiar efflorescence characterizes the weathering of the sandy members of these upper beds in many places. At the top of the formation are two bands of thinly laminated, alternating hard white and soft drab shale, separated by about 125 feet of coarse sandstone, the latter being shown on the map (Pl. XVIII) by a special legend. These two shale bands, with their interbedded and underlying thin-bedded sandstone, mark the principal oil-bearing zone in the Los Angeles district.

Associated with the shale at the top of the lower half of the upper Puente shale is a 50-foot band of coarse arkose sandstone, which is shown on the map in the same color as the Puente sandstone.

OIL SANDS.

As mentioned in the preceding section, the productive oil sands occur interbedded with the shale near the top of the Puente formation. Exposures of these sands are to be found almost continuously along the mapped oil-sand zone, running from the Sisters' Hospital, on Sunset boulevard, to the bend in the Hollywood and Cahuenga Valley Railroad, on Western avenue. The surface exposures of the upper sands, which aggregate about 125 to 150 feet in thickness, usually either are more or less impregnated with oil or asphaltum or else by their color show the effects of its former presence in the beds. These sands vary in color from brown to dark drab and in some instances show bright tints of pink, purple, and yellow. As a rule they are coarse and in places, notably toward the west end of the district, they are more or less finely conglomeratic. The concretionary tendency is also characteristically shown in certain of the beds. In the low hilly region flanking the Elysian Park hills on the west what is supposed to be the equivalent of a part of the oil sands is characterized by large, hard concretions. (See Pl. XXI, *A*.) At one place these concretions are round, while at others they vary from elliptical to irregular; they are usually 4 feet or less in diameter. In some of the layers of this band the grains of quartz and feldspar attain a diameter of three-eighths of an inch, in others the grain is finer. The color of the sands here varies from gray through light yellow to purple, the latter color indicating the former presence of oil in the rock.

About 300 feet stratigraphically beneath the upper oil sands is the second productive layer. This consists of 40 to 50 feet of thick to medium-bedded arkose strata, similar in all practical respects to the upper sands. Between these two principal layers and in the shale beneath the lower are other sandy beds, which are shown by the well records in the west end of the field to be more or less productive. The great bulk of the oil, however, is derived from the two principal layers just described.

MIOCENE BASALT.

Large masses of basalt are associated with the Puente sandstone and shale in the region about the mouth of Cahuenga Pass and to the east as far as Laughlins Hill. From evidence to be obtained at different localities in this region, both intrusive masses and surface flows are represented by the rock. Outcrops of a spheroidal type, such as that forming the little knoll three-fourths of a mile northwest of Hollywood, indicate the intrusions, while the vesicular facies found in the east end of Laughlins Hill tends to prove the existence of the flows. The usual color of the weathered outcrops is purplish red to reddish brown, the overlying soil in nearly all cases partaking of the characteristic color of the underlying rock. The igneous rock in the knoll three-fourths of a mile northwest of Hollywood, although doubtless genetically identical with the fine-grained basalt lying farther east, somewhat resembles in hand specimens certain forms of diabase.

The age of the basalt is the same as that of similar rocks found north and northwest of Santa Monica in the Santa Monica Mountains, also in the Puente Hills, north of Brea Canyon, and in many regions of the Coast Range at least as far north as the Santa Cruz Mountains. The rock intrudes or is interbedded with the Vaqueros sandstone and Monterey shale or contemporaneous formations at one locality or another, but is unknown, except as worn pebbles in conglomerate, in any of the later formations. It is therefore of middle Miocene age.

FERNANDO FORMATION.

GENERAL CHARACTER.

The line of demarkation between the Miocene and Pliocene formations in the region about Los Angeles is not at all distinct. There is no doubt of the existence of a decided break between the white shale of the Miocene and the upper fossiliferous sand and conglomerate of the Pliocene, represented by a period of deformation and subsequent erosion. Just what plane in the stratigraphic sequence of beds marks this period, however, has not been determined. The interbedded conglomerate found in the fossiliferous lower Pliocene sandstone contains numerous waterworn and pholas-bored fragments of the characteristic white Miocene shale, and this evidence clearly proves the conditions of a break or unconformity. A marked unconformity is usually discernible between the Monterey shale and subsequent formations at most places throughout the Coast Range where the two formations are in contact, so that it is not at all surprising to meet this evidence here. Over many areas, both north and south of the Los Angeles district, similar evidence is corroborated by the presence of marked structural unconformities. Here this latter evidence appears to be lacking.

It is necessary, therefore, to draw an arbitrary line separating the two formations. Because of the almost complete absence of the hard white siliceous shale from the Pliocene (Fernando) the line separating the Miocene (Puente) and the Pliocene (Fernando) has been drawn at the top of the uppermost layer of hard, white shale. This line is probably somewhat lower than if it were drawn on paleontologic evidence. In other words, the lower part of what is here termed the Fernando formation (Pliocene) is possibly Miocene and may be contemporaneous with some portion of the San Pablo (upper Miocene) of central California.

The basal portion of the Fernando formation consists of about 500 feet of soft to compact, thin-bedded sandstone and sandy shale, with some zones in which the shale is fine grained and clayey. (See Pl. XXIV, *A*.) The color of the beds ordinarily varies from gray and light yellow to rusty brown, except in those strata that are or have been impregnated with oil, many of which are chocolate, purple, or bright yellow. Above the purely sandy strata is a zone about 500 feet thick in which some of the shale is calcareous and very hard. Some of this hard shale, especially that which shows a tendency to concretionary structure, closely resembles certain of the Miocene shales. This zone of calcareous shale is also rich in gypsum, some of the veins being 2 inches wide. Most of the veins occur between the bedding planes of the shale, although some cut the strata transversely.

Above the shaly portion of the Fernando are thick-bedded, soft gray to light-yellow sandstone and coarse conglomerate associated with some thin-bedded bluish-gray sandy shale or shaly sandstone. The thin beds of conglomerate in this portion of the formation are those already mentioned as being composed largely of waterworn and pholas-bored fragments of the siliceous Puente shale. This conglomerate, as well as the sandstone and sandy shale, yields a characteristic lower Pliocene marine molluscan fauna. The thickness of the upper part of the formation is somewhat problematical, although the evidence at hand shows that it is 1,000 feet or more, making the total thickness of the Fernando over 2,000 feet.

The areal distribution of the formation is most interesting when considered in its relation to the Puente. In the region of the oil belt the Fernando rests upon the uppermost Puente white shale in a great southward-dipping monocline. East of the oil belt and Los Angeles River this simple relation seems to be changed. Here, in the meager exposures afforded by rare gaps in the Pleistocene and alluvium deposits, occur what appear to be the lower, thin-bedded sandstone and sandy shale of the Fernando in contact with the Puente sandstone, the white shale apparently being absent through the agency either of an unconformity or of a fault, or of both combined. The Fernando also extends southeastward to San Gabriel River, comprising the bulk of the sediments of the Raphetto hills, the west end of which is shown on the map. (Pl. XVIII.)

FOSSILS.

The following fossils were obtained by Homer Hamlin from the Third street tunnel in Los Angeles and indicate the lower Pliocene age of at least this part (upper sandstone, sandy shale, and conglomerate) of the Fernando formation:

Lower Pliocene fossils from the Fernando beds in the Third street tunnel, Los Angeles.

Arca multicostata Sowerby (Pl. XXXVIII, fig. 1).
Astarte sp.
Lima hamlini Dall.
Macoma sp. indiv.
Ostrea veatchii Gabb (Pl. XXXIX, fig. 1).
Pecten ashleyi Arnold (Pl. XXXIV, fig. 2).
Pecten latiauritus Conrad (Pl. XXXVI, figs. 2, 3).
Pecten opuntia Dall (Pl. XXXVI, fig. 8).
Pecten pedroanus Trask (Pl. XXXVI, figs. 5, 6).
Pecten stearnsii Dall (Pl. XXXV, fig. 2).
Buccinum sp. indet.
Fissuridea murina Carpenter (Pl. XL, figs. 3, 3a).
Nassa hamlini Arnold (Pl. XL, fig. 9).
Neverita recluziana Petit (Pl. XXXVIII, fig. 6).
Pleurotoma sp. indet.
Priene oregonensis Redfield var.? angelensis Arnold (Pl. XL, fig. 11).

The following is a list of fossils collected by W. L. Watts in the vicinity of Los Angeles and largely identified by J. G. Cooper:[a]

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[a] Bull. California State Mining Bureau, No. 11, 1897, pp. 79–81.

Pliocene fossils from Los Angeles and vicinity.

Name.	Los Angeles oil wells.	Well on Green-Meadow ranch.	Shatto estate, West Los Angeles.	Normal school, Los Angeles.	Other localities.
Bittium asperum Gabb				×	
Calliostoma costatum Martyn				×	
Carcharodon rectus Agassiz			×		
Cancellaria tritonidea Gabb			×	×	
Cerithidea californica Haldeman	×				
Chama exogyra Conrad	×				
Clathurella conradiana Gabb	×				
Corbula luteola Carpenter				×	
Crepidula princeps Conrad	×		×	×	
Cryptomya californica Conrad			×	×	
Drillia n. sp. (?)					Hays Canyon.
Diplodonta orbella Gould				×	
Glycymeris barbarensis Conrad	×				
Hinnites giganteus Gray	×				
Kellia suborbicularis Montague		×	×	×	Reynolds & Wiggins well, Los Angeles.
Laqueus californicus ? Koch					Temescal Canyon.
Lithophagus plumula Reeve				×	
Macoma inquinata Deshayes	×				
Macoma nasuta Conrad	×			×	
Mactra californica Conrad			×	×	
Mitra maura Swainson	×				
Nassa fossata Gould		×		×	
Nassa californiana Conrad				×	
Nassa mendica Gould		×		×	
Nassa perpinguis Hinds		×			
Neverita recluziana Petit					First and Olive streets, Los Angeles.
Ocinebra lurida Middendorff		×			
Ostrea veatchii Gabb	×				Brown Canyon.
Oxyrhina plana Agassiz			×		
Oxyrhina tumula Agassiz			×		
Petricola carditoides Conrad		×	×	×	
Pecten auburyi Arnold				×	
Pecten healeyi Arnold					Temescal Canyon.
Pecten pedroanus Trask				×	Clark estate, Los Angeles.
Pecten stearnsii Dall					Hays Canyon, Brown Canyon.
Periploma discus Stearns					First and Olive streets, Los Angeles.
Phacoides californicus Conrad					
Placunanomia n. sp	×				
Platyodon cancellatus Conrad	×				
Saxidomus gibbosus Gabb			×		
Semele decisa Conrad	×				
Tapes staleyi Gabb			×		
Tellina idea Dall				×	
Terebratalia occidentalis Dall					Temescal Canyon.
Venericardia ventricosa Gould					Reynolds & Wiggins well, Los Angeles.

PLEISTOCENE.

GENERAL CHARACTER.

The Pleistocene deposits in the Los Angeles region comprise gravel, sand, and clay, the first mentioned predominating. The gravel and sand capping the Fernando in the region of the oil belt and farther south, especially on the top of the ridge on which the normal school is situated, are probably of marine origin; the rest of the deposits are largely fluviatile.

The thickness of the Pleistocene, especially along the southern edge of the area mapped, is probably 300 to 500 feet, while in certain of the terrace deposits, such as those on the hills north of Sherman and on the terraces flanking Los Angeles River and Arroyo Seco, it may be only from a few inches to, say, 50 feet.

BREA DEPOSITS.

In the region immediately northwest of the Baptist College, in the territory one-half to three-fourths mile southwest of Colegrove and on the south side of the Rancho la Brea the Pleistocene and alluvial deposits are impregnated with asphaltum, forming brea. This material originates in two ways—heavy oil or asphaltum exudes from the surface and becomes filled with drifting dust and sand, or the fluid exuding from the underlying hard strata impregnates overlying porous gravel and sand. Details concerning the brea deposits are quoted under the heading "Previous knowledge of the region," the older geologists having had an exceptional opportunity for studying these "tar springs," which at the time of their visits were almost untouched and much more extensive than at present. In the Rancho la Brea deposits at the south side of the Salt Lake oil field many bones of extinct mammals have been found. (See Pl. XXIV, *B*.) The following notes concerning these remains are quoted from an unpublished manuscript by Dr. J. C. Merriam:

The beds in which the bones occur extend over many acres. So far as I am aware the bottom has not been reached in excavations carried on to the depth of at least 15 feet in quarrying the asphalt. Bones are scattered through a large part of the deposit, but are very unevenly distributed. In some localities they are present in large numbers and in fairly defined layers.

The asphalt has in many cases penetrated even the minute pores of the bone, but the original material of the skeleton is itself practically unchanged.

The remains recognized up to the present include the following: *Elephas*, *Equus*, *Bison*, *Mylodon* (?), *Smilodon*, *Canis indianensis* (?), *Canis* small species and camel remains. Numerous bird bones and remains of insects are also found.

In a considerable number of cases large parts of the skeleton are found together, showing that the carcasses were entombed so quickly that there was not sufficient time for decomposition to permit separation of the parts.

Of the remains recognized up to the present time, an extraordinarily large percentage represents Carnivora. The number of carnivores is certainly relatively larger than the usual percentage in a well-balanced fauna, and this abundance must be attributed to peculiar conditions under which the bones accumulated. Undoubtedly most of the remains are those of animals that have been entrapped or mired in the asphalt at times when it formed a sticky deposit around tar springs. The surface of the asphalt is very sticky in some places at the present time, and where cuts are opened in it tar may ooze out. Such pools have probably existed here interruptedly through a long period, and particularly during Quaternary time when the deposit was forming. Carnivores are numerous, because they were attracted by birds and mammals caught in the asphalt. Perhaps it is not entirely a coincidence that the carnivore remains are usually associated with those of birds or mammals, which would be their natural prey. The considerable number of young saber-tooth cats present may indicate that the younger and less experienced individuals were more easily lured into the tar pools.

Aside from their scientific value, these bones have the added significance of indicating that the brea-forming conditions which are now prevalent in this field were in operation during a large portion of Pleistocene time. In view of the great number of years during which the gas and oil have been escaping in this field, it seems rather remarkable that such prolific deposits of petroleum are still to be found in the underlying strata. These facts indicate the almost incomprehensible amount of oil that was originally contained in the Tertiary rocks over certain areas of the Coast Range belt.

STRUCTURE.

GENERAL FEATURES.

The structural features in the region about Los Angeles are dependent on two systems of disturbances. The older of these consists primarily of folds, with which are usually associated minor faults. This system dominates the Miocene strata and was probably largely developed during the post-Puente (late middle Miocene) readjustment, which had such a widespread effect throughout the Pacific coast of the United States. The axes of disturbance of the Miocene system trend, approximately, N. 60° W. The younger system, in which faults are apparently the dominant features, was developed during late Pleistocene time and affects all the formations in the area. The general trend of the axes of the Pleistocene system is east and west. Minor faults with planes striking in various directions are common throughout the district.

The most prominent structural feature in the district is the great flexure in the Puente sandstone and shale which lies northeast of the business portion of Los Angeles and trends N. 60° W. This will be referred to as the Elysian Park anticline. (See Pl. XX, sec. E–F.) This anticline might almost be regarded as an elliptical structural dome, as it appears to plunge at both its northwest and southeast ends. Not far from the northwest extremity of the anticline where it approaches the fault zone lying along the southern base of the Santa Monica Mountains the fold develops into a fault. Near the axis of the anticline the beds in the southern limb dip gently, the slope becoming steeper and steeper, however, toward the south until, in the region of the shaly beds, dips of 60° are not uncommon. The northern limb is obscured by erosion, but the rocks composing it appear to dip at angles as great as 40°. Toward the south end of the anticline minor flexures are developed on its flanks and these in turn are squeezed up into what appears to be one or more closely folded overturns in the hills 1½ miles east of Eastlake Park. Other folds of considerable extent and at least one prominent fault trending approximately in the same general direction as the Elysian Park anticline are exhibited in the Puente shale and sandstone to the northeast of the major flexure. Many of these latter folds are very sharp, dips of 60° or more being the rule. They are doubtless the result of tangential compressive stresses. South of Eastlake Park are violently disturbed beds whose structure is rather uncertain. Apparently, however, they lie in a closely compressed anticline, with axis trending in a general east-west direction along a line making a compound curve. This fold affects beds of probable Fernando age. The apparent analogy of this anticline, if such it be, to those in certain oil-producing areas of southern California leads to the inference that oil may be confined beneath it. However, those wells which have been put down east of Los Angeles River have not proved successful.

Southwest of the Elysian Park anticline is a syncline accompanied by a zone of faults. This flexure extends from the region southeast of Prospect Park in a broad northeasterly convex curve to the vicinity of the Sisters' Hospital on Bellevue avenue and separates the steeply dipping shale on the northeast from the softer flatter beds of the rolling-hill country southwest of the line of disturbance. (See Pl. XX, sec. E–F.) The southern extension of this syncline is traceable as a fault from the corner of Sunset boulevard and Sutherland street to a point just south of Innes street and thence southeastward toward the Sisters' Hospital, and is doubtless responsible for the breaks in the productive oil belt which occur in the vicinity of the hospital.

The most prominent structural feature belonging to the east-west Pleistocene system is the fault zone extending along the southern face of the Santa Monica Mountains from Los Angeles River at least as far as Hollywood and probably much farther west. (See Pl. XX, sec. C–D.) This fault zone has been largely instrumental in the formation of the range. It allows the upper Puente shale to come into contact with the granite, from which it is ordinarily separated by at least 2,000 feet of conglomerate and sandstone. Associated with this profound displacement are minor parallel faults in a zone which is characterized by many fractures and much distortion of the strata.

STRUCTURE OF THE OIL BELT.

The Los Angeles oil field is developed in strata at the top of the Puente formation on the southern limb of the great Elysian Park anticline. (See Pl. XX, sec. E–F.) The trend of the productive belt, however, instead of conforming to the axis of the main fold follows the strike of the formations on the south side of a divergent subordinate fold and hence has assumed a direction closely approximating east and west. The axis of the subordinate fold is traceable from a point near the corner of Lake Shore avenue and Temple street south of Echo Lake, westward to a point north of Westlake Park where its trend changes to N. 70° W. Thence it passes westward at least as far as a point 1 mile southeast of Colegrove, where it is probably deflected still farther north of west and merges with the great anticline which tilts the Puente sandstone in a northeasterly direction on the west side of Cahuenga Pass. (See Pl. XX, sec. C–D.) Between Lake Shore and Bellevue avenues the fold either blends with the Elysian Park anticline or is replaced by some undiscovered fault or other form of disturbance. The latter theory is strengthened by the evidence obtainable both east and west of the Sisters' Hospital where directly in line with an eastward extension of the fold there is a sharp line of disturbance (probably a complicated thrust fault) which extends to the east end of the field at the Catholic cemetery. (See Pl. XX, sec. G–H.) Another line of fracture, consisting of several more or less disconnected minor reverse faults, lies south of the subordinate flexure just described and toward the west diverges slightly from it. (See Pl. XX, sec. E–F, and fig. 13, p. 171.) This fault zone appears in general to mark the northern boundary of the productive belt. As a rule the beds lie nearly horizontal along the axis of the flexure, but dip more and more steeply toward the south as they approach the productive zone. The oil appears to have accumulated in the sands of the southern limb of the anticline just below the point where the steeply dipping beds bend toward the horizontal before passing over the axis of the fold. The structure in the Salt Lake field, in the southern part of the Rancho la Brea, appears to be that of a minor flexure developed on the flanks of the fold along the southern limb of which the other Los Angeles fields are located. (See fig. 17, p. 189.) Apparently the axis of this minor flexure trends northeast and southwest. The brea along the south side of the Salt Lake field is formed by oil from underlying beds which probably has been forced upward by gas pressure along lines of fracture accompanying this flexure.

JOINT CRACKS.

All the rocks in the Los Angeles district are intersected by numerous joint cracks, along which, in many instances, slight displacements have taken place. These tiny fissures have doubtless played a most important part in the accumulation of the oil, for it is probable that whatever was its original source the transverse joint cracks in the shale and sandstone are largely responsible for its transference to the upper porous beds of the formation. Without these cracks the numerous impervious beds in the series would have precluded the passing of any fluid, least of all low-gravity oil, upward through the strata.

OIL FIELDS.

LOCATION.

The oil-bearing zone begins near the Catholic cemetery on Buena Vista street, at the southern base of the Elysian Park hills, and trends in an almost westerly direction to a point north of West Lake; here it bends to N. 60° W. and extends into the region south of Colegrove. Two miles southwest of Colegrove, on the almost level Los Angeles-Santa Monica plain, is the field locally known as the Salt Lake (so named from the principal company operating there), which, though topographically isolated from the main Los Angeles field, is, nevertheless, probably genetically related to it. In discussing this subject it has been deemed advisable to divide the productive territory into four parts, differentiated more or less sharply along structural lines. The area extending eastward from the Sisters' Hospital to the eastern limit of the productive territory at the Catholic cemetery will be described as the eastern field; that extending from the hospital to a line passing northward through West Lake as the central field; that extending northwestward from the region about the Baptist college as the western field; and that on the Rancho la Brea, southwest of Colegrove, as the Salt Lake field. (See Pl. XIX.)

DEVELOPMENT.[a]

The development of the Los Angeles oil district has taken place spasmodically, four periods of activity marking its history. The first period, during which the central field was first opened, covers the time from late in 1892 to 1895; the second, in which the eastern field was developed, includes 1896 and 1897; the third, or period of exploitation in the western field and the west end of the central field, embraces 1899 and 1900; and the fourth, which marks the development of the most important part of the district, the Salt Lake field, extends from 1901 up to the present time.

The history of the Los Angeles oil wells, or, more properly speaking, of the Second Street Park oil field at Los Angeles, is as follows: For many years a small deposit of brea was known to exist on Colton street near Douglas street, in the city of Los Angeles, and the brea was locally used for fuel. In 1892 Messrs. Doheny & Connon sunk a 4 by 6 foot shaft, 155 feet deep, at the corner of Patton and State streets, close to the deposit of brea previously mentioned. The formation penetrated is sandy shale, with a few thin strata of siliceous or calcareous rock. Near the surface the oil was very heavy, but at about 7 feet deep it was found to be lighter and it seeped from the sides of the shaft. The oil exuded from porous material and from the surface planes of the hard strata. The formation was found to dip toward the south at an angle of about 40°. Excavation below a depth of 155 feet was prevented by gas. An 18-inch hole was then drilled in the bottom of the shaft and yielded 7 barrels of oil daily for several weeks. In July, 1894, the yield had decreased to 2 barrels of oil a day. In November,

[a] The writer is largely indebted to the reports of W. L. Watts for data of a historical character used in this paper.

1892, an oil well was sunk at Second Street Park by Messrs. Doheny & Connon. As soon as this well was found to be a success other wells were sunk on adjacent lots, and the Second Street Park oil field grew rapidly. By the end of 1895 there were more than 300 wells within an area of less than 4,000,000 square feet. During 1895 the price of crude oil at Los Angeles fell to a ruinously low rate, the average price for that year being 60 cents a barrel. Indeed, there were sales at a much lower rate—it is said even as low as 25 cents a barrel. The reason for this depression was the lack of cooperation among the oil producers and the lack of facilities for storing and handling the oil. Early in 1896 the price of oil commenced to recover, and in July, 1896, it had reached $1 a barrel. The reason of this recovery was the diminishing of the supply, the organization of the oil producers, and the increased facilities for storing and handling the oil.[a]

Development in the central field proceeded eastward until it encountered the disturbed and barren beds in the region just west of the Sisters' Hospital, where exploitation ceased. On the theory that this break was only local and that the productive zone continued eastward along the strike of the oil-bearing strata, a well was sunk by Maier & Zobelein at the corner of Adobe and College streets, in what is now the eastern field. This well was completed in November, 1896, and as soon as it was found to be successful many other wells were begun in the immediate vicinity, and by the middle of 1897 the wells in the new field were almost as closely crowded as those in the old or central territory. Prospecting was continued east of Los Angeles River, but no economically productive wells were developed.

The exploitation of the western field and the extension of the central field from the corner of Quebec street and Ocean View avenue westward took place largely during the latter part of 1899 and 1900. Some wells, notably the Ruhland, at the corner of Seventh and Hoover streets, and several of the Maltman wells, north of the Baptist college, however, were sunk previous to 1897.

The entrance of the Salt Lake Oil Company into the Rancho la Brea region in 1901 marks the beginning of the development of the field now bearing that company's name. For years the oil seepages and brea on this ranch had been known, and large quantities of brea had been hauled away for paving purposes. At least one prospect well had been put down near the brea deposit, but no important results were obtained from any of these operations. The first well drilled by the Salt Lake Company was abandoned on account of the caving in of the casing, caused by gas pressure. This fact being construed as a good indication, several other wells were sunk in the same locality until finally a "gusher" was struck and the value of the field assured. Since the beginning of 1902 the development in this territory has been rapid, and now it stands first in importance among the oil fields south of Santa Barbara County.

Owing to the proximity of the wells to each other the oil-bearing strata in the central and eastern fields have been rapidly exhausted,

[a] Bull. California State Mining Bureau No. 11, 1897, p. 5.

and many of the once-productive wells are now abandoned. During the past year (1905) the council of the city of Los Angeles took cognizance of this fact, and in order to do away with the nuisance of abandoned wells and pumping plants in a thickly populated residence quarter outlined certain districts within which all traces of the oil industry are to be removed within a certain period. This policy, if carried out, will eventually result in the abandonment of the city fields, so that probably in only a few years the thickly set derricks which now extend through the northern part of the city will be a thing of the past.

EASTERN FIELD.

LOCATION.

The eastern field comprises that portion of the productive oil territory of Los Angeles which lies between the Sisters' Hospital grounds, corner of Sunset boulevard and Beaudry avenue, on the west, and the Catholic cemetery, corner of Cottage Home and Buena Vista streets, on the east. Its northern boundary is a line running from the northern part of the hospital grounds eastward to a point on the western line of the cemetery 600 feet north of Buena Vista street; its southern limits are Alpine street from the hospital southeastward to Figueroa street, and thence a line slightly north of east to the southwest corner of the cemetery. This area is nearly three-fourths of a mile long, with a maximum width of about 1,000 feet near the middle and a minimum of less than 400 feet at the ends; it contains approximately one-eighth of a square mile.

TOPOGRAPHY.

The eastern field lies on the southwestern flank of the Elysian Park hills, along the southern faces of the two well-developed minor ridges which are separated by Chavez Ravine. The topography, however, appears to have no connection whatever with the structure of the field or the extent of the productive zone, the line of wells forming an approximately straight belt from the low southwestern slope of the western ridge at the Sisters' Hospital, up over the face of this same ridge, down into and across the mouth of Chavez Ravine, and eastward over the lower portion of the eastern ridge.

GEOLOGY.

All the formations from the Puente sandstone to the Fernando beds are involved in the geology of the eastern field. North of the field and forming the bulk of the Elysian Park hills is the thick-bedded gray to light-yellow and rusty-brown sandstone of the Puente formation. This outcrops along some of the park roads and is exceptionally well exhibited on Buena Vista street east of the field and west of Los Angeles River, where the peculiar jointing features, previously described, are prominently developed. Above the sandstone is the typical white siliceous shale, which extends in a broad band from the region of the Catholic cemetery northwestward along the flank of the Elysian Park hills. At the northwest corner of the cemetery this shale is very much crumpled, but northwest of this point it appears to be little distorted and dips about 45° S. 30° W. The top of the shale is marked by a 50-foot band of heavy-bedded, coarse light-yellow to brown concretionary sandstone, which is well exposed on the southwest side of Sunset boulevard near its intersection with Sutherland street. At the west end of this exposure the sandstone is cut off by a fault which has thrown some shale beds down against the sandstone on the west. The sandstone, together with its underlying and overlying white-shale bands, may be traced in a southeasterly direction from the locality last mentioned toward the oil field as far as the quarries on the west side of the Chavez Ravine road. Its dip along this line is also 45° S. 30° W. What is probably a continuation of the same sandstone band is exposed on the east side of the ravine a short distance north of the corner of Adobe and Bernardo streets, but the rocks here are so near the fracture zone and so much disturbed that the correlation is more or less uncertain. This sandstone layer and its associated shale are easily differentiated in old surface exposures, but in fresh road cuts and quarries their identification is more difficult. The overlying band of shale, which is characteristically thinly laminated and of flinty siliceous composition, underlies a considerable thickness of medium- to thin-bedded soft sandstone and sandy shale. These beds are well exposed in the brick company's quarries on the southwest side of Chavez Ravine. At the sharp bend in Figueroa street on the south end of the ridge west of the ravine, and extending westward at least as far as Ramona street just north of its intersection with College street, is another band of thin-bedded white shale which normally lies above, but which here is probably faulted down against the soft sandstone and sandy shale last described. This white shale is similar to that lying above the oil sands in the region west of the Sisters' Hospital and, like it, is much more resistant to weathering than the oil sands. If the two shales are identical it would be reasonable to suppose that the oil sands lie only a short distance beneath the shale at the Figueroa and Ramona street outcrops. This supposition is borne out by the wells only a short distance south of the white-shale outcrop, which strike productive sands at depths somewhat greater than 600 feet. Owing to the faulting down of the oil-bearing beds against the older strata on the north, no outcrops of the oil sands have so far been discovered in the eastern field. The beds overlying the oil zone are similar to those found in the same position in the central and western fields and consist largely of soft, thin-bedded sandstone and sandy shale, dipping approximately S. 10° W.

GEOLOGY OF THE WELLS.

The underground geology of the eastern field is similar to that of the central, and is what would be expected from an examination of the surface evidence in the region. Within the productive territory the wells first penetrate the sandy shale of the Fernando, after which they enter the Puente clayey shale and "shell" beds which mark the top of the productive zone. Oil occurs in two sands, the upper being about 55 feet and the lower about 25 feet thick. At the present time the upper sand is practically exhausted, having been pumped continuously for nearly seven years. Ten or twelve barrels per day was not an unusual yield when the sand was first struck, and even three years ago some of the wells were still yielding 1 or 2 barrels. The gravity of the oil in the upper sand is said to be between 18° and 19° B. The lower sand is medium to coarse grained and at first yielded as high as 25 barrels in some of the wells, but, like the upper sand, soon fell off and is now practically exhausted. The gravity of the oil in this stratum is about 16° B. Considerable quantities of gas accompanied the oil in the lower sand. Water occurs at a depth of about 900 feet in the neighborhood of Yale and Bernardo streets and in the extreme west end of the field was so abundant as to stop development work in the region south of the Sisters' Hospital.

The two following logs illustrate the strata penetrated in the areas of low and steep dip, respectively, in the productive territory of the eastern field:

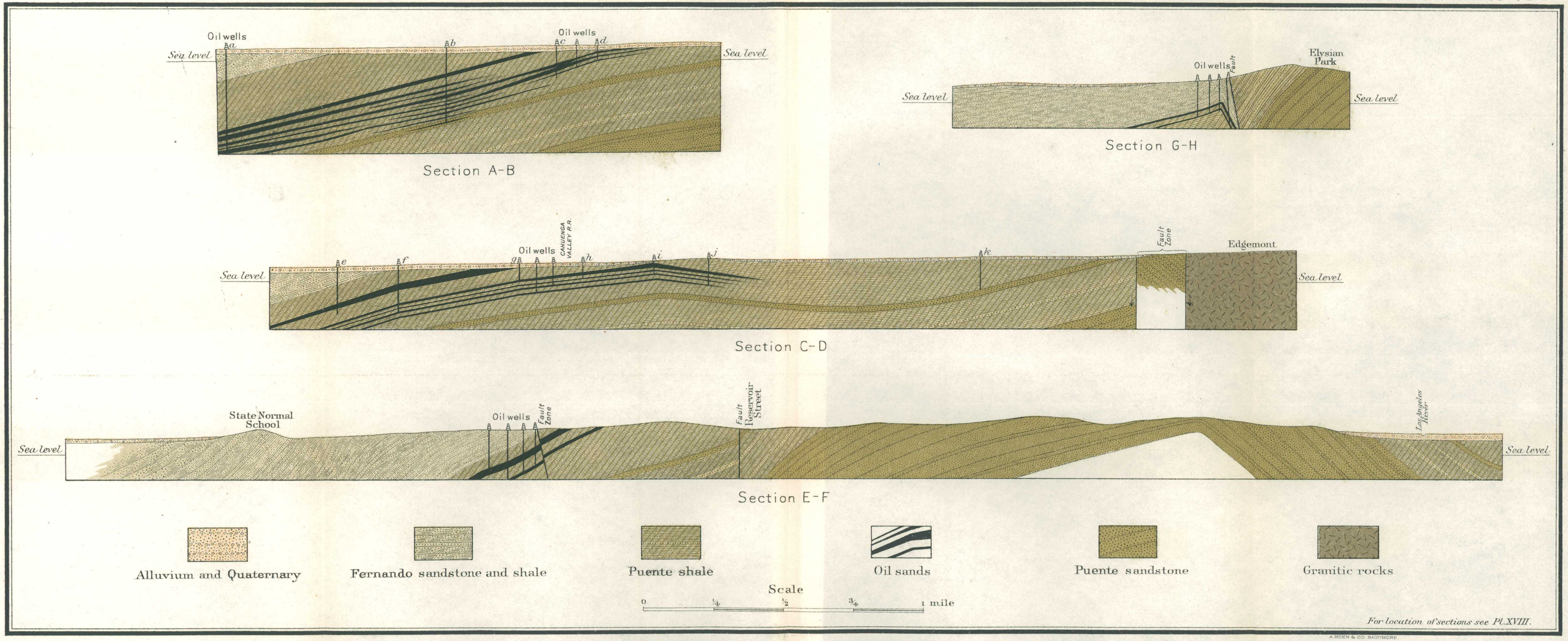
Typical well log in the central portion (strata of low dip) of the eastern field, Los Angeles.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy shale	325	325
Clayey shale, bituminous	55	380
Hard shale	3	383
Clayey shale	12	395
Oil sand (oil 18.75° B.)	55	450
Hard shale	3	453
Tough clay shale	30	483
Hard shale	2	485
Oil sand (oil 16° B.)	25	510
Hard shale	2	512
Tough clay shale	40	552

[a] Hershey, O. H., Bull. California State Mining Bureau, No. 19, 1900. p. 45.

Typical well log in the eastern portion (strata of steep dip) of the eastern field, Los Angeles.

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy shale with clayey shale toward base	700	700
Oil sand (nearly exhausted when penetrated in 1902)	200	900
Clayey shale	160	1,060
Medium to coarse oil sand (25 barrels oil and considerable gas)	100	1,160
Clayey shale	44	1,204



GEOLOGIC STRUCTURE SECTIONS THROUGH LOS ANGELES OIL FIELDS, CALIFORNIA

STRUCTURE.

Pl. XX, sec. G-H, illustrates the probable relations of the beds in the eastern part of the eastern field. The contour lines[a] in Pl. XIX, showing the distance of the upper oil sand below the Los Angeles city datum (255 feet above sea level), also help to make clear the structural features of this district. As would be expected in a region where two important flexures come together at an acute angle, the structure is complex. The flexures referred to are the Elysian Park anticline, which trends N. 60° W., and the anticline and fault along the north side of the oil field, which trend in an approximately east-west direction. As the beds of sandstone and shale in the Elysian Park anticline approach the east-west line of disturbance, they tend to deviate so that their strike is more nearly east and west. Similarly, the beds following the line of the east-west disturbance are inclined to turn so that their trend is somewhat north of west as they approach the thick beds of the Elysian Park anticline. This tendency to change in strike occurs not only in the beds at the surface, but also in the oil sands, as is shown by the contours in Pl. XIX.

The structure in the major part of the eastern field is irregular, the average dip, however, being less than that of the central field. The inclination of the strata appears to be most regular just east of the Sisters' Hospital. From this point almost to Bernardo and Yale streets the dip becomes less and less, but near the latter point it increases abruptly to 50° or more. Toward the east the beds are very much disturbed. Near the corner of Ramona avenue and College street the dip is about 35°. Immediately south of this point is a line of fracture, on the south side of which the strata dip 45°. The conditions beyond the east end of the field are not known because of the lack of surface outcrops and well logs.

The line of disturbance which begins west of Sunset boulevard, northwest of the Sisters' Hospital, and extends almost in a straight line to the corner of Bernardo and Adobe streets, appears to be a very sharp anticline bounded on the north by a fault in which the downthrow is on the south side. In a small cut on the west side of Sunset boulevard, in the axis of this zone of disturbance, the beds dip from 80° N. to 80° S. This has the appearance of an overturn. However, dips obtained in the subway between the Sisters' Hospital and the boiler house and immediately north of the latter show an anticline with dips ranging from 45° S. through horizontal to 45° N. A similar northerly dip is found northeast of the hospital on the corner of Beaudry avenue and the alley between Beaudry and Hinton avenues. These dips occur in thinly laminated yellow sandstone

[a] The lines showing the position of the oil sand in the central and eastern fields are copied from W. L. Watts's map of this field, given in Bull. California State Mining Bureau, No. 19, 1900, fig. D.

interbedded with minor amounts of arenaceous shale. The anticline, if such it be, is also exposed at the corner of Bernardo and Adobe streets, where the dip ranges from 75° N. through perpendicular to 40° or 50° S. Here, again, the surface evidence indicates an overturn while the well logs suggest a sharp anticline. The productive wells are found, with few exceptions, on the south side of this line of disturbance.

As before mentioned, there also appears to be a fault a short distance south of this anticlinal axis, but what relation, if any, it bears to the productiveness of the oil sands is at present unknown. The fault which throws the oil-bearing beds in the field down against the older Puente strata of the Elysian Park anticline is apparently closed so far as escape of the oil is concerned, for no indications of oil or asphaltum have yet been discovered along its trace. The sealing of the north end of the truncated oil sands by the impervious material of this fault zone may account in a measure for the retention of the oil.

In the vicinity of Chavez Ravine, and immediately north of the main east-west fault, which limits the productive territory of the eastern field on the north, the strata strike N. 80° W., with dips varying from 20° to 30°. A disturbance affects the beds, however, at the corner of Elysian Park avenue and Innes street, just north of Reservoir Hill, where they dip in a northwesterly direction, although the dips all around this point are uniformly toward the south or southwest.

The territory between the eastern and central fields is considerably broken up and, as reported by the drillers, contains much water and little oil. This condition is doubtless due to a zone of disturbance which branches off from or is a continuation of the fault at the corner of Sunset boulevard and Sutherland street, and which extends from this point in a general south-southeasterly direction past the corner of Sunset boulevard and Innes street toward the Sisters' Hospital. The character of this line of disturbance has not been determined, but it appears quite probable that it is a fault zone, with the downthrow on the east.

DEVELOPMENT.

The first well drilled in the eastern field was sunk at the corner of Adobe and College streets in November, 1896. From the time this well was found to be successful until the latter part of 1897 development went on rapidly until nearly the whole of the productive territory was exploited. Since 1897 few wells have been put down, while a number of those which at one time produced considerable quantities of oil have become exhausted and have been abandoned. There are at present (February, 1906) 270 wells in the field, of which 211 are pumping and 59 are either not pumping or are abandoned. The wells vary in depth from 500 to more than 1,200 feet and yield from 1 to 12 barrels of oil per day. Some of the wells are said to have yielded as high as 50 or 60 barrels at their inception, but these were unusual. In addition to oil the wells produce more or less gas. The oil is black and varies in gravity from 16° to 19° B., the lighter oil coming, it is said, from the higher sand.

CENTRAL FIELD.

LOCATION.

The central field occupies the territory lying between the Sisters' Hospital, corner of Sunset boulevard and Beaudry avenue, on the east, and Coronado street, one-fourth mile north of Westlake Park, on the west. Its northern boundary is an almost straight east-west line drawn from the middle of the west side of the hospital grounds to a point on Coronado street about 100 yards north of Ocean View avenue; its southern boundary is Ocean View avenue from Coronado street east to Arnold street, thence a line east to the corner of First and Lucas streets, thence a line to the corner of Temple street and Beaudry avenue, and finally Beaudry avenue from Temple street to Sunset boulevard. The productive territory is about 1½ miles long, 1,000 feet wide near its east end, and 300 feet near its west end. The total area is approximately nine-twentieths of a square mile. Like the eastern field, the central is a narrow band through one of the thickly populated residence districts of the city, the wells in many cases being put down in close proximity to houses and store buildings.

TOPOGRAPHY.

Northwest of the business portion of Los Angeles and east and northeast of Westlake Park is a tableland or terrace lying at an elevation of about 100 to 150 feet higher than the main portion of the city. This table-land is bounded on the north and west by a ravine extending southwestward from a point immediately west of the north end of Echo Lake and is bisected by a narrow valley which contains Echo Lake and extends south-southwestward toward the business center. In addition to these, several small ravines drain toward the southwest from the top of the terrace. The central field occupies the top of the terrace immediately south of the ravine first mentioned, extends eastward across the table-land to the Echo Lake valley, down into and across this depression and up again on to the terrace, and thence across it to the eastern limit of the field at the Sisters' Hospital.

GEOLOGY.

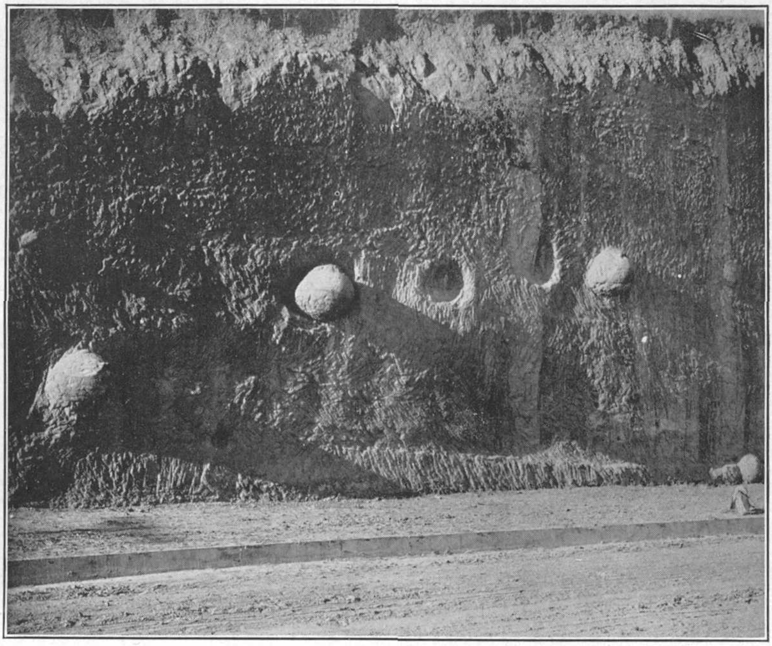
The formations involved in the geology of the region immediately adjacent to the central field comprise the upper portion of the Puente formation, with its two bands of white siliceous shale and the intervening sandstone layer, and the soft sandstone and sandy shale of the Fernando. There is also a more or less persistent layer of Pleistocene gravel, which caps the upturned edges of the older beds over portions of the terrace.

The sandstone between the two white-shale layers, which is the principal oil sand in this as well as in the eastern field, consists of about 150 feet of coarse yellow arkose sandstone in layers 3 to 24 inches thick, interbedded with minor quantities of fine gray shale. Good exposures of this sandstone are found on Court street immediately west of Lake Shore avenue and also on Burlington avenue a short distance north of First street. In the region directly north of Westlake Park the color of this same band, which here approaches a grit in certain layers, varies from chocolate and purplish gray to brown. The discoloration is doubtless due to the petroleum which the sands at one time contained. Similar colors were noted in sands which are supposed to be stratigraphically equivalent on Sunset boulevard northwest of Echo Lake. (See Pl. XXI, *A*.)

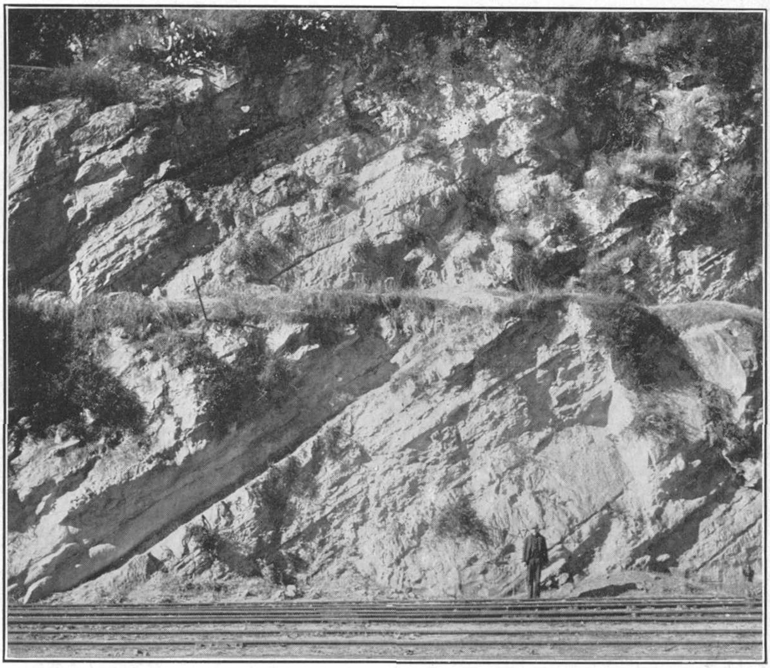
Interbedded with the thin white shale which underlies the sandstone are darker, softer shale and fine sandstone which locally appear to be petroliferous. A cut in First street west of Burtz street offers a good exposure of this oil-bearing shale. These beds occupy the hilly country north of the central field, lying in low folds with dips that vary from horizontal to 10° or 15° and showing no continuous lines of structure. As indicated by well records, they carry traces of petroleum as far east and north as the region immediately northwest of Echo Lake, but the accumulations are not of economic importance, as they are in the same beds northwest of Coronado street in the western field.

The band of white shale above the main oil sand already described is not over 50 feet thick, but owing to the resistant qualities of the thin flinty laminæ of which it is composed it can be more easily traced along its surface outcrop than any other stratum in the region. Angular fragments of thin shale strew the surface of the ground throughout the greater part of the distance from Lake Shore avenue westward to a point 1½ miles southeast of Colegrove. If it were not for this hard, flinty shale the difficulty of tracing the continuity of the formations north of the central field would be greatly increased.

Above this flinty shale band lie the soft conglomerate, heavy and thin-bedded fine-grained sandstone, and sandy and clayey shale of the Fernando. This formation is probably over 2,000 feet thick, only the lower part, however, being exposed in the central field. In this field the soft, thin-bedded sandstone is confined largely to the lower 500 feet of the formation. This sandstone appears to be more or less petroliferous toward the west end of the field, and as a consequence its outcrop is stained rusty red, purple, and pink. This coloration of



A. NODULAR MIOCENE SANDSTONE AT LOS ANGELES.



B. TYPICAL LOWER MIOCENE SANDSTONE AT LOS ANGELES.

the beds is particularly noticeable along Ocean View avenue west of Alvarado street. Toward the east end of the field the sandstone is usually light to dark yellowish brown. Above the soft sandstone and sandy shale is a zone of fine-grained shale, several hundred feet in thickness. Some of this shale is hard and appears to be more or less calcareous. Veins of gypsum are abundant in this part of the formation. Excellent exposures of this fine-grained shale are found on Beaudry avenue near Fourth street and in many road cuts both northeast and west of this locality.

The uppermost beds of the Fernando exposed in Los Angeles lie south of the central field, occupying the ridge on which the State Normal School is located. These are soft clayey shales and heavy-bedded, fine, light-colored sandstone with some interstratified conglomerates. The fossils listed on page 153 came from these beds in the region south of the central field.

GEOLOGY OF THE WELLS.

As indicated by the well logs, the underground geology varies somewhat throughout the extent of the central field. The southerly dip of all the beds, however, is common from one extremity of the field to the other. The strata in general are less disturbed and dip at lower angles in the east end of the field, and the oil sand on that account appears thinner in that region. In the territory east of Belmont avenue most of the wells penetrate sandy and clayey shale (Fernando) for the first 500 or 600 feet. Beneath this is the oil sand, consisting of 125 feet of thick layers of coarse arkose material interbedded with thin clayey shale. About 200 feet beneath this sand is the lower productive zone, which consists of 40 to 50 feet of medium to coarse sand in layers similar to those of the upper zone. The two oil-bearing beds are separated in the northern part of the field by about 200 feet of tough blue clay, but toward the south this thins out and the productive sands tend to coalesce. On the south edge of the field the rocks below a depth of 950 feet consist of alternating clayey and coarse sandy layers, which replace the heavy, well-defined 10 to 15 foot sands farther north. The gas pressure is stronger and the oil more abundant, heavier, and redder along the south edge of the field than in the same beds nearer the surface in the northern portion. This reddish oil, it is said, gradually turns black on exposure to the air. Below the lower productive zone is 15 to 20 feet of clayey shale and thin-bedded sandstone carrying considerable quantities of water. The south edge of the field is defined by the line where this water becomes so abundant that it completely hinders development. The water level is said to be between 900 and 950 feet below the surface east of Belmont avenue and 1,050 feet west of it.

The following is a characteristic well log from the northern part of the central field:

Log of well two blocks east of Lake Shore avenue, Los Angeles.

[Elevation approximately 400 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Alternating blue clayey shale and fine soft sandstone	600	600
Same, with oil seepages in sandstone	40	640
Blue clayey shale	60	700
Coarse oil sand	70	770
Blue clayey shale, with sandy layers containing oil	180	950
Medium to coarse oil sand	50	1,000
Blue clayey shale	10+	1,010+

The following log is characteristic of the region about Second Street Park, immediately east of Lake Shore avenue, the well being two blocks southwest of that whose log has just been given:

Log of well in Second Street Park, near Lake Shore avenue, Los Angeles. [a]

[Elevation approximately 325 feet above sea level.]

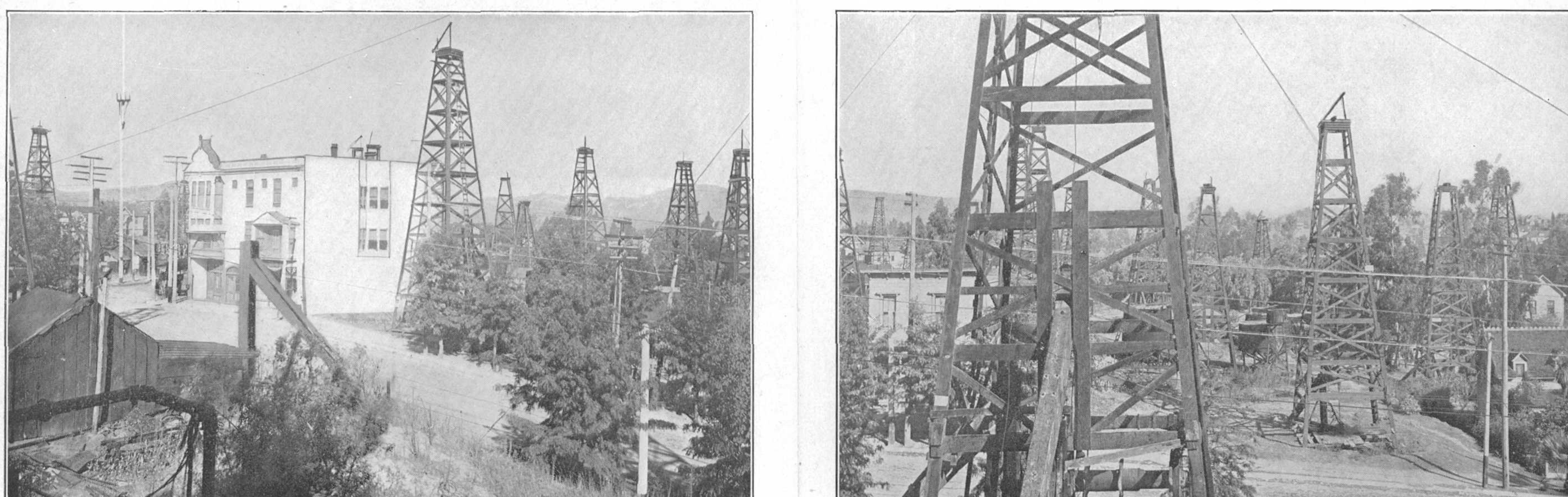
	Thickness.	Depth.
	Feet.	*Feet.*
Sandy and clayey strata with thin strata of hard rock ("shells")	650	650
Oil sand interstratified with sandy clay	125	775
Tough clay ("putty")	200	975
Oil sand, with water	3	978
Sand with water.		

[a] Watts, W. L., Bull. California State Mining Bureau, No. 11, 1897, p. 6.

West of Belmont avenue the dip becomes steeper, and although the water line becomes lower, and the wells consequently can go deeper, the field narrows appreciably. Between Burlington avenue and Alvarado street the productive territory is about 600 feet wide; west of Alvarado street it narrows to 500 feet, and at the end of the field, near Coronado street, to about 300 feet. Near the corner of Belmont avenue and First street the wells penetrate soft fine sandstone and sandy and clayey shale for the first 850 feet, below which they pass into a 50-foot zone of clayey shale, in which are interbedded petroliferous sandy beds called "stray" sands by the drillers. The oil sand is struck at about 900 feet and is 100 feet thick, the dip here being between 30° and 40°. At 1,040 feet there is a 70-foot sand, which grades below into a white sand bearing salt water. This constitutes the lower limit of the productive zone.

A. EASTERN OIL FIELD, LOS ANGELES.

Looking north from Baker Iron works.



B. CENTRAL OIL FIELD, LOS ANGELES.

Looking east from near corner of First street and Belmont avenue.

A typical log for the part of the central field lying near Belmont avenue is as follows:

Log of well at corner of Belmont avenue and First street, Los Angeles.

[Elevation approximately 400 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clayey and sandy shale	850	850
Clayey shale with interbedded oil producing sand ("stray" sand)	50	900
Good oil sand, medium to coarse	100	1,000
Clayey shale	40	1,040
Oil sand	70	1,110
White sand with salt water	10+	1,120+

In the region between Burlington avenue and Alvarado street the dip is steep, the oil sand being struck at about 700 feet on the north side of the productive belt, 900 feet in the middle, and 1,100 feet at the south edge. The strata above the oil sand consist largely of dark-colored shale and thin-bedded sandy layers, the latter occasionally petroliferous or water bearing toward the base of the section. Owing to the steep dip in this part of the field, the wells remain in the oil sand for a much greater distance than they do farther east. There are also indications of a tendency toward coalescence of the oil sands here, caused by a partial pinching out of the shale beds. One well near the north side was drilled for over 300 feet through productive sand, with only a few thin layers of shale. The water plane in this portion of the field appears to be almost level, being struck at a depth of about 1,200 feet on the north side and 1,250 feet on the south side. The water is salt, and displaces the oil in the sandy beds below these depths.

From Alvarado street westward to the end of the field the beds dip at angles varying from 50° to 70°, and the width of the field is reduced to a minimum of 300 feet. The strata are practically the same as those penetrated east of Alvarado street, the only difference being that the water plane is a little lower—at a depth of about 1,300 feet—and the wells are in consequence a little deeper. The wells here are said to be the most productive in the field, some of them having yielded 60 barrels a day at the start and kept up a steady production of 20 barrels for at least a year. Owing to the steepness of dip and the close proximity of the wells to the structural disturbance at the bend in strike, which occurs only a short distance west of the west end of the field, considerable difficulty is experienced from caving. Toward the northern edge of the field the wells go to 1,200 feet and obtain good results, but much water is encountered in many of the beds above the 700-foot level. At the south edge of the field the productive zone, which extends from a depth of 1,000 or 1,100 feet to the water plane at 1,300 feet, consists of clayey shale interstratified with oil-bearing "stray" sands.

STRUCTURE.

The most important structural feature in the central field is a line of disturbance which extends from the region 100 feet or so north of the corner of Patton and Temple streets westward to a point on Benton street about 200 feet south of First. (See Pl. XX, sec. E–F.) Near this last point it bends and passes to the northwest toward Colegroove. This structural feature is in alignment with the fault along the north side of the eastern field, and is probably a continuation of it. In fact, the only stretch of territory over which it can not actually be traced is that lying between the corner of Sumner place and Bellevue avenue, northwest of the Sisters' Hospital, and a point north of Temple street near Patton. Throughout this stretch and north and south of it for some distance the beds all dip to the south at angles varying from 8° to 35°, and no evidences of folding or important faulting were observed.

The anticlinal structure of the flexure is attested by the fact that the beds dip to the south on Court street near Lake Shore avenue and to the north two blocks farther north. The more or less irregular position of the beds in the axis of this anticline near the corner of Temple street and Lake Shore avenue indicates that considerable faulting accompanied the folding. The exposures on Sumner place between Sunset boulevard and Bellevue avenue, in the region northwest of the corner of Patton and Temple streets, on Burlington avenue 200 feet or so south of Temple, and on Benton street about 200 feet south of First offer further evidence in favor of the fault theory.

The southern or productive limb of the anticline, although much the steeper, shows more regularity throughout the central field than the northern limb. It is considerably broken and irregular at its east and west ends, but these conditions are probably due to other lines of disturbance crossing its strike. The dips near the axis of the anticline are usually low, becoming steeper toward the south. The oil appears to accumulate in the steeper beds just below the point where they bend to the lesser dips near the axis. This is well shown in fig. 13, a section along C–F, Pl. XVIII, across the field near Lake Shore avenue. The dips in the southern limb of the anticline in the east end of the field vary from 10° to 45°, becoming abruptly steeper toward the east end and reaching a maximum of 70° near the corner of Bellevue avenue and Victor street, just west of the Sisters' Hospital. This marked change in the dip is doubtless in some way related to the line of disturbance described in discussing the structure of the eastern field (pp. 163–164) as extending southward from the corner of Sunset boulevard and Sutherland street toward the Sisters' Hospital. To the west of Belmont avenue the dips become steeper, some of them being 70° or more, and the breadth of the field decreases in a corresponding manner. The productive area is locally interrupted in the region immediately west of Coronado street, by the fractures attending the change in the direction of the strike of the beds.

A line of minor faults, some normal, others reverse or thrust, is developed on the south flank of the major flexure. A normal fault occurs on Welcome street 150 feet south of Council, and an excellent example of the thrust faults is shown about 25 feet north of Colton street on the west side of Lake Shore avenue. This secondary line of disturbance seems to mark practically the northern limit of the productive territory over a considerable portion of the field, but it is problematical whether this is merely a coincidence of position—the productiveness of the sands depending on their distance from the axis of the anticline or their depth below the surface, or both—or whether the minor faults really seal the upper ends of the oil-bearing beds

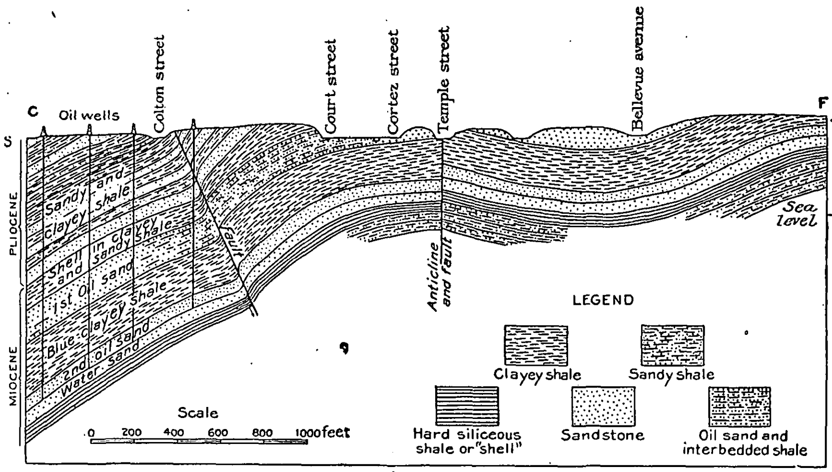


FIG. 13.—North-south section across the central field on the line C-F, Pls. XVIII, XIX, along the western side of Lake Shore avenue, Los Angeles.

and thus limit the field. The fact that a few productive wells are found north of the line of faulting offers evidence refuting the absolute effectiveness of the barrier even though it is operative over a portion of the territory, unless the explanation is that these wells pass through the tilted fault plane and derive their oil from the productive beds below and to the south of it.

North of the main line of disturbance the beds for the most part show local flexures with low dip; these apparently bear little relation to the major structural features or to each other. The general anticlinal structure of the major flexure described in the preceding paragraphs is evidenced, however, by the recurrence in two knolls, cut through by Sunset boulevard northwest of Echo Lake, of the coarse sandstone (oil sands) found south of the axis in immediate proximity to the northern boundary of the central field.

DEVELOPMENT.

The central is the oldest field in the Los Angeles district, its first productive well having been sunk in 1892. As soon as oil was assured other wells were drilled in the immediate vicinity, and the field grew rapidly. The development of that part of the field lying east of First street was practically complete by the end of 1896, while most of the wells in the western part were sunk during the period from 1897 to 1900. There are at present (February, 1906) 516 wells in the central field, of which 206, or about 40 per cent, are pumping, while 310, or about 60 per cent, are either abandoned or not pumping. In the region west of Bonnie Brae street the proportion of pumping wells is 60 per cent, but in the eastern part of the field it is only 31 per cent. This is doubtless due to the greater age of the eastern wells. The wells vary in depth from 500 to 1,400 feet, averaging deeper in the western than in the eastern part. The eastern wells now produce from 2 to 8 barrels per day, and the western wells go considerably higher, some possibly to 12 or 15 barrels. The average for the field is said to be about 4 barrels. At their inception some of the wells in the western part of the field gave 60 barrels per day, but soon fell off to 20 barrels. The gravity of the oil in this field varies from 14° to 16° B.

WESTERN FIELD.

LOCATION.

The western field includes all of the oil-producing territory lying to the west and northwest of Coronado street, north of Westlake Park, with the exception of the area described on pages 186–195 as the Salt Lake field. In its restricted sense the western field is a belt trending N. 70° W., about one-half mile wide at its southeast end and one-fourth mile wide at its western terminus southeast of Colegrove. Within this area of about 1⅛ square miles are four rather distinct groups of wells, the area covered by them being something less than one-half the total area of the oil-yielding belt.

TOPOGRAPHY.

The region of the western field, viewed topographically, is one of transition from the pronounced hilly country northwest of Elysian Park to the broad, gently southward-dipping Los Angeles-Santa Monica plain. Its characteristic features are low rolling hills, separated by more or less strongly pronounced ravines, which run in a southerly or southwesterly direction.

GEOLOGY.

Superficial Pleistocene deposits cover a large part of the western field, but from the examination of exposures along the ravines in its eastern part and from a study of the well logs it is known that the formations underlying it are the same as those exposed in the eastern and central fields. These are the lower Puente sandstones, the Puente shale and thin-bedded sandstone, the Fernando sandstone, and the Pleistocene gravel, sand, and clay.

The most prominent bed exposed is the coarse sandstone which lies between the bands of hard, white, thin-bedded shale at the top of the Puente formation. Exposures of this sandstone may be traced from the hill one-half mile north of Westlake Park to the bend in the Hollywood and Cahuenga Valley Railroad at the corner of Western avenue and Temple road. The exposures one-half mile north of Westlake Park show a medium to coarse or rather gritty sandstone, with colors varying from light yellow and brown to chocolate, gray, and dark brown. The beds are considerably disturbed, being near the point of change of strike from N. 80° W. to N. 65°–70° N. West of this locality, toward the Baptist College, the sandstone outcrops along the face of the hill east of Occidental boulevard. Still farther west, at the corner of Commonwealth avenue and Geneva street, the sandstone dips 20° S. 20° W. and is interbedded toward the top with some thin layers of hard siliceous shale. Immediately southwest of the Baptist College the same sandstone, highly impregnated with oil, in layers from 12 to 36 inches thick, has a dip of 20° S. At this point the sandstone is coarse and chocolate colored, and is interbedded with 1- to 12-inch layers of chocolate-colored shale, which contains large quantities of carbonaceous matter and some sulphur.

Immediately north of the Baptist College are some exposures of white thin-bedded shale, interbedded with softer, darker-colored shale which dips toward the south, under the coarse sandstone. This shale continues toward the northwest and is exposed in a much crumpled condition on First street about one block east of Vermont avenue. It also occurs in a small ravine near the junction of Rosedale avenue and the Hollywood and Cahuenga Valley Railroad. The last good exposure is found on Western avenue, just north of Temple road. Interbedded in the shale about 300 feet stratigraphically below the main layer of coarse sandstone, is a band of somewhat similar sandstone which appears to be the principal productive bed in the western field. This lower sand is well shown in a cut on the Hollywood and Cahuenga Valley Railroad at Vermont avenue. The dip here is 10° due west. The sandstone looks very much like that exposed on Sunset boulevard and has similar large ellipsoidal concretions. It does not appear to contain any prominent shale layers, although it is overlain and underlain by the thin white siliceous beds. As exposed in this railroad cut the sand is about 50 feet thick, but the records of wells in other parts of the field show that it varies considerably in thickness and also in the number and prominence of the included shale layers.

Above the upper coarse sandstone are some layers of thin-bedded white shale, which may be traced westward from the region immediately north of Westlake Park toward the corner of Fifth and Hoover streets, and thence northwestward across Vermont avenue to Western avenue, which it crosses about one-fourth of a mile south of Temple road. This shale, according to the well records in the region southwest of the corner of Western avenue and Temple road, probably averages somewhat thicker in the western field than it does in the central.

The Fernando is represented in the western field by rather hard gray to chocolate-colored shale, exposed on a small creek southwest of the Baptist College. The beds dip 22° S. 25° W. Some soft, thin-bedded sandstone and sandy shale also occur in the formation above the hard beds near the base. Although there are few outcrops to corroborate the assertion, it is exceedingly probable that the Fernando overlies the Puente over the whole extent of the Los Angeles-Santa Monica plain, south of Temple road and at least as far west as the west end of Rancho la Brea.

As previously stated, the Pleistocene deposits consist of gravel, sand, and clay and lie unconformably upon the older rocks from the foot of the Santa Monica Mountains southward across the Los Angeles-Santa Monica plain. An excellent exposure of the Pleistocene occurs in the ravine northwest of the Baptist College. This deposit consists of sand and gravel of granitic quartz, sandstone, and shale fragments, some of the cobbles attaining a diameter of over 6 inches. The whole is richly impregnated with heavy oil, which seeps from the underlying sandstone and shale and imparts a dark chocolate color to the mass. Pleistocene deposits, consisting of roughly bedded sand and gravel, lying in an approximately horizontal position, may also be seen in cuts along some of the roads west of Hoover street.

GEOLOGY OF THE WELLS.

For convenience of discussion, the western field will be divided into four areas corresponding to the four more or less distinct groups of wells which it comprises. The first area—the largest and by far the most important—embraces the territory in the vicinity of the Baptist College, and is bounded by Coronado street on the southeast and by Rosedale avenue on the west; the second area includes the region about the bend in the Hollywood and Cahuenga Valley Railroad at the corner of Western avenue and Temple road; the third is located two or three blocks northwest of the second; and the fourth covers a few acres at the east end of the Rancho la Brea about a mile south of Colegrove.

BAPTIST COLLEGE AREA.

A reference to the geologic map (Pl. XVIII) will show that within the Baptist College area are the outcrops of five distinct zones, which are, from the base up, the oil-bearing thin-bedded shale and sandstone of the Puente formation, southwest of these the 150-foot oil sand of the central field, the white-shale zone at the top of the Puente, the thin-bedded sandstone of the Fernando, and over all in more or less scattered patches the Pleistocene gravel and sand. Oil is derived principally from a zone (probably corresponding with the lower oil zone of the central field) of interbedded clayey shale, "shell," and oil sands, the top of which lies from 200 to 400 feet below the bottom of

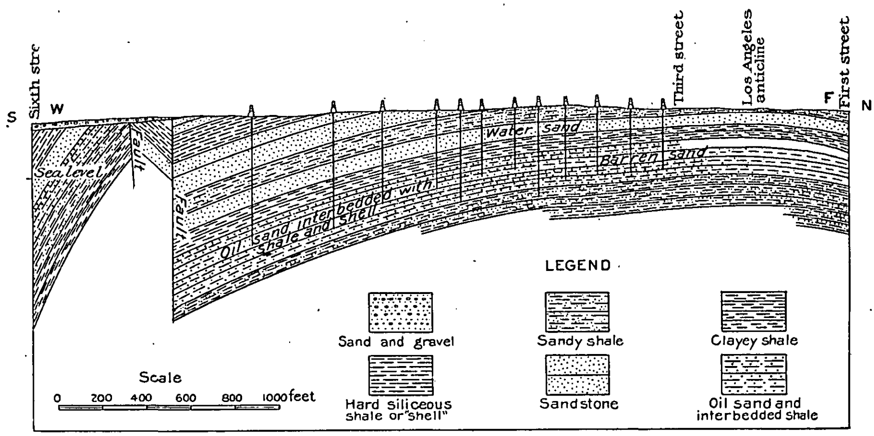


FIG. 14.—North-south section on the line W-F, Pls. XVIII, XIX, along Hoover street from First to Sixth streets, Los Angeles, showing the structure of the western field.

the main oil sand of the Los Angeles district. As would be expected, the logs of the wells in this area farthest toward the southwest give the most complete records. The Fernando formation consists of sandy shale and fine sandstone, beneath which are the clayey shale and interbedded "shell" layers which lie above the thickest sandstone bed. This sandstone bed (first oil sand), where reached by wells south of its outcrop, usually gives a small yield of heavy oil. Below the sandstone the wells penetrate about 400 feet of thin-bedded blue clayey shale, thin hard "shell," and interbedded oil-bearing sands. Between 130 and 170 feet above the bottom of this shale is a layer of coarse, water-bearing sand, and at its base is a 20 to 50 foot oil sand, the greater thickness in wells in the southwestern part of the area, the less in the wells which start down north of First street. From this horizon down the well logs show considerable discrepancy. Blue clayey shale, containing thin to moderately thick beds of oil sand with some water-bearing strata between appears to lie beneath the lower or second oil sand in most of the wells. Water with a temperature of 104° was struck in a well at the corner of First street and Vermont avenue at a depth of 800 feet. In this well from 800 down to 1,735 feet the strata are blue clayey shale and some "shell." A heavy flow of water was encountered at 1,400 feet. The sandy shale from 1,400 to 1,735 feet yielded some oil and gas. The record of a well drilled immediately southwest of the corner of Fourth and Hoover streets reveals some interesting facts. The first oil sand in this well (probably the second of the above discussion) was encountered at 250 feet and extended to 350 feet. This productive sand, as reported, was succeeded below by water-bearing sand, with no shale or other parting between. When the depth of 350 feet was reached the well yielded from 75 to 100 barrels of oil containing no water for a time, but finally water came from below and the well was temporarily abandoned. After it had lain idle for five or six months operations were again begun, but the moment the water in the well was agitated the strong gas pressure threw water and oil 30 or 40 feet into the air. Drilling was recommenced after this spasmodic "gush," but water-bearing sands and some shale were the only strata penetrated to 1,000 feet, where a 6-foot layer of coarse bowlders was encountered. From 1,000 feet down the formation was clayey shale, with a 20-foot oil sand between 1,100 and 1,200 feet and another 50-foot sand between 1,300 and 1,400 feet. These sands were very productive, but owing to the softness of the beds the water could not be shut off and was always troublesome.

In the territory southwest of the corner of Sixth and Hoover streets the wells start down in the beds overlying the first oil sand (here almost barren), penetrate the sand for about 150 feet, pass through 300 to 400 feet of clayey and sandy shale and reach the second or productive sand, from 60 to 90 feet thick, at a depth of about 525 feet. North-northeast of this locality, in the region about the corner of Hoover and Geneva streets, the second sand (the first encountered in these wells) is struck at about 190 feet and is 22 feet thick. About 50 or 60 feet below this sand is another 60-foot productive zone. The same relative conditions as have just been described exist along the strike of the beds toward the northwest, the shallow wells, varying in depth from 140 to 400 feet, occurring in the northeastern portion of the field, while the deeper wells are found along the southwestern border.

The oil in many of the wells in the Baptist College area has been succeeded by water, which appears to follow up the oil from below. There is also more or less water in all the producing wells, some, it is said, yielding 75 barrels of water for each 25 barrels of oil. Gas occurs in most of the wells, but not in sufficient quantities to be of economic importance. The oil is mostly black, but the emulsion of oil and water as it is pumped from the wells usually appears bronze colored. Some of the wells near the corner of Dome and Hoover streets, high up on the rise of the oil sands and not far from the axis of the anticline, yield red oil, which, however, becomes black on exposure to the air. The gravity of the oil in the Baptist College area varies from 12.5° to 14.5° B. The production is from a fraction of a barrel to 5 or 6 barrels per day. Some of the wells are said to have started with a production of 75 to 100 barrels but fell off to 30 barrels after ten months, 3 barrels after two years, and 1½ barrels after three years. The effect of the new wells on the old was imperceptible, the decrease in production being due to a local sapping of the sand immediately surrounding the well.

The three following logs are characteristic for their respective localities:

Log of well immediately southwest of the corner of Hoover and Fourth streets, Los Angeles.

[Elevation approximately 275 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Coarse sand, with clayey and sandy shale and occasional thin "shell" layers toward the base	250	250
Excellent oil sand, yielding 75 to 100 barrels of oil at start	100	350
Alternating thin-bedded sandstone and shale containing water	650	1,000
Layer of coarse conglomerate ("bowlders")	6	1,006
Alternating thin-bedded sandstone and shale, with water	94	1,100
Good oil sand; some water	20	1,120
Clayey shale	180	1,300
Good oil sand; some water	50	1,350
Soft clayey shale, too soft to hold casing for shutting off water	80	1,430

Log of well immediately northeast of the corner of Hoover and Geneva streets, Los Angeles.

[Elevation approximately 290 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown clayey shale	60	60
Coarse sand and water	130	190
Oil sand	22	212
Very hard "shell"	3	215
Barren oil sand	55	270
Oil sand	58	328

Log of well southeast of the corner of Vermont avenue and First street, Los Angeles.

[Elevation 260 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Hard sandstone	80	80
Blue clayey shale alternating with thin oil sands	400	480
Oil sand, also containing little water under pressure	20	500
Blue clayey shale and thin sandstone, some of latter oil bearing; water sands between oil sands	300	800
Sandstone containing hot water, 104° F	2	802
Oil sand containing light oil	28	830
Sandstone containing water	5	835
Clayey shale	15	850
"Marble" (calcareous scale or "shell")	3	853
Alternating blue clayey shale and medium- to fine-grained, thin-bedded sandstone	547	1,400
Heavy flow of water in sand	1+	1,401
Sandstone and light oil strata with gas all the way down	334	1,735

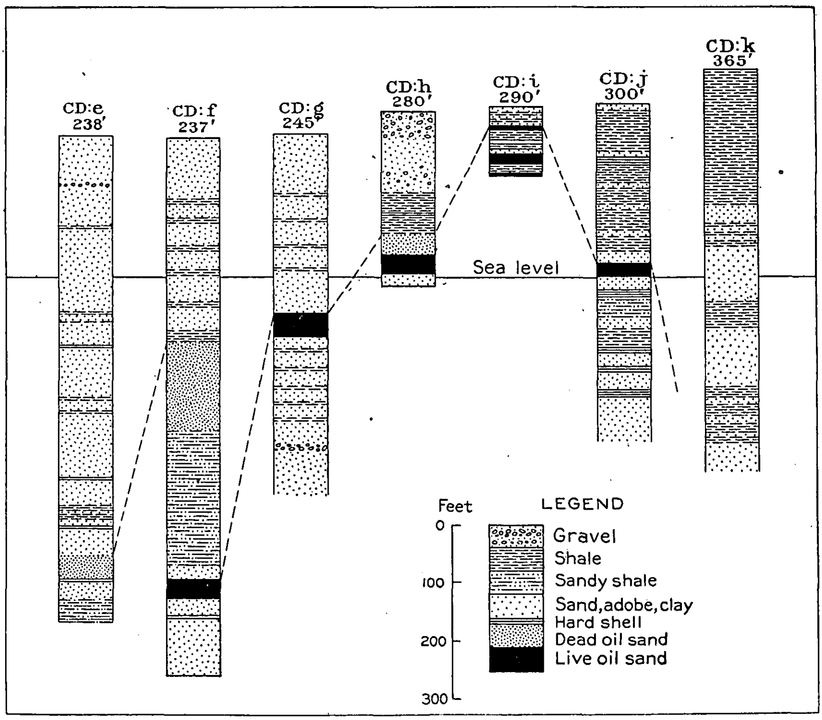


FIG. 15.—Detail of section along the line C-D, Pls. XVIII, XIX, western oil field. Small letters refer to locations of wells on section C-D, Pl. XX.

VICINITY OF WESTERN AVENUE AND TEMPLE ROAD.

The formations underlying the area east of the corner of Western avenue and Temple road are the same as those found toward the southeast, in the region of the Baptist College. The surface outcrops seem to indicate that the dip of the beds is toward the southwest, but from the evidence offered by a group of wells just south of Temple road one-fourth mile east of Western avenue, the dip appears to be south-southeastward about 4 feet in 300 feet. This discrepancy is doubtless due to the proximity of the area to the axis of the Los Angeles anticline.

The wells in the northern part of the area, near Temple road, after penetrating gravel and sand for approximately 100 feet pass through alternating clayey shale and fine sandstone for about 250 feet. At this depth the oil sand, which appears to be barren at the top but productive below, is encountered and extends for 35 feet. About 20 feet below this is a layer of sand which yields flowing water. The wells in this part of the area yield an average of 1 to 2 barrels of 15° B. oil per day; and in addition considerable quantities of gas and usually less than 2 per cent of water.

About one-fourth mile to the southwest down the dip from the territory just described the wells reach the oil sand at 310 feet. The sand is here 40 feet thick and is somewhat more productive than it is higher up, yielding on an average 6 barrels per day per well. The same strata were penetrated and the same amount of water is encountered in these deeper wells as in the wells to the northeast.

Still farther southwest, about one-half mile southwest of the corner of Western avenue and Temple road, the wells strike an oil sand at a depth of about 350 feet which outcrops at the surface in the vicinity of the wells just described. This sand furnishes the main yield of these wells. About 350 feet below this upper oil sand is encountered a second oil zone corresponding to the productive sand of the wells half a mile to the northeast. The strata above the first sand are largely clayey and sandy gray shale, possibly Fernando in part, with some harder shale and "shell" layers immediately above them. Between the first and second oil zones are alternating clayey and sandy shale with a few thin layers of hard siliceous shale or "shell;" isolated accumulations of oil and gas occur throughout these beds.

The three following well logs are characteristic of the region near Western avenue:

Log of well one-fourth mile east of the corner of Temple road and Western avenue, Los Angeles.

[Elevation, 280 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Gravel and bowlders	45	45
Coarse white sand	30	75
Red gravel	20	95
Small pebbles	20	115
Soft sandstone	12	127
Hard sandstone	6	133
Hard light-yellow shale	15	148
Hard black shale	17	165
"Shell" or hard white siliceous shale	3	168
Black shale	38	206
"Dead" oil sand	35	241
"Live" oil sand	35	276
Black shale underlain by stratum of artesian water	20	296

Log of well one-fourth mile east-southeast of the corner of Temple road and Western avenue, Los Angeles.

[Elevation, 245 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	50	50
"Adobe" or sandy shale	20	70
Yellow clay	20	90
"Adobe"	10	100
Sand and shale	135	235
"Adobe"	75	310
Oil sand	40	350
Thin-bedded clayey shale and sand; artesian water at 390 feet	40	390
Thin-bedded clayey shale and sand	70	460
Clayey shale; artesian water in fine white sand at 470 feet	10	470
Clayey and sandy shale and fine sandstone	30	500
Same as last, with artesian water in quicksand	40	540
Conglomerate	10	550
Sandy shale	5	555
Hard white sandstone	70	625

Log of well one-half mile southwest of the corner of Temple road and Western avenue, Los Angeles.

[Elevation, 238 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Depth.*
Red gravel and sand	40	40
Water sand	8	48
Blue clayey shale	4	52
Gray clayey shale	22	74
Blue sand	23	97
Gray clayey shale	9	106
Hard sandstone	1	107
Gray clayey shale	27	134
Hard shale	1	135
Hard sandstone and clayey shale	14	149
Hard shale	2	151
Hard sandstone and clayey shale	30	181
Black and green clayey shale	79	260
Hard shale	1	261
Black shale	38	299
Hard oil sand	41	340
Soft oil sand	61	401
Hard sandstone	2	403
Soft oil sand	6	409
Hard sandstone	2	411
Soft oil sand	2	413
Clayey shale	3	416
Hard sand	4	420
Alternating clayey shale	14	434
Black shale	60	494
Hard sandstone and shale	5	499
Black shale	21	520
Green clayey shale and sandstone	70	590
Hard sandstone	1	591
Clayey shale and sandstone	20	611
Very hard shale or "shell," gas underneath	1	612
Clayey shale and sandstone	6	618
Clayey shale and hard sandstone	21	639
Soft shale and sand; some oil	19	658
Stiff clay and hard sandstone	31	689
Hard sandstone	1	690
Hard sandstone and shale	10	700
Hard sandstone	9	709
Hard sand, mostly shale	21	730
Hard siliceous shale or "shell;" "oil cap"	3	733
Oil sand and clayey shale	7	740
Oil sand, good	15	755
Stiff clayey shale	7	762
Oil sand and shale	4	766
Hard sandstone and shale	2	768
Oil sand	35	803
Clayey shale	30	833
Hard shale or "shell"	2	835
Water sand	33	868
Clayey shale	5	873
Water sand	30	903
Clayey shale	3	906
Sand	29	935

AREA ONE-FOURTH MILE NORTHWEST OF TEMPLE ROAD AND WESTERN AVENUE.

The underground geology in the vicinity of the little group of wells in the SE. ¼ sec. 14, T. 1 S., R. 14 W., one-fourth mile northwest of the corner of Temple road and Western avenue, introduces a new structural factor in the shape of a northeast-southwest line of disturbance. In a journey westward through the western field this is the first evidence encountered of the secondary zone of disturbance which to the southwest develops into the Salt Lake flexure. The line of disturbance or fault appears to extend in a southwesterly direction from the northeast corner of the SE. ¼ sec. 14, through a point 80 feet west of Loma Vista well No. 5, and thence indefinitely toward the Salt Lake field.

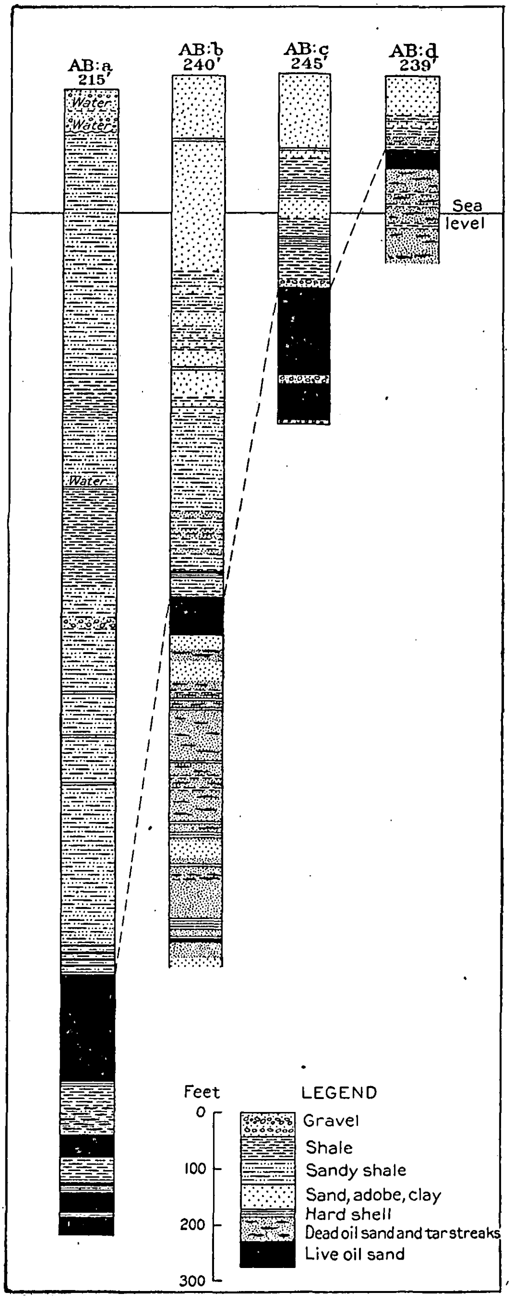


FIG. 16.—Detail of section along the line A-B, Pl. XVIII, western oil field. Small letters indicate locations of wells on section A-B, Pl. XX.

East of this line of disturbance the main oil zone, which is here from 80 to 90 feet thick, is encountered at a depth of between 195 and 210 feet, the overlying beds consisting of Pleistocene sand and gravel near the surface, with thin-bedded shale and fine sandstone below. The wells yield as high as 20 barrels per day when they first come in, but this production falls off and at the end of two years is in few cases over 2 barrels. The original high production is caused by the gas pressure, which is rather strong in this area. West of the line of disturbance water is encountered in the wells at a depth of 400 feet, but no oil was struck, although one of the wells was continued to 580 feet.

AREA SOUTH OF COLEGROVE.

The wells in and near the SE. ¼ sec. 15, T. 1 S., R. 14 W., about a mile south of Colegrove, penetrate the same strata that underlie the Salt Lake field, a mile and a half to the southwest. The wells reach the oil zone near the surface, where it is unproductive and almost dry, while those of the Salt Lake field encounter it at depths of 1,000 to 3,000 feet, where it is exceedingly rich in oil and gas. The two areas offer an excellent illustration of the differences in saturation of a single zone at different points, and also of the fact that within reasonable depths oil-bearing strata which outcrop at the surface or whose truncated ends are overlain near the surface by comparatively thin deposits of porous material are deprived of most of the petroliferous contents of their upper portions either by slow distillation or by some other process.

The wells of the Colegrove area penetrate Pleistocene sand, usually water bearing at the base for about 50 feet, below which they enter thin-bedded clayey shale, sandstone, and "shell." The northeasternmost wells strike the oil sand at a depth of a little more than 100 feet, and from this point down for at least 300 feet pass through alternating layers of oil sand, clayey shale, and "shell," with here and there one of conglomerate. From the northeastern edge of the Colegrove area the oil sands dip toward the southwest at an angle of about 22°, being encountered at greater and greater depths in the wells as the Salt Lake field is approached. The wells farthest northeast start down in beds which underlie what has been called the "first" of "150-foot" oil sand, but those situated southwest of the middle point of the line dividing the SW. ¼ from the SE. ¼ of sec. 15 penetrate this sand at depths varying from 100 feet down. A well located about one-eighth of a mile west of the middle of the south line of sec. 15 strikes this first oil sand at 722 feet and from this depth down to 1,532 feet penetrates an almost continuous series of oil- and gas-bearing sandstone and sandy shale interbedded with clayey shale and thin layers of hard siliceous shale or "shell." For some reason the sands here are not very productive and no important wells have been developed over this part of the area.

Northeast of the Colegrove area the oil-bearing shale and sandstone pass over the Los Angeles anticline and extend in low folds toward Prospect Park. Traces of oil and gas have been found in these beds in nearly all the wells drilled between the productive belt and the Prospect Park region, but no accumulations of consequence have been encountered.

The three following well logs indicate the character of the strata in the Colegrove area. They are given in order down the dip of the strata from the northeast edge of the area toward the Salt Lake field.

Log of well on northeast edge of the group drilled in the SE. ¼ sec. 15. T. 1 S., R. 14 W., Los Angeles.

[Elevation, 239 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	6	6
Hardpan	8	14
Blue clay	21	35
Gray clay	15	50
Fine black sand and clay; water at 47 feet, but soon exhausted	22	72
Fine black sand and shale	40	112
Oil sand; showing of oil from 60 to 119 feet	7	119
Sandy shale	6	125
Alternating brown shale and oil sand	29	154
Shale	6	160
Tar sand in 3-foot layers	36	196
Tar sand separated by thin layer of shale	84	280
Tar sand; dry toward top; tar bed at base	37	317
Quicksand with water	5	322

Log of well on southwest edge of the group drilled in the SE. ¼ sec. 15, T. 1 S., R. 14 W., Los Angeles.

[Elevation, 245 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Red sand	50	50
Yellow clay	83	133
Hard "shell"	4	137
Sandstone and shale	10	147
Shale; 1-foot "shell" at 186 feet	108	255
Tar sand	1	256
Shale; 1-foot "shell" at 284 feet; 3-foot "shell" at 302 feet	7	363
Conglomerate	1	364
Shale	7	371
Oil sand; 1-foot "shell" at 380 feet; 4-foot "shell" at 448 feet; 1-foot "shell" at 484 feet	156	527
Conglomerate	10	537
Oil sand	9	546
Conglomerate	2	548
Oil sand	48	596
Conglomerate	5	601

Log of well one-eighth mile west of middle of south line of sec. 15, T. 1 S., R. 14 W., Western Oil Field, Los Angeles.

[Elevation, 240 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy clay	11	11
Yellow clay	29	40
Water sand	70	110
Hard shale or "shell"	2	112
Blue clay	81	193
Hard shale and sandstone	11	204
Brown sandy shale; very sticky between 264 and 284 feet	139	343
Clayey shale; 2-foot "shell" at 506 and 570 feet	349	692
Alternating clayey shale and fine sandy shale to sandstone	80	772
Tar oil sand	6	778
Alternating shale and barren sand	12	790
Clayey shale, changing to sandy shale; 6 feet of coarse sand at 815 feet	60	850
Coarse gravel with gas and oil	2	852
Hard siliceous shale or "shell"	6	858
Sandy shale; considerable gas	17	875
Clayey shale	15	890
Oil sand carrying heavy oil	35	925
Alternating "shell" and sand with considerable gas and oil	35	960
Very hard "rock"	20	980
White sand with streaks of tar	20	1,000
Tar sand	6	1,006
Very hard "rock"	5	1,011
Sand rock	30	1,041
Tar sand in 3 to 10 foot strata, alternating, with "shell"	59	1,100
Tar sand with thin streaks of shale; more gas	85	1,185
"Shell"	5	1,190
Alternating tar sand and shale, showing of oil and gas between 1,249 and 1,254 feet	64	1,254
Tar sand with occasional hard "shell" layers	36	1,290
Alternating sand and shale, showing of oil and gas	6	1,296
Hard coarse sandstone	7	1,303
Sand interstratified with brown sandy shale	5	1,308
Hard "shell"	10	1,318
"Shell" and gray sand, carrying tar and gas; sand looks like water sand, but no water in it	18	1,336
Water sand	12	1,348
Hard "rock"	2	1,350
Sand, carrying tar and water	10	1,360
Fine sand carrying considerable tar	4	1,364
Dry tar sands interbedded with "shell;" "shell" from 1,364 to 1,366 feet	9	1,373
White sand, hard at base	13	1,386
Tar bed, with pure tar	7	1,393
White quicksand with water	3	1,396
Tar sand alternating with thin "shell;" hard "shell" 1,467 to 1,478 feet	82	1,478
White sand	15	1,493
Hard shell with gas and heavy oil just below it	3	1,496
White sand containing tar and gas	12	1,508
Sand and brown shale	7	1,515
Hard shell	5	1,520
White sand	8	1,528
Very hard shell with some tar and gas beneath it	4	1,532
Hard sand with streaks of shale	12	1,544

STRUCTURE.

The structural conditions in the western field are graphically illustrated by Pl. XX, which shows a section along the line C-D from 1 mile southwest of the corner of Western avenue and Temple road to Edgemont (see also fig. 15), and another section along the line A-B, showing the underground geology from the Colegrove area to the Salt Lake field (see also fig. 16), and by fig. 14, a section along Hoover street. The principal structural feature in the field is the northwestward continuation of the Los Angeles anticline. The trend of this flexure changes from N. 80° W. to N. 65°–70° W., at the east end of this field, west of Coronado street. The area of the change of trend lies northeast and southwest from the corner of Sixth and

Hoover streets, and is one of considerable fracturing and distortion, as is evidenced by the dips which occur in its vicinity. Northwest of the disturbed area the strata along the southwestern limb of the anticline are inclined at angles of 20°–25°, S. 20°–25° W. As the beds approach the axis they flatten out, passing gently over it into the low local folds and flexures which characterize the rolling country to the north, not only of the western, but of the central field also. (See fig. 14.)

The Los Angeles anticline is complicated by faulting in this field, as it is in the region to the east. This is well shown by an exposure on First street, one block east of Vermont avenue, where the beds are much distorted and broken up. From this point the line of disturbance passes near the junction of Rosedale avenue and the old Hollywood and Cahuenga Valley Railroad; thence, as shown by well records, across Western avenue at a point somewhere less than a quarter of a mile north of Temple road, and thence into the group of wells which lie about a quarter of a mile northwest of the corner of Western avenue and Temple road. A new line of disturbance, probably a fault and doubtless related to the Salt Lake flexure (see p. 194), is encountered in this last-mentioned group of wells and extends in a northeast-southwest direction across the trend of the anticline. The geologic conditions are different on the two sides of the fault line, and from this it is safe to assume that the structural conditions are also different, but just what effect the fault has had on the main anticline is problematical. Evidence offered by the logs of the Colegrove group of wells and of other wells between this group and the Salt Lake field and by the great monocline in the region of Cahuenga Pass, in the Santa Monica Mountains to the north, appears to indicate a northwestward extension of the anticline past the transverse fault, toward the mouth of Laurel Canyon. A glance at the geologic map of the western field clearly demonstrates that most of its structural features are determinable only by a comparison of the well logs. It has therefore been necessary to depend almost entirely on these logs in working out the structure of the great southwestern limb of the Los Angeles anticline. In the area southwest of the Baptist College, where the anticline recovers from the distortion and fracturing accompanying its change of strike farther east, this southwestern limb (or monocline, as it may be considered in this territory) dips at angles of 20°–22°, S. 20°–30° W. The dip near Western avenue and Temple road is a little more toward the south, and, being nearer the axis, is but about 12°, while half a mile to the southwest the dip is approximately 26°. One-half mile farther west the slope flattens out to 23°, and still farther northwest, in the area southwest of the Colegrove group of wells, it is only 22°, continuing practically at this angle, at least so far as its southwestern element is concerned, to the Salt Lake field. Evidence secured in this field indicates that a local flexure trending northeast and southwest probably changes the general dip of the beds from southwest in the region of the Colegrove group of wells to west and then to northwest toward the center of the Salt Lake field.

The contour lines on the map (Pl. XIX) give an approximation of the depth of the top of the upper oil sand or zone below Los Angeles city datum (255 feet above sea level).

SALT LAKE FIELD.

LOCATION.

The Salt Lake field—so named from its first important producing company—occupies an area approximately a mile square near the intersection of Fourth street and La Brea road, 7 miles west of the business portion of Los Angeles. The productive territory as now developed embraces the northwestern part of the SE. ¼, the northeastern part of the SW. ¼, and the southern part of the N. ½ sec. 21, T. 1 S., R. 14 W. In addition to this there are some important wells in the central part of the E. ½ sec. 20 and some small producers in the NW. ¼ sec. 28.

The field occupies a part of the Los Angeles-Santa Monica plain, which extends southward with a gradually lessening slope from the base of the Santa Monica Mountains toward the hills southwest of Los Angeles. (See Pl. XXIII.)

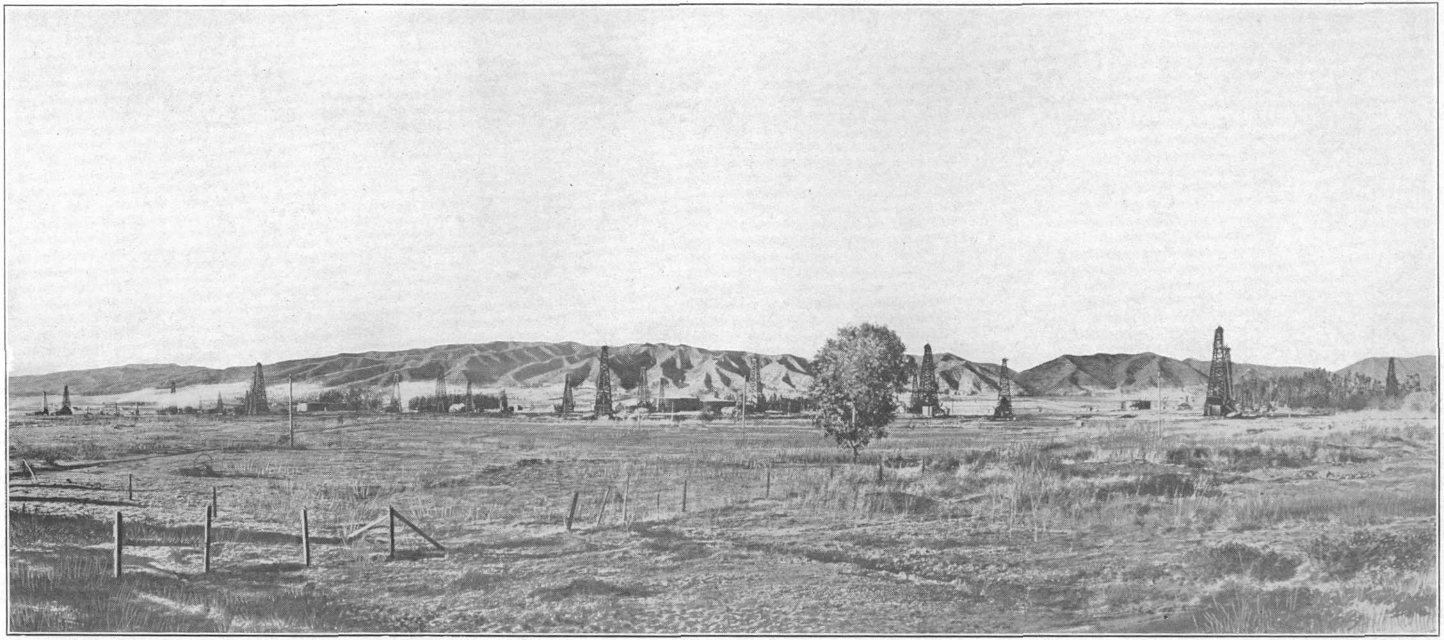
GEOLOGY.

GENERAL STATEMENT.

Alluvium and Pleistocene deposits of gravel, sand, and clay cover the plain in the region of the Salt Lake field, but surface outcrops of other beds are to be found no nearer than about 2 miles from the present developed territory. The well logs and a study of the adjacent territory indicate, however, that the formations involved in the geology of this field include at least a part of those exposed to the east in the vicinity of the Los Angeles city field. They are (*a*) 2,000+ feet of Puente sandstone; (*b*) 2,000± feet of upper Puente shale and thin-bedded sandstone; (*c*) 2,000+ feet of Fernando clayey and sandy shale, sandstone, and gravel, and (*d*) an unconformable capping of Pleistocene gravel, sand, and clay varying in thickness from 40 to 190 feet or more, the whole covered by alluvium. A detailed description of these formations is given in the discussion of the general geology of the district and will not be repeated here.

OIL SANDS.

The most productive sands occur at the top of the Puente formation although traces and locally more or less important accumulations of oil and gas are found in the shale above the principal oil zone.



SALT LAKE FIELD, LOS ANGELES.

Looking north from near lagoon.

The oil is supposed to be derived largely from the diatoms and other minute organic remains found in the underlying shale and finds its way into the sandy layers mainly through the multitude of joint cracks which penetrate both the shale and sandstone.

BREA DEPOSITS.

The brea deposits in the Salt Lake field are the most important in the Los Angeles district. They cover a considerable territory in sec. 21. (See Pl. XXIV, *B*.) A number of years ago large quantities of this brea were removed and used for paving purposes, the resultant depression filling up with water and forming a lagoon. The brea is largely the result of the impregnation of porous sand and soil by oil oozing up from below. That the process is still going on is evidenced by the heavy oil which may be seen oozing from the banks of the lagoon and of several other brea pits in the vicinity. Large quantities of gas are also escaping in the same region, as is shown by the intermittent streams of bubbles which rise to the surface of the water in the lagoon and other depressions thereabouts. (See Pl. XXIV, *B*.) The logs of several wells indicate that brea occurs in the basal Pleistocene beds over a considerable territory contiguous to the lagoon where it is invisible on the surface. The formation of brea over an area relatively so large implies the escape of vast quantities of oil from the underlying Tertiary beds. This escape of the oil and gas is probably made possible by the fractured condition of the rocks. On the evidence offered by the great brea deposits and the large quantities of escaping oil and gas in the region of the lagoon the theory is advanced that considerable fracturing has accompanied the formation of the Salt Lake flexure.

GEOLOGY OF THE WELLS.

For the convenience of discussion of the underground geology, the Salt Lake field will be divided into two parts by a hypothetical line running in a general northeast-southwest direction through the lagoon and coinciding in a general way with the axis of the supposed Salt Lake flexure. The area to the northwest of this line contains most of the productive wells, and there are no important producing wells in the area southeast of the line.

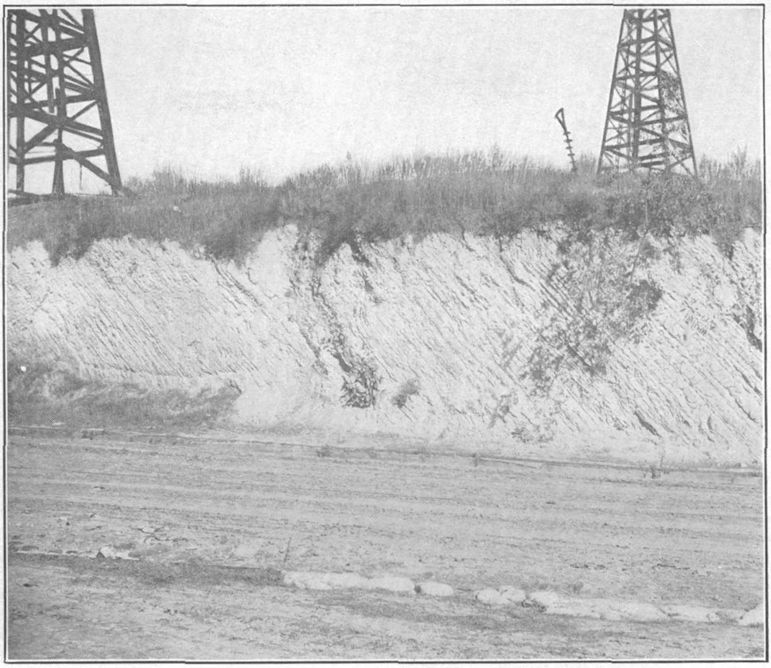
AREA NORTH AND NORTHWEST OF THE LAGOON.

In the area north and northwest of the lagoon the wells for the first 50 to 100 feet penetrate alluvium and Pleistocene clay, coarse sand, and gravel—the mantle of the older formations. The Pleistocene beds usually carry two water-bearing layers, one at a depth of 20 to 30 feet, the other (which appears to lie at the base of the formation) at 50 to 100 feet from the surface. In some of the wells the lower layer is highly charged with sulphur and other minerals, which are probably derived from the underlying shale. These surface waters are usually shut off in the sandy or clayey shale at depths of about 150 feet. Brea and heavy oil are also occasionally encountered at the base of the Pleistocene, having accumulated at the top of local fracture zones which penetrate the underlying oil-bearing strata. In fact in some parts of the field, especially in the vicinity of the supposed flexure, oil appears to impregnate the soil and rocks "from the grass roots down."

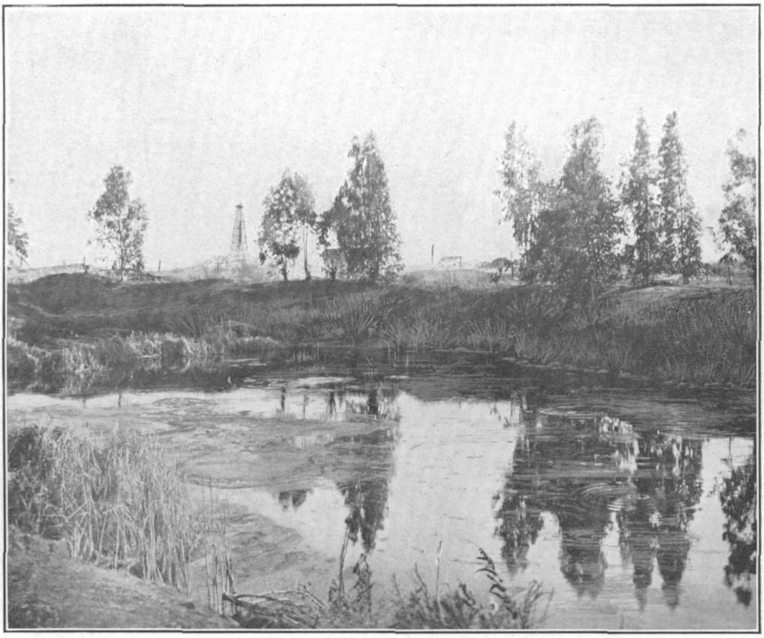
From the base of the Pleistocene to the first important oil sand, which is struck at 1,000 to 3,000 feet, the rocks penetrated are essentially clayey and sandy shale (the latter known locally as "adobe") interbedded toward the base with a few 1- to 5-foot layers of hard siliceous or calcareous shale (the "shell" of the drillers). The great bulk of this shale probably belongs to the Fernando formation. The sandy and clayey facies of the shale appear to grade into each other both laterally and vertically, so that the personal equation of the driller enters largely into their differentiation. Gravel and coarse-sand lenses are also encountered in some of the wells, but these are usually only local in extent and of little importance.

Gas and oil, increasing in quantity downward, are found in many of the beds of the formation, the most important accumulations occurring as a rule just beneath the hard, impervious "shell" layers. Some of these gas accumulations or pockets are confined under great pressure and when penetrated by the drill have been known to clean out the well with considerable force. The shale beds near the flexure or anticline appear to be more petroliferous than the same layers farther away, to the northwest of the flexure. This is doubtless due to the more or less fractured condition of the rocks in the vicinity of the disturbance, which allows the oil and gas to penetrate many of the beds of the shale which otherwise would be impervious. A persistent stratum of salt water occurs beneath a "shell" layer at about 950 to 1,000 feet above the top of the first important oil sand in the area northwest of the flexure, but does not appear in any of the wells southeast of it. (See fig. 17.) Salt water is also encountered in some of the wells at horizons 150 to 200 feet and 650 feet above the oil zone.

The oil zone proper varies in thickness from 150 to 500 feet and consists of fine to coarse sand interstratified with clayey shale and "shell." The logs of a few wells near the flexure show no well-defined oil sand, but rather a series of thin productive sands interbedded with clayey and sandy shales. Whether the sand occurs as persistent layers or as lenses is problematical, although from the evidence in hand it appears highly probable that it is present in both forms within the area under discussion. It is known, however, that the uppermost important oil sand in the wells over a large part of the



A. CHARACTERISTIC THIN-BEDDED PLIOCENE SANDSTONE, LOS ANGELES OIL FIELDS.



B. LAGOON IN SALT LAKE FIELD, LOS ANGELES.

Showing floating oil and bubbling water due to escaping gas.

area northwest of the flexure appears to occupy the same horizon. The sands beneath the uppermost persistent layer vary somewhat in

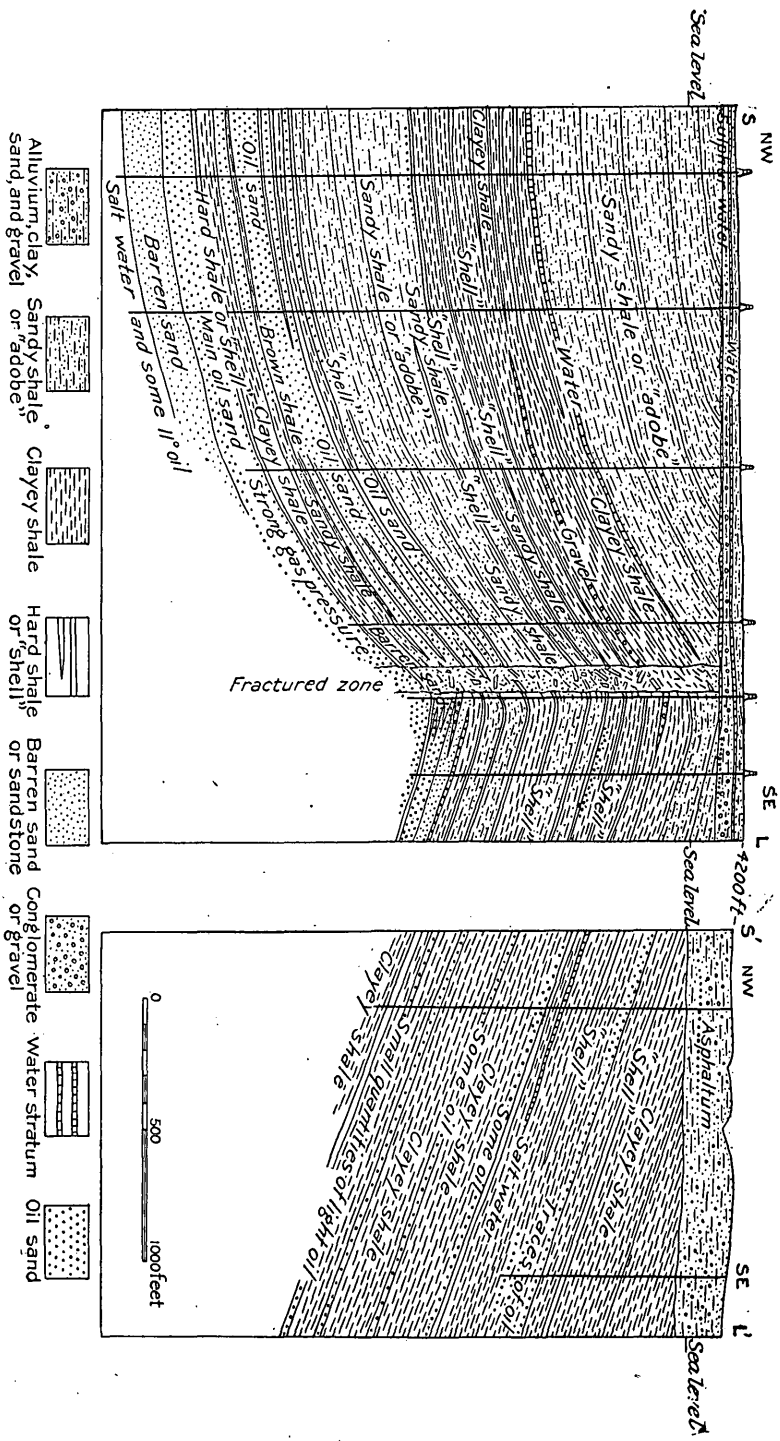


FIG. 17.—Northwest-southeast sections along the lines S–L and S'–L', Pls. XVIII, XIX, Salt Lake field, showing the character of the Salt Lake flexure and the mode of occurrence of the oil-producing strata.

thickness and composition in the different wells. This is to be expected, since individual layers in surface outcrops of similar beds in the Los Angeles region undergo important changes of thickness and grain within remarkably short distances. The upper oil sand on the northwest side of the flexure appears to become less and less impregnated with petroleum as it approaches the apex of the flexure. This condition is probably due to structural causes, such as the loss of the oil through fractures, although it may possibly be accounted for by a slight change in the grain of the sand near the flexure. The same beds, however, continue to carry considerable quantities of gas as they pass over the line of the disturbance.

The "main sand," which yields the bulk of the oil, is apparently fairly constant over a large part of the field. This sand is approximately 100 to 125 feet thick, rather coarse-grained, and highly impregnated not only with oil but with gas also. The tapping of the main sand usually results in the production of a "gusher," owing to the great pressure under which the gas is confined. The retention of the oil and gas in this sand is due to the presence of an overlying bed of impervious "shell," capped by 50 feet or more of hard clayey shale. The gravity of the oil in the same stratum is said to be different at different points down the dip. An illustration of this is found in a series of four wells running across the strike of the oil sand in the northern part of the field. The well highest up on the dip yields 14° oil; the next lower down, about 150 feet from the first, 15°; the third, 150 feet from the second, 16°; and the fourth, or lowest of the series, 100 feet from the third, 17°.

The two following well sections, one near the flexure, the other farther away and down the dip from it, are typical of the Salt Lake field:

Typical well log near the flexure, on its northwestern flank, Salt Lake field.

[Elevation about 225 feet; dip of strata approximately 40°.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	36	36
Sand and gravel	24	60
Heaving sand; first water cased off at 110 feet	30	90
Clayey shale	70	160
"Adobe" (sandy shale)	90	250
"Adobe," with salt water at base	12	262
Clayey shale; 2-foot "shell" at 275 feet	13	275
Clayey shale; no water	85	360
Clayey shale; 4-foot "shell" at 398 feet	38	398
Clayey shale	47	445
"Adobe" and clayey shale	41	486
Sticky "adobe"	19	505
Coarse gravel and "adobe"	21	526
"Adobe;" 4-foot "shell" at 632 feet	106	632
"Adobe;" last 10 feet very sticky	40	672
Clayey shale, 4-foot shell at 701 feet	29	701
"Adobe;" "shell" at 785 feet	94	795
Sticky "adobe;" second water shut off temporarily	5	800
"Adobe;" considerable water	118	918

Typical well log near the flexure, on its northwestern flank, Salt Lake field—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
"Adobe;" layer of soft clayey shale at 960 feet	42	960
"Adobe"	22	982
"Adobe" and small streaks of white sand; some water	40	1,022
"Adobe;" some clayey shale and sand; "shell" at 1,040 feet	29	1,051
Fair showing of oil in "adobe;" small "shell" at 1,075 feet	25	1,076
Sandy shale; good showing of oil between 1,070 and 1,080 feet	24	1,100
Shale; much gas; oil still coming in	10	1,110
Sand and shale; lots of oil	22	1,132
Shale carrying much oil	40	1,172
Shale and oil sand mixed; much gas and oil	44	1,216
Same formation; gas and oil	9	1,225
Broken shale formation; considerable oil	5	1,230
Shale and oil sand; considerable oil	20	1,250
Shale; gas increasing; oil	18	1,268
Shale and "adobe;" lots of oil	28	1,296
Shale; considerable oil	12	1,308
Passed through pulverized slate from 1,310 to 1,315 feet, light oil showing under this	11	1,319
Shale; oil still coming in	19	1,338
Gray shale; gas strong	4	1,342
Shale containing oil; pocket of gas at 1,340 feet	5	1,347
Shale	39	1,386
"Adobe;" considerable gas	19	1,405
"Adobe;" oil coming up on bit; gas flow heavy; well filled for 400 feet with mud, water, and oil	5	1,410
Big flow of gas; filled pipe 140 feet; good showing of oil	34	1,444
Light-colored shale; no mud and no oil	54	1,498
Light oil; large amount of gas; well filling rapidly with oil within 100 feet of top; large "shell" at 1,495 feet, under this the heavy flow of gas and oil; another shell at 1,505 feet	12	1,510
Well full of oil, commenced flowing; continues in oil sand	14	1,524
Struck shell; bottom of well; gushed to top of derrick; big flow at 1,495 feet	17	1,541

Oil zone, 490+ feet (1,051 to 1,541+); thickness of producing sands, 347+ feet.

Typical well log 1,500 feet northwest of the flexure, Salt Lake field.

[Elevation about 200 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium, clay, and sand; water at 28 feet, sulphur water at 49 feet	50	50
"Adobe" or sandy shale	750	800
Hard "shell;" salt water under "shell"	3	803
Clayey shale; 1 to 6 foot "shell" layers every 25 to 50 feet	297	1,100
Hard "shell;" salt water under "shell"	2	1,102
"Adobe"	163	1,265
Tar sand	5	1,270
"Adobe" with occasional clayey shale layers	470	1,740
Oil sand	20	1,760
Clayey shale	30	1,790
Oil sand	10	1,800
Clayey shale	20	1,820
Oil sand	20	1,840
Clayey shale	2	1,842
Oil sand	123	1,965
Tough brown clay	10	1,975
Oil sand	25	2,000
Clayey shale	10	2,010
Oil sand	10	2,020
Clayey shale	86	2,106
Oil sand (main sand)	129	2,235
Barren white sand	150	2,385
Sand with warm salt water and some 11° oil	10+	2,395+

Oil zone, 495 feet (1,740 to 2,235); thickness of producing sands, 337 feet.

AREA SOUTH AND SOUTHEAST OF THE LAGOON.

The underground geology in the area south and southeast of the lagoon is similar only in a very general way to that of the area to the north. The dip of the strata is probably toward the south or southeast, although there are some indications of steep northerly dips immediately southeast of the lagoon. The superficial or Pleistocene deposits become thicker and coarser toward the southeast, those in the SE. ¼ sec. 28 attaining a thickness of 190 feet and consisting of clay in the upper 20 feet and sand and gravel in the lower portion. Deposits of asphaltum appear to be common at the base of the Pleistocene, and in at least one of the wells heavy oil was encountered not far below the middle of the formation. (See fig. 17.) Water is usually found in these superficial beds, as in the area north of the lagoon.

From the base of the Pleistocene down to the bottom of the deepest wells the rocks appear to be largely clayey shale, interbedded at varying intervals with hard "shell" layers. Some sandy beds and a few pebbly lenses are also encountered in drilling. Indications of oil are abundant throughout certain horizons of the shale, but no really important productive sands have yet been found in the area. The wells near the lagoon on the south strike moderately productive sands between 700 and 1,000 feet, while those somewhat farther away get good showings of oil at less depths. In the territory a mile or so southeast of the lagoon the shale contains here and there thin oil-bearing strata beneath the "shell" beds from 400 feet down, but nothing approaching a pay sand has been reached here. Salt water is reported as very troublesome below a depth of about 500 feet in this last locality. It is also found in most of the other wells of the southern area. The wells near the lagoon usually yield flowing water.

The three following logs are characteristic of their respective localities.

Log of well near the middle of the north line of sec. 28, T. 1 S., R. 14 W. (immediately southeast of the lagoon), Salt Lake field.

[Elevation, 175 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium and clay	40	40
"Dead" oil sand and water	40	80
Clayey shale; occasional layers of hard "shell" averaging 2 feet in thickness and in places confining small quantities of oil and gas beneath them	620	700
Good oil sand flowing 1-barrel per day	5	705
Clayey shale similar to that from 80 to 700 feet	765	1,470
Clayey shale, but no oil sand or signs of oil in it	730	2,200

Log of well in the eastern part of the SE. ¼ sec. 28, T. 1 S., R. 14 W. (1 mile southeast of the lagoon), Salt Lake field.

[Elevation, 180 feet; dip approximately 20°.]

	Thickness.	Depth.
	Feet.	*Feet.*
"Adobe"	28	28
Sand and a little heavy oil (asphaltum)	100	128
Quicksand	45	173
Blue clayey shale	127	300
Hard "shell"; blue limestone	4	304
Blue clayey shale	226	530
Hard "shell"; blue limestone	4	534
Blue clayey shale	166	700
Hard "shell"; blue limestone	6	706
Blue clayey shale	229	935
"River" sand; some oil	5	940
Clayey shale	300	1,240
"River" sand having excellent quality but small quantity of light oil	5	1,245
Clayey shale	55	1,300
Hard shell; blue limestone	15	1,315
Clayey shale	81	1,396

Log of well in the western part of the NW. ¼ sec. 23, T. 1 S., R. 14 W. (1 mile south-southwest of the lagoon), Salt Lake field.

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy clay	90	90
Water sand containing heavy oil (asphaltum)	90	180
Heaving sand (gas); little water; no oil; carries considerable quantities of pebbles	325	505
Blue clayey shale interbedded with beds of sand and pebbles 1 foot or so in thickness carrying oil; richest horizon at about 700 feet	358	863

STRUCTURE.

Owing to the almost complete absence of surface evidence in the immediate vicinity, the determination of the local structure in the Salt Lake field depends largely on the interpretation of the well logs. Unfortunately, not all of these were available at the time of the writer's visit to the field, so that the conclusions reached, although probably correct in the main, lack that detail and definiteness which is so desirable in an economic report of this sort.

The strictly local structure of the field under discussion will be more fully comprehended if its relation to the general structure of the Los Angeles district as a whole is again briefly outlined. Practically all the productive oil sands of the different Los Angeles fields lie on the southern limb of a flexure, usually a more or less well-defined anticline, whose axis extends in a westerly direction to the region approximately half a mile north of Westlake Park, where it bends about 20° to the north and extends to a point about three-fourths of a mile southeast of Colegrove and something over a mile northeast of the Salt Lake field. Here it appears to bend again to the north, probably trending about N. 60° W. In the Los Angeles city fields, that is, between the Catholic Cemetery and the Westlake Park region, the southern limb of the flexure dips normally at angles varying from 30° to 80°, while to the west, along that portion having a northwesterly trend, the dips flatten to 20° or 25°. The Salt Lake oil field is located on the northwestern flank of a minor, but probably somewhat complex fold or fault, or both, developed on the comparatively low-dipping southwestern limb of the major flexure just described. The dip of this flank of the local fold is reflected in a general way by the surface slope, which descends gently from the region of the present productive field northwestward toward Sherman. This slope probably indicates a Pleistocene or post-Pleistocene orogenic movement similar to but apparently of much less magnitude than that which produced the original flexure.

The exact nature of the local flexure is not known, but it is probably an anticline, more or less complicated by faults near the apex. Its axis extends in a general northeast-southwest direction. The logs of certain wells located southeast of the lagoon appear to indicate the presence of a minor anticline developed just south of the main flexure and separated from it by a fault. Still other evidence suggests a local dome-shaped structure, or quaquaversal, having its summit in the region of the lagoon. The length of the Salt Lake flexure is unknown, although the available data seem to indicate its extension at least from a point near the center of the SE. ¼ sec 15, T. 1 S., R. 14 W., as far as the lagoon in the SW. ¼ sec. 21. Whether or not it continues farther to the southwest is problematical.

The large accumulations of brea in the immediate vicinity of the lagoon and to the north and northwest of it, in addition to the constantly exuding oil and escaping gas over the same area, indicate some sort of a profound local disturbance or fracture in the underlying beds. If this disturbance has an extensive longitudinal dimension in a northwesterly direction from the lagoon, as some of the evidence suggests, then it may possibly cut off the Salt Lake flexure from a southwesterly extension beyond the lagoon. If, however, the structure in the vicinity of the lagoon is a local bulge or dome in the underlying beds it is quite likely that the Salt Lake flexure may have a considerable southwestern prolongation.

The contour lines on the map of the Los Angeles field (Pl. XIX) and the section shown in Pl. XX, A–B, and in fig. 17 illustrate the writer's ideas concerning the local folds. From the map it will be seen that the strike of the oil sand probably swings around from a nearly east-west line in the region north of the lagoon to a direction slightly west of north in the NE. ¼ sec. 21. The dip of the sand in the region about the center of sec. 21 does not appear to be much more than 10° or 15°, but it increases rapidly in steepness toward the southeast up the rise and probably also toward the northwest, or down the dip.

The region immediately southeast of the Salt Lake flexure, although supporting some small producing wells—one of which attains a depth of nearly 3,000 feet—does not compare in productiveness with the territory to the northwest. This condition may be explained on several hypotheses, the two most probable being either (*a*) that the Salt Lake flexure is accompanied by a fault which has dropped the productive sands on the southeast down out of reach of the drill, or raised them up to such an elevation that they were eroded away in a period subsequent to the faulting, or (*b*) that the continuation of the productive beds passes over the flexure (in this case an anticline) and down on the southeastern flank, but under conditions unsuited to the accumulation of oil in large quantities. The second hypothesis is represented diagrammatically by fig. 17.

Faulting may be responsible for the cutting off of the upper oil sands immediately to the northwest of the axis of the flexure. If this be true it seems likely that the oil sand at the apex, which in fig. 17 is correlated with the main oil sand of the productive field, should be correlated with the uppermost sands northwest of the fold. In this case the fault would have a downthrow of about 250 feet on the southeast.

DEVELOPMENT.

There are at present (February, 1906) between 75 and 80 productive or drilling wells in the Salt Lake field, belonging to the following companies: Salt Lake Oil Company, about 50 or 55; Arcturus Oil Company, 9; Utah Oil Company, 1 (these three companies controlled by the Associated Oil Company); A. F. Gilmore, 4; Pacific Light and Power Company, 4; E. P. Clark Oil Company, 7. In addition to the wells mentioned above, there are several comparatively small producers, belonging to the last-named company. These are located near the northern half of the line separating secs. 28 and 29, and are pumped intermittently. The wells north of the Salt Lake flexure vary from 1,200 feet to over 3,100 feet in depth, the deeper wells being as a rule the more productive and yielding the lighter oil. The individual wells produce from 20 to over 1,000 barrels a day, the average being about 100 barrels. Owing to the tremendous gas pressure nearly all the wells "gush" when they first come in, and it is said that one of the deep wells produced about 18,000 barrels a day for a short time after its inception. The gravity of the oil varies from 11° to 22°, the heaviest oil coming, it is said, from an isolated sand below the main productive zone. The average for the field is between 16° and 18°.

The large quantity of gas which comes from the wells is used mainly for the generation of power for operating and development, although a small amount is used in the field for domestic purposes.

CONCLUSIONS CONCERNING FUTURE DEVELOPMENT.

Anyone at all familiar with the conditions of occurrence of petroleum in the California fields knows that any but the most tentative predictions as to the location of the oil are extremely hazardous. The following conclusions, based on the evidence in hand, although lacking definiteness for obvious reasons, may be of some assistance to those carrying on development in the Los Angeles fields.

CITY FIELDS.

All of the evidence, both geologic and that obtained by exploitation, indicates that the productive territory in the region of the eastern, central, and western fields has been largely developed, in fact overdeveloped, for the most part. It is very improbable, therefore, that prospecting outside of the already proved productive area, either immediately north or south of the oil belt, would result in success.

EAST OF LOS ANGELES RIVER.

Certain outcropping oil sands in the ravine occupied by the old Rapid Transit Railroad track indicate that oil-bearing strata underlie the region east of Los Angeles River and south of this ravine. A number of wells have been sunk in this territory, however, and the greatest recorded production has been that of the Scott & Loftus well No. 1, which is said to have yielded 7 barrels of 17° B. oil per day.[a] It is to be borne in mind that the deepest well so far sunk in this territory is less than 1,000 feet deep and that deeper wells farther down the dip than those already drilled may possibly yield better results, providing water does not interfere with their operation.

The structure of the Fernando sand and gravel in the area northeast of Brooklyn Heights appears to be analogous to that in certain productive areas in the eastern field, as well as in the Puente Hills and Sulphur Mountain (Ventura County) fields. Moreover, the area mentioned is in the same formation and lies in the strike directly between the eastern field and the Whittier field. It does not seem improbable, therefore, that oil-bearing strata underlie the area here considered, although no direct evidence, such as seepages and brea, are known in the vicinity.

Were the thick deposits of Pleistocene and late Fernando sediments that conceal the structure of the older beds in the Raphetto Hills removed, these hills might be found to offer a remunerative field for exploitation with the drill.

[a] Watts, W. L., Bull. California State Mining Bureau, No. 19, 1900, p. 73.

SOUTHWEST AND WEST OF LOS ANGELES.

It seems probable that the productive zone of the Salt Lake field extends northward and possibly a little westward from the territory now developed. Just where the northern limit is located is problematical, but it is quite certain that it is considerably south of the base of the Santa Monica Mountains. Within this northern extension the beds in general dip to the west, and for this reason the most productive area will doubtless be found west of La Brea road. East of this road the oil sands approach the surface and consequently yield smaller quantities and heavier oil than the same beds farther down the dip.

The region southeast of the Salt Lake flexure, as shown by several wells, does not appear to offer many inducements for exploitation, at least in the immediate vicinity of the Salt Lake field. Farther east, however, in the region west and southwest of Westlake Park, should deep wells strike a local flexure similar to that in the Salt Lake field they would doubtless yield large quantities of oil and gas. If the disturbance or fracture already mentioned as occurring in the vicinity of the lagoon does not have a northwestern extension, terminating the Salt Lake flexure and the productive zone on its northwestern flank, then it appears highly probable that deep wells will strike productive sand in the southern part of section 20 and the northern part of sections 29 and 30, T. 1 S., R. 14 W.

Outside of the territory mentioned in the preceding paragraphs there is little or no evidence of remunerative oil deposits in the immediate vicinity of Los Angeles. Were it not for the great thickness of Pleistocene sand and gravel, which cover the great Los Angeles Plain from the Santa Monica Mountains and Raphetto Hills to the ocean, it would be more than likely that productive territory could be developed over this plain. At least it is almost certain that the oil-bearing strata underlie it, but whether or not the structural conditions are at any place conducive to the accumulation of gas or oil in paying quantities can be determined only by costly exploitation with the drill.

PRODUCTION.

Owing to the large number of independent companies operating in the Los Angeles district, it has been impossible to obtain even approximately complete data concerning the annual production. However, the following figures derived from various sources are probably as nearly correct as any that are available:

Approximate production of petroleum in Los Angeles district, 1895 to 1905, inclusive.

Date.	Field.	Production.
		Barrels.
1895 [a]	Central	729,695
1896 [b]	.....do	900,000
1897 [c]	Largely from central	1,072,000
1898 [c]	About 50 per cent central, 50 per cent eastern	1,168,000
1899 [c]	43 per cent central, 30 per cent eastern, 27 per cent western	1,032,036
1900 [b]	Central, eastern, and western	1,500,000
1901 [b]	.....do	2,500,000
1902 [d]	Central, eastern, western, and Salt Lake	3,074,000
1903 [d]	.....do	2,468,000
1904 [e]	.....do	1,199,850
1905 [e]	.....do	2,672,349
		18,315,930

[a] Watts, W. L., Bull. California State Mining Bureau No. 19, 1897, p. 21.
[b] Estimated by the writer.
[c] Watts, W. L., Bull. California State Mining Bureau No. 19, 1900, p. 53.
[d] Estimate of central, eastern, and western fields by Charles A. Blackmar, city oil inspector; Salt Lake field estimated by the writer.
[e] Statistics compiled by division of mining and mineral resources, U. S. Geological Survey.

STORAGE.

The storage facilities of the eastern, central, and western fields are largely confined to wooden tanks in the producing territory. Many of these are small, so that as a rule the operators are unable to hold their product for any considerable length of time. The storage capacity of the refineries in the city is also small, few of the individual refineries having a capacity of over 25,000 barrels.

The storage capacity of the Salt Lake field, on the contrary, is about 390,000 barrels. Steel tanks, holding 20,000 to 55,000 barrels, are largely used in this field, although smaller wooden tanks are employed in a few instances.

TRANSPORTATION.

The oil from the city fields is in large part used locally, being delivered in tank wagons. No pipe lines of any great length exist in the city. The largest is the Union Oil Company's line, from First street and Lake Shore avenue, in the central field, to the Southern Pacific Railroad at Palmetto and San Mateo streets, a distance of about 4 miles.[a] An 8-inch pipe line connects the Salt Lake field directly with Los Angeles, and smaller lines run from some of the properties to tanks and racks on the line of the Los Angeles Pacific Electric Railroad immediately south of the fields.

[a] Watts, W. L., Bull. California State Mining Bureau No. 11, 1900, p. 169.

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PHYSICAL AND CHEMICAL PROPERTIES OF SOUTHERN CALIFORNIA OILS.

Compiled by Ralph Arnold.

INTRODUCTION.

The United States Geological Survey has done very little in determining the properties and composition of the California oils, and the information here given is compiled from published reports or the work of private individuals. By far the greater part of the analyses were made by members of the scientific staff of the California State Mining Bureau and are published in bulletins Nos. 3, 11, 19, 31, and 32 of that bureau. The writer is largely indebted for data to Messrs. W. L. Watts, Frederick Salathè, H. N. Cooper, and Paul W. Prutzman. (See bibliography for list of papers, etc.)

GENERAL CHARACTER OF THE SOUTHERN CALIFORNIA OILS.

GRAVITY.

The gravity of the oil from the wells in the Santa Clara Valley, Los Angeles, and Puente Hills districts varies from 10° to over 50° B. The heaviest oils are found in the Los Angeles field; the lightest oil is that from the unique wells in the gneiss of Placerita Canyon, east of Newhall. Certain wells in the Miocene shale of the Puente and Olinda fields (Puente Hills district) and the fields south of Sulphur and San Cayetano mountains (Santa Clara Valley district) yield oil of 30° to 35° gravity, while that in some of the wells in the Pico field (Santa Clara Valley district) is said to go as high as 40°. The greater part of the production from southern California, however, is oil varying from 18° to 24°.

COLOR.

The crude oils from these districts are mostly black or brownish in color. The exceptions are the white oil of the Placerita Canyon wells, Santa Clara Valley district, and the greenish, light-gravity oils of the Sulphur Mountain and Pico Canyon fields, Santa Clara Valley district, and the Puente and Olinda fields, Puente Hills district. Greenish oil is also reported in one or two other instances.

COMPOSITION.

The following table gives the ultimate chemical composition of two California oils and, for comparison, of oils from Pennsylvania, Ohio, West Virginia, and Texas:

Ultimate composition of various crude oils.

Locality.	Specific gravity.	Nearest degree, Baumé.	C.	H.	O.	N.	S.	By whom analyzed.
Oil Creek, Pa.[a]	0.730	62	82.0	14.8	3.2	....	......	Deville.
Ohio[b]	....	....	85.0	13.8	0.60		0.60	
West Virginia[a]	.840	36	84.3	14.1	1.6	....	......	Do.
Beaumont, Tex.[b]	....	....	85.03	12.30	0.92		1.75	
California[a]	....	....	86.934	11.817	......	1.1095	......	Peckham.
California[a] [c]	.912	23.5	84.0	12.7	1.2	1.7	0.4	Salathè.

[a] Watts, W. L., Bull. California State Mining Bureau, No. 19, 1900, p. 207.
[b] Jour. Soc. Chem. Ind., vol. 20, pp. 161 *et seq.*
[c] Mixture of Ventura County oils.

FUEL AND GAS MAKING.

Oil is now largely used as a fuel in California in many places where coal was formerly employed, and is, in a measure, supplanting that commodity. The railroads and those electric lines not using power developed by water use oil almost entirely for fuel purposes. The gas companies also use it for the manufacture of gas, smelters for the smelting of ores, foundries for the heating and melting of metals, and other manufactories for nearly every purpose requiring the generation of heat.

Following is an analysis of a typical gas-producing oil from the Murphy Oil Company's wells, Whittier district, and an analysis of the gas derived from it:[a]

Results of crude oil test, Murphy Oil Company.

Gravity at 60° F..................°B.. 20.5
Moisture and nonpetroleum substances.[b] .... None.
Flash point.[b]
Sulphur..................per cent.. 0.05
Residue (dry lampblack)..................do.... .01

Analysis of the gas produced from Murphy Oil Company's crude oil.

[Based on the Lowe process—18-candlepower gas; 1,800 B. T. U.]

Carbonic acid (CO_2)	None.	Marsh gas (CH_4)	41.8
Illuminants	11.2	Nitrogen (N)	2.8
Oxygen (O)	.4		
Carbonic oxide (CO)	3.4		99.6
Hydrogen (H)	40		

This gas gave over 600 British thermal units per cubic foot. It took 7.75 gallons of crude oil to produce 1,000 cubic feet of gas.

[a] Furnished by Mr. E. A. Bacon, of the Murphy Oil Company, Whittier.
[b] Oil stored in tank eight months. Flash point in oil coming directly from well, in five tests, 130°, 88°, 90°, 92°, 94°.

PRODUCTS OF REFINERIES.

Sixteen refineries use the oil from the three districts under discussion, and as the natural product varies in gravity from 10° to 35° or 40°, the resultant distillates are varied. The higher-grade oil produces gasoline, benzine, kerosene ("water white"), No. 1 and No. 2 distillates, stove distillate, and a residuum of fuel and road oil. The heavier oils, those under 21° or 22°, yield No. 1 and No. 2 distillates, stove distillate, lubricating, fuel, and road oils, with a residuum of asphalt.

The No. 1 and No. 2 distillates are used mostly in gas engines in many places for irrigation plants. No. 1 is suitable for engines under 15 horsepower; No. 2 is best suited to the larger engines. The stove distillate is used in hotels, bakeries, and similar places where the fluid is consumed without steam pressure, while the regular fuel oils are usually forced into the fire boxes by means of special pressure burners.[a]

The following is a list of the principal refinery products, together with the range in gravity of each:

Refined products of California petroleum. [b]

	° B.		° B.
Gasoline	68	Fuel distillate	28–24
Benzine	62	Neutral oils	24–22
Engine distillate	56–40	Light lubricants	24–20
Kerosene	44–40	Engine oils	20–18
Stove oil	35–32	Cylinder oils	18–15
Gas oil	30–28	Crude lubricants, car oil, etc	17–15

ANALYSES.

The following tables give, in a condensed form, the results of a large number of analyses and tests of oils from all the principal fields in the Santa Clara Valley, Los Angeles, and Puente Hills districts. The compiler wishes to reiterate the acknowledgment of his indebtedness to the California State Mining Bureau for the very free use he has made of its publications. The text of Bulletin No. 31[c] of that bureau, is here copied in its entirety to explain Table 1 which is a part of that bulletin.

If a sample of ore containing gold and silver is sent to an assayer he will doubtless report practically the same results as would another assayer who had used an entirely different method of assaying. The same is true of two chemists determining the quantity of sulphur in pyrites, etc. But in organic analysis two different methods may vary as much as 10 per cent, from which it is obvious that data on oil given without the methods by which or the apparatus in which they have been obtained are almost useless and can not be duplicated or proved correct by another chemist. For this

[a] See Prutzman, Paul W., Bull. California State Mining Bureau No. 32, 1904, pp. 58 et seq.
[b] Prutzman, Paul W., Bull. California State Mining Bureau No. 32, 1904, p. 187.
[c] By H. N. Cooper, 1904.

reason it is considered proper to give the following description of the methods by which the data in the above table were determined.

Specific gravity.—Two pycnometers were used, one holding 25 c. c. and the other 1½ c. c., the larger one for the light oils and the smaller for the heavy oils. Both were calibrated with pure distilled water and the water content calculated to 4°. A heavy oil may be introduced into either pycnometer by first filling a small beaker and allowing a very small drop to fall into the pycnometer. This drop will carry with it a thread of oil, which may be increased to a stream, and thus the pycnometer can be filled without getting any air bubbles mixed with the oil. If the oil once touches the side of the neck it is an interminable job to fill the instrument. It would be better to clean out with gasoline and start over again. If the oil is too thick to pour, as above, then use the little pycnometer, which is nothing more than a little bottle with a wide neck and a glass stopper carefully ground in. The little bottle is put next to the lip of the beaker containing the sample and the oil allowed to drain in. If the draining takes place slowly no air will get mixed with the oil. Then the stopper is slowly squeezed in, until by turning it, it grates on the ground glass of the bottle. The excess oil is wiped off with a rag, without undue handling of the bottle with the fingers. After weighing, the temperature is taken with an accurate thermometer and a correction of 0.0006 in specific gravity made for heavy oils and 0.0007 for light oils for each degree centigrade variation from 15°—15° being taken as normal.

Example: The little pycnometer full of sample No. 31 weighs 6.6195 at 18.5°.

6.6195 wt. of pycnometer and oil.
4.8413 wt. of pycnometer.

1.7782 wt. of oil in pycnometer.

1.7782 (wt. of oil) ÷ 1.8431 (wt. of water) = .9648.

.9648 + (3½ × .0006) = .9669 sp. g. of No. 31 at 15°.

This seems a long process, but it is quickly carried out. I made 16 specific-gravity determinations in four hours, or an average of 1 in fifteen minutes. An error in the specific gravity causes a corresponding error in the distillation and also in the calorific value per c. c., and too much care can not be taken in its determination. To take the gravity of heavy oils by the hydrometer is as long as this, and, moreover, very inaccurate. On first consideration it might seem that the specific gravity taken in a little bottle as small as 1.5 c. c. would be inaccurate, but I compared this with the 25 c. c. pycnometer and obtained results agreeing to 0.0001 in specific gravity, or practically identical.

Viscosity.—There are many viscometers, but none of them are ideal. Nevertheless, I could not invent one that would answer all requirements and expect the public to use it. It takes time to introduce a new idea or instrument. The Redwood viscometer seems to me to be the best now on the market, for the following reasons: It is the English standard; the tip is made of agate, and so will not wear out; the tip is surrounded by heavy brass, thus keeping the oil in the tip at approximately the same temperature as the oil in the cup.

In the above data the viscosity has been taken at two temperatures—at 15° C. (about 60° F.) and at 85° C. (185° F.). It was taken at 15° C. because this is generally taken as "ordinary temperature," and at 85° C. because it is impossible to heat the contents of the Redwood viscometer up to 100° C. (212° F.) with boiling water, so some lower temperature must be chosen. It is easy to heat the instrument up to 85° C. (185° F.), and, moreover, a pipe line may be heated to 85° C., but with great difficulty higher than this. Since our main object in finding the viscosity is to ascertain whether the oil can be piped without too great cost for pumping, the last consideration is important. To see whether it is practical to pass the oil through pipes 85° C. has been chosen.

It is customary to give the results in the number of seconds that it takes 50 c. c. to run through the instrument. To compare this with water (which runs through in 25 seconds) the results must be divided by 25. Through the instrument which I used water ran in 27½ seconds. Therefore I give two sets of results; one set consists of the number of seconds it took the oil to run through the instrument which I used; the other set, the same number of seconds divided by 27½. The data of the last set approximately tell how many more times viscous the oil is than water at 15° C. (about 60° F.). Just before the test is made the level of the oil is made even with the tip.

Flash-point.—Nothing can be more inaccurate than the open tester, since it may be manipulated at will to give results varying by 10°. The most accurate of the open testers is liable to great variations in its results from drafts of air. The Abel closed tester gives results which may be duplicated within 1° or 2°. It is the English standard, and with the Pensky attachment it is the German standard. It seems to be perfect in every respect for its purpose, i. e., for determining the flash from 60° F. to 160° F. (Why not adopt it as the standard for California?) If the instructions for opening the slide are carefully followed, the Pensky clockwork for opening the slide is not necessary; it was invented to do away entirely with any tampering with results. In making the above determinations of flash point the directions given in Redwood's Manual were followed exactly. Since the flash was taken with reference to safety in transportation, the test was not made on those samples flashing below 15° C. (60° F.) and above 70° C. (168° F.).

Calorific value.—All the determinations were made with the Atwater bomb. The thermometer used was a Beckman, graduated in one one-hundredths, whose accuracy I tested. The basis was the average between Berthelot's calorific values for cane sugar and naphthalene. I carefully determined the value of these two substances. The naphthalene used was made by De Häen, Germany; its boiling point was between 79° and 80°, and it was melted before using. The sugar was three times crystallized cane sugar, whose composition by organic combustion agreed with the theoretical by 0.03 on the H and 0.05 on the C; in other words, perfectly pure sugar. Before using, it was dried at 50° in the oven. My average of several results on sugar and naphthalene had to be increased by 1.08 per cent to make it the same as Berthelot's average for sugar and naphthalene, and all my results on petroleum are increased by the factor 1.0108, which is evidently the correction factor of the bomb calorimeter plus my personal equation. My results are certainly within 0.5 per cent of the absolute, and on repetition the duplicates agree within 0.3 per cent.

Samples Nos. 1, 2, 3, 4, 6, 7, 9, 10, 14, 17, 19, 25, 29, 38, 40, 41, 42, 43, 46, and 48 were taken from the top of the cans after the oil had stood for three or four months, and the calorific value found without preliminary treatment. Since Nos. 3, 4, 17, 29, and 40 had water present, the calorific value obtained for these was increased by the same number of per cent as the oil held water; in other words, the calorific value was calculated on the dry sample. All other calorific values that were made of samples containing water first had the water removed by distillation. The calorific value of an oil containing water is useless for most purposes unless the percentage of water is given also; for how can anyone get concordant results on a sample half water? (See sample No. 30.) Oil is bought by the gallon and not by the pound, and the column headed "Calorific value per c. c." gives the comparative value of the oils by volume.

Sulphur.—The sulphur was determined from the sulphuric acid left over from the combustion in the platinum cup. The cup or lining as well as the lid of the bomb was carefully washed into a beaker, the liquid filtered to about 100 c. c., $BaCl_2$ added, and the precipitated $BaSO_4$ weighed and the sulphur calculated. The gases of combustion I found to contain no sulphuric acid. (And of course no SO_2, since HNO_3 was present.) I passed the gases slowly through glass wool soaked in $\frac{N}{10}$ KOH, and found almost no consumption of the alkalinity of the KOH, showing that all the H_2SO_4 and HNO_3 stuck to the lining.

Distillation.—An ordinary ¼-liter glass distilling flask was used. The exit tube is bent upward for 2 inches just after leaving the neck of the flask; this is to facilitate filling and to intercept any liquid spurted out during the distillation. I do not give the measurements of the flask, because in California we have to take what we can get in the line of glassware. But if the flask holds 300 to 325 c. c. up to the bottom of the neck, the diameter of the neck is about one-fifth the diameter of the bulb, the exit tube joined to the neck halfway between the top of the bulb and the top of the neck, and the neck about one and one-half times as long as the diameter of the bulb, the flask will fulfill the requirements. To prevent condensation in the upward bend it is surrounded by fluffed asbestos fiber about half an inch thick. The exit tube should be 30 inches long from the top of the bend to the tip of the tube. The thermometer is placed so that the top of the bulb is level with the bottom of the exit tube. During the distillation up to the 250°–300° fraction the exit tube passes through a water condenser. After this fraction passes over the condenser is removed and the exit tube used as an air condenser.

The specific gravity of the sample is first determined; then the flask is placed on one pan and counterbalanced with shot. The balance must be accurate to 50 mg. with a 300-gram load. Enough oil is poured in to make a volume of 200 c. c. (calculated from the specific gravity) at the temperature of the room in which the distillation is to take place. The condenser is attached, the 50-c. c. graduated cylinder put under the tip of the exit tube, and the oil is cautiously heated until all the water is driven over. In making the fractional distillation I do not recommend putting in any measured amount of gasoline or other light-boiling liquid to drive off the water. I have never seen a sample that could not be fractionated in its original condition, if care and patience are used. The oil is then fractionated between the following temperatures: Up to 100°, 100°–150°, 150°–200°, 200°–250°, 250°–300°, 300°–asphalt, asphalt. The flame is so regulated as to cause the oil to distill over no faster than two drops per second. Just before the thermometer reaches the point where the distillation is to be stopped the flame is moderated to allow the thermometer to rise gradually to the stopping point. The flame is now removed to allow the temperature to fall, 20° for the 100° fraction, 100° for the 300° fraction, and a proportionate fall for the fractions in between, and then heated up again. This is repeated until no more than three drops can be squeezed over. The receiver is then changed and the next higher distillate run over. An exception must be made with the 250°–300° fraction, if much cracking takes place. With some oils very varying results may be obtained for the 250°–300° fraction, because every time the temperature goes up to 300° cracking takes place and more distillate passes over. In such cases I have arbitrarily stopped at 50 c. c. and made a note to that effect in the tables (the fraction is marked [*b*]), or else I have kept the temperature at 290° until the cracking had almost stopped. This last procedure is too long to be practical, and I recommend the former. The asphalt was run down to grade D. It was tested by running a looped wire down the neck of the distilling flask, drawing out a drop and testing it by chewing or by the finger nail. Of course, with such small quantities it does not make much difference in the results whether the asphalt is run down to grade C, D, or E. The asphalt is measured in this way: Fill the flask with water to a mark on the neck; pour out the water and save for future use. Dissolve the asphalt in waste lubricating oil (heat the flask over the flame) and remove the traces with gasoline and then with hot sulphuric acid and potassium bichromate. Dry, and pour back the water. Now run in water from a burette to the mark. The number of cubic centimeters run in represents the asphalt.

TABLE 1.—*Chemical analyses of southern California petroleum.*[a]

[By H. N. Cooper, chemist. All samples taken direct from pump by Marion Aubury, field assistant, California State Mining Bureau.]

No. of sample.	Name of company.	County.	Location.	Field.	Elevation.	Shipping station.	Address.	Number or name of well.	Formation.	Depth of well.	Daily yield.	Total amount produced.
	SANTA CLARA VALLEY DISTRICT.				*Feet.*					*Feet.*	*Bbls.*	*Bbls.*
1	Union Oil Co. of California.	Ventura	Rancho Ex-Mission	Adams Canyon		Santa Paula	Los Angeles	No. 27	Sand	2,745	35	
2	do	do	do	do		do	do	Green Oil Tunnel.	Sand and shale.			
3	do	do	do	Salt Marsh Canyon.		do	do	No. 11	Sand	520	100	
4	do	do	Sec. 12, T. 3 N., R. 20 W.	Bardsdale Canyon.		Ventura	do	Robinson No. 2	Red and white sand.	685	25	
5	Burrows & Sons	do	11 miles northwest of Santa Paula.	Wheeler Canyon	1,010	do	Santa Paula	No. 6	Sand	958	20	1,800
6	do	do	do	do	1,300	Santa Paula	do	Garrett Tunnel	do	640	3½	
7	Westlake-Rommell Oil Co.	do	Secs. 17 and 18, T. 4 N., R. 21 W.	Silver Thread	1,350	do	Los Angeles	Old No. 6	Sand and shale.	1,000	3-5	
8	Los Angeles Pacific Rwy. Co.	do	Sec. 16, T. 4 N., R. 21 W.	do	1,375	do	do	Capital Crude No. 20.	do	1,000	30	2,000
9	Whidden-Double	do	NW. ¼ sec. 12, T. 4 N., R. 22 W.	Ojai	1,450	do	Santa Paula	No. 4	Sand	284	16	2,000
10	Los Angeles Pacific Rwy. Co.	do	Sec. 18, T. 4 N., R. 20 W.	Timber Canyon	2,500	do	Los Angeles	Timber Canyon No. 3.	do	1,180	12	4,500
11	Union Oil Co. of California.	do	Sec. 6, T. 4 N., R. 19 W.	Little Sespe Canyon.	1,000	Ventura	do	No. 7	do	1,175	15	
12	Sulphur Mountain Petroleum Co.	do	15 miles northwest of Santa Paula.	Sulphur Mountain.	2,500		Fullerton	No. 1	do	2,150	18	300
13	Buckhorn Oil and Transportation Co.	do	Sec. 13, T. 4 N., R. 19 W.	Hopper Canyon	1,100	Buckhorn	Buckhorn	No. 15	Sand and shale.	950	20	
14	Union Oil Co. of California.	do		Torrey Canyon	1,650	Ventura and Santa Paula.	Los Angeles	No. 52	do	1,410	13	
15	Modelo Oil Co	do	Sec. 8, T. 4 N., R. 18 W.	Modelo Canyon	2,350	Piru	Piru	No. 22	Sand	1,100	15	
16	Santa Ana Oil Co	Los Angeles		Elsmere Canyon	1,500	Newhall	Santa Ana	Santa Ana No. 2	do	1,000	40	
17	Pearl Oil Co	do	Sec. 13, T. 4 S., R. 16 W.	San Fernando	1,500	do	Los Angeles	Pearl No. 2	Gravelly sand.	662	18	
18	Santa Ana Oil Co	do		Elsmere Canyon	1,300	do	Santa Ana	Santa No. 2	do	1,000	40	
19	Pacific Coast Oil Co	do	Sec. 2, T. 3 N., R. 17 W.	Pico Canyon	1,900	Ventura	Newhall	No. 4	Sand and shale.	1,400		

[a] Bull. California State Mining Bureau, No. 31, 1904.

TABLE 1.—*Chemical analyses of southern California petroleum*—Continued.

No. of sample.	Name of company.	County.	Location.	Field.	Elevation.	Shipping station.	Address.	Number or name of well.	Formation.	Depth of well.	Daily yield.	Total amount produced.
	SANTA CLARA VALLEY DISTRICT—cont'd.				*Feet.*					*Feet.*	*Bbls.*	*Bbls.*
20	Pacific Coast Oil Co	Los Angeles	Sec. 7, T. 3 N., R. 15 W.	Elsmere Canyon	1,400	Newhall	Los Angeles	No. 2	Sand and shale.	1,000	......	......
21	do	do	Sec. 16, T. 3 N., R. 16 W.	Wiley Canyon	1,700	Ventura	do	No. 6	do	750	......	......
	LOS ANGELES DISTRICT.											
22	I. W. Shirley	Los Angeles		Central	......	Los Angeles	Los Angeles	No. 12	Sand	1,340	10	......
23	Proudfit & Parker	do		Eastern	200	do	do	No. 2	do	1,225	20	......
24	Davis & Harrison	do		do	440	do	do	No. 10	do	1,275	10	8,000
25	do	do		do	440	do	do	Solano	do	950	4	6,000
26	M. Manley & Co	do		do	360	do	do	Saunders	do	1,035	3	20,000
27	West Lake Oil Co	do		Western	250	do	do	No. 7	do	370	1-3	15,000
28	Los Angeles Rwy. Co	do		do	250	do	do	Hubbel No. 2	Sand and shale.	1,250	10	10,950
29	Park Crude Oil Co	do		Central	425	do	do	No. 13	Sand	1,060	5	5,000
30	E. A. Clampitt	do		do	435	do	do	Clampitt No. 1	do	1,080	50	10,000
31	Consolidated Crude Oil Co.	do		Eastern	265	do	do	No. 21	do	800	4	......
32	Salt Lake Oil Co	do		Salt Lake	200	do	do	No. 4	do	1,284	40	......
33	La Brea Rancho Oil and Asphalt Co.	do		Western	200	do	do	No. 14	do	410	6	......
	PUENTE HILLS DISTRICT.											
34	Whittier-Fillmore Oil Co.	Los Angeles	SE. ¼ sec. 22, T. 2 S., R. 11 W.	Whittier	950	Whittier	Whittier	No. 1	Sand	2,300	65	......
35	Union Oil Co	do	Sansinena Ranch	La Habra	......		Los Angeles	No. 5	do	1,500	......	......
36	Puente Oil Co	do	T. 2 S., R. 11 W	Puente	1,200	Chino	do	No. 66	do	1,425	25	......
37	Home Oil Co	do	Sec. 22, T. 2 S., R. 11 W.	Whittier	900	Whittier	Whittier		do	1,713	40	5,000
38	Central Oil Co. of Los Angeles.	do	Sec. 23, T. 2 S., R. 11 W.	do	450	Los Nietos	Los Angeles		do	1,856	105	28,342
39	Columbia Oil and Producing Co.	Orange		Olinda	......	Olinda	do		do	680	25	......
40	Santa Fe	do	Sec. 8, T. 3 S., R. 19 W	do	535	do	Olinda		do	2,404	300	206,744
41	do	do	Sec. 9, T. 3 S., R. 9 W.	do	610	do	do	No. 39	Sand and shale.	1,705	90	4,473
42	Brea Canyon Oil Co	do		Brea Canyon	710	Norwalk	Los Angeles	No. 12	do	1,515	400	300,000

No. of sample.	Time operated.	Depth to oil sand.	Thickness of oil sand.	Pipe line.	Gravity.	Specific gravity of crude at 15° C. (about 60° F.).	Flash.	Viscosity. At 15° C. (about 60° F.). Seconds.	Viscosity. At 15° C. (about 60° F.). Seconds divided by 27½ or water=1.	Viscosity. At 85° C. (185° F.). Seconds.	Viscosity. At 85° C. (185° F.). Seconds divided by 27½ or water=1.	Sulphur.	Calorific value of dry sample. (To convert calories into British thermal units multiply by 1.8.)	Calorific value per cubic centimeter.
		Feet.	*Feet.*		° *B.*		°					*Per cent.*		
1	Since Sept. 9, 1891	600		10 miles	28.9	0.8814	−15	162½	5.91	37	1.34	0.48	10,647	9,384
2	15 years				20.1	.9326	68	247	8.95	38½	1.40	.32	10,604	9,889
3	Since May 14, 1897	48		10 miles	19.7	.9351	−15	878	31.82	55	1.98			
4	11 years	525	160	30 miles	27.6	.8881	−15	205	7.43	41⅖	1.51	1.74	10,484	9,310
5	Since Mar. 11, 1903	500	4–50	27 miles	29.7	.8767	−15	77	2.79	34⅕	1.24	.72	10,645	9,332
6	18 years	90, 200		do	28.6	.8828	29	53	1.92	31⅗	1.15			
7	35 years	600	80, 100, 105											
8	Since Sept., 1902	400–500	100, 200	7 miles	27.3	.8900	−15	61⅗	2.23	34½	1.24			
9	Since Aug., 1900	240		2½ miles	13.4	.9759	56	+1,800	+65	252	9.13	1.48	9,112	8,892
10	18 months	860, 1,100	60	7 miles	35.1	.8481	−15	45⅘	1.66	31⅕	1.13			
11	5 years	1,010	165	30 miles	30.9	.8701	−15	77	2.79	45⅘	1.66			
12	Since Apr. 27, 1903	1,975		No line	17.6	.9486	−15	2,240	81.15	73	2.65	1.46	10,306	9,776
13	3 years	80	10–50	2½ miles	14.6	.9685	+70	+1,800	+65	116	4.20			
14	do	900	510	30 miles	29.9	.8758	−15	103	3.73	38	1.38	.71	10,611	9,293
15	Since July, 1902	600	100	4 miles	28.4	.8838	−15	63	2.28	34	1.23			
16	2 years	930	60–120	2½ miles to Newhall	11.7	.9879	+70	+1,800	+65	131	4.75	.69	10,267	10,139
17	1 year	600	35		17.8	.9474	35½	1,335	48.37	58	2.10	.49	10,461	9,911
18	2 years	930	60–120	2½ miles to Newhall	14.5	.9687	+70	+1,800	+65	131	4.75	.72	10,368	10,044
19				45 miles	37.3	.8367	−15	38½	1.40	29½	1.07	.28	11,141	9,322
20	10 years			1½ miles	14.8	.9666	+70	+1,800	+65	114	4.13	.62	10,389	10,042
21				50 miles	29.9	.8758	−15	61	2.21	33½	1.22			
22	7 years	1,000	340	30 miles	16.5	.9559	+70	+1,800	+65	78	2.83	.85	10,437	9,976
23	1 year	750	10–100	No line	14.3	.9699	+70	+1,800	+65	130	4.71			
24	5 years	800	10–75	do	13.2	.9774	+70	+1,800	+65	330	11.96	.49	10,091	9,863
25	do	800	100	do	17.9	.9467	+70	1,700	61.59	55	1.99			
26	9 years	900	200	Union pipe line								a .74	b 9,016	
27	4 years	315	55	No line	12	.9860	+70	+1,800	+65	540	19.57			
28	3 years	800	10–20	do	16.5	.9558	+70	+1,800	+65	72	2.61			
29	do	750	1–20	do	14.2	.9706	+70	+1,800	+65	122	4.42	1.18	10,346	10,073
30	2 years	800	80	60 feet to Union line	13.8	.9736	+70	+1,800	+65	149	5.40	1.30	9,920	9,377
31	6 years	750	30–60	No line	12.6	.9815	+70	+1,800	+65	505	18.30			
32	Since Feb. 8, 1892	1,170	40	do	17.6	.9487	−15	2,170	78.63	78	2.83			
33	1 month	305	75	do	10	1.0100	+70	+1,800	+65	±2,700	±97.83			
34	5 months	1,700	20–150	do	14.8	.9669	+70	+1,800	+65	122	4.42	.93	10,409	10,064
35	5 years	1,300	200	Line to San Pedro	15	.9656	67	+1,800	+65	143	5.18			

a Not accurate.

TABLE 1.—*Chemical analyses of southern California petroleum*—Continued.

No. of sample.	Time operated.	Depth to oil sand.	Thickness of oil sand.	Pipe line.	Gravity.	Specific gravity of crude at 15° C. (about 60° F.).	Flash.	Viscosity. At 15° C. (about 60° F.). Seconds.	Viscosity. At 15° C. (about 60° F.). Seconds divided by 27½ or water=1.	Viscosity. At 85° C. (185° F.). Seconds.	Viscosity. At 85° C. (185° F.). Seconds divided by 27½ or water=1.	Sulphur.	Calorific value of dry sample. (To convert calories into British thermal units multiply by 1.8.)	Calorific value per cubic centimeter.
		Feet.	*Feet.*		° *B.*		°					*Per cent.*		
36	1 year		5-15	18 miles to Chino	29.5	.8775	−15	66½	2.35	34	1.23	0.36	10,699	9,389
37	3 months	675		2½ miles to Whittier	20.7	.9291	26	393	14.24	43	1.56			
38	9 months	1,636	220	4½ miles	21.9	.9215	17	325	11.78	42	1.52			
39	Since Feb., 1903	450	230	Union line to San Pedro.	19.3	.9378	−15	1,020	36.96	59½	2.16			
40	Since Mar. 4, 1902		720	No line	19	.9399	44	1,790	64.85	71	2.57	1.09	10,441	9,813
41	Since May 23, 1903	1,648	57	Olinda Union line	34	.8536	−15	45½	1.61	32½	1.18	.41	10,777	9,200
42	Since Jan. 18, 1902	950	30-133		23	.9147	−15	264	9.56	41½	1.50	.94	10,581	9,678

Distillation.

No. of sample.	Percentage. Water.	Percentage. Up to 100° C.	Percentage. 100°-150° C.	Percentage. 150°-200° C.	Percentage. 200°-250° C.	Percentage. 250°-300° C.	Percentage. 300° C. to asphalt. A.	Percentage. 300° C. to asphalt. B.	Percentage. Asphalt.	Percentage. Loss or gain.	Specific gravity of preceding fractions at 15° C. (about 60° F.). Up to 100° C.	Sp. gr. 100°-150° C.	Sp. gr. 150°-200° C.	Sp. gr. 200°-250° C.	Sp. gr. 250°-300° C.	Sp. gr. 300° C. to asphalt. A.	Sp. gr. 300° C. to asphalt. B.
1	None.	4	14.1	9.1	9.3	10.1	43		9.8	−0.6	0.7250	0.7736	0.8111	0.8388	0.8547	0.8778	
2	Trace.	0	.8	7.8	16.3	17.4	40		16.6	−1.1			.8083	.8368	.8718	.9013	
3	None.	1.4	8.7	8.3	8.7	8.9	40.1		20.7	−3.2	.7236	.7625	.8103	.8578	.8964	.9156	
4	None.	8.9	10.6	8.7	7.3	15.5	29		16.9	−3.1	.7039	.7611	.8013	.8340	.8631	.8778	
5	None.	12.8	13.8	9.9	7.7	9.8	30		14.8	−1.2	.6986	.7601	.7999	.8466	.8830	.8920	
6	None.	0	12.3	16.6	14.3	13.7	37.3		6.2	+ .4		.7798	.8129	.8460	.8787	.9014	
7																	
8	None.	9.3	16.5	11.8	7.7	9.1	31.8		13	− .8	.7228	.7724	.8202	.8613	.8901	.9154	
9	None.	0	0	6	6.1	18.9	30.8		38.1	− .1			.8102	.8510	.8820	.8925	
10	None.	15.3	15	9.5	9.9	9.9	28		10.6	−1.8	.7002	.7639	.8015	.8321	.8624	.8875	
11	None.	9.3	10.2	9.8	8.8	11.4	34.9		13.2	−2.4	.7057	.7623	.7998	.8285	.8570	.8769	
12	.8	3.1	4.8	8.1	7.4	[a] 28.8	20		25	−2	.7345	.7725	.8178	.8620	.8870	.9302	
13	9.3	0	0	5.9	15.3	6	23.7	16.7	23	− .1			.8607	.8888		.9156	0.9307

[a] Much cracking on reheating; percentage taken arbitrarily.

14	None.	8.3	10.4	9.1	8.8	10.2	23.9	9.8	16.6	−2.9	.7044	.7674	.8038	.8316	.8554	.8740	.8672
15	None.	7.7	15.6	10.7	10.8	14	15.3	8.9	16.6	− .4	.7119	.7722	.8126	.8493	.8827	.9066	.8644
16	4.2	0	0	0	12.8	16.8	37	6.7	22.6	+ .1				.8611	.8973	.9198	.8933
17	None.	0	1.2	8	11.2	*a* 21	24	10.8	22.7	−1.1		.7790	.8170	.8618	.8989	.9246	.9087
18	3.5	0	0	0	11.5	12.2	36.5	6.8	28.3	−1.2				.8561	.8962	.9137	.9008
19	None.	10.5	20.4	13.8	13	11.1	16.9	6.8	6.8	− .7	.7472	.7659	.8040	.8359	.8606	.8870	.8720
20	6.1	0	0	0	11.5	*a* 22.7	32.1	2.5	22.6	−2.5				.8512	.8970	.9091	.8913
21	None.	2.9	17.4	10.3	10.3	13.5	20.8	9.5	10.9	−4.4	.7297	.7751	.8127	.8409	.8662	.8852	.8929
22	.8	0	0	0	7.6	13.9	40	14.5	21.8	−1.4				.8625	.8849	.9021	.9053
23	.2	0	0	0	4	13.9	42.8	8.3	28.8	−2				.8741	.8908	.9087	.8957
24	30	0	0	0		12	30.5	5.8	19.8	−1.9					.8912	.9078	.9139
25	.2	0	0	0	6.6	17.5	47.8	9.8	17.3	− .8				.8568	.8855	.9099	.9094
26																	
27	35.7	0	0	0	0	18.6	20.1	2.3	21.3	−2					.9029	.9165	.9175
28	.5	0	0	0	9.7	15.8	43.4	8.2	21.5	− .9				.8642	.8930	.9082	.9049
29	1.6	0	0	0	6.9	19.4	39.7	4.5	25.3	−2.6				.8631	.8931	.9200	.9160
30	3	0	0	0	5.9	14.1	47.2		28.8	−1				.8637	.8876	.9026	
31	44.6	0	0	0	4.6	7.7	16.1	9.7	16.2	−1.1				.8642	.8951	.9032	.9177
32	None.	2.9	7.9	7.4	7.8	17	18.2	11.5	26.8	− .5	.7247	.7650	.8175	.8804	.8903	.9051	.8905
33	5	0	0	0	3.7	*a* 24.1	20.9		44.2	−2.1				.8648	.8882	.9240	
34	2.3	0	0	0	9.1	19.5	37.6	3.8	26.5	1.2				.8546	.8968	.9180	.9119
35	.2	0	0	5.2	11.6	*a* 25.1	28.5		28.4	1			.8197	.8648	.8915	.8910	
36	None.	8	15.4	9	10.1	14	23.1	5.7	13.1	1.6	.7265	.7720	.8155	.8413	.8648	.8862	.8837
37	None.	0	4.2	9.6	14	14.7	23	16.8	15.7	2		.7756	.8313	.8672	.8991	.9210	.9166
38	None.	0	6.9	8.8	12	11.9	33.2	6.2	20.6	.4		.7760	.8363	.8557	.8848	.8996	.8796
39	None.	1.9	6.2	9.2	8.1	17.3	27.4	3.8	25.8	.3	.7004	.7627	.8204	.8622	.8876	.9015	.8977
40	1.3	0	0	11.2	10.5	15.5	28.3	9.9	23.1	.2			.8113	.8551	.8850	.8857	.9001
41	None.	12.9	15.3	11.5	11.1	9.6	19.5	6.5	11	2.6	.7239	.7645	.8044	.8401	.8713	.8955	.8984
42	None.	4.2	13.9	8.9	9.7	18.3	24.2	5	13.3	2.5	.7252	.7701	.8172	.8597	.8937	.8955	.9062

a Much cracking on reheating; percentage taken arbitrarily.

TABLE. 2.—*Proximate analyses of Southern California crude oils.*[a]

[By Paul W. Prutzman.]

No. of sample.	Field.	County.	Section.	Township.	Range.	Taken from—	Gravity (° B.).	Distillation.					
								Below 150° C.		150° C. to 270° C.		Above 270° C.	
								Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).
	SANTA CLARA VALLEY DISTRICT.												
1	Elsmere	Los Angeles	13	3 N.	16 W.	Tank	17.2	0	.....	21.9	36.9	50.2	25.5
2	Placerita	do	4	3 N.	15 W.	Well	42.7	51	48.8	43	38	4	.....
3	Ojai	Ventura	11	4 N.	22 W.	Tank	11.8	0	.....	0	.....	56.6	24.7
4	Torrey	do				do	22.6	0	.....	30	38.8	53.2	.....
5	do	do				Well	23.9	7.2	54	26.7	38	38.9	.....
6	Santa Paula	do				do	25.2	12.5	53.7	25.5	37.6	50.2	23
7		do				Pipe line	25.6	10	58.5	24	41.5	38	29.8
8	Santa Paula	do				Well	26.	10	56	27	38.8	44	.....
9	Modelo	do	8	4 N.	18 W.	Tank	26.6	13.8	59.4	32.4	40.8	38.9	.....
10	Santa Paula	do				Well	26.8	13	54	26.5	39	45.9	.....
11	Silver Thread	do	17	4 N.	21 W.	Tank	27.4	19.4	59.2	26.1	40.1	35.2	.....
12	Bardsdale	do	12	3 N.	20 W.	Well	28.	13	61.6	20.5	43.4	40	.....
13	Torrey	do				do	28.1	16.6	53.7	23.6	39.8	35.7	.....
	LOS ANGELES DISTRICT.												
14	Los Angeles	Los Angeles				Well	15.1	0	.....	20	30.2	63.7	23
15	do	do				do	15.7	0	.....	17.2	30.2	54.1	.....
	PUENTE HILLS DISTRICT.												
16	Olinda	Orange	8	3 S.	9 W.	Well	15.9	1	.....	14	36.8	41	.....
17	do	do	8	3 S.	9 W.	Tank	20.3	Tr.	.....	23	41.2	42.9	.....
18	do	do	8	3 S.	9 W.	Well	20.5	3.4	55.8	18.8	39.3	47.6	25.5
19	Brea Canyon	do	1	3 S.	10 W.	do	23.3	10.5	57	25.5	39.9	31.4	.....
20	do	do	9	3 S.	9 W.	do	32.4	21.7	59.1	25.8	41.5	41 8	24.7
21	Olinda	do	9	3 S.	9 W.	do	32.8	23.8	59.6	27.7	40.7	31.2	.....
22	do	do	9	3 S.	9 W.	do	33.	24.8	60.9	27.6	42.8	31.4	.....
23	do	do	9	3 S.	9 W.	do	33.4	22.1	60.9	30.8	41.3	37.6	.....
24	do	do	9	3 S.	9 W.	do	34.5	22.9	62.1	27.9	43	33.4	26.5
25	Puente	Los Angeles	35	2 S.	10 W.	do	26.8	10.5	59.2	28	43.6	33	.....
26	do	do	35	2 S.	10 W.	do	26.8	12.5	58.8	29	42.4	33	27.3
27	do	do	35	2 S.	10 W.	do	29.1	21	58.2	24	41.4	30.9	.....
28	Whittier	do	26	2 S.	11 W.	do	20.4	0	.....	23.4	38.1	45.3	.....
29	do	do	26	2 S.	11 W.	do	21.	2.1	55	23.9	38.2	48.4	22.6
30	do	do	26	2 S.	11 W.	do	23.1	5.2	55	27.3	38.4	44.7	.....
31	do	do	26	2 S.	11 W.	do	23.2	4.7	57.3	24	39.3	46.9	24.5

[a] Bull. California State Mining Bureau, No. 32, 1904, Table 25, opp. p. 198.

TABLE 2.—*Proximate analyses of Southern California crude oils.*

[By Paul W. Prutzman.]

Distillation.			Calculated analysis.														
Asphalt.			Total gasoline.		Kerosene.		Middlings.		Lubricants.			Asphalt.				Remarks.	No. of sample.
Per cent.	Grade.	Loss (per cent).	Per cent.	Gravity (° B).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B).	Per cent.	Gravity (° B.).	Middlings and lubricants (per cent).	Per cent volume.	Per cent weight.	Pounds per barrel.	Loss (per cent).		
25.9	D	2	0.5	....	12.1	40	23.8	.....	35.7	.....	.....	25.9	28.6	94.9	2	....	1
0	....	2	52.3	49	25.8	40	19.9	.....	0	.....	.....	0	.....	......	2	White oil.	2
41.7	D	1.7	0	....	0	....	24.3	34.1	32.3	17.5	.....	41.7	44.4	153.1	1.7	....	3
15.4	D	1.4	1.5	54	19.5	41	.....	.....	.....	.....	62.2	15.4	18.1	56.4	1.4	....	4
25.5	D	1.7	8	54	16	41	.....	.....	.....	.....	48.8	25.5	29.5	93.6	1.7	....	5
11.8	D	0	13.3	53	15.3	41	24.5	.....	35.1	.....	.....	11.8	13.7	43.2	0	Green oil.	6
25.3	D	2.7	12.4	57	19.2	42	21.4	.....	19	.....	.....	25.3	29.5	92.9	2.7	....	7
16	D	3	11.4	55	17.5	41	.....	.....	.....	.....	52.1	16	18.8	59	3	....	8
12.9	C	2	16.4	59	24.3	42	.....	.....	.....	.....	44.4	12.9	15.2	47.4	2	....	9
11.1	D	3.5	14.3	53	17.2	41	.....	.....	.....	.....	53.9	11.1	13.1	40.8	3.5	Greenish oil.	10
18.8	D	.5	21.2	58	18.3	42	.....	.....	.....	.....	41.2	18.8	22.1	69	.5	....	11
25.6	D	.9	15	60	18.5	42	.....	.....	.....	.....	40	25.6	29.1	92.1	.9	....	12
21.1	D	3	18.3	54	16.5	42	.....	.....	.....	.....	41.1	21.1	25.1	77.7	3	....	13
13.3	B	3	0	....	4	40	37.2	31.8	42.5	18.7	.....	13.3	13.8	46.7	3	Greenish oil.	14
25.7	D	3	0	....	3	40	.....	.....	.....	.....	68.3	25.7	28.1	93.9	3	....	15
42	D	2	1.2	....	7.7	40	.....	.....	.....	.....	47.1	42	45.9	154.3	2	....	16
32.1	D	2	1.8	55	17.9	42	.....	.....	.....	.....	46.2	32.1	36.1	117.9	2	....	17
25.9	E	4.3	4.4	54	12.3	41	18.4	34	34.7	20.9	.....	25.9	29.2	95.1	4.3	....	19
31.6	D	1	12.3	56	17.8	42	.....	.....	.....	.....	37.3	31.6	36.3	116.2	1	....	18
9	D	1.7	24.3	58	20.6	42	15.4	33.7	29	21	.....	9	10.7	32.3	1.7	....	20
16.7	D	.6	26	59	20.8	42	.....	.....	.....	.....	35.9	16.7	20.5	61.7	.6	....	21
15.6	D	.6	27.6	60	24.8	42	.....	.....	.....	.....	31.4	15.6	18.1	57.3	.6	....	22
8	D	1.5	24.6	60	23.1	42	.....	.....	.....	.....	42.8	8	9.6	29	1.5	....	23
12.9	D	2.9	25.7	61	25.1	42	12.1	32.7	21.3	23	.....	12.9	16	49	2.9	....	24
26	D	2.5	13.3	58	25.2	42	.....	.....	.....	.....	33	26	30.7	95.7	2.5	....	25
24	F	1.5	15.4	58	24.7	42	16.4	32.5	18	22.3	.....	24	28.5	88.2	1.5	Mixture from four wells.	26
22.1	D	2	22.9	58	17	42	.....	.....	.....	.....	36	22.1	26.3	81.4	2	....	27
27.3	D	4	.7	....	14	41	.....	.....	.....	.....	54	27.3	30.8	100.2	4	....	28
21.4	D	4.2	2.8	54	14.4	41	23.1	31.8	34.1	18.6	.....	21.4	24.2	78.4	4.2	....	29
20.2	D	2.6	6	55	16.4	41	.....	.....	.....	.....	54.8	20.2	23.2	74.3	2.6	....	30
19.7	E	4.7	5.9	56	15.6	41	20.6	33.2	33.5	19.5	.....	19.7	22.6	72.3	4.7	....	31

TABLE 3.—*Distillation tests of southern California crude oils.*[a]

[By W. L. Watts.]

No. of sample.	Well.	Gravity of crude oil (° B.).	Naphtha.						Illuminating oil.				Lubricating oil.			
			100° C.		125° C.		150° C.		200° C.		250° C.		300° C.		350° C.	
			Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (°B.).	Per cent.	Gravity (° B.).
	SANTA CLARA VALLEY DISTRICT.															
1	Tar Creek........	23	......	....	......	....	7.6	60	11	55	10.4	41	12.4	34	6	29
2	.....do............	23	......	....	......	....	8.4	63	8	58	10.4	45	14.2	33	4	....
3	Fourfork.........	22	......	....	......	....	Tr.	....	6.9	52	16.8	45	9.7	38	6.6	33
4	Kentuck..........	25	......	....	......	....	6	64	8.6	54	10	44	12.2	36	2.5	32
5	Pico Canyon No. 4	40	9.1	69	10.4	59	9.3	54	13.4	48	13.9	41	8.3	35	......	....
	LOS ANGELES DISTRICT.															
6	Central field......	17	......	....	......	....	Tr.	....	Tr.	....	8	38	13.6	32	3	....
7	.....do............	17	......	....	......	....	Tr.	....	Tr.	....	7	38	15.3	29	7.1	27
8	.....do............	17	......	....	......	....	Tr.	....	Tr.	....	6	39	16.8	31	8	27
9	.....do............	17	......	....	......	....	Tr.	....	Tr.	....	9.6	40	17.6	36	5	27
10	.....do............	17	......	....	......	....	Tr.	....	Tr.	....	8	42	12	32	4	....
11	.....do............	16	......	....	......	....	Tr.	....	Tr.	....	1.6	....	11.4	32	3.4	....
12	.....do............	16	......	....	......	....	Tr.	....	Tr.	....	2.2	....	11.2	30	7	29
13	Macintosh........	13	......	....	......	....	Tr.	....	Tr.	....	Tr.	....	1.6	....	4.4	....
14	Maltman.........	14	......	....	......	....	......	....	......	....	1	....	8	31	9.6	....
	PUENTE HILLS DISTRICT.															
15	Puente...........	23	......	....	......	....	Tr.	....	15.9	52	10.8	45	9.3	35	2.9	33
16	.....do............	28	......	....	......	....	10.2	61	13.5	55	12.2	43	10.2	36	8.3	34

[a] Bull. California State Mining Bureau No. 19, 1900, pp. 203–205.

TABLE 4.—*Distillation tests of southern California crude oils.*

No. of sample.	Source of sample.	Gravity of crude oil (° B.).	Specific gravity of crude oil at 60° F.	Gasoline (68° B.).		Naphtha or benzine (62° B.).		Engine distillate (56°–40° B.).		Kerosene (44°–40° B.).		Stove oil (35°–32° B.).		Gas oil (30°–28° B.).		Fuel distillate (28°–24° B.).		Lubricants (24°–15° B.).		Asphalt, foreign matter, and loss.
				Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.	Gravity (° B.).	Per cent.
	SANTA CLARA VALLEY DISTRICT.																			
1	Happy Thought wells, Sespe field	26.2								20		12.18		24.48		19.38				22.95
2	do	26.2		5	66			7	50	12				59						17
3	Sespe field	19.8						6	50			4		55				9		22
4	do	25.2	0.9022			7.3	60			19.5	42			25	28			35.8	24	12.4
5	Fourfork wells, Sespe field	24	.9090			6	60			17.1	42			29.5	28			34.4	24	13
6	Torrey Canyon	27	.8917			9.2	60			21.5	42			26	28			30.3	24	13
7	Eureka Canyon	29	.8805			14.1	60			26.4	42			24	28			27	24	8.5
8	Adams Canyon, Sulphur Mountain field[a]	24	.9090			5.2	60			24.5	42			17.3	28			46	24	7
9	Ventura County, pipe-line average	26		10.4	63					28	42.5			16.1	28			20.3	23	25.2
10	do	25.2						14.5	55	13.8	42	14.4	33			22.8	26	16.	21	18.5
	LOS ANGELES DISTRICT.																			
11	Central field	14.3										8.1	35			9.9		42.2		39.7
12	do	14.2	.9708			Tr.				6	42			17.5	28			51.5	24	25
13	Salt Lake field	19						11		7		8		29				10		35
14	do	21		4				9		8		7		34				10		28
	PUENTE HILLS DISTRICT.																			
15	Murphy Oil Co.'s wells, Whittier field	21						3.8	59	13.5	43.5	45	33							
16	do	21						4.5	50	8.7	45	8.9	35			57.1	22–26			20
17	Puente lease, Olinda field	32		8				19.5		12		21.5						29		10

[a] Greenish oil.

1, 2. Furnished by Mr. Herbert Mills, secretary Happy Thought Oil Company, 123 California street, San Francisco.
3, 11, 13, 14, 15, 17. Furnished by Mr. James Jordan, Union Consolidated Refining Company, Los Angeles.
4, 5, 6, 7, 8, 12. Salathè, Frederick, Bull. California State Mining Bureau No. 11, 1897, p. 76.
9, 10. Prutzman, Paul W., Bull. California State Mining Bureau No. 32, 1904, p. 193.

TABLE 5.—*California oil refineries using southern California crude oil.*[a]

Company.	Location of plant.	County.	Still capacity for crude.	Still capacity for rerunning.	Number of stills.	Principal source of crude used.	Products made.
			Barrels.	*Barrels.*			
American Oil and Asphalt Co	Los Angeles	Los Angeles	1,075	0	5	Los Angeles	Distillate and asphalt.
Asphalt and Oil Refining Co	do	do	500	250	5	Fullerton and Coalinga	Light.
British-California Refining Co	do	do	200	200	2	Whittier	Light, distillate, and asphalt.
Coombs Refining Co	do	do	150	150	2		Light, lubricants, and asphalt.
Densmore-Stabler Refining Co	do	do	600	100	5	Various	Do.
Hercules Oil Refining Co	do	do	1,000	1,000	6	Whittier	Do.
Meriden Oil Co	do	do	100	100	2	Los Angeles	Lubricants and asphalt.
New Franklin Oil and Refining Co	do	do	500	135	6	do	Distillate, lubricants, and asphalt.
Pacific Coast Oil Co	Point Richmond	Contra Costa	[b] 5,000	[b] 4,000	[b] 19	Ventura, Newhall, and Coalinga.	Light, lubricants, and coke.
Pacific Oil Refinery	Los Angeles	Los Angeles	30	10	2		Light, lubricants, and asphalt.
Puente Oil Co	Chino	San Bernardino	600	100	5	Puente	Light.
Southern Refining Co	Los Angeles	Los Angeles	500	250	4	Whittier	Light, lubricants, and asphalt.
Sunset Oil Refining Co	Obispo	do	2,400	2,000	16	Whittier and Ventura	Light.
Texas and California Refining Co	Los Angeles	do	450	0	2	Los Angeles	Distillate and asphalt.
Union Consolidated Refining Co	do	do	800	350	6		Light, lubricants, and asphalt.
Union Oil Co	Oleum	Contra Costa	([c])			Ventura, etc	Light, distillate, and asphalt.

[a] Prutzman, Paul W., Bull. California State Mining Bureau, No. 32, 1904, opp. p. 208.
[b] Figures doubtful. Owners refused information.
[c] Owners refused information.

FOSSILS OF THE OIL-BEARING FORMATIONS OF SOUTHERN CALIFORNIA.

By Ralph Arnold.

INTRODUCTION.

Many of the oil-bearing rocks of southern California contain the fossil remains of living organisms such as plants, foraminifera, sea urchins or echinoderms, marine and fresh-water mollusks, crabs, fish, and some of the higher vertebrates. The marine mollusks, owing to their peculiar composition and habitat, are relatively much more liable to be preserved in the rocks than the individuals of most of the other groups, and, as a consequence, they are the most abundant of the organic remains, and therefore the most useful for purposes of correlation, not only in this region, but in all regions abounding in marine sediments.

A fossil may be the more or less altered remains of the plant or animal; it may be the empty mold from which all of the original material of the organism has been removed; or it may be the cast of the original form in hardened silt, sand, or some crystallized mineral which has replaced the organism.

It is well known that associations of species (fauna or flora) are governed by two important factors—one of time and the other of environment. The fossil fauna of any formation, unless it be an unusually thick one requiring a very long time for its deposition, is generally fairly constant throughout for rocks of similar lithologic character, owing to the fact that faunas living at approximately the same time, under similar conditions, and in the same general region or biologic province are closely related or nearly identical. Conversely the faunas of the different kinds of rocks in the same formation and even of the same kind of rock in two different formations are always more or less distinct. As the different marine sediments reflect the varying conditions of their deposition, so the faunas reflect their environment; fossils are usually found in a matrix whose deposition was governed by the conditions forming the environment of the fossils. Thus a deep-water fauna is usually found in shale or limestone, a shallow-water or littoral fauna in sandstone or gravel, and so on. Coarse conglomerates, owing to the disturbed conditions surrounding their deposition, rarely contain recognizable fossils.

It follows, then, that similar faunas from two or more different outcrops indicate in a general way the contemporaneity and similarity of conditions of deposition of the beds; that is, they indicate the same horizon or formation. The converse of this statement, however, is not always true, for it often happens, for example, that the shale fauna of one formation bears a stronger affinity to the shale fauna of a second formation either above or below it than to the fauna of contemporaneous sandstone or conglomerate within its own formation.

Some faunas are characterized by the predominance of one or more families or broader groups; some only by the occurrence or abundance of certain species. Analogous to the formations which contain them, certain faunas are distinctly isolated from others of the same region. A formation having an isolated, unique, or so-called characteristic fauna is the most easily identified and correlated, as the determination of only a few of its species often suffices to locate it definitely. The correlation of those rocks whose fauna is not so distinctly separated from the fauna of stratigraphically adjacent formations is much more difficult and generally requires some special training along paleontologic lines. Fortunately most of the formations in southern California contain fairly characteristic faunas, so that with a sufficient amount of identifiable material from any given stratum its correlation, or the determination of its relative position in the stratigraphic column, may be readily approximated.

It is a well-known fact that the only way to determine the relative position or age of any bed in a series where the rocks of the different formations are so much alike and the structure so complex as in the southern California oil districts is by a determination of its fossil contents. Ordinarily lists of fossils are absolutely meaningless except to the few who have devoted at least a little time to the study of paleontology. But when these lists are supplemented by the figures of the species named it is an easy matter for anyone to find out for what each name really stands. The following plates are given to add meaning to the lists of fossils included in the text. The species figured do not represent all of those found in the oil-bearing formations of southern California, but rather those which are commonly found in or are characteristic of the principal formations there developed. It is thought that by means of these figures anyone will be able to locate approximately any bed in the geologic column if he can obtain from it a few recognizable fossils.

The fossils are arranged on the plates in the order of the occurrence of the rocks containing them, beginning with the oldest, the Eocene.

PLATES.

PLATE XXV.

EOCENE PELECYPODA.

(All figures natural size.)

FIG. 1. *Venericardia planicosta* Lamarck. U.S.N.M. 164973. Left valve; longitude 84 mm. Eocene, Little Falls, Wash. This is the most widespread and characteristic Eocene species in the world. Found in the Sespe and Silver Thread districts, Ventura County.

FIG. 1*a*. Same specimen as fig. 1. View of anterior end of both valves.

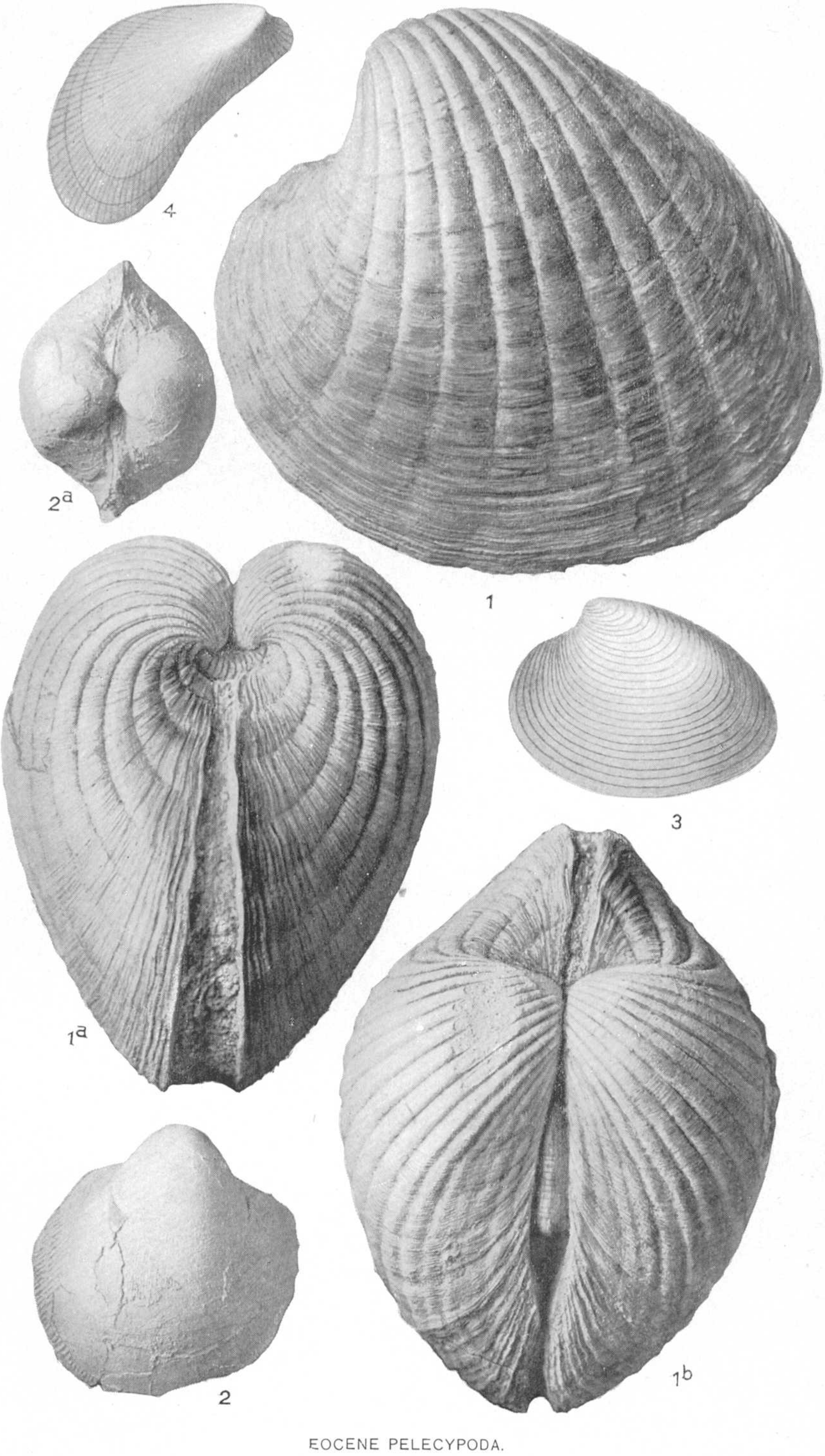
FIG. 1*b*. Same specimen as fig. 1. View of both valves from above.

FIG. 2. *Cardium cooperii* Gabb. U.S.N.M. 164998. A decorticated right valve; longitude 35 mm. Eocene, Rose Canyon, San Diego County. A common species in the Eocene of the west coast.

FIG. 2*a*. Same specimen as fig. 2. View of both valves from above.

FIG. 3. *Meretrix hornii* Gabb. Left valve; longitude 36 mm. Pal. Cal., vol. 2, pl. 30, fig. 78. A common species in the Eocene of the west coast.

FIG. 4. *Modiolus ornatus* Gabb. Right valve; longitude 38 mm. Pal. Cal., vol. 1, pl. 24, fig. 166. Another species found in most Eocene faunas of the west coast.



EOCENE PELECYPODA.

PLATE XXVI.

EOCENE PELECYPODA AND GASTEROPODA.

(All figures natural size unless otherwise noted.)

FIG. 1. *Pecten (Chlamys) calkinsi* Arnold. Univ. California. An imperfect left valve; altitude 45 mm. Eocene, Sisar Creek, Ventura County.

FIG. 2. Same species as fig. 1. Univ. California. Imperfect right valve; altitude 29 mm. Same locality as fig. 1.

FIG. 3. *Pecten (Propeamusium) interradiatus* Gabb. Left valve; altitude 25 mm. Pal. Cal., vol. 2, pl. 33, fig. 98. Eocene shales at New Idria, San Benito County, and in Silver Thread district, Ventura County.

FIG. 3*a*. Same specimen as fig. 3. Interior of left valve. Pal. Cal., vol. 2, pl. 33, fig. 98.

FIG. 3*b*. Same species as fig. 3. Outline of ears of right valve. Pal. Cal., vol. 2, pl. 33, fig. 98*a*.

FIG. 4. *Glycymeris veatchii* Gabb var. *major* Stanton. U.S.N.M. 165003. Imperfect left valve; longitude 30 mm. Eocene, Rock Creek, Los Angeles County. Found in the lower Eocene (Martinez formation) in California.

FIG. 5. *Cardium brewerii* Gabb. Right valve; longitude 51 mm. Pal. Cal., vol. 2, pl. 24, fig. 155. Common in the Eocene (Tejon formation and equivalents).

FIG. 6. *Teredo* sp. U.S.N.M. 164972. Type. Imperfect section of tube, lateral view; diameter 11 mm. Eocene, Sisar Creek, Ventura County.

FIG. 6*a*. Same species as fig. 6. U.S.N.M. 164972. Cotype. Cross section of a crushed specimen; maximum diameter 15 mm. Same locality as fig. 6.

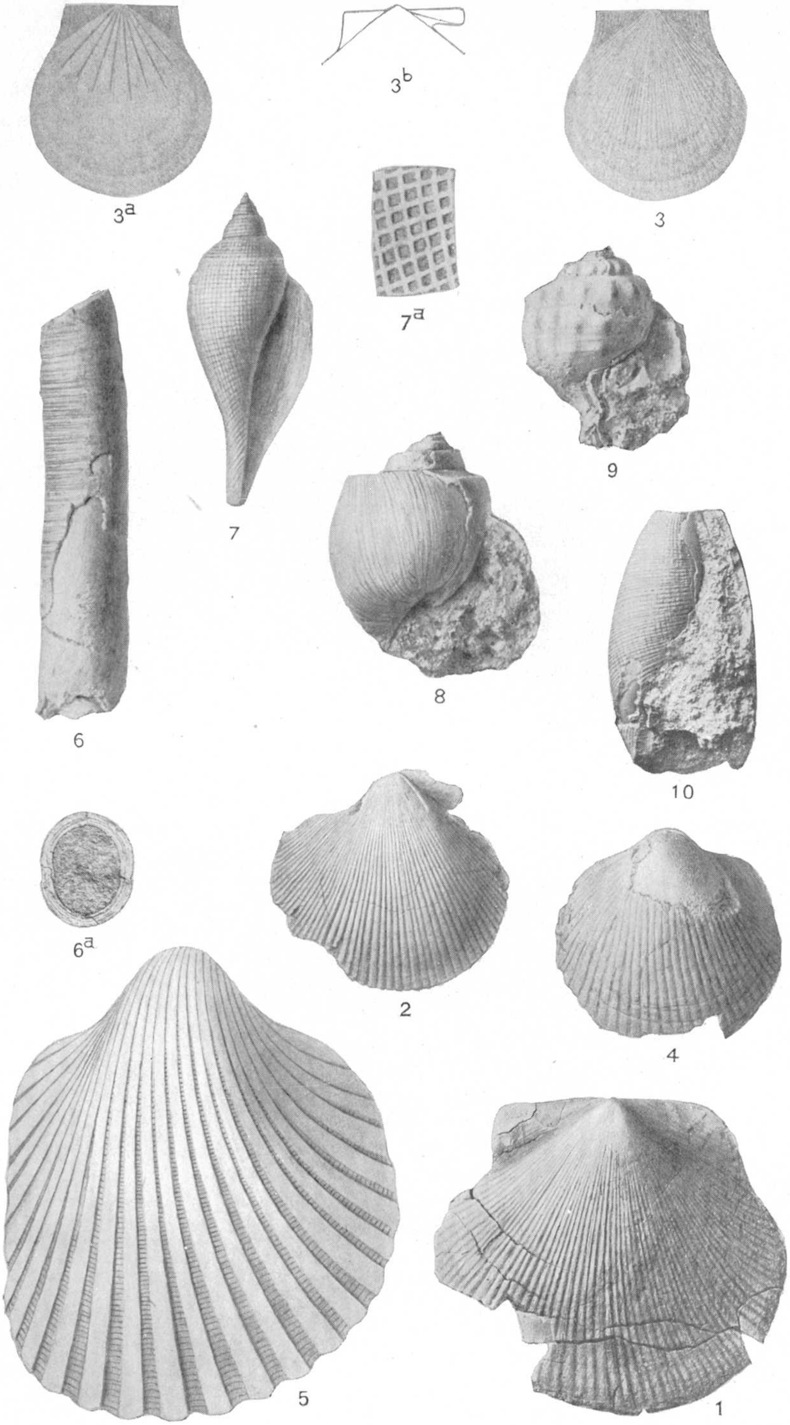
FIG. 7. *Fusus remondii* Gabb. Front view; altitude 41 mm. Pal. Cal., vol. 1, pl. 18, fig. 36. Common in Eocene (Tejon formation and equivalents) on west coast.

FIG. 7*a*. Same specimen as fig. 7. Magnified view of surface.

FIG. 8. *Amauropsis alveatus* Conrad. U.S.N.M. 165000. Front view of partially decorticated specimen; altitude 32 mm. Eocene, Rose Canyon, San Diego County. A characteristic Eocene gasteropod.

FIG. 9. *Morio (Sconsia) tuberculatus* Gabb. U.S.N.M. 164999. Front view of an imperfect and decorticated specimen; altitude 27 mm. Eocene, Rose Canyon, San Diego County. Perfect specimens have an anteriorly plicate plate over the inner lip; outer lip crenulate; revolving lines on surface.

FIG. 10. *Cylichna costata* Gabb. U.S.N.M. 165001. Front view of slightly imperfect specimen; altitude 18 mm., twice natural size. Eocene, Rose Canyon, San Diego County. Common in the Eocene (Martinez and Tejon formations and equivalents).



EOCENE PELECYPODA AND GASTEROPODA.

PLATE XXVII.

Miocene Pelecypoda and Gasteropoda.

Fig. 1. *Pecten* (*Lyropecten*) *bowersi* Arnold. Univ. California. Type. Right valve; altitude 150 mm.; about two-thirds natural size. Lower Miocene, Santa Inez Mountains, Santa Barbara County. Also abundant at same horizon in Santa Monica Mountains and elsewhere. Left valve of this species more convex than right; otherwise very similar.

Fig. 2. *Ostrea titan* Conrad. U.S.N.M. 164987. Side view of both valves; altitude of large valve 131 mm.; two-thirds natural size. Lower Miocene, 3 miles south of Calabasas, Los Angeles County. This species is found in both the upper and lower Miocene, and often grows to a length of 20 inches (500 mm.) (See Pl. XXXII, fig. 2.)

Fig. 3. *Purpura edmondi* Arnold. U.S.N.M. 164983. Type. Aperture view; altitude 19 mm.; about 1⅓ times natural size. Lower Miocene, 3 miles south of Calabasas, Los Angeles County.

Fig. 3*a*. Reverse view of same specimen as fig. 3; same enlargement.

Fig. 4. *Chlorostoma* (*Omphalius*) *dalli* Arnold. U.S.N.M. 164984. Type. Aperture view; latitude 12.5 mm.; 1⅓ times natural size. Lower Miocene, 3 miles south of Calabasas, Los Angeles County. A common species in this horizon.

Fig. 4*a*. Top view of same specimen as fig. 4.

Fig. 4*b*. Base view of same specimen as fig. 4.

Fig. 5. *Chlorostoma* (*Omphalius*) *dalli* var. *inornatus* Arnold. U.S.N.M. 164986. Type. Top view; latitude 13.5 mm.; 1⅓ times natural size. Same locality as fig. 4.

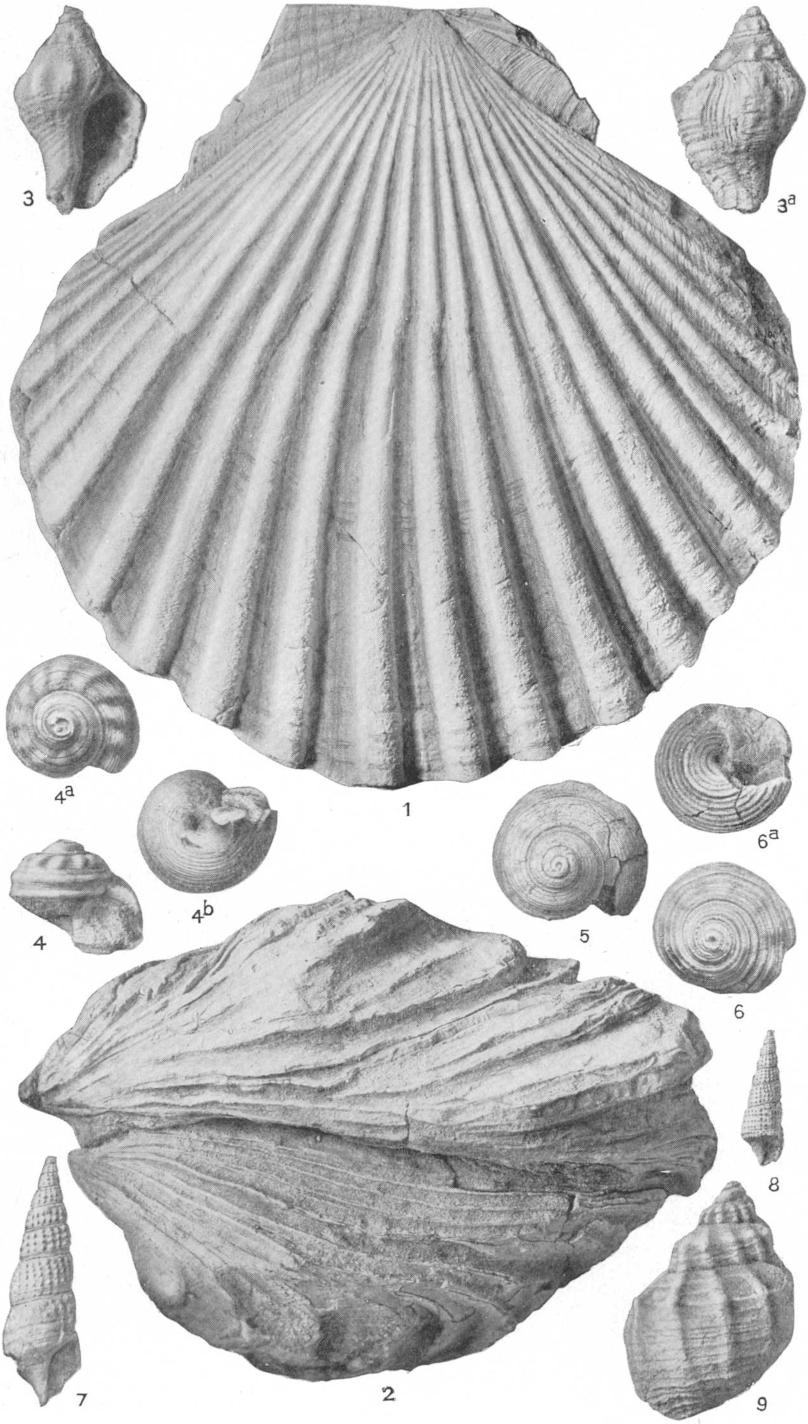
Fig. 6. *Chlorostoma* (*Omphalius*) *dalli* var. *subnodosus* Arnold. U.S.N.M. 164985. Type. Top view; latitude 13 mm.; 1⅓ times natural size. Same locality as Fig. 4.

Fig. 6*a*. Base view of same specimen as fig. 6.

Fig. 7. *Cerithium topangensis* Arnold. U.S.N.M. 164976. Type. Aperture view of imperfect specimen; longitude 23 mm.; 1⅓ times natural size. Lower Miocene, 3 miles south of Calabasas, at head of Topanga Canyon, Los Angeles County. A common species at the type locality.

Fig. 8. *Cerithium topangensis* Arnold. U.S.N.M. 164976. Cotype. Aperture view of imperfect specimen; longitude 13 mm.; 1⅓ times natural size. Same locality as fig. 7.

Fig. 9. *Cancellaria* cf. *condoni* Anderson. U.S.N.M. 164981. Back view of imperfect specimen; altitude 21 mm.; 1⅓ times natural size. Lower Miocene, 3 miles south of Calabasas, Los Angeles County. This species appears to range from the San Joaquin Valley to the Santa Monica Mountains in the lower Miocene.



MIOCENE PELECYPODA AND GASTEROPODA.

PLATE XXVIII.

Miocene Pelecypoda and Gasteropoda.

Fig. 1. *Pecten (Lyropecten) magnolia* Conrad. Univ. California. Imperfect right valve; altitude 14.5 mm.; about two-thirds natural size. Lower Miocene, Vaqueros formation, Ojai Valley, Ventura County. Characteristic of the lower Miocene throughout central and southern California. The left valve has narrow, more rounded ribs.

Fig. 2. *Pecten (Lyropecten) estrellanus* Conrad. U.S.N.M. 164851. Left valve; altitude 97 mm.; about two-thirds natural size. Upper Miocene, Wildhorse Canyon, Monterey County. This species is usually abundant in both the lower and upper Miocene faunas of central and portions of southern California. Ribs of right valve broader and anterior ear notched; otherwise similar to left.

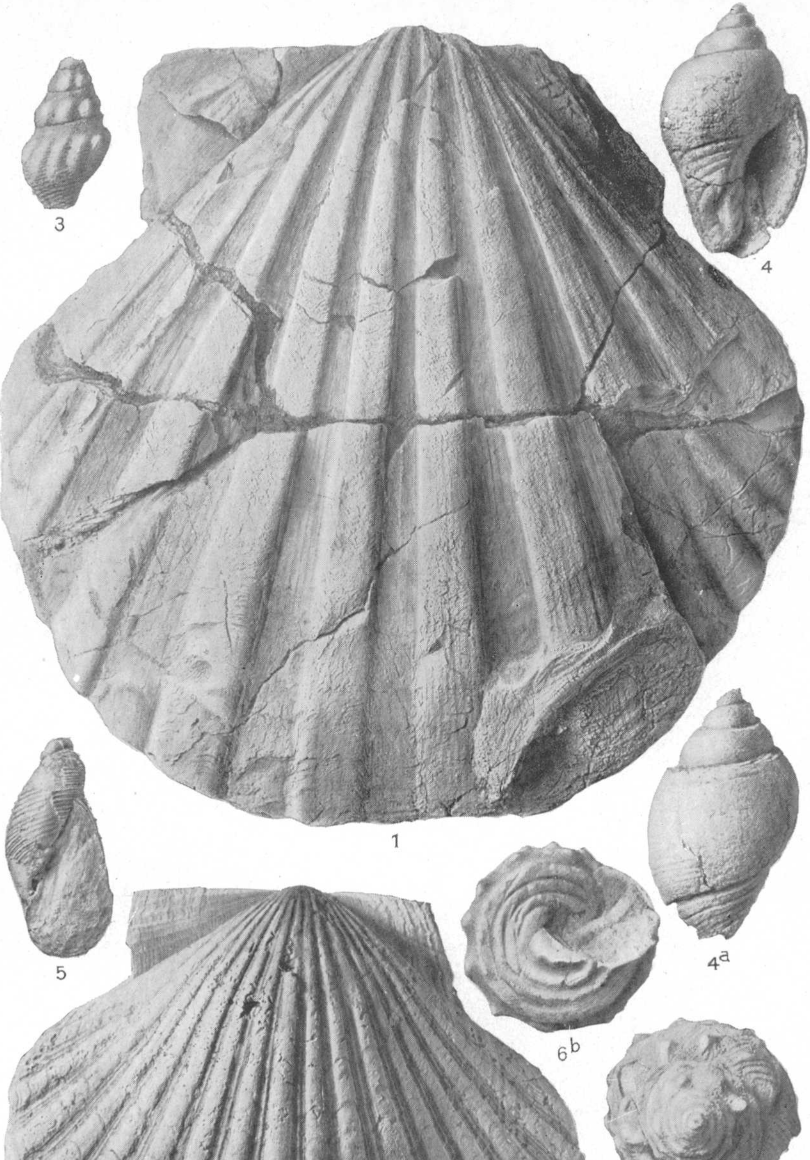
Fig. 3. *Drillia* sp. U.S.N.M. 164977. Type. Back view; longitude 13.5 mm.; about 1⅓ times natural size. Lower Miocene, head of Topanga Canyon, 3 miles south of Calabasas, Los Angeles County.

Fig. 4. *Macron merriami* Arnold. U.S.N.M. 164982. Type. Aperture view; longitude 23 mm.; about 1⅓ times natural size. Lower Miocene, same locality as fig. 3. This species appears to range over central and southern California in the lower Miocene.

Fig. 4*a*. Back view of same specimen as fig. 4.

Fig. 5. *Sigaretus perrini* Arnold. U.S.N.M. 164979. Type. Aperture view of partially decorticated and imperfect specimen; altitude 18.5 mm.; about 1⅓ times natural size. Lower Miocene, same locality as fig. 3.

Fig. 6. *Turbo topangensis* Arnold. U.S.N.M. 164980. Type. Aperture view; altitude 18.5 mm.; about 1⅓ times natural size. Lower Miocene, same locality as fig. 3.



MIOCENE PELECYPODA AND GASTEROPODA.

PLATE XXIX.

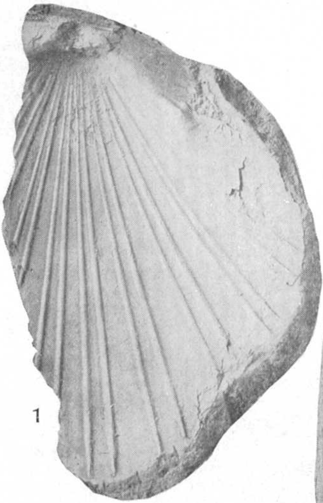
Miocene Echinoidea and Pelecypoda.

Fig. 1. *Pecten* (*Amusium*) *lompocensis* Arnold. U.S.N.M. 164852. Cotype. Interior view, showing internal liræ; altitude 90 mm.; about two-thirds natural size. Lower Miocene, Ojai Valley, Ventura County. This form, so far as known, is confined to the lower Miocene of Santa Barbara and Ventura counties.

Fig. 2. *Ostrea eldridgei* Arnold. U.S.N.M. 164986. Type. View of exterior of larger valve; altitude 14.7 mm.; two-thirds natural size. Lower Miocene, supposed equivalent of Vaqueros formation, Elkins ranch, east of Grimes Canyon, south of Fillmore, Ventura County.

Fig. 2*a*. Lateral view of same specimen as fig. 2.

Fig. 3. *Scutella fairbanksi* Merriam. U.S.N.M. 164963. View of top, showing details; maximum diameter 36 mm.; 1⅓ times natural size. Lower Miocene, supposed equivalent of Vaqueros formation, near Torrey Canyon wells, southwest of Piru, Ventura County; abundant. This species is also found near the base of the Vaqueros formation in the Sespe district. Supposed to be characteristic of the lower Miocene.



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MIOCENE ECHINOIDEA AND PELECYPODA.

PLATE XXX.

MIOCENE ECHINOIDEA AND PELECYPODA AND GASTEROPODA.

(All figures natural size.)

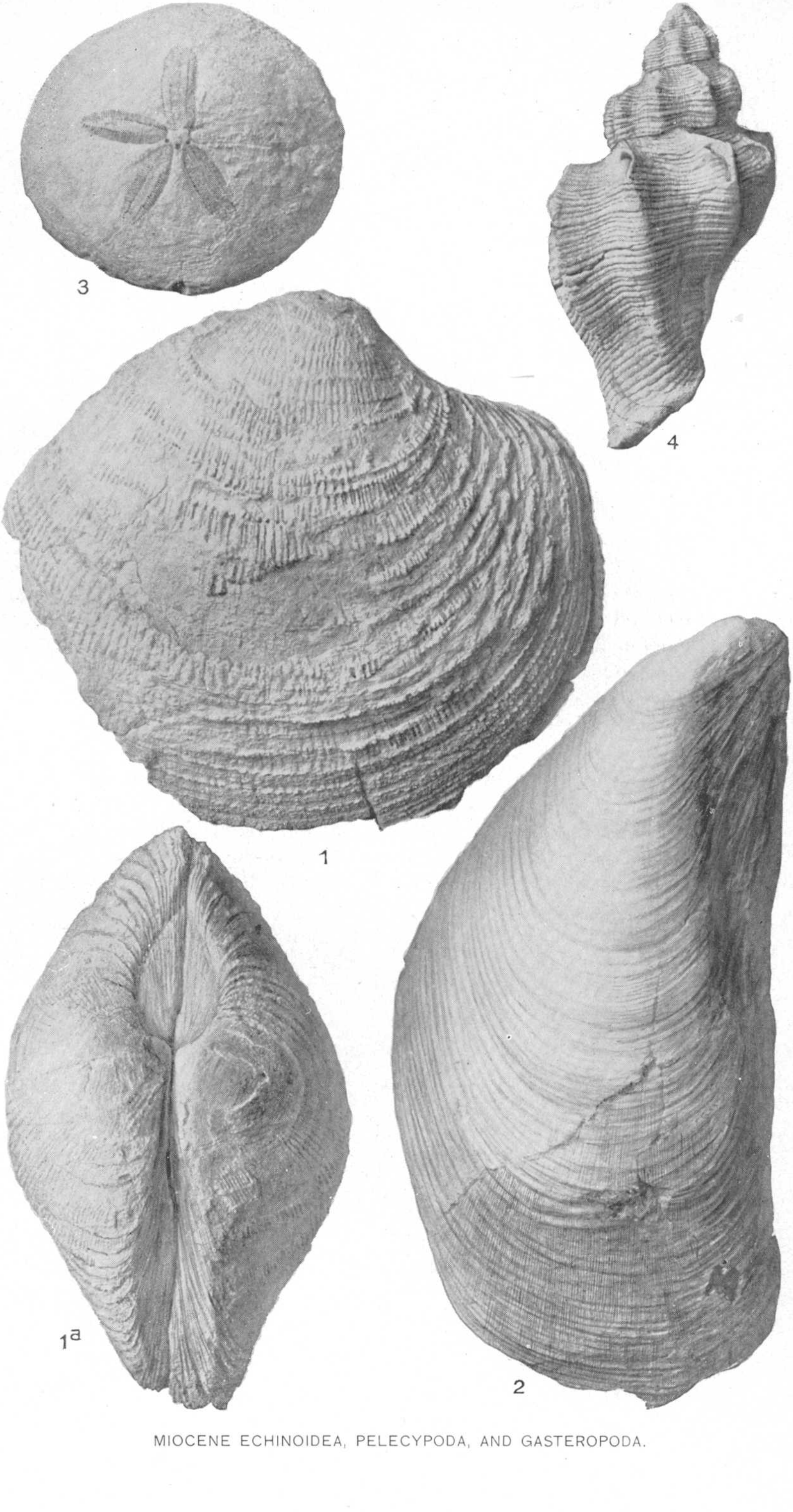
FIG. 1. *Venus (Chione) temblorensis* Anderson. U.S.N.M. 164989. Exterior of imperfect right valve; longitude 80 mm. Lower Miocene, head of Topanga Canyon, 3 miles south of Calabasas, Los Angeles County. Usually abundant in the lower Miocene; a nearly related, possibly identical form found in the upper Miocene.

FIG. 1*a*. Top view of same specimen as fig. 1.

FIG. 2. *Mytilus mathewsonii* Gabb var. *expansus* Arnold. U.S.N.M. 164968. Type. Right valve; altitude 10.5 mm. Lower Miocene, supposed equivalent of the Vaqueros formation, near Torrey Canyon wells, southwest of Piru, Ventura County. This species is usually found in the faunas of the lower Miocene through central and southern California.

FIG. 3. *Scutella fairbanksi* Merriam. U.S.N.M. 164963. Same locality as fig. 2, but possibly at a somewhat lower horizon.

FIG. 4. *Ocinebra topangensis* Arnold. U.S.N.M. 164995. Type. Back view; altitude 59 mm. Lower Miocene, Topanga Canyon, 3 miles south of Calabasas, Los Angeles County. So far known only from this horizon.



MIOCENE ECHINOIDEA, PELECYPODA, AND GASTEROPODA.

PLATE XXXI.

Miocene Pelecypoda and Gasteropoda.

(All figures natural size.)

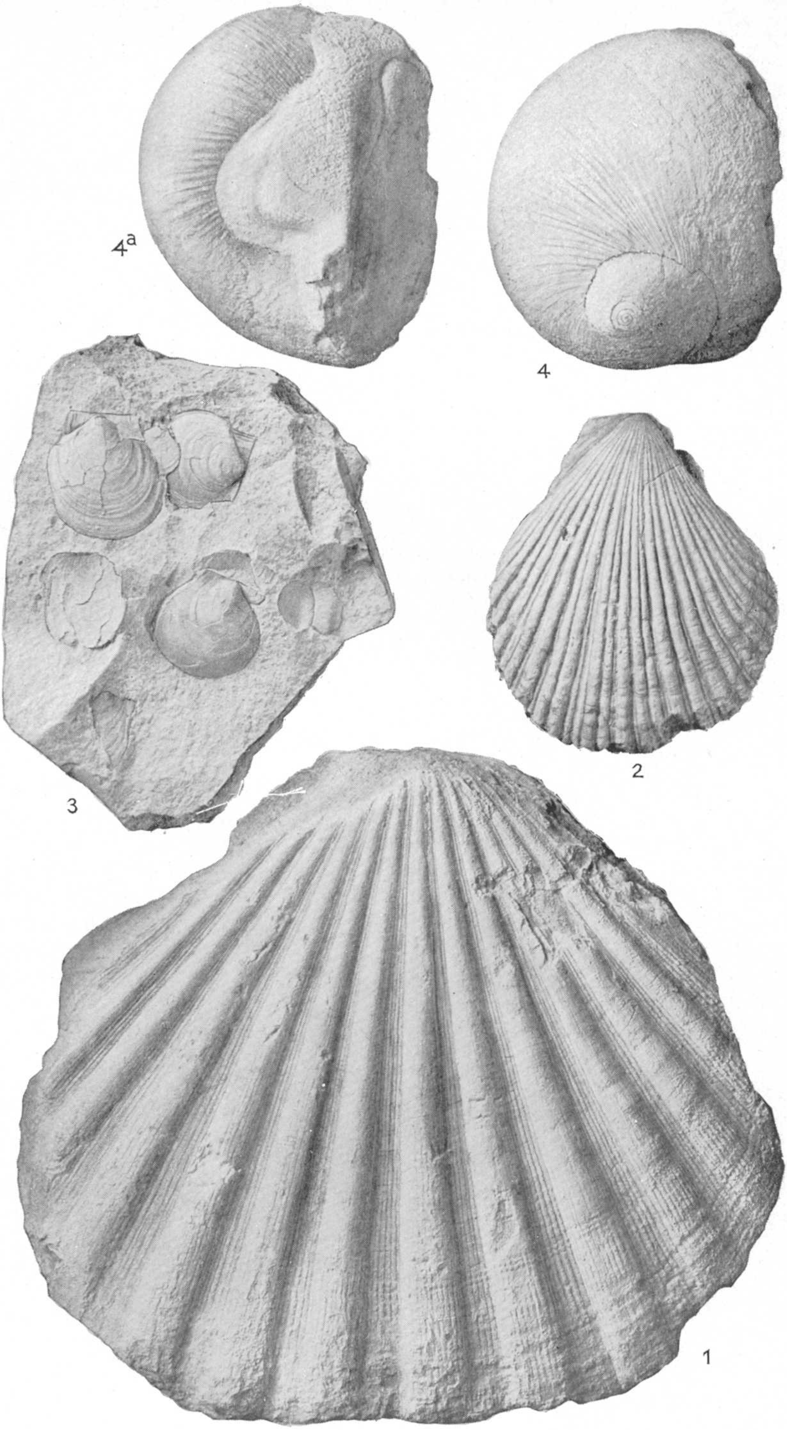
Fig. 1. *Pecten (Lyropecten) crassicardo* Conrad. U.S.N.M. 164967. Exterior of valve, showing characteristic sculpture; altitude 90 mm. Lower Miocene, Ojai Valley, Ventura County. This species ranges through the lower and upper Miocene, being commoner in the former in southern California, in the latter in central California. It is sometimes more convex than the figured specimen, and often shows concentric undulations of the disk.

Fig. 2. *Pecten (Chlamys) sespeensis* var. *hydei* Arnold. Collection of Delos Arnold. Type. Right valve, ear missing; altitude 46 mm. Lower Miocene, Lynchs Mountain, San Luis Obispo County. Found also in the Vaqueros formation, Little Sespe Creek, and, with *Mytilus mathewsonii* Gabb, in supposed equivalents of the Vaqueros formation near the Torrey Canyon wells, Ventura County.

Fig. 3. *Pecten (Pseudamusium) peckhami* Gabb. U.S.N.M. 164839. Right and left valves in matrix; altitude of largest 17 mm. Monterey shale (middle Miocene), southeast of Pinole, Contra Costa County. The type of this species came from the Ojai Valley, Ventura County. It is the commonest form in the shales of the middle Miocene (Monterey, Modelo, and equivalent formations) and is also known from the Oligocene in the Santa Cruz Mountains.

Fig. 4. *Neverita callosa* Gabb. U.S.N.M. 164992. View from above, specimen slightly tilted; maximum latitude 44 mm. Lower Miocene, head of Topanga Canyon, 3 miles south of Calabasas, Los Angeles County. Ranges through the Miocene. Common in the lower Miocene of southern San Joaquin Valley and the Santa Monica Mountains.

Fig. 4*a*. Same specimen as fig. 4. View of base and aperture, showing characteristic shape of callous.



MIOCENE PELECYPODA AND GASTEROPODA.

PLATE XXXII.

Miocene Pelecypoda, Gasteropoda, and Crustacea.

(All figures natural size.)

Fig. 1. *Pecten* (*Hinnites*) *giganteus* Gray. U.S.N.M. 164965. Exterior of right valve; altitude 90 mm. Lower Miocene, supposed equivalent of Vaqueros formation, gulch east of Wiley Canyon, southwest of Piru, Ventura County. A very variable species ranging from the lower Miocene to the Recent fauna.

Fig. 2. *Ostrea titan* Conrad. U.S.N.M. 164987. View of exterior of larger valve; altitude 131 mm. Lower Miocene, 3 miles south of Calabasas, Los Angeles County. A common form in the upper and lower Miocene; often grows to a length of 20 inches (500 mm.) or more. (See Pl. XXVII, fig. 2.)

Fig. 3. *Trochita costellata* Conrad. U.S.N.M. 164994. View from above; maximum diameter 38 mm. Same locality as fig. 2. Common in the Miocene.

Fig. 4. *Phacoides richthofeni* Gabb. U.S.N.M. 164978. Right valve; altitude 17.5 mm. Same locality as fig. 2.

Fig. 5. *Balanus concavus* Bronn. U.S.N.M. 164971. Type. Lateral view; maximum latitude 26 mm. Lower Miocene or upper Oligocene, Little Sespe Creek, Ventura County. A very common species in this horizon.

Fig. 5*a*. Same species as fig. 5. Top view.

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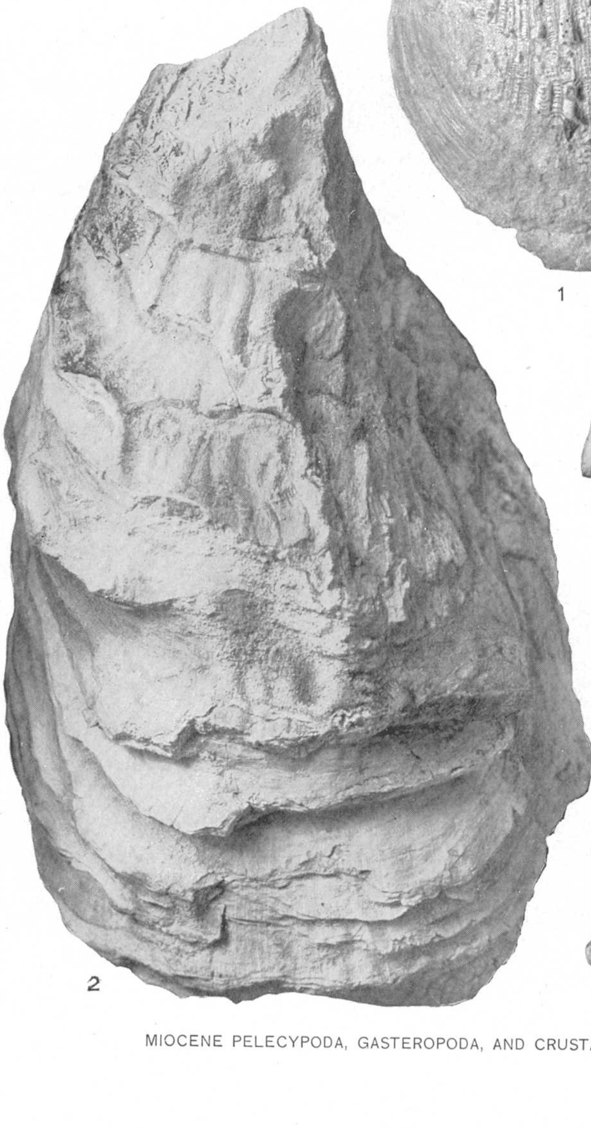

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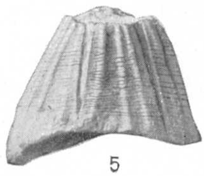

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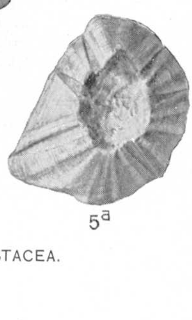

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MIOCENE PELECYPODA, GASTEROPODA, AND CRUSTACEA.

PLATE XXXIII.

Miocene Pelecypoda and Gasteropoda.

(All figures natural size.)

Fig. 1. *Pecten* (*Chlamys*) *sespeensis* Arnold. California State Mining Bureau. Cotype Portion of mold of interior of right valve; altitude 50 mm. Lower Miocene, Vaqueros formation, Sespe Canyon, Ventura County. A common species at the type locality; also found elsewhere in central and southern California in the lower Miocene.

Fig. 1*a*. Mold of interior of left valve of same specimen as fig. 1.

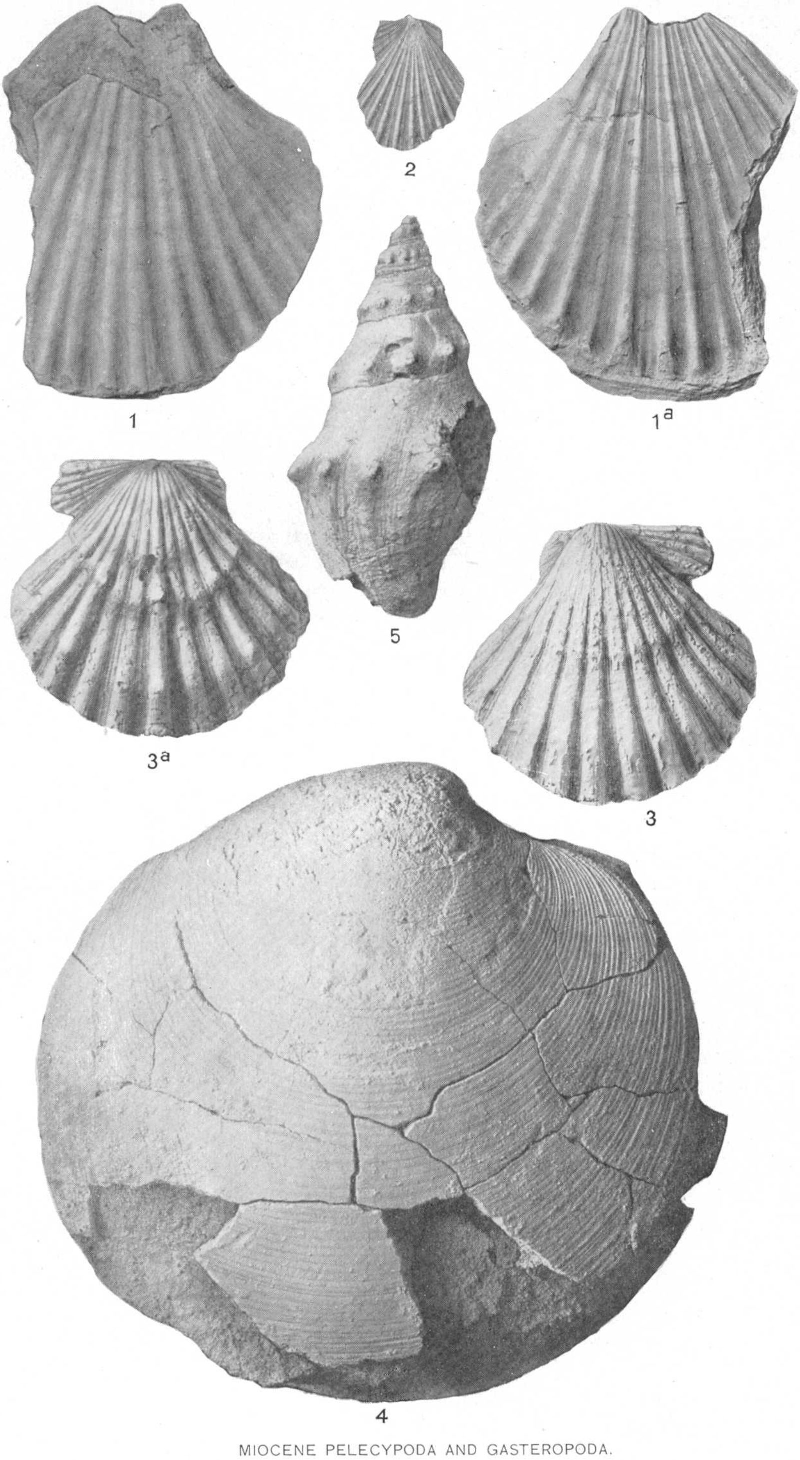
Fig. 2. *Pecten* (*Chlamys*) *sespeensis* Arnold. California State Mining Bureau. Plastotype. Cast of exterior of slightly imperfect left valve (young); altitude. 18 mm. Same locality as fig. 1.

Fig. 3. *Pecten* (*Lyropecten*) *vaughani* Arnold. Collection of Delos Arnold. Type. Right valve; altitude 37 mm. Lower Miocene, supposed equivalent of Vaqueros formation, Ojai Valley, Ventura County.

Fig. 3*a*. Same specimen as fig. 3. Left valve.

Fig. 4. *Dosinia ponderosa* Gray. U.S.N.M. 164988. Imperfect right valve; altitude 80 mm. Lower Miocene, 3 miles south of Calabasas, Los Angeles County. A common species from the lower Miocene to the Recent southern fauna of the west coast.

Fig. 5. *Pleurotoma* (*Dolichotoma*) *keepi* Arnold. U.S.N.M. 164993. Type. Back view of imperfect specimen. Same locality as fig. 4. Found also in this horizon at several localities in southern San Joaquin Valley.



MIOCENE PELECYPODA AND GASTEROPODA.

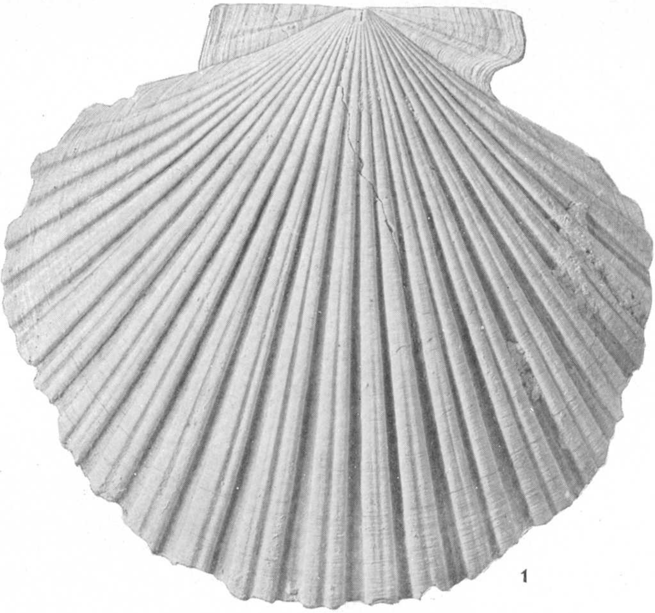
PLATE XXXIV.

Pliocene Pectens.

(All figures about two-thirds natural size.)

Fig. 1. *Pecten* (*Patinopecten*) *healeyi* Arnold. U.S.N.M. 148012. Type. Exterior of right valve; altitude 121 mm. San Diego formation (Pliocene), San Diego County. A characteristic form in the lower Pliocene from San Mateo County to the Mexican line. Left valve with narrow rounded ribs and intercalaries; disk also less convex.

Fig. 2. *Pecten* (*Lyropecten*) *ashleyi* Arnold. Univ. California. Type. Exterior of right valve; altitude 155 mm. Pliocene, Cerros Island, off Lower California. Also characteristic of the lower Pliocene, but so far known only as far north as Santa Barbara County. The left valve has slightly narrower ribs and no byssal notch in the anterior ear.



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PLIOCENE PECTENS.

PLATE XXXV.

Pliocene Pectens.

(Unless otherwise stated all figures are about two-thirds natural size.)

Fig. 1. *Pecten (Chlamys) wattsi* Arnold. California Acad. Sci. Type. Exterior of slightly imperfect left valve; altitude 66 mm. Lower Pliocene, Kreyenhagen's ranch, Fresno County. Also found in the lower Pliocene of southern California. Right valve with broader, flatter ribs.

Fig. 2. *Pecten (Pecten) stearnsii* Dall. U.S.N.M. 148008. Exterior of left valve; altitude 87 mm. San Diego formation (Pliocene), Pacific Beach, San Diego County. Not rare in the Pliocene. (See Pl. XXXVI, fig. 4, for right valve.)

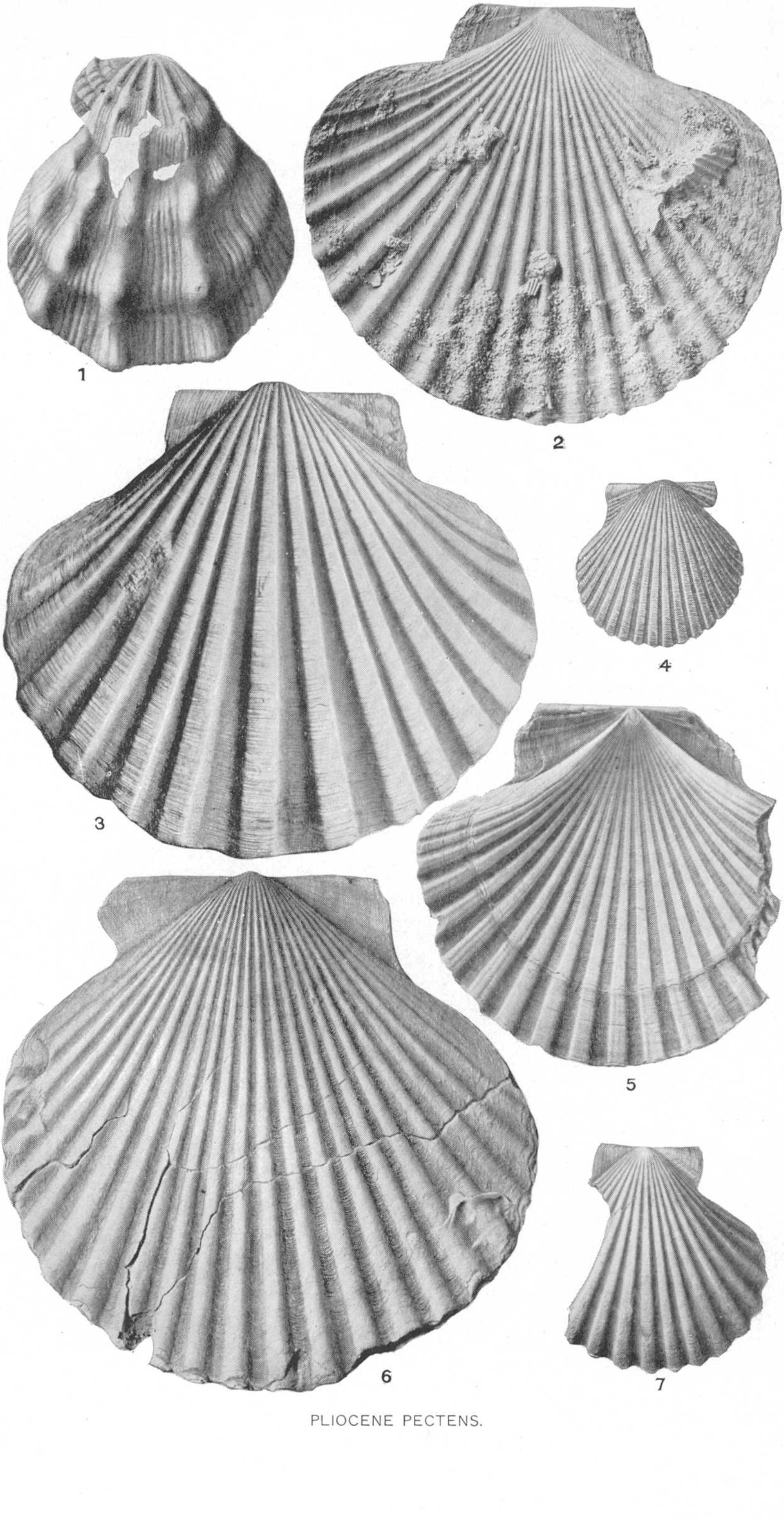
Fig. 3. *Pecten (Pecten) bellus* Conrad. Acad. Nat. Sci. Phila. 960. Exterior of right valve; altitude 80 mm.; about five-sixths natural size. Pliocene, Santa Barbara. Also found in Pliocene of Ventura, Santa Barbara, and adjacent counties. Left valve slightly concave, with narrower ribs than right; otherwise similar.

Fig. 4. *Pecten (Plagioctenium) circularis* Sowerby. U.S.N.M. 61246. Right valve; longitude 26 mm.; nearly natural size. Pleistocene, Ventura County. May also extend down into the Pliocene.

Fig. 5. *Pecten (Pecten) vogdesi* Arnold. California Acad. Sci. Cotype. Exterior of slightly imperfect left valve; altitude 74 mm. Pleistocene, Ventura County. Also occurs in supposed Pliocene near San Diego. Right valve very convex, with broad rounded ribs.

Fig. 6. *Pecten (Plagioctenium) cerrosensis* Gabb. Univ. California. Exterior of left valve (anterior ear slight broken); altitude 106 mm. Pliocene, Cerros Island, off Lower California. Also found in the Pliocene near Camulos, Newhall, and San Diego.

Fig. 7. *Pecten (Pecten) auburyi* Arnold. California State Mining Bureau. Type. Exterior of imperfect right valve; altitude 46 mm. Pliocene, Puente Hills, Los Angeles County. Left valve slightly concave, with ribs narrower than in right.



PLIOCENE PECTENS.

PLATE XXXVI.

Pliocene Pectens.

(All figures about two-thirds natural size.)

Fig. 1. *Pecten* (*Patinopecten*) *caurinus* Gould. Collection of Delos Arnold. Exterior of left valve; altitude 105 mm. Pliocene, Deadman Island, Los Angeles County. Specimens of this species measuring over 8 inches (200 mm.) have been found in the Pliocene of Ventura County. This form appears to be confined to the upper Pliocene and Pleistocene in southern California. Right valve more convex and with broader square ribs and plain concentric sculpture.

Fig. 2. *Pecten* (*Chlamys*) *latiauritus* Conrad. Collection of Delos Arnold. Exterior of right valve; altitude 25 mm. San Pedro formation (Pleistocene), San Pedro, Los Angeles County. Known also from the lower Pliocene at Los Angeles.

Fig. 3. *Pecten* (*Chlamys*) *latiauritus* Conrad. Collection of Delos Arnold. Exterior of left valve; altitude 27 mm. Same locality as fig. 2.

Fig. 4. *Pecten* (*Pecten*) *stearnsii* Dall. U.S.N.M. 148008. Exterior of right valve; altitude 87 mm. San Diego formation (Pliocene), Pacific Beach, San Diego County. (See Pl. XXXV, fig. 2, for left valve.)

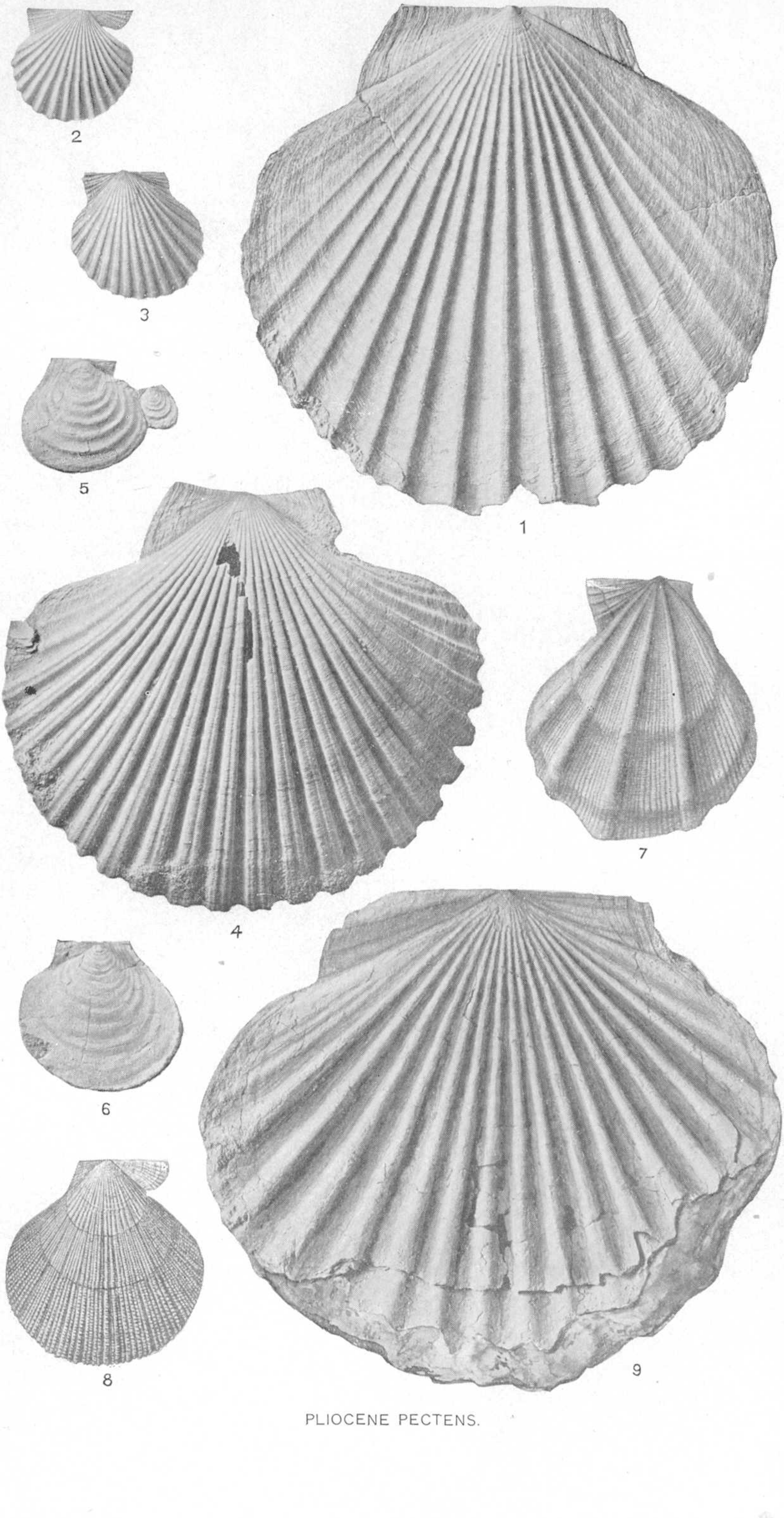
Fig. 5. *Pecten* (*Pseudamusium*) *pedroanus* Trask. U.S.N.M. 164840. Exterior of right valve and young left valve; altitude of former, 22 mm. Lower Pliocene, Third street tunnel, Los Angeles. Also found in beds of supposed Miocene age in the Puente Hills and San Pedro.

Fig. 6. *Pecten* (*Pseudamusium*) *pedroanus* Trask. U.S.N.M. 164840. Exterior of imperfect left valve; altitude 30 mm. Same locality as fig. 5.

Fig. 7. *Pecten* (*Chlamys*) *parmeleei* Dall. U.S.N.M. 154479. Type. Left valve; altitude 45 mm.; about five-sixths natural size. Pliocene, Pacific Beach, San Diego County. Also known in Pliocene of Puente Hills.

Fig. 8. *Pecten* (*Chlamys*) *opuntia* Dall. U.S.N.M. 107752. Type. Right valve; altitude 33 mm.; about four-fifths natural size. Pliocene, Pacific Beach, San Diego County. Also common in Pliocene at Santa Barbara and elsewhere in southern California.

Fig. 9. *Pecten* (*Pecten*) *merriami* Arnold. California State Mining Bureau. Type. Exterior of imperfect left valve; altitude 110 mm. Pliocene, Piru Creek, Ventura County. Characteristic of the lower Fernando horizon (lower Pliocene or upper Miocene) so far as known. Right valve convex, with broader squarer ribs.



PLIOCENE PECTENS.

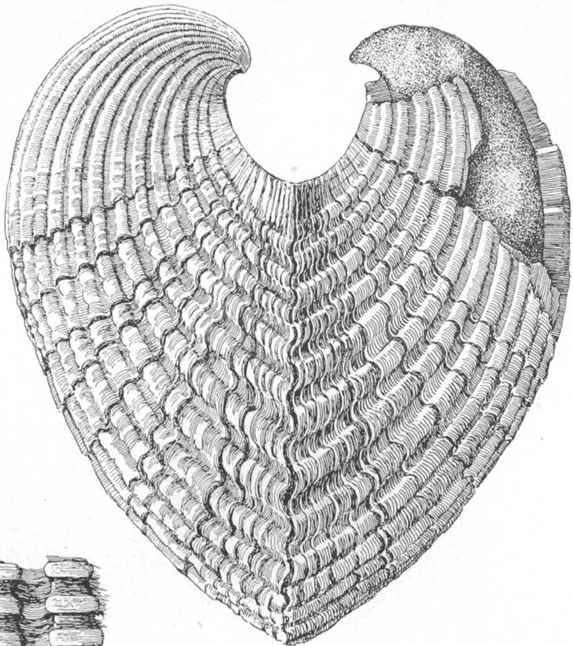
PLATE XXXVII.

Pliocene Arcas.

Fig. 1. *Arca camuloensis* Osmont. California State Mining Bureau. Type. Right valve; altitude 89 mm. Fernando formation, lower Pliocene or upper Miocene, 1 mile north of Camulos, Ventura County. So far as known this species is characteristic of the lower horizon of the Fernando formation. Also reported from the Puente Hills.

Fig. 1*a*. End view of same specimen as fig. 1.

Fig. 1*b*. Portion of surface of same specimen as fig. 1, enlarged, showing nodose ribs.



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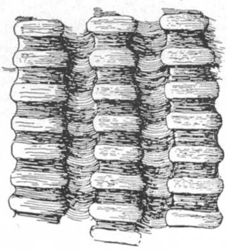

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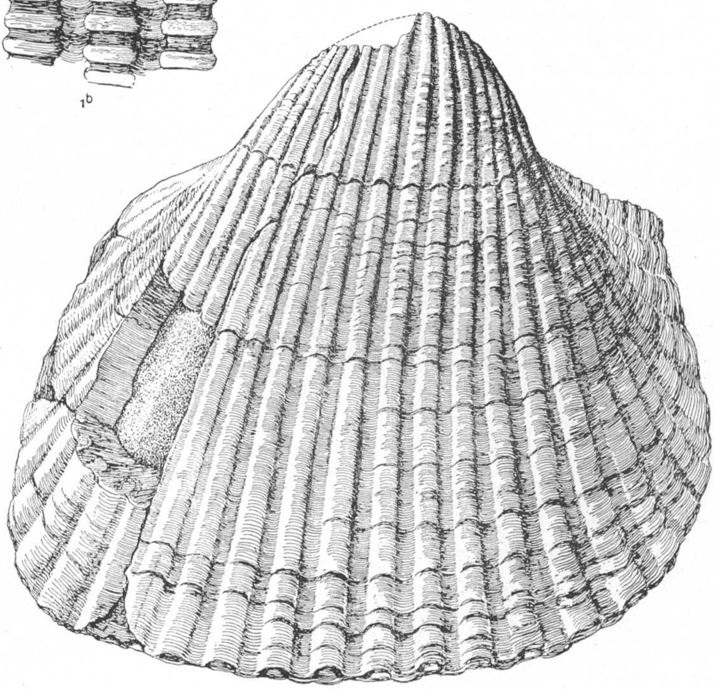

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PLIOCENE ARCAS.

PLATE XXXVIII.

Pliocene Pelecypoda and Gasteropoda.

(Unless otherwise stated all figures natural size.)

Fig. 1. *Arca multicostata* Sowerby. U.S.N.M. 12574. Right valve; longitude 101 mm. Recent, San Diego. Found in the lower Pliocene (Fernando formation) in the Puente Hills, Orange County, and in the vicinity of Los Angeles.

Fig. 2. *Cardium quadrigenarium* Conrad var. *fernandoensis* Arnold. U.S.N.M. 164947. Type. Imperfect left valve; longitude 58 mm. Lower Pliocene (Fernando formation), Elsmere Canyon, near Newhall, Los Angeles County. A common variety in the lower Pliocene. The typical form with 44 ribs and less obliquity is found in the Recent.

Fig. 2*a*. Same specimen as fig. 2. View of umbos from above.

Fig. 3. *Arca trilineata* Conrad. U.S.N.M. 164948. Right valve of medium-sized specimen; longitude 40 mm. Same locality as fig. 2. A common species in the Pliocene of California. Also appears to extend down as far as the middle Miocene (Monterey).

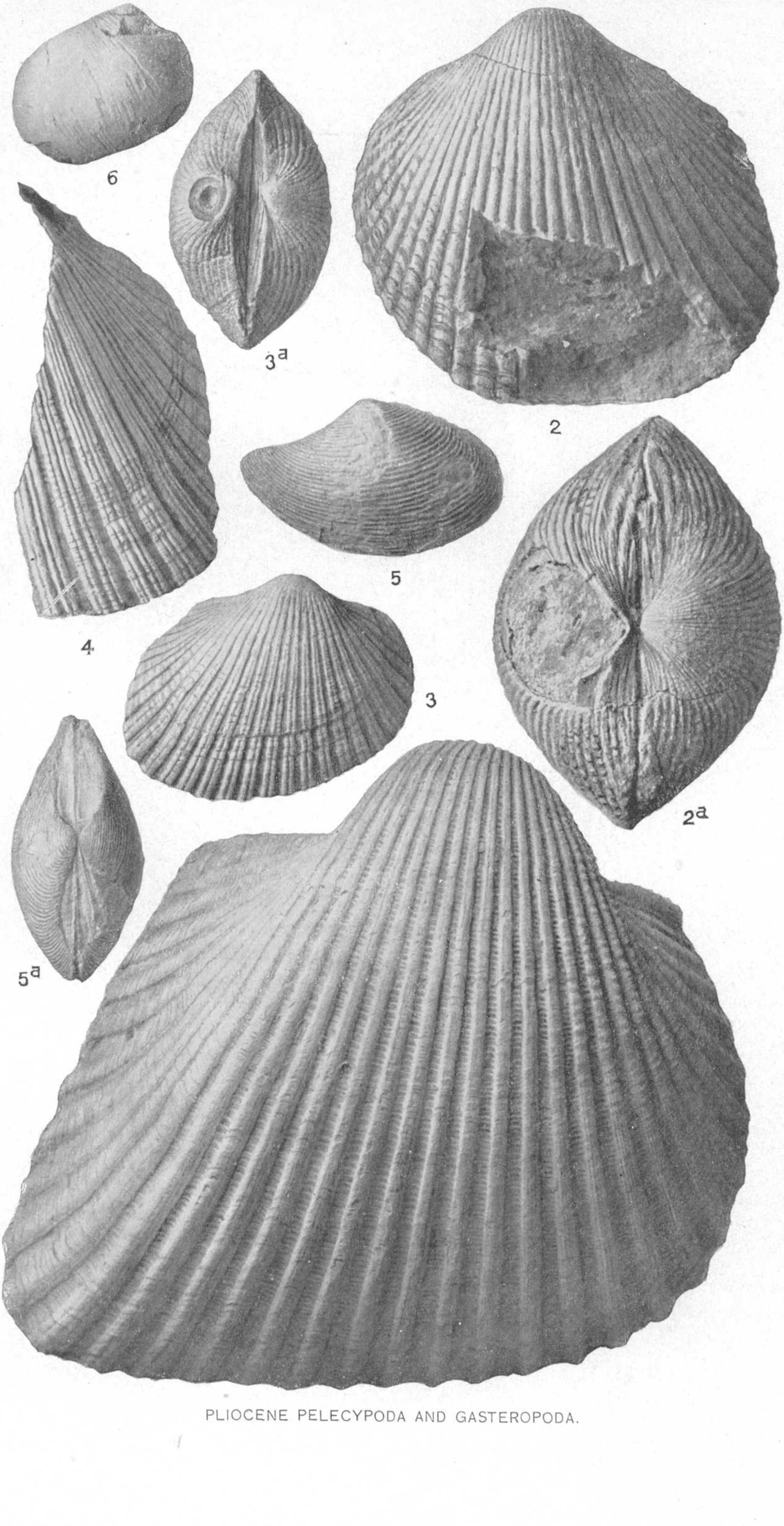
Fig. 3*a*. Same specimen as fig. 3. Umbos and hinge area viewed from above.

Fig. 4. *Arca trilineata* Conrad. Portion of an adult left valve, showing the more complex sculpture of the ribs in the later stages of growth; altitude 60 mm. Same locality as fig. 2.

Fig. 5. *Leda taphria* Dall. U.S.N.M. 164952. Right valve; longitude 36 mm.; twice natural size. Same locality as fig 2. This species is common from the Pliocene to the Recent fauna in the California province.

Fig. 5*a*. Same specimen as fig. 5. View of umbos from above.

Fig. 6. *Neverita recluziana* Petit. U.S.N.M. 164960. Back view; latitude 25 mm. Same locality as fig. 2. A common species from the Pliocene to the Recent fauna; also probably occurs in the Miocene.



PLIOCENE PELECYPODA AND GASTEROPODA.

PLATE XXXIX.

PLIOCENE BRACHIOPODA AND PELECYPODA.

(All figures natural size.)

FIG. 1. *Ostrea veatchii* Gabb. U.S.N.M. 153827. Exterior of valve; altitude 90 mm. Lower Pliocene, San Diego. An abundant and characteristic species in many of the Pliocene localities from southern California to Cerros Island, off lower California.

FIG. 2. *Callista* (*Amiantis*) *callosa* Conrad. U.S.N.M. 164953. Imperfect left valve; altitude 50 mm. Lower Pliocene (Fernando formation), Elsmere Canyon, near Newhall, Los Angeles County. Base evenly rounded in perfect specimens. Common from Pliocene to Recent.

FIG. 3. *Callista subdiaphana* Carpenter. U.S.N.M. 164951. Imperfect right valve; longitude 41 mm. Same locality as fig. 2. Abundant in the Pliocene and also found in the Recent.

FIG. 4. *Terebratalia smithi* Arnold. U.S.N.M. 164977. Pedicle valve; longitude 42 mm. Pliocene, Temescal Canyon, 3 miles north of Santa Monica, Los Angeles County. Known only from the Pliocene. A somewhat variable species.

FIG. 4*a*. Same specimen as fig. 4. Brachial valve.

FIG. 5. *Terebratalia smithi* Arnold. U.S.N.M. 164977. Pedicle valve; longitude 29 mm. Same locality as fig. 4. More prominent ribbing than specimen shown in fig. 4.

FIG. 5*a*. Same specimen as fig. 5. Brachial valve.

FIG. 6. *Terebratalia occidentalis* Dall. U.S.N.M. 164996. Brachial valve; longitude 40 mm. Same locality as fig. 4. This species is most variable, as is evidenced by this and the following figures, which show a series collected at one locality. Found in the lower Pliocene (and possibly upper Miocene).

FIG. 7. Same species and locality as fig. 6. Pedicle valve; longitude 29 mm.

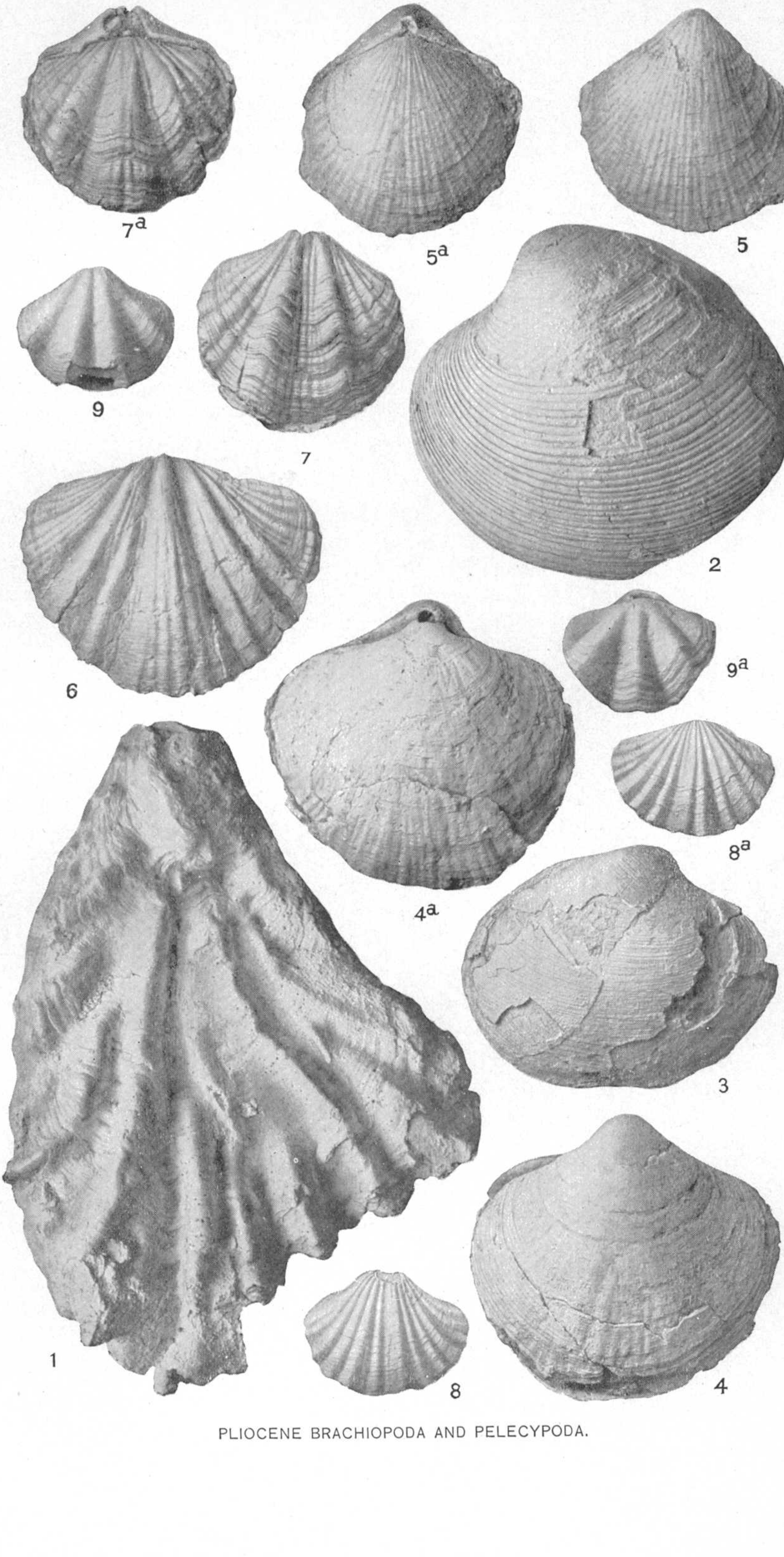
FIG. 7*a*. Same specimen as fig. 7. Brachial valve.

FIG. 8. Same species and locality as fig. 6. Pedicle valve; longitude 22 mm.

FIG. 8*a*. Same specimen as fig. 8. Brachial valve.

FIG. 9. Same species and locality as fig. 6. Pedicle valve of a less rugose variety; longitude 21 mm.

FIG. 9*a*. Same specimen as fig. 8. Brachial valve.



PLIOCENE BRACHIOPODA AND PELECYPODA.

PLATE XL.

Pliocene Pelecypoda and Gasteropoda.

(Unless otherwise stated, all figures are natural size.)

Fig. 1. *Mya truncata* Linné. U.S.N.M. 164950. Left valve; longitude 46 mm. Pliocene (Fernando formation), Elsmere Canyon, near Newhall, Los Angeles County. Found also in the Recent fauna of the Arctic regions.

Fig. 2. *Trochita filosa* Gabb. U.S.N.M. 164949. Slightly imperfect specimen viewed from above; maximum diameter 20 mm.; twice natural size. Same locality as fig. 1. Also found in the upper Miocene.

Fig. 2*a*. Same specimen as fig. 2. View from the side.

Fig. 3. *Fissuridea murina* Carpenter. U.S.N.M. 164945. Specimen viewed from above; longitude 14.5 mm.; twice natural size. Lower Pliocene, Third street tunnel, Los Angeles. Also found in the Pleistocene and Recent fauna of the coast.

Fig. 3*a*. Same specimen as fig. 3. View from the side.

Fig. 4. *Cancellaria fernandoensis* Arnold. U.S.N.M. 164956. Back view of imperfect specimen; altitude 17 mm.; twice natural size. Same locality as fig. 1. A similar or identical form was found in the Pliocene of the San Diego well.

Fig. 5. *Tritonium* sp. U.S.N.M. 164954. Back view of imperfect specimen; altitude 20 mm.; twice natural size. Same locality as fig. 1.

Fig. 6. *Pisania fortis* Carpenter var. *angulata* Arnold. U.S.N.M. 164959. Aperture view of imperfect young; altitude 30 mm. Same locality as fig. 1. A rather common species in the Pleistocene and Pliocene of central and southern California.

Fig. 7. *Pisania fortis* Carpenter var. *angulata* Arnold. U.S.N.M. 164958. Aperture view of imperfect adult; altitude 49 mm. Same locality as fig. 1.

Fig. 8. *Cypræa fernandoensis* Arnold. U.S.N.M. 164961. Type. View from back; longitude 40 mm. So far known only from same locality as fig. 1.

Fig. 8*a*. Same specimen as fig. 8. Aperture view.

Fig. 9. *Nassa hamlini* Arnold. U.S.N.M. 164946. Type. Aperture view of imperfect specimen; longitude 15 mm. Same locality as fig. 3.

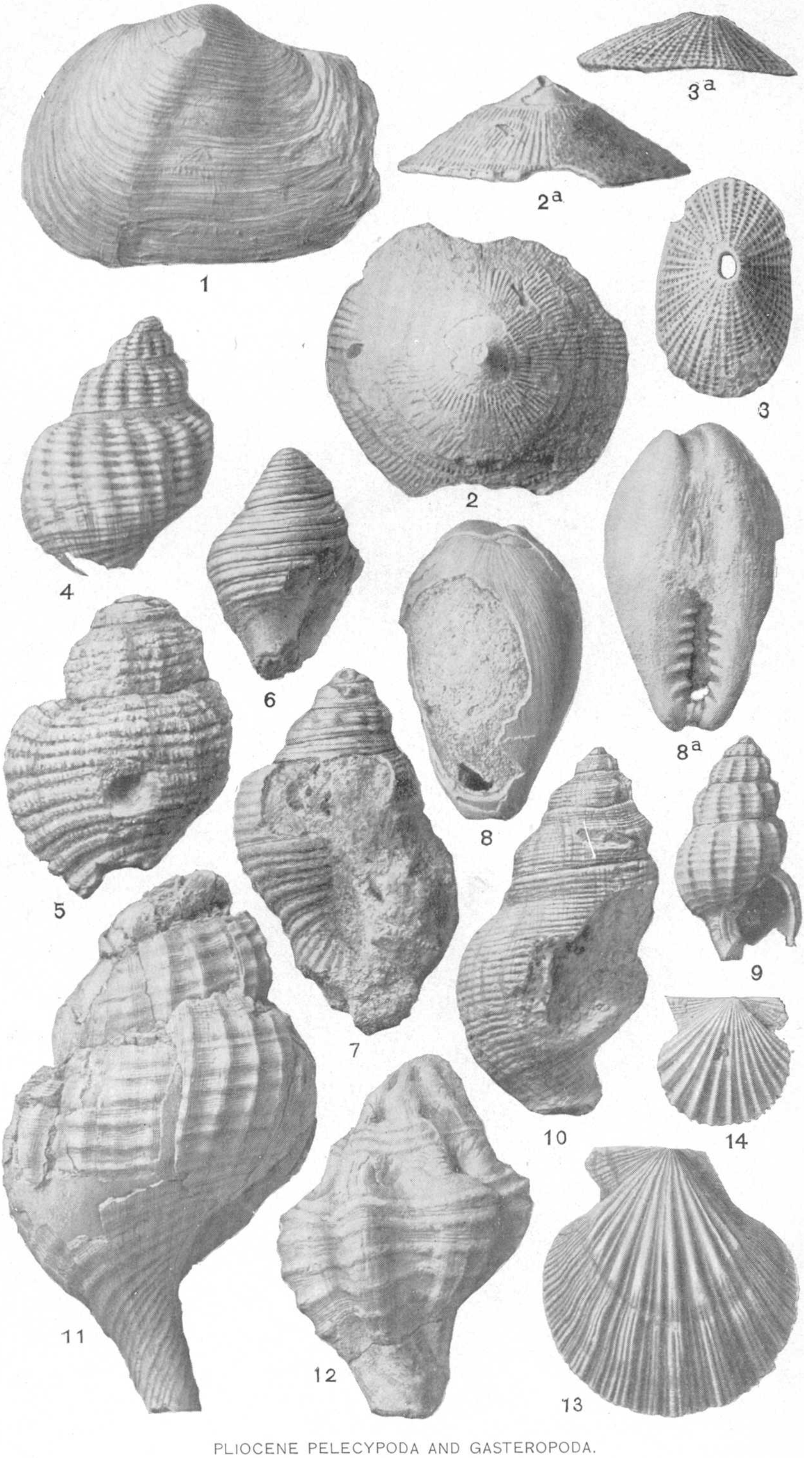
Fig. 10. *Chrysodomus* cf. *arnoldi* Rivers. U.S.N.M. 164962. Back view of imperfect specimen. Same locality as fig. 1. Known also from the Pleistocene of San Pedro, Los Angeles County.

Fig. 11. *Priene oregonensis* Redfield var(?) *angelensis* Arnold. U.S.N.M 164975. Back view of imperfect and slightly contorted specimen; longitude 71 mm. Same locality as fig. 3. Common in the lower Pliocene of the Pacific coast. It is the precursor of the Recent *Priene oregonensis* Redfield.

Fig. 12. *Murex eldridgei* Arnold. U.S.N.M 164955. Type. Back view; longitude 24 mm.; twice natural size. Known only from the same locality as fig. 1. Near the Recent *M. incisa* Broderip.

Fig. 13. *Pecten* (*Chlamys*) *hastatus* Sowerby var. *strategus* Dall. Collection of Delos Arnold. Left valve; altitude 36 mm. Pliocene, Santa Barbara. Also found in the Pliocene of southern California.

Fig. 14. *Pecten* (*Chlamys*) *bellilamellatus* Arnold. Type. Right valve; altitude 18 mm. Pliocene, Pacific Beach, San Diego. Known only from this horizon at this locality.



PLIOCENE PELECYPODA AND GASTEROPODA.

PLATE XLI.

Tertiary Turritellas.

(All figures natural size.)

Fig. 1. *Turritella pachecoensis* Stanton. U.S.N.M. 165002. Back view of imperfect specimen; altitude 59 mm. Eocene, Rock Creek, Los Angeles County. This species is supposed to be characteristic of the Martinez formation (lower Eocene.)

Fig. 2. *Turritella uvasana* Conrad. U.S.N.M. 164974. Wax cast, back view; altitude 41 mm. Sespe Canyon, Ventura County. Supposed to be characteristic of the Tejon formation (middle Eocene).

Fig. 3. *Turritella uvasana* Conrad. U.S.N.M. 165004. Back view of imperfect specimen; altitude 44 mm. Eocene, Rose Canyon, San Diego County.

Fig. 4. *Turtriella ineziana* Conrad (+ *T. hoffmanni* Gabb). U.S.N.M. 164964. Lower Miocene, supposed equivalent of the Fourfork formation, Chaffee Canyon, southwest of Piru, Ventura County. Supposed to be characteristic of the lower Miocene; found from San Mateo to San Diego counties.

Fig. 5. *Turritella ineziana* Conrad. U.S.N.M. 164969. Back view of imperfect specimen; altitude 36 mm. Tar Creek, north of Fillmore, Ventura County. Common in the Vaquers formation, but good specimens are hard to obtain.

Fig. 6. *Turritella ineziana* Conrad var. *sespeensis* Arnold. U.S.N.M. 164970. Type. Aperture view of imperfect specimen; altitude 34 mm. Same locality as fig. 5.

Fig. 7. *Turritella ocoyana* Conrad. U.S.N.M. 164990. Back view of imperfect large specimen; altitude 60 mm. Topanga Canyon, 3 miles south of Calabasas, Los Angeles County. Supposed to be characteristic of the lower Miocene. Common in central and southern California.

Fig. 8. Same species and locality as fig. 7; altitude 58 mm.

Fig. 9. Same species and locality as fig. 7; altitude 32 mm.; upper whorls.

Fig. 10. *Turritella variata* Conrad, U.S.N.M. 164991. Back view of imperfect specimen; altitude 34 mm. Same locality as fig. 7. Supposed to be characteristic of the lower Miocene; so far known only in Fresno County and south.

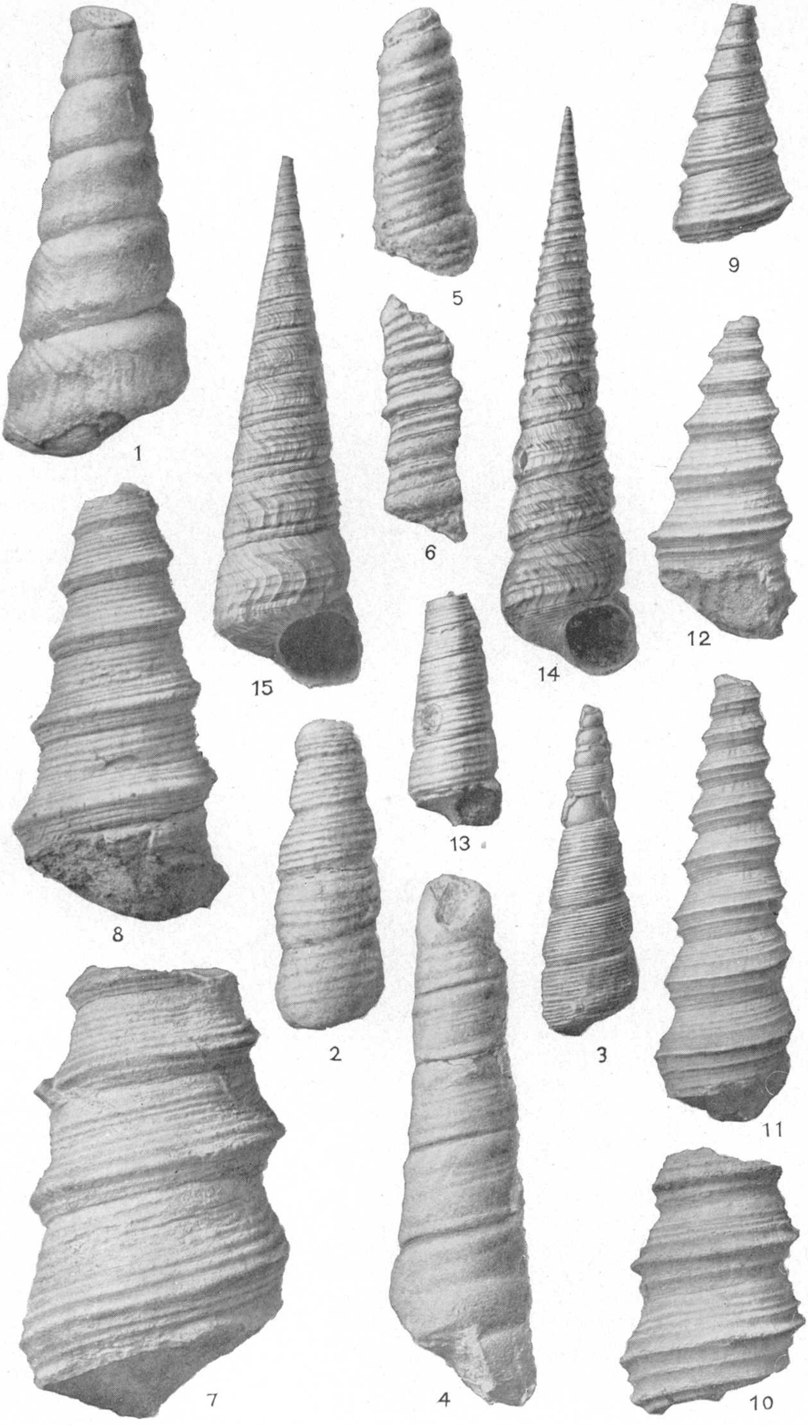
Fig. 11. Same species and locality as fig. 10. Slender variety; altitude 59 mm.

Fig. 12. Same species and locality as fig. 10. Broad variety; altitude 43 mm.

Fig. 13. *Turritella cooperi* Carpenter (var.?) *fernandoensis* Arnold. U.S.N.M. 164957. Type. Aperture view of imperfect specimen; altitude 31 mm. Lower Pliocene, Fernando formation, Elsmere Canyon, near Newhall, Los Angeles County. A common form in the lower Pliocene of southern California.

Fig. 14. *Turritella cooperi* Carpenter. Collection of Delos Arnold. Aperture view of typical form. Lower Pleistocene, lower San Pedro formation, Deadman Island, San Pedro, Los Angeles County. Common in the Pliocene and lower Pleistocene from Ventura County southward.

Fig. 15. *Turritella jewetti* Carpenter. Collection of Delos Arnold. Typical form, aperture view; altitude 70 mm. Same locality and horizon as fig. 14; geologic and geographic range also about the same.



TERTIARY TURRITELLAS.

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Figures in *italic* denote illustrations of fossils.