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# GEOLOGY AND OIL RESOURCES OF THE PUENTE HILLS REGION, SOUTHERN CALIFORNIA

BY
WALTER A. ENGLISH

WITH A SECTION ON THE

## CHEMICAL CHARACTER OF THE OIL

BY
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# ILLUSTRATIONS



NOTE.—The small tract near the west end of the area shown on Plate VIII, just east of the tract of the Fullerton Oil Co., should be marked "Birch Oil Co."

# GEOLOGY AND OIL RESOURCES OF THE PUENTE HILLS REGION SOUTHERN CALIFORNIA

By Walter A. English

## INTRODUCTION

### AREA COVERED

The area described in this report occupies a block roughly 25 miles square, the northwest corner of which is 10 miles east of the center of the city of Los Angeles. It includes parts of Los Angeles, Orange, Riverside, and San Bernardino counties. (See fig. 1.) About a third of the block is hilly or mountainous country, including the Puente, San Jose, and Coyote hills and the north end of the Santa Ana Mountains. The rest is comparatively level valley or coastal plain and is highly cultivated, much of the land being the most valuable citrus land of the State.

The proved oil fields occupy only comparatively small areas and with the exception of the Richfields and Santa Fe Springs fields are along the edge of or within the hills, where the land is less valuable for agriculture than elsewhere. There are nine productive fields, of which four are along the south side of the Puente Hills, two in low detached hills, two on the plain south of the Puente Hills, and one in Santa Ana Canyon. These fields form a majority of the productive fields of southern California, and their combined production is normally a third of the State's total.

### PURPOSE AND SCOPE OF EXAMINATION

A study of this district was undertaken in continuation of the Geological Survey's policy of investigating the geology and oil resources of the California fields. It is hoped that publication of the results of such work will lead to the more efficient development of known resources and will aid wildcatters in finding new pools with a minimum of unsuccessful drilling.

In recent years there has been considerable study of the geologic conditions in developed fields as an aid to the drilling of wells. This study is being carried on by the State Mining Bureau as well as by most of the larger companies in greater detail than would be possible for the Survey. Furthermore, such detailed work, if it is to be of any great value, must be constantly revised to include the results of the latest drilling, and revision of that sort is impossible under the Survey's methods of study and publication. For these reasons the writer has confined his work to the broader features of geology in their relation to the proved and prospective fields. Only such descriptions of the developed fields are included

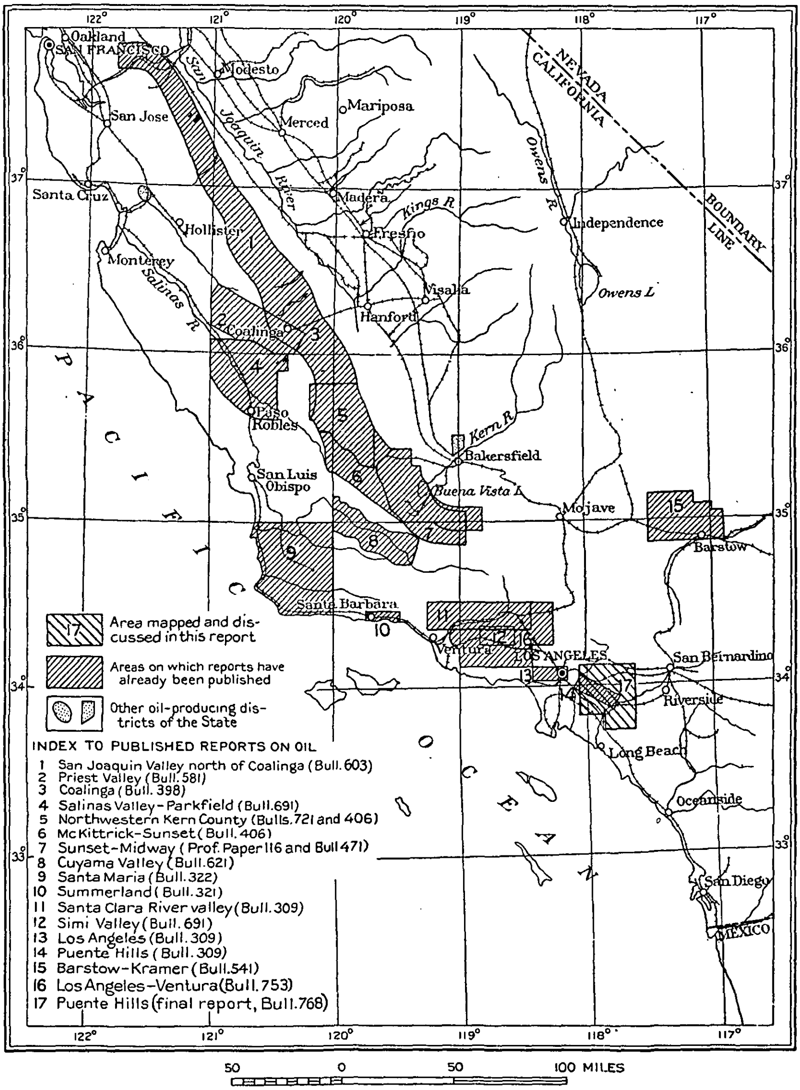


**FIGURE 1.—Index map of a part of southern California**

as are necessary to the understanding of the relation of the geologic structure and sequence of formations to the occurrence of oil. Subsurface conditions in the developed fields as worked out by well logs are treated from the viewpoint of the structural geologist rather than from that of the development engineer.

## CHARACTER AND METHODS OF FIELD WORK

The writer spent approximately six months in the field and was assisted for three months by W. S. W. Kew. Most of the time was spent in mapping areal geology, as much of the country requires very detailed examination because of the complicated structure and the lack of any easily recognized characteristics by which the several formations could be differentiated. Despite the careful mapping, several areas were found in which the conditions are subject to more than one interpretation, and it is doubtful if another geologist going over the same ground with equal care would agree with all the details of the writer's mapping.

As a base for recording field observations photographic enlargements of the Geological Survey's topographic maps were used, mostly on a scale of 1½ and 2 inches to the mile. Locations for plotting geologic data were determined by the intersection of Brunton compass sights taken to prominent topographic or cultural features. No altitudes were determined except as an aid in making corrections in topography to be used on the base map prepared for this report. This method of field work, though less accurate than determinations of location and altitude with a plane table, permits fairly rapid work, and the geologist's attention can be concentrated on problems of geology rather than of surveying.

Because of the irregularity in structure, numerous unconformities, variations in thickness of formations, and lack of key beds it is not practicable to construct a structure-contour map for the undrilled territory of the type that is commonly made for the more gently dipping and less variable beds of the Mid-Continent region. Any prediction of depth to possible oil sands in untested areas must be of a very general nature, and the estimates may easily be in error 500 feet or more. For wildcat territory the California geologist is usually well satisfied if he is able to work out the main features of stratigraphy and structure correctly and make a rough estimate of the probable depth of the supposed productive zone.

Because of many changes that have taken place in the cultural features since the Survey's topographic maps were made and because they exhibit some errors in the delineation of topography it was found difficult to use these maps for some parts of the Puente Hills. In the Anaheim quadrangle the writer located a number of prominent points by plane-table triangulation, starting from the primary triangulation points of the Geological Survey. Wherever possible Brunton compass sights to these accurately located points were used for determining locations during the course of geologic mapping. Later, such data as had been gathered being used as a control, surface contours were sketched so that the altitudes of the main ridges and valleys would correspond with those given on the topographic map of the same area. The land net for the district south of the central part of the Puente Hills is taken from an accurate triangulation survey made by the Union Oil Co. of California and kindly made available to the writer. The rest of the land net is adapted from the development maps published by the State Mining Bureau and was tied to the other work by plane-table location of wells that are shown on the development maps. The surface contours for the region of La Habra Canyon are taken from an accurate map showing 10-foot contours prepared for the La Habra Heights Co. by Olmstead & Gillelen. For the south flank of the Puente Hills east of La Habra Canyon and for the north flank of the Whittier Hills the contours are taken from some excellent topographic maps prepared by the Shell Oil Co.

## ACKNOWLEDGMENTS

During the greater part of the time spent in the field the writer had the assistance of W. S. W. Kew, whose work is gratefully acknowledged. Mr. Kew also kindly undertook the preparation of structure-contour maps of most of the developed fields, as acknowledged on the maps themselves. Owing to the pressure of other work after the writer's resignation from the Survey he found it impossible to prepare these maps, and he therefore feels particularly grateful to Mr. Kew for his help.

Mr. Paul W. Prutzman, chief chemist for the General Petroleum Corporation and an authority on the chemical character of California oil, kindly consented to prepare the section on the chemical character of the oil of this field. Mr. Prutzman undertook this work without any remuneration and despite the pressure of other work. The writer feels both pleased and honored by Mr. Prutzman's cooperation.

The writer encountered a uniformly friendly attitude among operators and geologists, and practically all the data he requested from the different companies were obtained without difficulty. Among those to whom the writer and Mr. Kew are indebted for information are Messrs. I. V. Augur, Ward B. Blodgett, Rod. Burnham, J. B. Case, R. E. Collom, W. E. Dunlap, J. E. Elliott, S. H. Gester, J. Jensen, Ben Laase, C. R. McCollom, G. A. Macready, R. B. Moran, E. D. Nolan, W. W. Orcutt, R. M. Overbeck, Van Holst Pellekaan, Robert Phelps, A. T. Schwennesen, M. H. Soyster, C. C. Thoms, L. Vanderleck, C. M. Wagner, E. W. Wagy, and E. J. Young.

## GEOGRAPHY

### DEFINITIONS OF GEOGRAPHIC NAMES

Because of the loose manner in which many names of topographic features are applied to different areas by different authors it is desirable to define the application of certain of the names that will be used for this district. The following definitions conform to current usage for the district as far as possible.

Puente Hills: The whole group of hills lying between the towns of Pomona, Whittier, and Corona and a small area directly south of the town of Puente. As there is no other name applicable to the larger division, the name should preferably be used for the group of hills lying between Santa Ana and San Gabriel rivers. As thus defined the hills are triangular in outline, being bounded on the northwest by San Gabriel Valley, on the northeast by San Bernardino Valley, and on the southwest by the Santa Ana coastal plain, La Habra Valley, and Santa Ana River canyon.

San Jose Hills: The northern part of the Puente Hills; includes the hills north of San Jose Creek.

Whittier Hills: The part of the Puente Hills directly north of the city of Whittier and east to La Habra Canyon.

Chino Hills: The northeastern part of the Puente Hills, facing San Bernardino Valley. As there is no topographic line of separation from the rest of the Puente Hills, the name is probably best applied to the hills as far west as the divide at the head of the drainage toward Chino Valley. A preferable term would be Chino slope of the Puente Hills.

San Gabriel Valley: The valley in which is the old San Gabriel Mission, founded in the days of Mexican administration. The valley is semicircular in shape, the San Gabriel Range, on the north, forming the base of the semicircle. To the south are the Pasadena (San Rafael) Hills, East Los Angeles (Repetto) Hills, Merced Hills, and Puente Hills. Toward the east, between the Puente Hills and the San Gabriel Mountains, is a pass connecting the San Gabriel and San Bernardino valleys. On the south side of San Gabriel Valley is a pass between the Puente and Merced hills which opens on the coastal plain and through which San Gabriel River flows.

Puente Valley: A small reentrant part of San Gabriel Valley south of the town of Puente, between the Whittier and San Jose hills.

San Bernardino Valley: The large valley northeast of the Puente Hills, bounded on the north by the San Gabriel Range, on the south by low hills that parallel Santa Ana River on its south side, and on the northeast by the San Bernardino Range. Different parts of this valley have been called Pomona Valley, China Valley, Cucamonga Plains, San Bernardino Basin, Riverside Valley, and Redlands Valley. There is very little uniformity in the way in which the names of these various subdivisions are used.

Coyote Hills: Two groups of low hills a few miles south of the Puente Hills, known as the East Coyote Hills and West Coyote Hills.

La Habra Valley: The valley lying between the Puente and Coyote hills and opening out on the Santa Ana Plain to the west and east. It should not be confused with La Habra Canyon, which lies at the head of La Habra Creek, within the Puente Hills.

Santa Ana Mountains: Mountains southeast of the Puente Hills, from which they are separated by the canyon of Santa Ana River. To the southeast they extend 40 miles to Temecula River, the first stream southeast of Santa Ana River to break through their crest.

Santa Ana coastal plain: The low seaward-sloping plain that stretches from the southwest side of the Puente Hills and Santa Ana Mountains to the Pacific Ocean. To the southwest this plain is limited by the San Joaquin Hills. To the northwest its limit has been arbitrarily placed at San Gabriel River, beyond which is the Los Angeles coastal plain. Mendenhall[1] called the Santa Ana coastal plain the "eastern coastal plain of southern California."

Oil districts: Whittier, Brea Canyon, Olinda, Santa Fe Springs, West Coyote Hills, East Coyote Hills, Richfields, old Puente, and Santa Ana Canyon fields. These names follow current usage, which is uniform except that the Santa Ana Canyon field is also known as the Yorba and the Yorba Linda field. In some of the older publications different names are used. The name Whittier-Fullerton fields was formerly applied to the fields on the south flank of the Puente Hills, and the Brea Canyon and Olinda fields were known as the Fullerton field. At that time these two and the old Puente and Whittier fields were the only ones known. Since the development of the East Coyote Hills field, between the Fullerton field and the town of Fullerton, the name Fullerton has been dropped. In some of the bulletins of the State Mining Bureau the East Coyote Hills field was called the La Habra field, though it lies a considerable distance from the town of La Habra and directly between the so-called Fullerton field and the town of Fullerton.

## TOPOGRAPHY AND DRAINAGE

Inasmuch as the character of most of the topographic features of this region can be seen by an examination of the topographic map, the following description is confined to a few generalities and to features not evident on the map.

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[1] Mendenhall, W. C., Development of underground waters in the eastern coastal plain region of California: U. S. Geol. Survey Water-Supply Paper 137, 1905.

In common with other areas in southern California, this district includes both nearly level plains and hills of considerable relief, and the dividing line between the two types of topography is fairly abrupt. This sharp division between hills and plain is a characteristic feature of topography developed in the arid climate of the Western States. The plains slope at low angles away from the hills, and the slopes become less as the distance from the edge of the hills increases. The height of the plains above sea level is considerably greater on the landward side of the hills than on the oceanward side. Near Whittier the plains are 300 feet above sea level, and at the east end of San Gabriel Valley they lie at nearly 1,000 feet.

The two highest points in Puente Hills are Workman Hill (1,391 feet) in the west and San Juan Hill (1,780 feet) in the east. The height of each of these peaks above the nearest part of the plains is about 1,000 feet, which gives a measure of the maximum relief of the hills. Within the hills the relief is only moderate, the canyon depths being mostly not more than 400 feet. The canyons, even though narrow, are flat bottomed. The adjacent ridge slopes are convex upward—that is, the steepest slope is close to the lower edge of the ridge, the slope lessening toward the crest, which is generally rounded. Sharp peaks, narrow gorgelike canyons, and similar features are entirely lacking. Every part of the hills can be reached on foot without hard climbing, and generally an automobile can be driven within a short distance of any point a visitor desires to reach.

The Santa Ana Mountains, at least in their northeastern part, are higher and more rugged than the Puente Hills. Sierra Peak, near their north end, is over 3,000 feet in altitude, or more than half a mile higher than Santa Ana River, less than 2 miles away. Much of the higher part of these mountains is so rugged as to be reached with difficulty, even on foot, and many of the slopes are so steep as to be practically impassable. From Sierra Peak the crest of the mountains trends southeast, parallel to the eastern edge of the mountains, and the width of the rugged belt increases and the peaks become higher toward the southeast. The range is asymmetric, the crest line lying much nearer to the northeastern edge of the mountains than to the southwestern edge. Toward the southwest there is a gradual decrease in height and ruggedness, the outer hills in this direction partaking of the same topographic character as the Puente Hills.

Santa Ana River is by far the largest stream in this district and the only one worthy of the term river. It has its source in the lofty San Bernardino Mountains and flows across the broad San Bernardino Valley before entering the narrow canyon that it follows for that part of its course between the Santa Ana Mountains and the

Puente Hills. Beyond this canyon it flows across a wide, nearly featureless plain (Pl. II, *B*) into the sea at Newport Beach. During floods the river may be 10 or even 15 feet deep where it flows through the canyon, but this stage lasts for only a short time, usually not more than a few hours, and for the greater part of the year the stream is from 2 to 4 feet deep and 50 to 100 feet across. At the upper end of the canyon, where the river flows across bedrock for a short distance, a considerable part of the normal flow is diverted into canals for irrigation.

Santiago Canyon receives the water from a good-sized drainage basin in the northern part of the Santa Ana Mountains and carries a small perennial stream. In winter the creek averages 25 feet across, but in summer the surface flow ceases entirely in the lower part of the canyon. As on most other streams in this district, the underground flow during summer is greater than the surface flow.

The rest of the canyons and small valleys in both the Puente Hills and the Santa Ana Mountains have very small drainage areas and contain streams only immediately after rains.

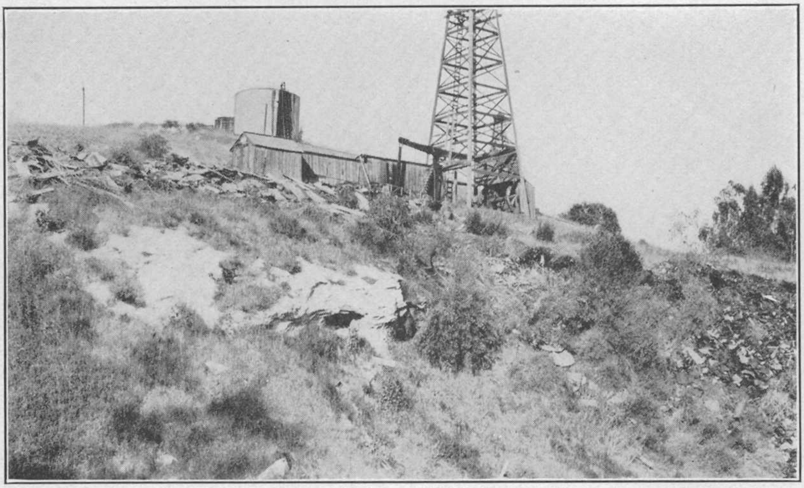
## CLIMATE

The climate of southern California is so well known that little description is necessary here. Because of its situation, facing the coast, this area gets the full effect of the ocean in moderating the temperature. As a result there are no extremes of temperature either in winter or summer. In winter light frosts occur occasionally, and in summer a temperature of over 90° is uncommon, though 100° is sometimes reached for short periods of time.

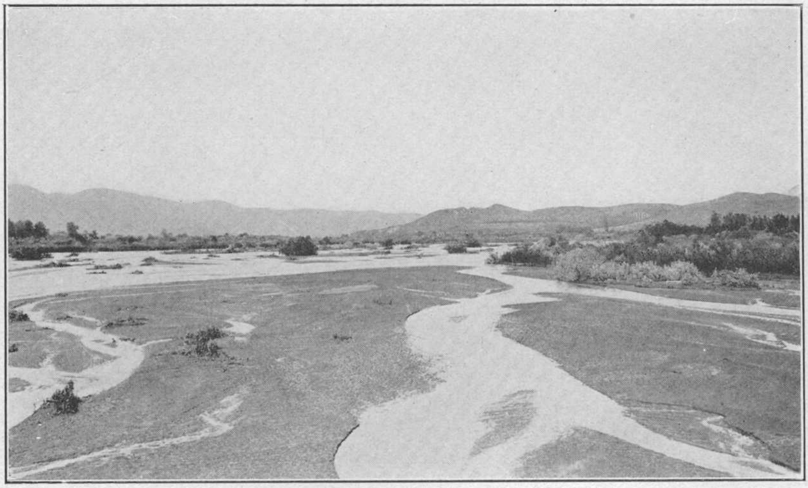
The rainfall is small and comes almost entirely in the winter. At Anaheim the average annual rainfall over a series of years has been 11.5 inches, which is a fair average for the plains. The amount of precipitation increases with the altitude, and the top of the Santa Ana Mountains probably receives several times as much rain as the plains.

## NATURAL VEGETATION

As a result of the semiarid climate this region has only a sparse growth of natural vegetation, particularly on the plains and low hills. Most of the plains are cultivated at the present time, but formerly they were covered during spring and early summer with an abundant growth of annual grasses and wild flowers. The rainless summer changed this vegetation to brown by the middle of June, and for the rest of the year only a few drought-resisting shrubs survived. Though mostly barren of larger plants, the Puente Hills have a light growth of chamisal on the steeper sandstone



*A*. SUPERFICIAL GYPSUM DEPOSIT



*B*. FLOOD PLAIN OF SANTA ANA RIVER

ridges, and a few clumps of wild walnut, liveoak, and California holly grow at points where local conditions are particularly favorable. On the higher and more rugged parts of the Santa Ana Mountains the brush is thicker; the mountain laurel and scrub oak, because of their thorns and wiry branches, are most impressive to the traveler who is not particularly interested in botany.

## CULTURE

This district is part of the southern California region that is noted throughout the country for its production of citrus fruits. The best land for oranges is near the upper edges of the plains, next to the hills; here the soil is lighter and there is less danger of frost than farther out in the valleys. Possibly two-thirds of the area within 5 miles of the edge of the hills is planted to oranges or lemons. That there is some land within this area not so planted is due to extremely local variations in soil or climate or to the lack of sufficient water for irrigation. Many expensive engineering developments have served to increase the amount of water available for irrigation above that naturally flowing in the streams as they emerge from the mountains. Some of these dams, tunnels, and wells disturbed the natural flow of surface and underground water and resulted in many lawsuits over water rights. Land accompanied by the right to sufficient water for proper irrigation is worth as much as $1,000 an acre for the raw land, and good bearing citrus groves sell for several times that amount.

On the lower land with heavier soil walnuts, alfalfa, and sugar beets are among the principal crops.

As is to be expected with high-priced land and crops, the individual holdings tend to be small, and the farmers resort to intensive cultivation. There is a large rural population per square mile, and to serve the needs of the orchardists, towns of several thousand people are scattered every few miles through the orange-growing district. Santa Ana (population in 1920, 15,485), Pomona (13,505), Whittier (7,997), Anaheim (5,526), Orange (4,884), Fullerton (4,415), and Corona (4,129) are the principal towns.

All the principal highways are paved, and most of the less traveled roads are good, though some of the macadam and oiled roads that were built before the effect of heavy automobile traffic on different types of road was understood have become rough. Orange County is well known for its good roads, as well as for its insistence that they be traveled only at legal speed. Steam railway and interurban electric lines connect the principal towns with Los Angeles and with one another.

## PREVIOUS PUBLICATIONS

The following annotated list includes the better-known and more easily obtained works dealing with geology and oil developments within the area described in this report.

Prutzman, P. W., Production and use of petroleum in California: California State Min. Bur. Bull. 32, 230 pp., 1904. The greater part of the volume is devoted to a discussion of the uses to which crude and refined petroleum can be put, as at the time the report was written an increased consumption of oil was more to be desired than greater production. The first 50 pages is devoted to production; notes on development, maps, and a summary of the operations in each field are given, as well as a few remarks on the cost of drilling, drilling conditions, and geology. The bulletin is of interest at the present time chiefly as it gives data on the history of the fields.

Mendenhall, W. C., Development of underground waters in the eastern coastal plain region of southern California: U. S. Geol. Survey Water-Supply Paper 137, 140 pp., 1905. This paper describes the water resources and gives a contour map of the water table for the Anaheim and Santa Ana quadrangles. Geologists have found these maps of interest in the search for possible buried structural features beneath the plain, irregularities in the water table being thought by some to give indications of geologic structure.

Mendenhall, W. C., Development of underground waters in the central coastal plain region of southern California: U. S. Geol. Survey Water-Supply Paper 138, 138 pp., 1905. This paper is similar to the preceding in scope and describes the two quadrangles adjacent to the west (Downey and Las Bolsas).

Eldridge, G. H., The Puente Hills oil district, southern California: U. S. Geol. Survey Bull. 309, pp. 102–137, 1907. The report includes a geologic map and detailed description of the western portion of the Puente Hills, which at the time of publication included all the productive fields.

Mendenhall, W. C., in Willis, Bailey, Stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, pp. 505–506, 1912. Description of the Triassic beds of the Santa Ana Mountains. Largely a product of a careful study of the Triassic and older rocks of the Santa Ana Mountains made by Mendenhall and E. S. Larsen.

Prutzman, P. W., Petroleum in southern California: California State Min. Bur. Bull. 63, 430 pp., 1913. Chapters 13 to 16, containing 80 pages, are devoted to the Whittier-Fullerton area and give many valuable data on wells drilled, depth, and production; general statements on probable geologic structure and extent of the fields; physical characteristics and results of distillation tests on 52 samples of oil from wells in the area. The book is particularly valuable for data on old wells, for many of which there is no other source of information.

McLaughlin, R. P., and Waring, C. A., Petroleum industry of California: California State Min. Bur. Bull. 69 and map folio, 1914. Pages 308–349 give the history of early developments in the Whittier-Fullerton fields, statistics on the production and life of wells, cost of drilling, financial results of typical companies, and a directory of operating companies. Pages 305–367 contain notes by Waring on the geology of the region and of the fields that were developed at that time. The data on the proved fields are the best published up to that time in regard to structure, sands present, and limits of the fields. The map folio shows the geology of the Puente Hills and Santa Ana Mountains on a scale of half an inch to the mile. Most of the mapping is of a reconnaissance character.

Dickerson, R. E., The Martinez and Tejon Eocene and associated formations of the Santa Ana Mountains: California Univ. Dept. Geology Bull., vol. 8, pp. 257–274, 1914. This paper embodies part of the results of a summer-school field trip of University of California students and the subsequent laboratory study of the fossils collected. It gives the best data available on the paleontology of the formations present in the Santa Ana Mountains.

Packard, E. L., Faunal studies in the Cretaceous of the Santa Ana Mountains: California Univ. Dept. Geology Bull., vol. 9, pp. 137–159, 1916. This is a companion paper to the one by Dickerson cited above. It gives the results of a careful study of a large collection of Cretaceous fossils and a good description of the lithologic character of the Cretaceous of the Santa Ana Mountains. The map is the same as the one published by Dickerson except that a division line in the Cretaceous is added.

McLaughlin, R. P., First annual report of the State oil and gas supervisor: California State Min. Bur. Bull. 73, pp. 1–278, 1917. Chapter 4, pp. 173–191, by R. B. Moran, gives a concise and accurate statement of development, geology, and water conditions in the fields. Pages 236–271 give statistics of production by fields and a directory of operating companies.

McLaughlin, R. P., Second annual report of the State oil and gas supervisor: California State Min. Bur. Bull. 82, pp. 1–412, 1918. Chapter 2, pages 123–153, by M. J. Kirwin, gives an account of developments during the current year and progress made in the study of subsurface geology, construction of peg models, etc.

McLaughlin, R. P., Third annual report of the State oil and gas supervisor: California State Min. Bur. Bull. 84, pp. 1–617, 1918. A report on the Whittier-Fullerton fields by M. J. Kirwin is given on pages 199–224. It comprises a statement on water conditions and a correlation of oil sands in the different fields.

Vander Leck, Lawrence, Petroleum resources of California: California State Min. Bur. Bull. 89, pp. 131–143, 1921. The chapter on southern Los Angeles and Orange counties is devoted to a short description of each of the productive fields. The possibilities of the discovery of other fields in untested areas are discussed.

## GEOLOGY

### STRATIGRAPHY

#### GENERAL CHARACTER OF FORMATIONS

The Puente Hills region contains a representative though by no means complete section of the formations that occur in the Coast Ranges of California. (See Pl. I, in pocket.) Unmetamorphosed marine sedimentary formations ranging in age from Cretaceous to Quaternary are present in what for many regions would be considered unusual thickness. The Cretaceous beds are separated from older formations by a profound unconformity, which marks the time of intrusion of a granite batholith with accompanying folding and metamorphism. Only a few formations that antedate this intrusion have been identified either here or elsewhere in the Coast Ranges. Within the area studied for this report the only pre-Cretaceous formation from which fossils have been obtained is a black slate of Triassic age. Various other types of rock are present in the pre-Cretaceous complex, but their character was not studied for the present report, and they were not separated from the Triassic slate or the granite in mapping.

The Cretaceous, here as in other parts of the Coast Ranges, consists of dark-gray to green clay shale, with minor amounts of sandstone and conglomerate. In a comparison with the Tertiary formations the dark color is the most distinctive feature. Sections of great thickness are found in which there are only minor variations in lithology from top to bottom. Several sections of Cretaceous strata from 20,000 to 30,000 feet thick have been measured in the central and northern parts of the State.

The post-Cretaceous orogenic movements caused a marked change in the type of sediment that was brought to the basins of deposition of the Coast Range province. Contrasting with the dark Cretaceous shale are the Tertiary sediments, in which the predominating lithologic types are buff conglomerate and sandstone, pink to nearly white diatomaceous shale, and light-colored clay shale. Débris of varying degrees of coarseness derived from the erosion of granitic rocks, together with the skeletons of diatoms, makes up the material out of which the Tertiary beds were formed. The coarser material, consisting of granite boulders and pebbles, has gone to make thick conglomerates. From such beds there is a gradation through ordinary arkosic and quartzose sandstone to beds of extremely fine sand in which the individual mineral grains can hardly be seen except with a lens. Other types of fine material are clay, diatom remains, and possibly precipitated silica. These various types of sediments are found mixed in all ratios of relative abundance. There are many variations, both vertical and horizontal, from one to another of these lithologic types, so that a description of the lithologic character of the formations tends to become a monotonous repetition of the names of a very few types of sediment.

Although there is much lateral variation within the Tertiary formations, still there are some broad distinctions based on lithology which may be made between the formations. Each formation contains beds of all lithologic types, yet there is usually a particular type which is most abundant and is characteristic of the formation, or some peculiar type may be sufficiently abundant to identify the formation. The Martinez formation, which contains white and green sandstone but consists mainly of dark shale that is very similar to the dark shale in the underlying Cretaceous, is identified lithologically by the presence of glauconite. The Tejon contains much yellow quartzose sand, beds of which tend to weather to prominent cavernous reefs. Beneath the Miocene is the Sespe, a formation identified by its characteristic red beds of clay and sand, with which are interstratified blue and green shaly and sandy beds and white sandstone. The widespread presence of this type of varicolored beds near the base of the Miocene has led to considerable discussion of the reason for the red color, but no very definite conclusions have yet been reached. The Sespe is of nonmarine origin. The marine Vaqueros formation is undoubtedly represented in the region but has not been separated from the Sespe formation. The overlying Topanga formation is typically buff to white sandstone, more arkosic and with the grains less rounded than in the Tejon. In the succeeding Puente formation, which is in part, at least, equivalent to the upper portion of the Monterey group of central California, the most characteristic feature is the presence of siliceous shale. Some phases of this shale consist of pure diatomaceous remains, but most of it is fine siliceous mud with considerable amounts of sand and clay in the less pure shale. Conglomerate and sandstone of extreme lenticularity are present locally. Because of lithologic variations from place to place the different horizons in the formation can not be recognized with certainty over the comparatively small area here mapped. The overlying Fernando deposits consist of thick conglomerate of fairly well rounded boulders, with which are interbedded sandy clay shale and yellow sandstone. The conglomerate, like that in the Puente, is very lenticular, and in general the change from conglomerate to sandstone or sandy shale seems to be one of lateral gradation rather than of a thinning of the beds to a feather edge. The succeeding San Pedro (?) formation consists of rather poorly indurated shaly sandstone and conglomerate, not differing greatly from the Fernando in lithology, though the induration is notably less. Terraces of considerable thickness but of small areal extent are found around the edges of the hills and along some of the streams, and the plains are covered to a considerable depth by recent alluvial fans.

The Tertiary formations of this district are as a whole well indurated as compared with the Tertiary of other geologic provinces. Each of the several unconformities between the formations represents a period of folding, during which the heat and pressure incident to the folding had a tendency to harden the rocks. The post-Fernando folding, being the most severe of these movements, had the greatest effect, and consequently the Fernando is nearly as well indurated as some of the older Tertiary formations. However, each successively younger formation is slightly softer than its predecessors.

There is much difference in the amount of induration between beds of different lithologic type. Cementation seems to have been less effective on the sandstones and conglomerates than on certain types of shales. The sandstones made up almost entirely of quartz are usually not very hard on the surface, and some of them are very incoherent. Where there is a mixture of clay with the sand the bed is generally harder. Where lime is present, as in fossiliferous reefs, a very hard sandstone may be formed. The beds of clay and sandy clay are usually hard where unweathered, though surface outcrops are almost all weathered to a soft crumbly shale which can be dug easily with a geologist's pick. The diatomaceous shale, especially the purer varieties, varies much in induration, some beds being soft and powdery, though an adjacent bed may be hard and flintlike.

Resistance to erosion does not vary directly with the hardness of the bed in its surface outcrops. The beds of pure quartz sand and the conglomerates are notably resistant to erosion. The shales are in general more easily eroded, and in a series of alternating sandstone and shale beds the sandstones form the ridges and the shales form the swales.

## CONDITIONS OF TERTIARY DEPOSITION

One of the most interesting features of the Tertiary succession is the overlap within short distances of thick formations that appear to be conformable beneath the overlapping beds. This would ordinarily be explained as overlap along a steep mountain front which gradually became submerged beneath the sea. In some places this explanation fits local conditions. In others, as at the overlap of the lower shale member of the Puente, there is no coarse material in the overlapped formation, such as would be present in a formation deposited in the vicinity of a steep scarp facing the ocean. It is believed that in such places the land was never much above sea level, but that it was being uplifted and the adjacent basin was being depressed during the course of deposition. At places the abruptness of the overlap suggests very strongly that the differential movement between the basin and land areas was accomplished by movement along a fault. Locally the faulting occurred along one of the present major falts, so that the basin of deposition coincided roughly in area with the structural block on which the formation now crops out. The fact that the differential movement between blocks on which deposition was taking place and adjacent blocks that were furnishing the sediment was produced by faulting served to give a certain definiteness in outline to the blocks, which is lacking where the movement was one of folding.

Thus southern California furnishes some striking examples of conditions of deposition characteristic of the Coast Ranges, which have been described by the writer[2] as follows:

In the Coast Range province conditions of sedimentation were subject to great local variation during the Tertiary period. The variations were necessary results of the constantly changing relations of land and sea caused by the many warping movements to which the province was subjected. Tectonic forces were active, with varying degrees of intensity at different times and at different parts of the Coast Ranges, practically throughout the Tertiary period. There were both widespread movements that elevated or depressed the major part of the province and caused marine waters to retreat from or transgress over most of it, and more local movements that caused the relative elevation or depression of small blocks of the earth's crust within the province. Differential uplifts similar to those that formed the present ranges accompanied the earlier general movements of subsidence and uplift and formed long island ridges in the sea which during parts of the Tertiary period covered the Coast Range area and in which the sediments now constituting the Tertiary formations were deposited. The mingling of sediment derived from these islands with that derived from the mainland areas and the effect of the islands of low relief in sheltering certain areas from deposition of such material produced the puzzling variations in lithology shown by the Tertiary formations.

As a result of the repeated warping movements which the Coast Range region suffered during Tertiary time, land masses of pronounced relief existed for a considerable part of that period. Erosion was active, a large amount of sediment was carried to the areas of deposition, and formations many thousands of feet in thickness were laid down during the same period in which only a few hundred feet of deposits accumulated in more stable areas such as the eastern part of North America.

## TRIASSIC SLATE AND ASSOCIATED FORMATIONS

The central part of the Santa Ana Mountains is made up of a complex of metamorphic and partly metamorphosed sediments, together with granitic intrusives. At least part of the metamorphosed rocks are of Triassic age. This complex forms the crest of the mountains from Santa Ana River southward, and the belt widens toward the southeast to form nearly the whole of the southeast end of the mountains. Because of their hardness these rocks make up most of the float in Santiago Creek, on the western flank of the mountains, and it was chiefly from these pieces of float that the writer gained his ideas of this formation. W. C. Mendenhall,[2a] who was in charge of some mapping done by the United States Geological Survey in the region of the Santa Ana Mountains about 20 years ago, gives the following description of the Triassic slate and associated formations:

[2] English, W. A., Geology and oil prospects of Cuyama Valley, Calif.: U. S. Geol. Survey Bull. 621, p. 195, 1916.

[2a] Mendenhall, W. C., in Willis, Bailey, Stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, pp. 505–506, 1912.

The Santa Ana Mountains, usually regarded as a southern extension of the Coast Ranges, form a part of the boundary between Riverside and Orange counties in southern California. The group, which lies for the most part south of the lower course of Santa Ana River and west of the Temescal Wash, culminates in Santiago Peak, 5,680 feet high. Its axis is made up of a series of dark-gray or black slates with minor amounts of interbedded brown sandstones, the whole sparingly intruded by a series of medium acidic dikes and overlain unconformably by remnants of the associated effusives, whose aspect is generally that of andesites or slightly more acidic rocks.

The slates exhibit varying degrees of metamorphism. They usually have a well-developed cleavage, which, however, is generally not sufficiently perfect to obscure the original bedding planes. In general appearance they resemble the Mariposa slate of central California, although as a rule they are less extensively altered. These sediments are the oldest rocks of the mountain range in which they occur. The effusives already mentioned overlie the slates but have been affected by a part of the same metamorphism.

Both the sediments and the associated effusives have been intruded and slightly altered by great masses of granitic rocks, and this threefold series, after a long time interval, represented by an extensive physical unconformity, has been at least partly buried under Cretaceous conglomerates and shales of Chico aspect that are now entirely unaltered though extensively deformed. These Upper Cretaceous rocks form an encircling outcrop that flanks the dome of older rocks.

The determination of the age of the slates is based on small collections made in Ladd Canyon, on the south slope of the range, and near the mouth of Bedford Canyon, on its north slope. These collections were examined by Dr. Stanton, who reports as follows on the Bedford Canyon collection:

"The two Triassic lots, both from the neighborhood of Bedford Canyon, evidently came from essentially the same horizon. No. 230 contains fine specimens of a large species of *Rhynchonella* of a Mesozoic type and a single specimen of *Spiriferina*. No. 321 contains the same species as 230 and in addition a plicate form of *Terebratula* and fragments of crinoid stems. These fossils taken together clearly indicate the Triassic age of the fauna, but in the absence of ammonites and other diagnostic forms it is not possible to determine the exact horizon, although it is probably Upper Triassic rather than older."

Thus the collections, although meager, seem abundantly sufficient to establish the Triassic age of the slates. Accepting this age, then, as determined, we must assign the later granitic intrusions to the Jurassic or the early Cretaceous.

The Triassic beds probably extend considerably beyond the area in the Santa Ana Mountains where they have been carefully examined. Similar beds are known to occur in Railroad Canyon between Elsinore and Perris, and fragmental masses of them apparently caught up in the widespread granitic intrusions of the area occur farther east in the vicinity of Paloma and Los Alamos valleys, in Riverside County.

In the north end of the Puente Hills, near Pomona, are two areas of granite. The exposures of granite are very good in Ganesha Park, in the northwestern part of the city, where several of the road cuts reach a depth of 10 feet below the previous surface. Even this depth is not sufficient to expose any but a much weathered phase of the granite, with the feldspars mostly decomposed. The rock is coarsely crystalline and locally shows a schistose tendency. Possibly this granite is older than the granitic rock that is intrusive in the Triassic slate of the Santa Ana Mountains and more closely allied to the granite present in the San Gabriel Range, which some observers have classed as possibly pre-Cambrian. However, there does not seem to be any good reason here for separating this granite from that intrusive in the Triassic.

### TRABUCO FORMATION (CRETACEOUS)

Unconformably overlying the pre-Cretaceous rocks is a bed of red conglomerate, which is considerably softer than the overlying gray sandstone and which may be of nonmarine origin. It is thus described by Packard,[3] who called it the Trabuco formation:

The basement complex comprising the core of the Santa Ana Mountains is unconformably overlain by a massive red conglomerate, which is traceable as a distinct mappable unit for a distance of about 10 miles along the strike. It occurs as a narrow belt 300 or 400 feet in width, extending from North Star Canyon nearly to Trabuco Canyon. The term Trabuco formation is here proposed as a local name for these red beds so well exposed along the western flank of the Santa Ana Mountains.

The best section of the Trabuco formation may be seen in Harding Canyon, where the beds have a dip of about 45° S. and a strike of N. 15° W. The metamorphosed sedimentaries of the basement complex dip about 45° N. and strike N. 15° W. In places the low dip carries the red basal conglomerates some distance up the slope of the ridges into the area of the basement complex in such a way that small isolated patches of the beds may be found, separated by erosion from the main mass or connected with it by a thin veneer of residual gravels.

The loosely cemented conglomerates of the Trabuco formation develop upon weathering a rounded topography which is in marked contrast to the abrupt cliffs formed by the gray conglomerates of the overlying Chico. The conglomerates of the basal Chico lie in apparent conformity upon those of the Trabuco, but in most localities the change from the red to the gray beds is very abrupt, suggesting an erosion interval. Direct evidence for such a structural break is lacking. That the Chico conglomerates are conformable upon those of the Trabuco appears to be indicated at one locality where a gradation from a red to a gray conglomerate was noted.

These red Trabuco conglomerates are composed of both angular and water-worn boulders varying in size up to those having a diameter of 3 feet. The boulders represent a considerable range of rock types, the majority of the igneous rocks being basic. In places subordinate bands of red sandstone occur interbedded with the conglomerates.

The peculiar color, the angular form of most of the pebbles and sand grains, and the lack of marine fossils suggest that the Trabuco formation was deposited upon a narrow coastal plain by torrential streams arising in a mountainous region but a short distance to the eastward. After about 200 feet of this material had been laid down, marine conglomerates of the basal Chico accumulated within the waters of the transgressing sea.

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[3] Packard, E. L., Faunal studies in the Cretaceous of the Santa Ana Mountains: California Univ. Dept. Geology Bull., vol. 9, pp. 140–141, 1916.

The age of the Trabuco horizon is not definitely known, since as yet it has yielded no fossils. Judging from its stratigraphic relations the formation is probably but slightly older than the Chico group and presumably represents some phase of the pre-Chico Cretaceous.

As explained in the description of the Chico formation, there is no evidence of the presence of oil in the Trabuco formation.

## CHICO FORMATION (UPPER CRETACEOUS)

Above the Trabuco is the marine Chico, the lithology of which is described by Packard[4] as follows:

Resting with apparent conformity upon the Trabuco formation is a series of conglomerates differing from those of the lower formation in the lighter color of the matrix, in the firmer cementation, in the greater abundance of pebbles of quartzites and slates, and in the inclusion of marine fossils in the matrix and in the rounded boulders. The fossils from the boulders comprise fragments of *Inoceramus* and of an indeterminate gastropod, suggesting the occurrence of earlier Cretaceous deposits now completely removed by erosion. The conglomerate resting upon the Trabuco grades upward into coarse light-colored sandstone with subordinate strata of hard, fine-grained calcareous sandstone bearing a characteristic fauna. Following these are several hundred feet of laminated bluish shales, often containing limestone nodules. The nodules are occasionally fossiliferous. Above the shales the strata again become coarser, being composed of sandstones, which in places grade laterally into conglomeratic lenses. These beds are succeeded by a series of alternating strata of sandstone and shale, which in turn are replaced in the upper portion of the section by hard, fine-grained calcareous sandstones, fine tan-colored shales, and lenses of carbonaceous shales, interstratified in places with seams of coal of an inferior quality.

On both sides of the central core of metamorphic rocks of the Santa Ana Mountains there is a considerable thickness of the Chico formation. On the northeast flank of the range there is a narrow belt of steeply dipping beds, which are correlated, on the basis of lithologic character, with the similar Chico beds on the opposite side of the granitic core. On the southwest flank of the range the belt of Chico is several miles wide, and the widest part is traversed by Sierra Canyon. The beds consist of dark-gray to green marine shale and sandstone and include several thick zones of conglomerate. The predominating dark color, the persistence of certain zones of conglomerate and massive sandstone, and the somewhat greater induration are features that serve to differentiate the Chico from the overlying Tertiary formations.

North of Black Star Canyon the structure is complicated by minor folds, and the stratigraphic position of the different beds was not determined. South of Black Star Canyon is a monocline of westward-dipping beds in which the succession is well exposed.

[4] Idem, pp. 141–142.

Packard, who made a careful study of the fauna of the Chico of this district, divided it into three faunal zones. He found the upper zone to be the nearest in age to the type Chico of Chico Creek. The fauna of the lower zones is not similar to that of the Horsetown formation of northern California, but the beds may be of the same age as the lower beds that have been referred to the Chico on the west side of Sacramento Valley. Packard lists a total of 131 different forms of fossils, most of which he determined specifically.

There is no evidence of the presence of oil in the Cretaceous beds in this region, though the beds are of a type that might possibly have been an original source of oil, which could have been retained in the sandstone members. The entire absence of oil and gas seepages either here or in similar Cretaceous beds in other parts of the State and the failure to get oil in wells that have been drilled in similar Cretaceous beds make it seem very unlikely that any oil will be found in the Cretaceous of this area.

A rather hard but pure clay shale is mined at a point 1½ miles slightly north of west of Sierra Peak and is used in the manufacture of pottery in a factory near Corona.

### MARTINEZ FORMATION (LOWER EOCENE)

The Martinez formation is found in three irregular areas in the northern part of Santa Ana Mountains; the most northerly area reaches Santa Ana River, and the most southerly area extends beyond the area mapped. Besides containing a characteristic fauna, this formation is of a somewhat lighter color and softer than the underlying Chico, and it lacks the yellow conglomerates that are characteristic of the overlying Tejon.

A particularly good horizon marker is the basal bed of the Martinez, a 25-foot bed of light-brown to gray rather arkosic sandstone that contains abundant large flakes of mica as hexagonal plates which have been subject to very little grinding. This bed is found in all the Martinez areas north of Black Star Canyon, but south of that canyon the basal bed of the formation is a greenish sandstone and conglomerate, which is well exposed in Baker Canyon. Above the basal bed is a zone of light-gray sandstone in which are layers of shale and lignite. This zone, which is about 300 feet thick, includes the beds explored in the "coal mines." In some of the shale beds of this zone are olive-green concretions probably containing glauconite. Next higher comes 100 feet of light-buff to brown sandstone that has a conspicuous outcrop, in this respect resembling some of the beds in the Chico. This bed is at the top of the section exposed at the Santiago mine. Overlying the hard sandstone elsewhere is about 500 feet of soft brown fine-grained sandstone in which calcareous concretions are prominent. These upper beds are well developed along the ridge crest north of Santiago Creek. A few fossils were found in them by Dickerson. Though there are a few resistant beds in this zone, the bulk of the upper part of the Martinez is made up of the soft fine-grained brown sandstone. The maximum thickness of the Martinez seen by the writer was in the area 2 miles directly north of the Santiago mine, where the formation is about 900 feet thick. The following section was measured at this point:

*Section of Martinez formation north of Sierra Canyon*

| Top of formation. | Feet |
|---|---|
| Brown fine sandstone, thin bedded; weathers to appearance of shale, especially when seen from distance | 400 |
| Greenish-gray medium-grained sandstone | 75 |
| Coarse nearly white sandstone | 100 |
| Greenish-brown medium-grained cross-bedded sandstone | 75 |
| Coarse calcareous sandstone with fossils | 2 |
| Light thin-bedded sandstone below tan sandstone | 150 |
| Basal conglomerate and sandstone | 100 |
| | 902 |

Well-marked unconformities separate the Martinez from the underlying Chico and the overlying Tejon. The unconformity at the top is well exposed in the first small canyon east of the Santiago coal mine, where the truncation of successive beds of the Martinez by the basal beds of the Tejon is clearly seen. There is an equally clear discordance between the Martinez and Chico all along their contact to the north and west of Sierra Canyon. South of Black Star Canyon there is no observable discordance in dip and strike between the two formations.

Fossils are not particularly abundant in the Martinez of this area, but wherever they occur they include *Turritella pachecoensis*, which serves to identify the formation. Dickerson,[5] who made a very good collection of fossils from the Martinez of this area, followed by careful identification of the forms, lists the following fauna from the vicinity of Santiago Canyon. Only specifically determined forms are given here.

Crassatellites unioides.
Cardium cooperi.
Glycimeris veatchi var. major.
Leda cf. L. gabbi.
Meretrix dalli.
Meretrix stantoni.
Modiolus ornatus.
Spisula? weaveri.
Tellina undulifera.
Tellina kewi.
Tellina cf. T. herndonensis.
Venericardia planicosta.
Calyptraea excentrica.
Ringinella cf. R. pinguis.
Turritella infragranulata.
Turritella pachecoensis.

[5] Dickerson, R. E., The Martinez and Tejon Eocene and associated formations of the Santa Ana Mountains: California Univ. Dept. Geology Bull., vol. 8, pp. 257–270, 1914.

Of these species *Turritella pachecoensis*, *Crassatellites unioides*, *Tellina undulifera*, and *Meretrix stantoni* are distinctive Martinez species. This Martinez fauna is small but characteristic, and when compared with that of the typical Martinez of the San Francisco Bay region it appears to represent the lower and middle portions only. *Crassatellites unioides*, *Meretrix stantoni*, and *Ringinella pinguis* are characteristic of the lowermost and middle zones of the Martinez.

There does not seem to be any reason to suspect that this formation may be oil bearing. It does not show any surface oil stains or seepages, and it is not known to contain oil elsewhere in the southern part of the State. The Orange County Park well, near the mouth of Santiago Canyon, probably reaches this formation at a shallow depth. This is the only well that has been drilled to test the Martinez, and its location was probably not selected with that specific purpose in mind.

Although several prospect shafts for coal have been driven in the lignitic zone of the Martinez in Santiago Canyon, apparently no coal beds of commercial value were discovered. All the shafts and tunnels have been abandoned for many years, and most of them can not be entered. Material on the dumps suggests that the strata explored contain lignitic shale rather than coal.

Some of the lignitic shale contains oil that is obtainable by destructive distillation. Lignitic shale taken from a small tunnel in a canyon on the south side of Santa Ana Canyon near its east end is probably from the Martinez formation. This shale yields as much as 20 gallons of oil to the ton of shale, but the rich shale forms only a thin streak, and the deposit is not of commercial value.

### TEJON FORMATION (UPPER EOCENE)

Because of irregularity of structure due to faulting and to overlap by the Miocene, there are two disconnected areas of the Tejon formation in the northern part of the Santa Ana Mountains. This formation, like the underlying Martinez and Chico, is entirely lacking in the Puente Hills, where the Sespe (Oligocene?) rests directly on granite or other igneous rocks. One of the characteristic features of the Tejon in this as in other parts of California is the presence of yellow quartzose sandstone, which weathers to prominent buff outcrops. Marine fossils were found in the lower beds, but none were found in the upper part of the formation, which was identified on lithologic character alone.

The area of Tejon along the north side of Santiago Canyon is characterized by a basal conglomerate 50 feet thick with well-rounded boulders and pebbles as much as 8 inches in diameter, though the average is around 3 inches. The sand is quartzose and of a creamy-yellow color. The boulders consist of quartzite, fine-grained light-colored igneous rocks, and granite. Above the conglomerate is 500 feet of yellow sandstone that exhibits the characteristic buff weathering of the Tejon, with numerous rugged cliffs and irregular caves. Some of the beds in this member are slightly conglomeratic, and dark-brown concretions are sparingly present. Characteristic fossils were found in several parts of this succession.

The Tejon 2 miles north of Sierra Canyon consists of alternate beds of massive yellow sandstone and conglomerate and was identified on lithologic character, no fossils being found in that area. The creeks that cut through these beds generally have narrow bottoms and nearly vertical walls, and at several places the ridge crests are so narrow and steep as to be impassable.

The Tejon is separated from both the overlying and the underlying formations by angular unconformities. The unconformity between the Tejon and the Martinez is marked by difference in dip and strike at the contact, together with overlap, as described in connection with the Martinez formation. The irregular thickness of the Tejon and the locally complete overlap of the Tejon by the Sespe indicate that there is an unconformity between the two. The small tongue of Sespe in the syncline on the north side of Santiago Canyon 2 miles east of the mouth of Rabbit Canyon rests with angular unconformity on the underlying Tejon and Martinez. Elsewhere, particularly in the area north of Sierra Canyon, there is no noticeable discordance, and the base of the Sespe has been placed at the lowermost red beds, even though yellow sandstone and conglomerate rather similar to those in the Tejon are found higher in the beds mapped as Sespe.

The following specifically determined fossils from the Tejon of this area are listed by Dickerson:

Meretrix hornii.
Spisula cf. S. merriami.
Tellina longa.
Tellina ovalis.
Tellina cf. T. hornii.
Cardium cf. C. breweri.
Solen parallelus.
Cadulus pusillus.
Bulla hornii.
Cylichna costata.
Ficopsis remondi.
Turritella uvasana.

Of these, *Turritella uvasana* is found at most fossil localities and is a reliable key fossil for the formation.

There is nothing to indicate that the Tejon formation in this area is likely to be oil bearing. The sandstone shows no traces of ever having contained any oil, and even if any oil should reach it by migration, the writer believes that the great thickness of sandstone without any shale partings would favor dissemination rather than concentration.

SESPE AND VAQUEROS FORMATIONS (OLIGOCENE? AND LOWER MIOCENE)

The beds that lie beneath the Topanga formation and apparently grade into it with conformable relations have a distinctive lithology, indicating different conditions of origin and deposition of the sediments. Red clay and sand, together with green and blue clay and sand, are characteristic features of the formation. Buff sandstone lithologically similar to that of the Topanga is also present. There was apparently an alternation of the two types of sedimentation.

In this area there seems to be no lithologic or structural reason for recognizing more than one formation between the Topanga and the Tejon, and the writer has therefore mapped the rocks under one color and has been inclined to assign all of them to the Sespe formation. In neighboring areas, however, Clark[6] and Kew[7] have defined the Vaqueros formation as characterized by the fauna of the *Turritella inezana* zone, and this zone has been recognized by its fossils in the hills west of Santiago Canyon, in the Santa Ana Mountains, several hundred feet below the top of the red beds. It is therefore necessary to regard this succession as including the Sespe formation and at least part of the Vaqueros formation. Dickerson[8] has listed the following species from the *Turritella inezana* zone of the Santa Ana Mountains:

Scutella fairbanksi.
Scutella norrisi.
Pecten bowersi.
Tivela inezana.
Turritella inezana.
Thais vaquerosensis.

The Sespe formation, from which the *Turritella inezana* zone is excluded, has no known fauna unless a few vertebrate fossils recently found in the Tejon Hills 20 miles southeast of Bakersfield belong to it.

Possibly half of the total thickness is red clay and sandy clay, in beds ranging from a few feet to 100 feet in thickness. Interstratified with the red beds are blue and green strata and buff to white sandstone. Many of the beds are of soft, nearly incoherent material, and bedding planes are indistinct except for the color separations. The sandstones are made up of angular fragments, decomposed feldspars and mica being prominent in the red sandstones. The few thin conglomerates have angular pebbles and boulders in a matrix of sandy clay. In Santiago Canyon, east of the mouth of Rabbit Canyon, there is an intermediate zone of white sandstone separating lower and upper red beds. This white sandstone zone is well exposed on the west side of Santiago Canyon at the bend 2 miles east of Rabbit Canyon. The lower 400 feet is buff to white

[6] Clark, B. L., Jour. Geology, vol. 29, p. 596 and chart opp. p. 586, 1921.
[7] Kew, W. S. W., Oil and gas resources of parts of Ventura and Los Angeles counties, Calif.: U. S. Geol. Survey Bull. 753, 1924.
[8] Dickerson, R. E., op. cit., p. 268.

sandstone, which tends to form a strike ridge directly west of Santiago Canyon. It contains several lenses of conglomerate with boulders 6 inches or less in diameter, but the rest of it is soft, rather fine-grained sandstone, without any prominent outcrops. Above this is 200 feet of soft yellow sand, followed by 100 feet of more resistant white sandstone, the outcrop of which could be traced for several miles. This is followed by the upper red zone, several hundred feet thick. No accurate measurements of the thickness of the beds were made, but from scaling several sections on field maps it appears that there is a maximum of about 3,000 feet of beds belonging to these formations.

The red color of so much of the material may be due either to the original character of the formations from which the sediments were eroded, to peculiar conditions connected with the process of erosion, to conditions connected with the process of deposition, or to more than one of these factors acting together. Inasmuch as very similar characteristics are found in red beds of other geologic provinces, the problem of the origin of the color of these rocks is much the same as that of the origin of red beds elsewhere. This problem is still unsettled, and weak points may be found in all the explanations that have been offered. It is the writer's view that the red color is due both to the original character of the material and to the process by which it was eroded, and that the sediment was red when it arrived at the point of deposition. The evidence points to deposition in bolsa valleys that were surrounded by steep ranges, the topography being similar to the range and basin topography that is characteristic of Nevada and southern California at the present time. With minor oscillations in level the type of deposition changed back and forth between marine and nonmarine.

### TOPANGA FORMATION (MIDDLE MIOCENE)

The Topanga formation consists almost entirely of buff to white arkosic sandstone, in which are found marine fossils of middle Miocene age. It rests with apparent conformity on the Vaqueros, the separation between the two being made on lithologic character. The Puente rests unconformably on the Topanga, though the structural evidence of the unconformity is not apparent at all places where the two are in contact. Thus the unconformity is not observable in the western part of the Burruel Ridge section but is proved by the mapping in the area south of Santiago Canyon. The name Topanga is used in order to follow the usage for the area immediately to the west, where according to Kew[9] this formation lies unconformably on the Vaqueros. The fauna of the Topanga is characterized by *Turritella ocoyana.* Other geologists have called the beds in the Santa

[9] Kew, W. S. W., op. cit.

Ana Mountains containing this *Turritella ocoyana* fauna an upper phase of the Vaqueros formation.

The Topanga as shown on the map probably includes some beds of Vaqueros age, as there has been a certain amount of confusion over the question of proper formation units to be used between the base of the Sespe and the base of the Puente. In the field the writer attempted to map only one line between these limits—namely, the top of the red beds. The upper limit of occurrence of the Vaqueros fauna may lie within the succession of beds mapped as Topanga formation.

From Burruel Point eastward to the prominent north-south fault the Topanga formation is about 600 feet thick and consists of white sandstone. A bed of abundant fossils is present about 200 feet above the base. East of the fault the thickness is several times as great, though the basal contact is hard to approximate, as the transition zone to the underlying red beds occupies a considerable thickness.

The small exposure of the Topanga formation south of the lower part of Santiago Canyon is a hard, much seamed and jointed calcareous sandstone, which weathers to a pitted surface. Beds of the same character are found farther south, close to the contact with the volcanic rocks, and possibly their character is due to the effect of the igneous intrusions. There are several outcrops of tuffaceous beds close to the base of the Topanga where it rests on the volcanic rocks near the point where the main road leading east from El Modena crosses the first ridge. Just north of the road is a 15 to 20 foot bed of white ash that contains fossils. Above the ash is 30 feet of tuffaceous white sandstone, which is overlain by a flow of volcanic rock. South of the road a thin flow of rather hard basalt appears beneath the ash bed, and the tuffaceous sandstone becomes agglomerate. Though the volcanic rocks in contact with the Topanga are flows that seem to overlie the sandstone without any great discordance in dip, a short distance to the west there is a volcanic rock of denser type, which is probably intrusive.

About 2½ miles up Rabbit Canyon from Santiago Canyon the following succession of Topanga beds overlies the Sespe and Vaqueros:

*Section of Topanga formation in Rabbit Canyon*

| | |
|---|---|
| Base of Puente formation. | |
| **Topanga formation:** | **Feet** |
| White arkosic sandstone with thin calcareous reefs containing abundant *Balanus* and other fossils | 300 |
| Buff arkosic sandstone, grains angular and poorly sorted; few streaks of red; soft and only fair outcrops | 300 |
| Conglomerate of angular schist blocks in matrix of yellow and red sand and clay | 25 |
| Massive yellow and white pebbly sandstone | 75 |
| | 700 |

North of Santa Ana River the Topanga is exposed between the Whittier fault and the river for a distance of a mile. The formation is closely folded here, and perhaps for this reason some of the beds are more indurated than elsewhere. Hard white sandstone forms the axis of an anticline close to the river. Above this are yellow sandstone and sandy shale similar to those in the Puente. As no fossils were found in this area, it is possible that some of the beds should more properly be classed with the Puente, though a small area of red beds close to the fault indicates the presence of basal Topanga with the customary gradation into the underlying Vaqueros.

The Topanga of the Santa Ana Mountains belongs to the *Turritella ocoyana* faunal zone. One of the best collecting localities for fossils seen by the writer is on the crest of the small hill just east of the contact with the volcanic rocks on the west side of the small anticline south of El Modena. Dickerson[10] lists the following fossils from this and other localities in the Santa Ana Mountains:

Scutella norrisi.
Spisula cf. S. catilliformis.
Chione temblorensis.
Tellina cf. T. ocoyana.
Cardium cf. C. vaquerosensis.
Venus pertenuis.
Phacoides cf. P. richthofeni.
Cunus hayesi.
Phacoides santacrucis.
Calyptraea costellata.
Trophosycon cf. T. kernianum.
Thais vaquerosensis.
Turritella ocoyana.
Pecten lompocensis.
Pecten crassicardo.

In the same paper Dickerson gives a list of fossils from a lower zone, called the *Turritella inezana* zone, now referred to the Vaqueros formation. These were obtained from beds that lie within the red-bed series and in the present report are mapped with the Sespe formation.

## PUENTE FORMATION (MIDDLE AND UPPER MIOCENE)

### GENERAL CHARACTER

The Puente formation has a greater areal extent than any other within the district, and the fact that it was probably the original source of the oil makes it especially important in the present study. The name was given by Eldridge[11] and is derived from the Puente Hills, over the greater part of which the formation crops out. A lithologically similar formation of approximately the same age found to the west, in Ventura and western Los Angeles counties, is called the Modelo formation. In the central part of the State rocks of

[10] Dickerson, R. E., The Martinez and Tejon Eocene and associated formations of the Santa Ana Mountains: California Univ. Dept. Geology Bull., vol. 8, p. 269, 1914.

[11] Eldridge, G. H., and Arnold, Ralph, The Puente Hills oil district, southern California: U. S. Geol. Survey Bull. 309, p. 103, 1907.

corresponding age are known as the Salinas shale and Maricopa shale. In the past these formations have been called "Monterey shale," but according to present Geological Survey usage the name Monterey is to be used as a group name, to include both sandstone and shale formations—that is, the Vaqueros formation and the overlying shales.

The Puente formation crops out over nearly the whole of the Puente Hills north of the Whittier fault and also forms a belt along Burruel Ridge south of Santa Ana River. Over most of these areas outcrops are fairly good, especially in the sandstone phases of the formation; however, there are only a few places where the sandstone is hard enough to form rugged outcrops. The shale outcrops are subject to considerable slumping and surface creep. In some places the sandstone beds appear to have slumped from their original position, even where there is no topographic evidence of slumping. These surface slumps render many of the dips observed on small outcrops so unreliable that from 10 to 25 per cent of such dips must be disregarded.

The Puente formation consists of an alternating succession of coarse and fine grained beds. The material of which they are composed is of all degrees of coarseness, ranging from boulders to clay and siliceous mud. The shale, though made up mostly of clastic material, consists in part of the skeletons of diatoms and similar small marine organisms. The sand, which is the most abundant material, ranges from well-rounded and sorted quartz grains to angular and subangular grains of quartz and feldspar.

The sandstone members of the Puente are buff to tawny yellow and generally contain more or less interbedded conglomerate. Much of the conglomerate has a purely local distribution. A conglomerate several hundred feet thick may disappear entirely within a distance of less than half a mile. The conglomerate beds consists of granite boulders in a matrix of sand, and the lateral change seems to be simply a disappearance of the boulders, the bed retaining the same thickness but being an ordinary sandstone. Such features suggest that the conglomerates were deposited in circumscribed areas immediately offshore from the mouths of rivers, the boulders being dropped near the mouths, but most of the sand being carried out a greater distance.

The shales consist of fine quartz grains, siliceous mud, and clay, with which is mixed more or less diatomaceous material. The finer varieties of diatomaceous shale are nearly white, are chalky, and have a light punky feeling. The sandy shales are generally pink to chocolate-colored where weathered but gray where unweathered.

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The pink color may be due to discoloration by petroleum or more likely to a slight content of hematite.

The degree of induration of individual beds in the Puente is to some extent a function of the folding that has affected them, the beds being harder than elsewhere at points where considerable folding has taken place. In general, the formation is somewhat harder than the overlying Fernando and does not differ greatly in hardness from the underlying Vaqueros and Sespe formations. The sandstone in most outcrops is sufficiently soft to fall to a powder when hit with a hammer and will not break in a clean, sharp fracture. The hardness of the shale varies between wide limits, some beds being soft and incoherent, whereas an adjacent bed may be hard and flintlike. This is particularly true of the shale of the siliceous type. Davis,[12] who devoted considerable study to the mode of origin of the Tertiary siliceous shale and chert, came to the conclusion that this variation in hardness was due to variations in the amount of colloidal silica that was deposited as an original constituent of the bed. The harder varieties of shale contained an abundance of colloidal silica, and this material formed a cement, binding together the other constituents of the bed. Strata in which colloidal silica was not originally present remained soft and incoherent. Probably secondary solution and redeposition of silica as a cementing material took place as a result of the heat and pressure developed in folding the beds, but this factor is thought by Davis to have been of less importance in determining the hardness of a bed than the original composition.

Chemical analysis shows that the siliceous shales are richer in silica than ordinary clay shales. In the latter, when the calcium carbonate content is eliminated from the calculation, the proportion of silica is about 60 per cent. In the siliceous shales and cherts of the Monterey group the proportion of silica varies between 65 and 98 per cent. Arnold and Anderson,[13] in their description of the so-called "Monterey shale" of the Santa Maria region, give the following analyses of ten samples of shale and chert of varying degrees of hardness:

[12] Davis, E. F., The radiolarian cherts of the Franciscan group: California Univ. Dept. Geology Bull., vol. 11, pp. 282–298, 1918.

[13] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria district, Calif.: U. S. Geol. Survey Bull. 322, p. 45, 1907.

*Analyses of "Monterey shale"*

| | Diatomaceous shale | | | | | Flinty shale | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| $SiO_2$ | 65.62 | 72.50 | 83.19 | 80.59 | 86.89 | 92.88 | 86.92 | 92.37 | 97.02 | 98.1 |
| $Al_2O_3$ | ------ | 11.71 | ------ | ------ | 2.32 | ------ | 4.27 | 2.46 | ------ | (a) |
| $Fe_2O_3$ (total iron) | ------ | 2.35 | ------ | ------ | 1.28 | ------ | ------ | ------ | ------ | (a) |
| CaO | ------ | .32 | ------ | ------ | 1.43 | ------ | 1.60 | 1.70 | ------ | ------ |
| MgO | ------ | .83 | ------ | ------ | Trace | ------ | Trace | ------ | ------ | ------ |
| Alkalies ($Na_2O$, $K_2O$) | ------ | 1.88 | ------ | ------ | 3.58 | ------ | 2.48 | ------ | ------ | ------ |
| Ignition | {11.00 | 9.54 | ------ | ------ | 4.89 | ------ | 5.13 | {2.74 +$CO_2$} | ------ | ------ |
| | ------ | 99.13 | ------ | ------ | 100.39 | ------ | 100.40 | 99.27 | ------ | ------ |

[a] Not determined.

1. Soft white diatomaceous shale; Purisima Hills, 3½ miles southwest of Harris, Santa Barbara County, Calif. Analyst, W. T. Schaller, 1907.
2. Soft white diatomaceous shale; Graciosa Ridge, 3 miles southeast of Orcutt, Santa Barbara County, Calif. Analyst, W. T. Schaller, 1907. Approximate analysis.
3. Soft white diatomaceous shale; San Julian ranch, at junction of El Jaro and Salispuedes creeks, Santa Barbara County, Calif. Analyst, E. C. Sullivan, 1907.
4. Soft white diatomaceous shale; San Antonio terrace, 2 miles south of Casmalia, Santa Barbara County, Calif. Analyst, E. C. Sullivan, 1907.
5. White shale, Monterey, Monterey County, Calif. Lawson, A. C., and Posada, J. de la C., California Univ. Dept. Geology Bull., vol. 1, p. 25, 1893; specific gravity, 1.8–2.1.
6. Gray glassy porcelain shale; from same hand specimen as No. 4. Analyst, E. C. Sullivan, 1907.
7. White porcelain shale; region of Point Sal, Santa Barbara County, Calif. Analyst, H. W. Fairbanks, California Univ. Dept. Geology Bull., vol. 2, No. 1, p. 12, 1896.
8. Opaque flint; Point Sal, Santa Barbara County, Calif. Analyst, H. W. Fairbanks, op. cit.
9. Hard black clear flint; 1½ miles west of Zaca, Santa Barbara County, Calif. Analyst, E. C. Sullivan, 1907.
10. Hard black clear flint; Point Sal, Santa Barbara County, Calif. Analyst, H. W. Fairbanks, op. cit.

The five analyses of the soft variety of shale show from 65 to 86 per cent of silica and from 5 to 10 per cent of water in chemical combination. Most of the other minerals present are probably hydrous silicates of the same general type as kaolin. As calculated from these analyses it appears that from 50 to over 90 per cent of the material of these shales is silica, mostly in the form of opal. The remainder may be classed as clay. In the harder varieties of shale and chert the proportion of silica is much greater, ranging from 87 to 98 per cent. Evidently the proportion of clay present was much less in the sediment which formed chert than in that which formed the softer varieties of shale.

Although the shales are often termed diatomaceous shales, there is a diversity of opinion as to how much of the siliceous material of which they are made up was derived from the remains of diatoms and similar minute organisms which have siliceous skeletons. At the request of Arnold and Anderson,[14] F. J. Keeley, of the Philadelphia Academy of Sciences, made an examination of several specimens of siliceous shale, concerning which they say:

He found diatoms plentiful in the unaltered earthy shale and less common in the more compact shale and in the less pure, either gritty or argillaceous shale. Sponge spicules were common in all the samples, and in those last mentioned they were more abundant than the diatoms. No examination was made of the

[14] Op. cit., p. 40.

indurated varieties. Mr. Keeley was unable to make more than a hasty examination, but on request he estimated roughly that the purest material contained from 5 to 10 per cent of diatoms and that the soft shale, in which fewer could be seen, contained possibly 1 per cent. He found a few Radiolaria but no Foraminifera in the pure siliceous shale, diatoms and next to them sponge spicules being by far the predominant organic remains.

Besides the material that can be definitely recognized as derived from particular types of skeletons, there is a somewhat greater amount of fine angular fragments that are probably of organic origin. It is therefore certain that as much as 10 per cent of the total material of some of the shales is of organic origin. In the less "pure" shales, which are the more abundant, less than 5 per cent can be recognized under the microscope as derived from the skeletons of small organisms.

A part of the remaining material of the shales appears to be minute sand grains, but most of it is so fine grained that very little regarding its character can be made out by examination under the microscope. It has been supposed by several observers that this fine material is the broken and unrecognizable fragments of diatom skeletons, sponge spicules, and similar remains of minute organisms. Nearly all the material of the shale would be classed by them as of organic origin. This conclusion is probably based on two lines of reasoning. First, some samples of the shale are so light and porous as to suggest that the material of which they are made up consists of extremely angular particles, which would not be easily compacted. Organic remains would furnish material of this type. The second line of reasoning is that siliceous muds composed of the remains of organisms are known to be accumulating on the ocean floor at the present time. No siliceous muds formed of clastic material or formed by the direct precipitation of silica from solution have been described as recent deposits.

Against the first of these lines of reasoning it may be urged that although diatom remains and similar material form a porous, light rock, similar rocks are sometimes formed of clay and of volcanic ash. All very porous sedimentary rocks are not necessarily composed of organic remains.

All evidence available indicates that the shales of the Monterey group were deposited under conditions very different from those under which the present-day accumulations of diatom remains are found. The latter are deep-sea oozes such as were described in the reports of the *Challenger* expedition. They are found only in very deep parts of the ocean, mostly below 2,000 fathoms. The shales of the Monterey group are associated with sandstone and in some places conglomerate, which were deposited in shallow water. Unless repeated profound oscillations in depth of the basin of deposition are assumed the diatomaceous shales must be classed as deposits laid down in water that was only moderately deep. The diatom-bearing oozes of the ocean depths are of trifling thickness and have accumulated very slowly. Teeth from sharks that were extinct in Tertiary time are found only a few centimeters beneath their surface. The siliceous shales of the Monterey group, by contrast, are several thousand feet thick and were accumulated in a space of time during which similar thicknesses of sandstone were being deposited elsewhere. The period of accumulation of the siliceous shales was therefore not abnormally long as compared with that of equal thicknesses of other formations of a different lithologic type. These considerations lead to the conclusion that the shales of the Monterey are not at all similar in origin to the deep-sea oozes. The recent formation of deposits similar to those of the Monterey has apparently not been described. Therefore the rule of uniformity[15] does not point to any particular mode of origin of the siliceous material of these shales.

The results of microscopic examination of the shales contradict the hypothesis that nearly all the fine-grained material of the shales is derived from organic remains. In the soft shale, in which very fine material is the most abundant constituent, nearly perfect specimens of diatoms may be found. It would be hard to account for the complete destruction of most of the skeletons in the same bed in which some of them are so perfectly preserved if all the material is assumed to be diatom remains. In some of the harder varieties of shale also well-preserved diatoms may be found. Furthermore, the amount of recognizable diatom remains in the shale in which the silica content is high is less than that in the less siliceous shale. This would indicate that the abundance of diatom remains was not the controlling factor in determining the proportion of silica to other minerals in the shale, but that the more siliceous shale had some source of silica other than diatom remains.

It appears likely that most of the siliceous material other than that recognizable under the microscope as being derived from organic remains was a fine siliceous mud which originated both as a clastic sediment derived from rock decay and by direct precipitation of silica from sea water. In most textbook discussions of the materials that make up sedimentary rocks neither of these sources of silica

[15] The so-called rule of uniformity argues that as the character of geologic processes is determined by physical laws, which are unchanging, the processes by which earth changes have been brought about have been uniform throughout geologic time. It is assumed that the surface of the earth presents so great a diversity of conditions that every process should be found going on at some point at the present time. Any process that has not been so recognized is considered as of very doubtful existence. This rule, though true in the main, is subject to exceptions, one of which may be the case here under consideration.

is recognized in its true importance. In coarsely crystalline rocks such as granite the quartz crystals are so large that when they are released by the decomposition of the feldspar matrix they form coarse sand, which later becomes part of a sandstone. But in the decay of fine-grained rocks that are equally rich in quartz, such as rhyolite, a large amount of finely divided quartz must be released. The decomposition of feldspar during the normal course of rock weathering releases silica, which may either be carried away in solution or remain as a fine-grained sediment. Thus the ordinary sediment carried to the ocean should contain a considerable amount of finely divided silica.

Silica in solution in river waters ranges from 1 to 40 per cent of the total solids, depending on the type of rock present in the river basin and on the abundance of rainfall.[16] The most siliceous waters are those of rivers that drain areas of acidic igneous rocks. Average river water contains in solution about one-fourth as much silica as calcium carbonate, so that for rocks being formed in the ocean at the present time we should expect to find those formed by the deposition of silica from solution one-fourth as abundant as those formed by the deposition of lime. Presumably there were periods in the past when the rivers draining certain areas carried a very high proportion of silica in solution, just as the periods of deposition of the great limestone formations are supposed to have been characterized by river waters that were abnormally rich in lime. If the shales of the Monterey group were deposited in a period characterized by silica-rich river water an adequate source of silica would have been at hand in fine sediment of the nature of a siliceous mud and in silica deposited from solution.

Another hypothesis in regard to the silica-rich shales is that they contain fine volcanic ash of an acidic type. Thin strata of ash of this type have been found locally in the siliceous shale, and the chemical character of an acidic ash would fit the analyses of some of the shales. However, there is nothing else to support the ash hypothesis, and if volcanic ash were present in most of the shale there would probably be more coarse material in which the volcanic character would be evident in thin sections if not from an examination with a hand lens.

Davis, in his study of the cherts of the Franciscan formation already cited, encountered a problem similar to that of the shales of the Monterey group. In the Franciscan cherts a few well-preserved specimens of radiolarians and transparent spots believed to be caused by the presence of altered radiolarian skeletons are found embedded in a matrix of amorphous to finely crystalline silica.

[16] Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, chapter 3, 1916.

After careful investigation he came to the conclusion that most of the material of the groundmass was deposited by direct chemical precipitation, and not as the skeletons of radiolarians, diatoms, and similar minute organisms. Only a very small proportion of the material was found to be derived from the remains of organisms. The present writer agrees with these conclusions and believes that they can be extended to the cherts and shales of the Monterey group.

Between the base and the top of the Puente formation there are a number of alternations of fine and coarse material, which make it desirable to map several separate units in the Puente. In the present report three divisions are recognized—a lower shale, a middle sandstone, and an upper member consisting of several zones of shale and sandstone. Locally each of the divisions has characteristic lithologic features, but in a broad sense there is very little difference in character between the individual shale or sandstone beds from top to bottom of the formation.

### LOWER SHALE

Throughout the Puente Hills the lower division of the Puente formation consists of a single shale unit, but in Burruel Ridge a sandstone divides this shale into a lower and an upper part. It is only in the Santa Ana Mountains that the base of the lower division is exposed, and there it appears to rest unconformably on Topanga sandstone.

To the south of Santiago Canyon the shale appears to be unconformable on the Topanga, though the tendency of the shale to become crushed and irregular in structure makes it difficult to say positively whether the irregularity is everywhere due to unconformity or whether in some places it is due to distortion of the shale during folding of the beds. East of the large north-south fault that crosses Burruel Ridge the shale seems to rest on different phases of the Topanga, indicating unconformity, which is also suggested by the presence of irregular calcareous sandy layers at the base of the shale, of a type that it would be natural to find in the basal phase of a formation which was encroaching on a previous land area. Toward the western part of Burruel Ridge, where the beds dip steeply, the unconformity at the base of the shale is not recognizable.

Throughout the Santa Ana Mountains district the shale is notably white in appearance and in places contains very pure soft siliceous earth like that mined for commercial use. Shale of this type may be found near the crest of the ridge 3 miles east of Olive. Although locally "pure," most of the shale is of a clayey nature and weathers light to dark pink.

On Burruel Ridge there is a lower shale separated from the main shale zone by several hundred feet of yellow sandstone similar to that found in the underlying Topanga. This sandstone is mapped as a lentil in the shale, to avoid including in the Topanga a shale which lies below the sandstone and which is distinctly diatomaceous. However, it is uncertain whether the base of the lower or of the upper of the two shale zones is to be correlated with the base of the shale as mapped over the area south of Santiago Canyon and in the Puente Hills.

In the Puente Hills the lower shale crops out on the north side of the Whittier fault between La Habra Canyon and Santa Ana River and in a small area south of the fault near the west end of the hills. Throughout these areas the most common lithologic type is a fine clastic shale in which the grains can be seen with a hand lens but not with the naked eye. This grades into a slightly coarser shale, which might be called fine siltstone or mudstone. Sandstone is interbedded with the shale, especially toward the east end of its area of outcrop. Many of the sandstone beds are obscured on soil-covered slopes by soil derived from the shale, and it is only where good outcrops are present that they may be recognized. Little if any of the shale is of the white porous type, though diatom remains may be seen in most samples. Where fresh the shale is of a light-gray color, but in nearly all outcrops it has weathered to brown or pink; the finer type of shale is usually of the lighter color. The shale commonly disintegrates into small button-like fragments, which later decompose to form a yellow or brown clay soil.

One of the remarkable features of the distribution of the lower shale is that it does not crop out beneath the middle sandstone southwest of the town of Pomona, where the sandstone rests directly on the granite and pre-Puente volcanic rocks. The basal part of the middle sandstone at that locality is somewhat shaly, though it contains lenses of conglomerate. But even if this basal phase is part of the lower shale, it is only about 200 feet thick, and therefore most of the lower shale is lacking. In the San Jose Hills also there is no trace of the lower shale.

South of Santa Ana River the greatest thickness of the lower shale noted is 1,500 feet, but north of the river the observed thickness is greater despite the fact that the base is not exposed. East of Olinda and north of the fault 2,000 feet of shale is exposed, and to judge by the logs of wells there must be 2,000 feet more beneath the lowest beds exposed at the surface.

### MIDDLE SANDSTONE

Next above the lower shale is the middle sandstone, which crops out over most of the central part of the Puente Hills. Though neither the base nor the top of the member may be precisely located, it is decidedly different in character from both the underlying and overlying shales. In its most characteristic development this member consists almost entirely of yellow sandstone.

Most of the central part of the Puente Hills is occupied by outcrops of the middle sandstone. The average thickness in this area is between 1,000 and 1,500 feet. A concretionary zone 200 to 300 feet above the base of the sandstone is characteristic. The concretions are round or oval and mostly about 3 feet in diameter. They are darker than the normal sandstone, being a reddish brown, probably from the presence of iron oxides, which act as a cementing material. The sandstone is tawny yellow, poorly bedded, and much of it soft. Most of the constituent grains are angular quartz, poorly sorted, with much fine powdery material between the coarser grains. Few or no dark-colored mineral grains are present. A zone in which oil-saturated sands are found lies near the middle of the member. The outcrop of this zone trends almost directly north from San Jose Peak to sec. 20, T. 2 S., R. 8 W., close to the edge of Chino Valley. Thence it runs west and northwest to the northwest corner of sec. 15, T. 2 S., R. 9 W. Throughout this distance there are scattered outcrops of tar sands, some of them rich in oil but none showing actual seepages of oil.

The basal beds of the middle sandstone member, where they rest on the granite and volcanic rocks southwest of Pomona, have a peculiar aspect. At the base is a brown clayey sandstone, overlain by 100 feet of an impure brown clay, followed by a zone 25 feet thick of clay and boulders, a rather novel type of conglomerate. Above the boulder bed is some clay shale, which in the section studied is overlain by buff sandstone.

At the head of Rodeo Canyon, close to the divide, are several large granite boulders, which have weathered out of the sandstone. One of them is 10 feet in diameter. There are perhaps half a dozen such boulders, all told. No small boulders or pebbles are clustered around the few large blocks, and the sandstone close to the boulders is not noticeably different from the fine yellow sandstone elsewhere in the formation.

The outcrop of the middle sandstone on Burruel Ridge is mostly massive yellow sandstone containing several hard yellow calcareous layers. Both coarse and fine grained sand beds occur, and mica is locally an abundant constituent. About 2 miles northeast of the Santa Ana Canyon oil field there is a fault block of this sandstone lying south of the Whittier fault. Good exposures are seen on the hill in the eastern part of sec. 24, T. 3 S., R. 9 W., where there is a tawny-yellow thick-bedded, rather hard sandstone. The southwestern part of the same hill is fine shaly sandstone and conglomerate, much crushed, in which no bedding planes are apparent. Half a mile southeast of this locality there is concretionary sandstone similar to that found in the beds north of the Whittier fault and to the south, across Santa Ana River. The concretionary zone is the feature by which the member is identified, as there is no similar zone in any of the other formations of this district.

Southeast of San Juan Hill several zones of soft fine sandstone are interbedded with the coarser-grained beds. As the underlying lower shale has several interbedded sandstones at this point, the separation between the lower shale and middle sandstone members of the Puente is not as clear cut as it is farther west.

In the San Jose Hills the massive conglomerate that forms San Jose Peak is mapped as middle sandstone because of its position beneath shale of the upper member. This conglomerate can hardly be less than 2,000 feet thick. Perhaps half of the thickness is coarse, poorly sorted sandstone. The rest is conglomerate, containing angular boulders of granite and schistose rocks. Some of the boulders are rounded, but nearly all the finer material is angular and very poorly sorted. The structural relations of the conglomerate are puzzling. It appears to be conformable beneath the overlying shale, yet it is absent at only a slight distance to the east, where the shale rests on a volcanic formation, and a few miles to the west the record of the Shell Co.'s Sentous well shows the conglomerate to be absent from that area, shale resting directly on volcanic rocks.

North of La Habra Canyon there is a northward-dipping monocline of the middle sandstone, which shows unusual thickness. At least 4,000 feet of beds are present here, a thickness greater than that present anywhere else. The sandstone is not particularly different from that to the east, though on the whole it is rather harder and has a greater tendency to form hard zones that weather in conspicuous ledges. Possibly duplication of beds by faulting or close folding may account for the unusual thickness apparently present.

#### UPPER MEMBER

The beds mapped as the upper member of the Puente include a succession of alternating shale, sandstone, and conglomerate, the individual beds of which can not be correlated over the different parts of the area mapped. There are three main areas in which the upper member crops out—in the San Jose Hills, in the Whittier Hills, and in the east end of the Puente Hills. In each of these areas the succession is slightly different from that in the other two, and the age of beds mapped as the upper member probably differs slightly from one area to another. The lower part of the upper member is shale, above which are several zones of sandstone, conglomerate, and shale. The conglomerates are very similar in character to those in the Fernando, and it is possible that some of them are actually of

Fernando age. In general, thick zones of conglomerate are more common in the Fernando than in formations of the Monterey group, but in the absence of any indication of unconformity it is thought preferable to include the whole succession in the Puente.

The upper member crops out over nearly the whole of the San Jose Hills. The shale at its base is very diatomaceous, in this respect differing from the lower shale member of the central part of the Puente Hills and resembling the lower shale of Burruel Ridge. The shale is typically pink to white and mostly soft and powdery. Diatom skeletons and fragments of other minute skeletal remains are abundant in it. The hardness varies widely, and in the same zone with the soft material may be found platy and flinty beds, although the softer shale is much more abundant. A few lenticular beds of conglomerate are interbedded with the shale. This is a rather remarkable association of two materials generally supposed to have been deposited under widely differing physical conditions. It is, however, by no means unique in this region, as nearly every extensive formation of siliceous shale in California has interbedded lenticular bodies of sandstone or conglomerate.

The shale at the base of the upper member in the San Jose Hills is overlain by a succession of clayey and slightly diatomaceous soft shales and lenticular conglomerates. These beds are well exposed on the flanks of the main anticline that trends west from San Jose Peak. The conglomerate beds tend to disappear toward the west, but the change seems to be one of substitution of finer material for the conglomerate boulders in the same bed and not a thinning of the bed itself. A thin but rather hard sandstone rests on the lower shale of the upper member around the nose of the anticline where it plunges to the west, but this sand is too thin to be shown as more than a line on the areal-geology map. Between the syncline bounding the main anticline of the San Jose Hills on the south and San Jose Creek on the southeast the structure and succession of beds are rather obscure. At very few of the outcrops can the dip be observed, and therefore the structure was not completely worked out. The areas of outcrop of shale and conglomerate were determined, but in the absence of complete knowledge of the structure the stratigraphic position of any particular bed of shale or conglomerate could not be ascertained.

It is possible that part of this shale and conglomerate series belongs to the Fernando (see p. 39), but in the absence of any evidence of unconformity there is no reason to place a dividing line at any particular horizon, and as the shale zones are more like the Puente shales it seems best to include all the beds in that formation.

In the eastern part of the Puente Hills the shale that forms the lower part of the upper member is less siliceous than in the San

Jose Hills and is similar in character to the lower shale of the same district in which it crops out. In fact, all the shales and sandstones of the eastern part of the Puente Hills are of uniform lithologic types. It would seem that lithologic character in the Puente Hills is as much a function of geographic position as of stratigraphic horizon. The shales of this area are pink to gray when fresh but weather to yellow and brown soil. Nearly all the material is clastic, clay and fine sand being present in varying proportions, with only minor amounts of diatom remains. Sandy lenses are common, particularly along the edge of San Bernardino Valley in the southern part of the hills, where the lower shale zone thins and is partly replaced by sandstone and conglomerate. The sandstones are yellow and similar to the middle sandstone member, except for the prevalence of conglomerate, which forms a part at least of each of the sandstone zones.

The uppermost sandstone zone, which is mapped along the axis of the syncline at the east end of the Puente Hills, is noticeably whiter than the underlying sandstone beds. Beds 30 to 100 feet thick of nearly white sandstone and coarse shingle alternate with light grayish-brown fine-grained sandstone and siltstone. Toward the top the coarser-grained beds predominate. The sandstones are made up of clean grains of arkosic sand, such as would be derived from granite. Many of the pebbles are of granite, a lesser number of quartzite, and a few of volcanic rocks, all well rounded. It is possible that this sandstone belongs to the Fernando, as it differs in lithology from the typical Puente yellow sandstones and as it resembles the lower part of the Fernando in the Santa Ana Canyon oil field.

In the Whittier Hills the succession of the upper member of the Puente is not as complete as elsewhere, only a single shale and an overlying sandstone being present. Except in the Turnbull Canyon area, the shale is mostly white and rather diatomaceous, though it includes the usual interbedded yellow sandstone lentils, as in the San Jose Hills. In the area north of La Habra Canyon the unconformity between this shale and the overlying Fernando is clearly evident. In the fault block of shale crossed by Turnbull Canyon the shale is less diatomaceous and darker, resembling the lower shale of the Puente of the central part of the hills. West of Turnbull Canyon is about 500 feet of thin-bedded olive-gray to buff sandstone or sandy shale, which forms the top of the Puente for this area. There is some irregularity at the base of this sandstone, possibly indicating an unconformity between it and the underlying shale. No unconformity is apparent between the sandstone and the basal conglomerate of the overlying Fernando.

### AGE

No diagnostic fossils have been found in the beds mapped as the Puente formation. The only fossils other than diatoms and foraminifers found by the writer were some whale vertebrae in the middle sandstone several miles east of Burruel Point. The age determination therefore rests on the position of the formation between the middle Miocene Topanga and the Pliocene Fernando and on such correlations as may be made on the basis of lithologic character. The distinctive lithologic character of the shale members, taken together with the stratigraphic position of the formation, leads to its correlation with several representatives of the upper part of the Monterey group, such as the Modelo formation, Salinas shale, and Maricopa shale, found in the central part of the Coast Ranges, northwest of the Puente Hills. It is of course useless to expect any exact correlation with the formations in other areas, as individual beds of considerable thickness can not even be correlated between separate outcrops within the small area of the present investigation. Such a general correlation with the upper part of the Monterey group would place the Puente in the middle and upper Miocene of the standard time scale.

### EVIDENCE OF OIL IN PUENTE FORMATION

The Puente formation shows surface evidence of the presence of oil at a number of places. In the middle sandstone member there is a zone of oil-impregnated sand that may be traced from a point just west of San Jose Peak northward several miles to the western part of sec. 29, T. 2 S., R. 8 W., and thence westward to the head of Rodeo Canyon. Several good-sized seepages are present in the vicinity of the old Puente field, particularly in the canyon that trends west from the field.

### FERNANDO GROUP UNDIFFERENTIATED (PLIOCENE)

Unconformably above the Puente is the Fernando group, named by Eldridge from San Fernando Valley, northwest of Los Angeles, where the group is well developed. It carries a distinctive fauna of marine shells of Pliocene age. It differs in lithology from the Puente in the general absence of siliceous shales, a greater abundance of conglomerates, and slightly less induration. Despite these general differences, there are several localities where it is difficult to decide whether the beds belong to one formation or the other. The chief areas of outcrop of the Fernando are in a strip directly south of the Whittier fault, between Whittier and Yorba Linda, in the vicinity of the Santa Ana Canyon oil field, in the Coyote Hills, at

Burruel Point, and on the north side of the Whittier Hills. In the northwestward-dipping monocline at the west end of the Whittier Hills there is a well-exposed section of the Fernando. An abrupt change from fine-grained sandstone to a coarse conglomerate marks the base of the Fernando group. From the basal beds of the Fernando to the edge of the hills there is a succession of lenticular conglomerates separating beds of sandstone, shaly sandstone, and sandy clay shale, of which the clay shale is the most abundant. The following section is scaled from the field maps on which the successive beds of each type were plotted.

*Section of Fernando group north of Whittier*

| | Feet |
|---|---|
| Top of section at edge of hills. | |
| Conglomerate and sandstone | 400 |
| Buff to red conglomerate, with many boulders of syenite | 100 |
| Light-gray siltstone which weathers yellow; several 6 to 8 inch calcareous layers | 550 |
| Yellow conglomerate | 100 |
| Fine gray siltstone; weathers to impure clay soil | 450 |
| Conglomerate | 50 |
| Fine gray siltstone | 1,000 |
| Conglomerate | 200 |
| Fine yellow siltstone and clay shale | 750 |
| Conglomerate | 150 |
| Massive nearly white sandstone | 150 |
| Conglomerate | 100 |
| Massive yellow sandstone | 600 |
| Hard massive sandstone | 200 |
| Buff coarse and fine sandstone and conglomerate | 550 |
| Upper sandstone of Puente formation. | |
| | 4,950 |

This section of the Fernando is the best exposed in the district. It shows a general prevalence of fine-grained material in the upper part of the section and of conglomerate and sand in the lower part and also at the top.

A thickness as great as or greater than that shown in the foregoing section of Fernando beds is exposed in the belt south of the Puente fault. Just east of Whittier there is nearly 6,000 feet of the Fernando, a yellow sandstone just south of the mouth of Turnbull Canyon being considered the base of the group, though it may be part of the middle sandstone member of the Puente. Eastward from Whittier successively lower beds of the Fernando are exposed next to the Puente fault as far as the eastern limit of the Whittier field. The strike is nearly parallel to the fault from the Whittier field east to La Habra Canyon, where the lowest exposed beds are soft yellow siltstone. These beds contain calcareous concretions and lentils, which are as much as 2 feet thick, similar to the concretionary layers found in the north Whittier section, and are probably at about the same horizon, 2,000 feet above the base of the formation.

Along the outer edge of the hills between Whittier and La Habra Canyon there are some beds of pink to red gravel that dip toward the valley at a slightly smaller angle than the underlying part of the Fernando. They may belong to the San Pedro formation, but in the absence of definite evidence of unconformity they have been included with the Fernando.

From La Habra Canyon to Olinda there is little change in the character of the beds exposed. On the ridge between Brea and Olinda canyons possibly 90 per cent of the Fernando is fine-grained impure sandy clay shale or siltstone with interbedded fine sandstone. The rest is conglomerate, containing large, well-rounded boulders in a sandstone matrix; the boulders are mostly of light-colored granitic rock, though there are some of volcanic rock and of sandstone similar to that in the Puente, also a few of siliceous shale. As the bedding planes are indistinct, observations of dip are difficult even on some very good exposures. The best exposures for examining the lithologic character of the Fernando in this area are in the small steep gulches on the west side of the lower part of Brea Canyon. Most of the hills have a rounded even contour, which does not lend itself to the development of good outcrops, even where the slopes are steep.

In the oil field immediately west of the mouth of Olinda Canyon terrace gravel hides the Fernando, except on the hill southwest of the town of Olinda, where several good outcrops of calcareous sand and conglomerate carrying Fernando fossils were found.

East of Olinda the beds dip at steep angles, and a nearly full section of 5,000 to 6,000 feet of the Fernando is exposed. The beds are somewhat coarser grained and conglomerates are more prominent than to the west of Olinda.

In the East Coyote Hills there are very good exposures of 1,500 feet of gray siltstone, including some pinkish beds in the upper part. The exposures are in small gulches on the south flank of the anticline. Only minor amounts of conglomerate are present. The lithologic character suggests a correlation with the upper part of the shaly beds of the north Whittier section.

In the vicinity of the Santa Ana Canyon oil field the lower 1,000 feet of the Fernando includes massive beds of white sandstone that are not seen in other parts of the Puente Hills. Above this zone there is softer sandy shale similar to that found above the basal coarse zone elsewhere. This white sandstone somewhat resembles the sandstone beds in the uppermost Puente occurring in the syncline in the southeast end of the Puente Hills.

In the West Coyote Hills only the outcrops at the west end of the hills certainly belong to the Fernando. At that point soft gray and yellow fine sand and sandy shale are interbedded with minor amounts of conglomerate. Fossils found in these beds suggest that they may represent the same horizon as fossiliferous beds found east of the Whittier field and elsewhere along the south side of the Whittier fault in the upper part of the shaly zone. The rest of the West Coyote Hills is covered with gently dipping beds of yellow gravel which probably belong to the San Pedro formation, but because of the presence of undoubted Fernando in some of the outcrops no separation was attempted in mapping.

In the small fault block of the Fernando 3 miles east of Whittier and just north of the Whittier fault there is in addition to the usual fine shaly sandstone and conglomerate a thin bed of pearl-gray limestone of peculiar appearance. This is similar to a limestone in the Paso Robles formation of the Salinas Valley, associated with fresh-water beds.

In the vicinity of Burruel Point the Fernando is well exposed, and the mapping of its basal contact shows its unconformable relation to the underlying Puente. Very little coarse material is here present in the Fernando; it consists of soft sandy shale and siltstone, gray when fresh and yellow after weathering. Small plates of mica are numerous, especially in the coarser-grained shale that approaches fine sandstone in character. Many of the beds are so soft that samples may be broken between the fingers, and the hardness of the formation as a whole is notably less than that of the adjacent Puente and is somewhat less than that of the Fernando in the belt south of the Whittier fault.

The lithologic character of the Fernando suggests that it was deposited near shore. Rather definite proof of this conclusion is presented by a collection of marine shells from the vicinity of San Gorgonio Pass, 40 miles east of the Puente Hills. These shells are of approximately the same age as those found in the Fernando, though they are all Gulf of California species and entirely different from those of the same age found on the Pacific coast. This difference indicates that a land barrier existed between the San Gorgonio Pass region and the area of deposition of the Fernando. This barrier probably occupied most of the area between the Chino-Elsinore fault and the San Jacinto fault. The lack of traces of Fernando beds within this area and the physiographic history of the area confirm the conclusion based on paleontology that this was a land area during Fernando time.

Marine fossils were found at several localities, all of them in a zone about 3,000 feet above the base of the group. Collections were made north of Whittier, in the eastern part of the Whittier field, along the ridge on the southeast side of La Habra Canyon, and in the West Coyote Hills, but the specimens have not yet been classified.

The following species are listed by Eldridge as coming mostly from the vicinity of Brea and Olinda canyons:

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

Gastropoda (univalves):
- *Astyris cf. A. gausapata.
- *Bulla cf. B. punctulata.
- *Calliostoma cf. C. costatum.
- †Cancellaria sp.
- *Conus cf. C. californicus.
- *Crepidula cf. C. rugosa.
- *Dentalium neohexagonum.
- Dentalium n. sp., like Miocene form.
- *Fissuridea murina.
- Fusus cf. F. barberensis.
- *Nassa fossata.
- *Nassa perpinguis.
- *Neverita recluziana.
- †Priene oregonensis var. angelensis.
- †Trochita costellata.
- *Trophon multicostatus.
- *Turritella cooperi.

Pelecypoda (bivalves):
- *Arca multicostata.
- Arca trilineata.
- *Cardium cf. C. corbis.
- *Cardium quadrigenarium var. fernandoensis.
- *Chione cf. C. fluctifraga.
- *Leda taphria.
- *Metis cf. M. alta.
- *Modiolus cf. M. rectus.
- †Ostrea veatchii.
- †Pecten ashleyi.
- †Pecten auburyi.
- *Pecten hastatus.
- †Pecten nutteri.
- †Pecten oweni.
- †Pecten wattsi.
- *Phacoides acutilineatus.
- *Phacoides californicus.
- *Phacoides nuttallii.
- *Phacoides richthofeni.
- Siliqua edentula.
- *Solen sicarius.

This fauna seems to indicate an age of the beds less than that of the basal part of the Fernando in northwestern Los Angeles County studied by the writer,[17] and greater than that of the beds in the vicin-

[17] English, W. A., The Fernando group near Newhall, Calif.: California Univ. Dept. Geology Bull., vol. 8, pp. 203–218, 1914.

ity of the city of Los Angeles studied by Moody.[18] On this basis, and in accordance with the correlations made for the above-mentioned faunas with the standard time scale, the fauna of the Fernando in the Puente Hills should be considered middle Pliocene.

The Fernando is the most important terrane of the district in relation to oil production, as most of the productive sands are within it, though some of the oil is obtained from sands in the upper part of the Puente formation. The oil sands include both fine-grained sandstone and conglomerate. The oil is usually found in the coarser beds in the lower 1,000 feet of the Fernando.

### SAN PEDRO (?) FORMATION (PLEISTOCENE)

In the Puente Hills there are two small outcrops of beds that have been doubtfully referred to the San Pedro formation. It is suspected that the uppermost beds mapped as Fernando in other areas may belong to the San Pedro. At both places in the Puente Hills the beds consist of slightly hardened yellow sands and thin conglomerates which lie with marked unconformity on the Fernando. As these beds are probably of nonmarine origin their correlation with the marine San Pedro is subject to some uncertainty, but owing to the small area covered by the beds it is not thought worth while to give them a separate name.

### TERRACE DEPOSITS

The terrace deposits of this region may be divided into those formed along the courses of streams within the mountains or hills, and those formed as outwash plains or fans where the streams have emerged from the hills. Deposits of the former type are small in both areal extent and thickness. Those of the latter type cover the whole of the coastal plain to a considerable depth. Where these fan deposits have been dissected they are classed as terrace deposits; elsewhere they are part of the valley fill.

The highest outcrops of river gravel occur toward the east end of Santa Ana Canyon. Some of them are several hundred feet above the present river level. These extend westward to the mouth of the canyon as disconnected patches of gravel lying at various heights above the river. Most of the terraces are about 200 feet above the present river level, corresponding to the present altitude of the dissected fan on the south side of the Puente Hills which in this report is called the La Habra terrace. The river terraces along Santa Ana River were formed while movement on the Chino-Elsinore fault was still taking place. Since their formation they have been up-

[18] Moody, C. L., Fauna of the Fernando of Los Angeles: California Univ. Dept. Geology Bull., vol. 10, pp. 39–62, 1916.

lifted relative to San Bernardino Valley the same amount that they now stand above the river level. As Santa Ana River has not changed its level relative to the surface of San Bernardino Valley, any discordance in level between the terraces and the valley must have been produced by faulting that took place subsequent to the deposition of the gravel that covers the terraces.

Within the Puente Hills there are no terraces of the river-bench type, though at two places fan deposits of the plains extend as small reentrants within the area of the hills. In the western part of the Olinda oil field the Fernando deposits are concealed by terrace gravel, and about 3 miles north of the east end of Santa Ana Canyon a terrace extends far up on a flat-topped ridge. Both of these terraces are of the alluvial-fan type, each being the feather edge of a fan or débris slope which at one time extended up on the edges of the present hills.

Along the south side of the Puente Hills is a dissected fan deposit which extends about 4 miles south from the edge of the hills. The central part of this area is known as La Habra Valley, and the name La Habra terrace is here applied to the terrace. Although this deposit is part of the older terrace deposits it is not distinguished on the map from the recent valley fill. The character of this terrace is shown on Plate IV (in pocket). The terrace gravel is probably 200 feet thick at some places, though the greatest thickness exposed in any of the canyons that dissect the terrace is slightly over 100 feet. The best exposures of these terrace sands are along Brea and West Coyote creeks. The material is mostly unconsolidated sand and silt derived from the erosion of the formations in the Puente Hills and differs from the granitic débris that makes up the fans of Santa Ana River.

Just back from the edge of the hills east of Orange the valley of Santiago Creek widens out, and there are extensive terraces of the same age as the La Habra terrace on both sides of the stream. These terraces stand somewhat higher above the present level of Santiago Creek than is usual for terraces of this age. The terraces on the north side of Santiago Creek are about 300 feet above the creek; those on the south side are not quite so high.

### VALLEY FILL AND ALLUVIUM

The Santa Ana Plain and San Gabriel and San Bernardino valleys are all underlain by soft sand and gravel, which is generally called valley fill. The surface soil or alluvium is sandy near the hills but becomes finer and more clayey away from the hills, where the slope is not so great. Beneath the soil and merging with it is the valley fill, which is the accumulated Quaternary outwash from the adjacent hills. There is no break between the surface soil and an underlying hard rock, as in regions where there is a "bedrock." The valley fill merges with the San Pedro (?) formation, which in turn merges with the Fernando. Thus in the outlying oil fields it is difficult to determine from drill records the thickness of the several post-Fernando formations.

## IGNEOUS ROCKS

Igneous rocks of various lithologic types and ages crop out in several parts of the area examined. No great amount of attention was paid to the petrographic character of these rocks, as it was deemed sufficient for the purposes of this investigation to determine their geologic mode of occurrence and their age relative to adjacent sedimentary beds. Most of these rocks are flows and intrusions younger than the lower shale of the Puente formation.

Most but not all of the igneous rocks in the vicinity of the San Jose Hills are flows and are older than the middle sandstone of the Puente formation. Where the igneous rocks are intrusive into sedimentary beds there is usually no very great evidence of contact metamorphism, though in some places the shale is contorted and has been turned black or made notably harder and more cherty than elsewhere.

In the Tustin Hills, on the west flank of the Santa Ana Mountains, there is an area 3 miles long of rounded hills formed of intrusive rocks and flows, with some agglomeratic and tuffaceous beds. Rocks of a number of petrographic types are present. The intrusive rocks are dark green to nearly black when fresh and weather rather easily to an olive-colored crumbly material that on further disintegration forms a yellow clay soil. The flows seem to be more resistant to erosion and weather to a red color. Possibly their hardness is due to silicification. Toward the base of the flows white tuff and agglomerate are interbedded with them. The flows were poured out during and just after the deposition of the Topanga formation, and the intrusions occurred probably only a short time later.

On the south side of Burruel Ridge, about 3 miles east of Olive, there is a patch of intrusive rock, not over 50 feet across, along the contact between the Topanga and the lower shale of the Puente. On account of its small size it is not shown on the geologic map of this area.

There are several areas of igneous rocks in the vicinity of the old Puente oil field. The largest is a double sill of rock classified by Eldridge as a diabase. The sill is about 2 miles long and not much over 100 feet thick at any point. It appears to show two lithologic types—one having diabasic texture and the other porphyritic texture with feldspar phenocrysts in a dense dark-colored groundmass. About 2 miles northwest of the old Puente field there is an irregular mass of softer rock similar to the intrusive rock found in the hills near Tustin. Outcrops are poor in this area, and the rock is so much weathered that as a rule close inspection is necessary to determine that it was originally an igneous rock.

West of Pomona, on both sides of San Jose Creek, igneous rocks rest on the granite. Flows of white, purple, and brown dense rocks dip west, away from the areas of granite, and some softer dark-colored basic rocks similar to the intrusive types found elsewhere are intruded into these flows. Agglomerate, vesicular flows, and tuffaceous sandstone are also found in the area north of San Jose Creek, though in only minor amounts.

South of Spadra there are a few small and very much crushed blocks of sandstone of unknown age which have been enmeshed in the intrusive rocks. Associated with this sandstone and with the adjacent intrusives is a vein of very coarsely crystalline calcite, which can be traced for a mile S. 20° E. from the edge of the hills. The vein is widest near its north end and has been mined on a small scale in several open cuts. The lime was burned for plaster by the early Spanish inhabitants.

## STRUCTURE

### PERIODS AND INTENSITY OF DEFORMATION

Geologic study of the Coast Ranges of California has shown that in each of the areas studied there were several periods of deformation during Tertiary time. Almost all the commonly recognized formations are separated from one another by angular unconformities that indicate orogenic movements of considerable intensity. Several of these periods of deformation can be correlated with a fair degree of assurance over the Coast Range province, though the intensity of the movements seems to have varied considerably from place to place.

In the Puente Hills area several periods of deformation can be recognized, though the record is by no means as complete as in many other parts of the State. The most severe folding took place at the end of Fernando deposition. All older formations dip steeply, and the Fernando dips almost as steeply as any of the older formations. Dips of 15° to 60° are most common, though vertical beds and overturns are by no means rare. The granitic and metamorphic rocks seem to have been sufficiently rigid to resist all tendencies toward folding, but there is evidence that faulting of great magnitude has taken place in areas where they lie at or close to the surface.

The post-Fernando deformation can be correlated by both physiography and paleontology with a deformation that affected the rest of the Coast Ranges and the Sierra Nevada. In terms of the standard. time scale this deformation is supposed either to mark the end of the Tertiary period or to have occurred in the early part of the Quaternary. There has been much discussion as to which is the correct view.

In the vicinity of San Francisco Bay there was an intense deformation at the end of the Merced epoch.[19] Lawson believes that despite the fact that paleontologists consider the upper part of the Merced formation to be Quaternary, the post-Merced deformation should be interpreted as marking the end of the Tertiary period. He holds that the physical evidence justifies the use of this deformation as marking a major time division for the Coast Range province.

Arnold and Anderson,[20] who found practically the same conditions in the Coalinga region, where the deformation is largely later than Paso Robles (post-" Tulare "), preferred to assign it to Quaternary time.

On the basis of physiographic studies, this period of movement in the Coast Ranges has been correlated with the most recent uplift of the Sierra Nevada. These mountains had nearly reached the stage of a peneplain when they were uplifted by a great movement along the faults that mark their eastern boundary. Block faulting and folding on an equally profound scale took place generally over the Great Basin region at the same time. This disturbance has usually been considered as marking the end of the Tertiary in the Great Basin region.

The present writer would prefer an independent nomenclature for each region within which physical changes can be correlated with a reasonable assurance of correctness, local events in the physical history of the region being used to mark the divisions between periods. Any comparisons or correlations with the standard time scale[21] could then be made on a strictly paleontologic basis.

There have been several lesser movements since the main post-Fernando folding, and in the neighborhood of San Pedro, where the record is more complete, evidence is found of several distinct post-

[19] Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (No. 193), p. 20, 1914.

[20] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, p. 162, 1910.

[21] The standard time scale of geologic periods is based on the geologic record of western Europe and has been used simply because that region was the first to be studied in detail. Its world-wide use has resulted from the very natural desire to use names familiar to all readers.

Fernando movements.[22] These lesser movements, which have continued from the end of the main folding down to the present time, have had considerable effect on the recent physiographic history of the region.

Next in importance to the post-Fernando folding is the deformation that occurred during and after the deposition of the Puente formation. As part of the Monterey group, the Puente formation was affected by the post-Monterey deformation. In some parts of the Coast Ranges there is a profound angular unconformity between formations of Monterey age and the next younger formation. Within the Puente Hills there is no striking evidence of the magnitude of this discordance in the shape of an angular unconformity between the Puente and Fernando where they are in contact, but the distribution of the Fernando mainly south of the Whittier fault suggests a movement, accompanied by change in area of deposition, at the end of Puente time. Moreover, the disappearance of diatom skeletons and of fine siliceous mud marks a pronounced physical change of some sort in the area from which the sediments were derived. The numerous overlaps of the different members of the Puente formation on one another and the presence of thick zones of conglomerate in certain areas indicate that earth movements of considerable magnitude were going on during the deposition of the Puente. All these unconformities are important, as they make it difficult to determine the thickness of covered formations, even only a short distance from points at which the formations crop out. This difficulty must be borne in mind in making predictions in regard to the depth to certain formations which it may be desired to reach in test wells.

Unconformities are found also at the top of the Tejon, Martinez, Chico, and Triassic formations, but as they affect formations beneath the oil measures they are of less importance in the present study. The most profound as well as the most interesting of these is the unconformity at the top of the Triassic. The Triassic beds were intruded by a batholith of granitic type. It seems likely that this intrusion is to be correlated with the Mariposa revolution of the Sierra Nevada, during which the Sierra batholith was intruded and the Mariposa slate was altered to its present lithologic character. This event is generally supposed to have occurred at the end of Jurassic time.

[22] Lawson, A. C., The post-Pliocene diastrophism of the coast of southern California: California Univ. Dept. Geology Bull., vol. 1, pp. 115-160, 1893. Arnold, Ralph, The marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, pp. 1–420, 1903.

## MAJOR FAULTS OF SOUTHERN CALIFORNIA

Before giving a description of the structural features of the immediate area studied in detail, the writer wishes to take up some of the features that are characteristic of a somewhat larger area in southern California. Several structural conditions of economic importance are more clearly shown in this way than otherwise, and some of the conclusions drawn are of considerable significance with reference to the possibility of obtaining oil.

Block faulting dominates the structure of southern California. Plate III has been prepared to show the principal faults and the structural and topographic units into which they divide the region. These faults have been recognized by their relation to topography and to geologic structure, by the presence of springs along their surface trace, and by the actual displacements that have occurred along the fault planes within historic times.

Probably the same faults were in the past important dividing lines in determining the areas and character of basins of deposition, so that a proper understanding of the stratigraphy as well as of the present structure is dependent on a knowledge of these faults.

It will be noted from the map that, with the exception of the Inglewood fault, the major faults mark approximately the dividing lines between mountains or hills and valleys. Some of these topographic dividing lines are so abrupt and striking that the existence of a fault has been accepted on physiographic evidence in places where, because of lack of outcrops, there is no corroborative evidence in the form of geologic discordance on the opposite sides of the fault. Thus the east end of the San Gabriel fault, which is believed to bound the San Gabriel Range on the south, is proved chiefly by the abrupt change along a fairly straight line from rugged mountains to gently sloping plain. Indeed, this area has been taken as a classic example of the topography developed by block faulting, with the subsequent building up of an alluvial apron sloping away from the mountain front. It is supposed that the alluvial apron gradually encroached on the mountain block as it was built up to higher and higher levels by the abundant outwash of material from the steep canyons of the adjacent range, so that at the present time the fault is covered by alluvium and is at a considerable distance south of the scarp that marks the edge of the mountains. The San Andreas, San Jacinto, and Elsinore faults also mark very distinct boundaries between major topographic divisions, and the approximate position of the faults may be determined on the basis of physiography, irrespective of their other characteristic features.

Geologic mapping demonstrates the importance and magnitude of movements along these major faults. Wherever detailed mapping has been done along the San Andreas fault, it has been found that beds of widely differing ages, normally separated by thousands of feet of strata, have been brought into juxtaposition. In fact. the whole stratigraphic column and geologic history of the territory on opposite sides of the fault seem to be dissimilar.[23] There is no published work showing the areal geology along the San Andreas fault in southern California, but unpublished reports by L. F. Noble on the north flank of the San Gabriel Mountains and by F. E. Vaughan on the area east of Redlands show that within these areas there is the usual structural complexity close to the fault.

The northern part of the San Jacinto fault in some way determines a subsurface ridge of impervious rock that forms the western limit of the San Bernardino artesian basin.[24] A little farther to the south this fault separates the Tertiary beds of the "badlands" from the metamorphic rocks southwest of them.[25]

The west end of the San Gabriel fault may be mapped as a definite geologic feature. Between Sunland and the vicinity of the Newhall tunnel it marks the contact between the granitic rocks of the range and the Fernando deposits.

The Elsinore fault has granite and metamorphic rocks on both sides for most of its length. There are undoubtedly discordances in the types of these rocks on the two sides of the fault, but detailed maps of this area are not available at the present time. Near the town of Elsinore some gently dipping Tertiary lake beds are probably limited on the west by the fault. To the north, where the Elsinore fault splits into the Chino and Whittier faults, there is a down-faulted strip of Cretaceous and Tertiary formations between blocks of metamorphic rocks. Tracing the two branch faults to the northwest shows that they are of geologic importance. (See pp. 56–57.)

Through the greater part of its length the Whittier fault forms the contact between steeply dipping beds of the Fernando and sandstones and shales of the Puente formation. Although the fault plane is traceable for the length of the Puente Hills, there are only a few points at which it can be actually seen. In the Whittier oil field, in the first small canyon east of Turnbull Canyon, there is a good exposure of the contact between steeply dipping sandstone and conglomerate of the Fernando and contorted shale of the Puente. Farther east, in a small gulch west of the road leading from La

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[23] For examples of structure and other features along this fault see Lawson, A. C., and others, The California earthquake of April 18, 1906, Carnegie Inst. Washington, 1908. See also U. S. Geol. Survey Bull. 581, pp. 119–160, 1915; Bull. 691, pp. 219–250, 1919; and Geol. Atlas, folios 163 and 193.

[24] Mendenhall, W. C., The hydrology of San Bernardino Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 142, pl. 8, 1905.

[25] Waring, G. A., Ground water in San Jacinto and Temecula basins, Calif.: U. S. Geol. Survey Water-Supply Paper 429, p. 9, 1919. The map (pl. 3) does not show the fault, although it is mentioned in the text.

Habra Valley to the old Puente oil field, a vein of tufa is present along the fault.

Both the San Pedro and Inglewood faults are what might be termed buried faults—that is, the surface structure does not give an adequate indication of the geologic importance of these lines as affecting the structure of the rocks older than those exposed. The surface expression of the San Pedro fault is a sharp flexure at the edge of the hills, where a steeply dipping monocline to the northeast replaces the gentle dips present in the main body of the hills. The Inglewood fault is marked by an interrupted low ridge, in which the exposed upper Tertiary beds show a low anticlinal structure. Because this line is long and straight it is believed to mark a fault some distance below the surface, of the same character as the other major faults of southern California. There is some minor faulting in the surface beds along the Inglewood fault north of the town of Inglewood, but it is not of as great magnitude as the faulting that is believed to exist at depth.

Two other characteristics of the major faults are recent movements and lines of thermal springs. It is significant of their continued importance through a long period of geologic time that movements along four of these faults have probably taken place within historic times and have been the cause of earthquakes in their vicinity. According to Wood,[26] there have been movements on the San Andreas, San Jacinto, Elsinore, and Inglewood[27] faults within recent times, and possibly the San Gabriel fault should be added to the list. According to Waring,[28] several groups of springs have their origin along the San Jacinto fault.

## PRINCIPAL STRUCTURAL DIVISIONS

*General features.*—The preceding discussion of the characteristic features of the larger faults is introductory to a study of the structural units of which in great measure they form the boundaries. In describing the rift faults of southern California and the structure produced by movements that have taken place along them, Hill[29] says:

> In southern California these movements have largely resulted in producing fault blocks, sometimes tilted, sometimes down-pressed, accompanied by faults of great vertical and lateral magnitude and persistent throughout long dis-

[26] Wood, H. O., California earthquakes: Seismol. Soc. America Bull., vol. 6, pp. 76–77, 1916.

[27] Taber, S. A., The Inglewood earthquake in southern California, June 21, 1920: Seismol. Soc. America Bull., vol. 10, pp. 129–145, 1920.

[28] Waring, G. A., Ground water in San Jacinto and Temecula basins, Calif.: U. S. Geol. Survey Water-Supply Paper 429, pp. 24–25, 1919.

[29] Hill, R. T., The rifts of southern California: Seismol. Soc. America Bull., vol. 10, pp. 146–149, 1920.

tances. There are also foldings of the rocks incidental to the great fault displacements.

I have frequently compared the relief of southern California to a series of unequal pavement blocks, some of which have been pushed up and others depressed, corresponding to our mountains and valleys, the seams between these blocks representing the lines of fault movement. Measurable data show that in some places the total vertical movement along the seams, which has probably extended through millions of years, has been at least 4 miles.

There are certain differences in both the topography and the structure of these blocks, depending on whether they are composed largely of granite and metamorphic rocks or largely of unmetamorphosed sedimentary formations. In the areas of granite and metamorphic rocks the structure is almost entirely of the fault-block type, with relatively little folding, but in the areas of thick sediments folding as well as faulting has occurred. Either because of superior resistance to erosion or greater original uplift the higher and more rugged ranges are formed of rocks of the granite type.

Within the area shown on Plate III there are four tilted blocks of the rigid type—namely, the San Gabriel and San Bernardino ranges and the San Jacinto and Perris fault blocks. The central cores of the Santa Ana and Santa Monica mountains are composed of granitic rocks, and the flanks of sedimentary beds, and these ranges as a consequence show structural features of both the rigid fault block and folded types. The Puente Hills, Repetto Hills, San Pedro Hills, San Gabriel Valley, and Los Angeles and Santa Ana coastal plain are underlain by sedimentary formations, which show folded structure as well as faulting.

*San Gabriel Range.*—The San Gabriel Range was uplifted in post-Fernando time along the San Gabriel fault. Whether it was tilted toward the north or uplifted equally on both sides has not been established. The contact between the granite and sedimentary rocks on the northeast side of the range lies along the zone of the San Andreas fault. This line marks a descent from the higher part of the range to the lower mountains bordering the desert to the north. According to Johnson,[30] this descent is due to recent faulting. There are several parallel branch faults here, and it appears that there were several step faults, instead of a single displacement along the San Andreas rift. Arnold has written a general description of the San Gabriel Range,[31] and the areal geology of a small area on the north flank of the range, in the vicinity of the mouth of Rock Creek, has been described by Dickerson.[32]

[30] Johnson, H. R., Water resources of Antelope Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 278, pp. 20–22, 1911.

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

[32] Dickerson, R. E., The Martinez Eocene and associated formations at Rock Creek [Calif.]: California Univ. Dept. Geology Bull., vol. 8, pp. 289–298, 1914.

*San Bernardino Range.*—Like the San Gabriel Range, the San Bernardino Range has been profoundly uplifted on its south side in comparatively recent time. As the rocks are mostly of the granitic type, any folding that took place at this time can not be recognized. However, physiographic evidence of lack of folding is afforded by remnants of the post-Fernando peneplain which do not show any evidence of having been folded. Baker[33] believes that the north flank of these mountains, as well as the south, is marked by faulting, with the range uplifted with respect to the adjacent Mohave Desert. Baker believes that the amount of uplift on each side was about 4,000 feet.

*San Jacinto fault block.*—The block that lies between the San Andreas and San Jacinto faults differs from the two blocks just described in that it is tilted on an axis normal to its length. To the southeast is the lofty San Jacinto Range, of equal height with the San Gabriel and San Bernardino ranges. To the northwest there is a descent to the hills adjacent to San Timoteo Canyon, which are composed chiefly of nonmarine Miocene and Pliocene formations. Still farther northwest is San Bernardino Valley, which occupies the north end of the block. The part of this valley belonging to the San Jacinto block was called by Mendenhall[34] the San Bernardino basin, because of the fact that it forms an artesian basin distinct from the rest of San Bernardino Valley. The subsurface structure that determines this feature is not accurately known, though it is in line with the San Jacinto fault and is probably in the nature of a fault with the downthrow on the northeast, rather than a fold.

The San Jacinto block narrows opposite the part in which the surface is occupied by sedimentary beds. These beds are moderately folded along axes parallel to the major faults, and it is probable that the narrowing is a measure of the amount of shortening that these beds suffered by folding. The part of the block occupied by metamorphic rocks is only very slightly folded and retains its original width.

*Perris fault block.*—Between the San Jacinto and Elsinore-Chino faults and limited on the northwest by the San Gabriel fault is the Perris block, one of the most regular and interesting of the fault blocks of this region. The northwestern part of the block is tilted down, but to a less extent than the adjacent San Jacinto block. The southern part of the Perris block is a region of moderate relief, which has been described as the Perris peneplain. This block contains numerous flat valleys of several square miles in extent, of which

[33] Baker, C. L., Notes on the later Cenozoic history of the Mohave Desert region in southeastern California: California Univ. Dept. Geology Bull., vol. 6, p. 369, 1911.

[34] Mendenhall, W. C., The hydrology of San Bernardino Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 142, pl. 8 and text, 1905.

the Perris Valley is typical. Between the valleys are ranges of hills which rise as much as 1,000 feet above the level of the adjacent valleys. The block has a slope to the northwest, at least as far north as the edge of San Bernardino Valley. Formations other than granite and metamorphic rocks are thin and occupy only small areas in the southern part of the Perris block. Near Elsinore there is a thin formation of gravel and clay which was deposited in a fresh-water lake during Miocene or Pliocene time. The lack of folding of these beds and the absence of evidence of warping of the peneplain indicate that during the post-Fernando deformation this block acted as a rigid mass. The height of the Perris block in relation to sea level suggests that this block was very slightly uplifted and tilted to the north at the same time that neighboring blocks were uplifted a much greater amount, so that, in comparison with its neighbors, the Perris block is in effect faulted down.

The northwest end of the Perris block is occupied by San Bernardino Valley. This valley is the surface of an alluvial apron (a series of coalescing alluvial fans) that has been built up by the outwash from the steep canyons of the San Gabriel Range. Unlike most valleys, it slopes in one direction only, to the south, the lowest point being at the southwest corner of the valley. Santa Ana River follows the trough between the northward-sloping Perris peneplain and the southward-sloping San Bernardino Valley.

The most natural assumption with regard to the formations beneath San Bernardino Valley is that the granitic rocks of the Perris peneplain extend beneath the valley fill to the north. It therefore seems unlikely that there is any great thickness of Tertiary formations beneath San Bernardino Valley. Some outcrops of nearly flat-lying Puente sandstone are found just east of the Chino fault a few miles north of Santa Ana River, and a similar nearly flat sandstone occurs half a mile north of Corona. The lack of folding in these beds suggests that the rigid granite is not far beneath the surface.

*Santa Ana Mountains.*—The Santa Ana Mountains are bounded on the northeast by the Elsinore fault, along which the range has been uplifted. The crest of the range, which lies only 3 to 5 miles west of the fault, is a core of granitic and metamorphic rocks. This outcrop of hard rocks narrows toward the north, ending at Santa Ana Canyon, but to the south it widens out, and to the southeast the Santa Ana Mountains merge with the Peninsula Range, where all the rocks are of a granitic type. On the southwest flank of the Santa Ana Mountains there is a monocline of sedimentary rocks dipping to the southwest, but the structure is complicated by numerous subsidiary folds and faults. The edge of the coastal plain adjacent to the southwest flank of the mountains is not marked by any prominent structural line. An irregular westward-plunging anticline trends west across the north end of the monocline of sedimentary rocks. This cross structure is marked by the triangular outcrop of the Chico formation, which extends from its north-south basal contact with the metamorphic rocks westward to a vertex at the lower end of Santiago Canyon. Burruel Ridge, on which the strike is slightly south of west, forms the north flank of this anticline. The other flank is formed by the beds dipping to the southwest on the southwest side of Santiago Canyon. There is a difference in strike of 90° between the two flanks of this anticline. Between Santiago Canyon and the edge of the coastal plain there are two minor folds parallel to the main trend of the range.

*Puente Hills.*—As the Puente Hills are within the area of detailed mapping, their structure has been more carefully studied than that of adjacent blocks. Plate I, showing the areal geology and cross sections, illustrates the chief features of the structure.

During the post-Fernando period of deformation the main block of the Puente Hills was uplifted with respect to the adjacent blocks, and the beds were moderately folded. On the northeast and southwest sides of the hills the greater part of the uplift probably took place along the faults that mark the approximate boundaries of the hills on those sides. To the northwest there is no definite structural limit, the edge of the hills being determined by the flanks of the San Jose Hills anticline and the monocline of Fernando beds north of Whittier. These features probably mark the edge of a geologically depressed area occupied by the San Gabriel Valley.

A peculiar feature of the Puente Hills is the alinement of structural lines on each side of the hills parallel with their edge. This might indicate that the hills were compressed by thrusts acting from all three sides; or, more probably, the compression of the hills by thrusts normal to the Whittier and Chino faults produced a component acting in a northwesterly direction by which the whole Puente block was pushed northwest against the San Gabriel Valley block.

The Whittier fault, on the southwest side of the hills, lies well within the area of the hills, though geologically the area south of the fault should be considered part of the coastal-plain block, rather than of the Puente block. A monocline of Fernando beds dipping steeply to the southwest forms the hills southwest of the Whittier fault as far east as the branch fault 2 miles east of Yorba Linda. East of this point the beds on the south side of the Whittier fault are part of the Santa Ana Mountain block. Owing to the tilting of these mountains to the southwest successively older beds are encountered on the south side of the Whittier fault as it is followed southeastward, and across Santa Ana River the older formation is on the south side of the fault instead of on the north. This reversal in direction of throw on the fault is due to the fact that the Santa Ana block has been tilted decidedly to the southwest, whereas the Puente block was not. An analogous condition for the San Jacinto fault has been described above. Another reversal in throw occurs near the west end of the Whittier fault, where, near the mouth of Turnbull Canyon, the Puente formation is on the south side and the Fernando on the north. At this locality the Puente block dips off toward San Gabriel Valley, which is here structurally lower than the adjoining part of the coastal-plain block.

Only a very small area northeast of the Chino fault lies within the Puente Hills. In this small area, which is 8 miles northwest of Corona, there is an abrupt change along the fault line from nearly vertical beds on the Puente Hills side to nearly flat beds of similar type on the opposite side. As stated in the discussion of San Bernardino Valley, this change is considered corroborative evidence for the conclusion that the rigid granitic basement lies at no great distance beneath the surface on the northeast side of the Chino fault.

The major structure of the east-central part of the Puente Hills is synclinal. The beds dip toward the center of the hills along the greater part of the length of both the Whittier and Chino faults. Along the Whittier fault there is a fairly regular northeastward-dipping monocline from Santa Ana Canyon to La Habra Canyon, with possibly a slight complication of minor crumples in the structure in the vicinity of the old Puente oil field. The dips close to the Chino fault are pretty regularly to the southwest from its junction with the Elsinore fault north to a point within a few miles of the granite area southwest of Pomona. Close to that area a small anticline lies between the fault and the central syncline. This central synclinal area consists of several small sinuous folds. The eastern limit of the synclinal area is fixed by an eastward-trending and closely folded syncline truncated by the Chino fault. En échelon with this fold, which is only 2 miles long, is another syncline, which trends slightly west of north for 4 miles. About 2 miles west of the north end of this fold lies the end of a sinuous fold that trends to the southwest and ends close to the Whittier fault, though the lowest point along the fold is a saddle considerably north of the west end of the fold and closer to the central part of the hills. An anticline that trends northeast from the Whittier fault to the area of granitic rocks southwest of Pomona bounds the central syncline on the northwest. This anticline is parallel in trend to the northwest end of the hills, and between it and the edge of the hills there is a series of folds, all with approximately the same trend. As both ends of this anticline are structurally higher than the center the central syncline apparently extends somewhat beyond this anticline.

Differences in the stratigraphy of the formations that crop out on the northeast and southwest sides of the central synclinal area require the conception of a simple synclinal structure to be somewhat modified. The lower shale of the Puente formation, which is at least 3,000 feet thick on the southwest side, is entirely absent in the area to the northeast, where the middle sandstone member rests directly on the granitic and pre-Puente volcanic rocks. This overlap may or may not be due to unconformity. If it is a simple overlap it means that the Puente block was tilted so much during early Puente time that deposition took place only on the southwest side of the block. Or possibly movement took place along a fault passing northwestward across the block in such a way that the southwest side was subject to a large amount of deposition while the northeast side was kept at or near sea level. If an unconformity is postulated, faulting rather than tilting seems the more likely type of movement, as the sandstone does not show any noticeable discordance of dip in its relation to the underlying shale, such as would be expected if the shale had been tilted and eroded. As the central part of the basin is in line with the Elsinore fault, and as there is evidence of a similar abrupt overlap in the upper member of the Puente along a continuation of the same line in San Jose Hills, the writer strongly suspects that there is a buried fault of major importance crossing the middle or eastern part of the Puente block.

The Whittier Hills, comprising the area west of La Habra Canyon, show some of the most complicated structure to be found within this district. Steep irregular dips, numerous faults, unconformities, and lithologic variations in the different formations and members make the structure, as well as the stratigraphy, difficult to work out. The writer has seen several maps of the area south of Workman Hill that were not in agreement with his own map or with one another.

In the San Jose Hills the general structural trend is N. 60° E., parallel to the edge of the hills and to the strike of the beds on the west end of the Whittier Hills. In the central part of the San Jose Hills there is a large anticline, which plunges westward from the vicinity of San Jose Peak. To the east from San Jose Peak the axis of the fold is occupied by a thick bed of conglomerate, which has been mapped with the middle sandstone member of the Puente. The shale is faulted down against the conglomerate on the south side, and the anticlinal axis is close to or along this fault.

Slightly farther east are outcrops of igneous rocks on which the shale rests. The shale is apparently conformable with the lower sandstone member of the Puente, yet it appears to rest with normal contact on the igneous rocks. How such a condition could come about is uncertain. It is hard to explain how the shale could overlap in so short a distance a thick formation which appears to be conformable beneath it. Possibly the igneous rocks are intrusive in the shale in this area. The exposures close to the contact between the shale and the igneous rocks are poor, and any conclusion as to the relation between them is open to some doubt. But if it is assumed that the igneous rock was intruded as a sill between the shale and the conglomerate then it would still be necessary to explain why the conglomerate does not crop out between the igneous rock and the granite farther east. The best explanation of the structure seems to be that the conglomerate was deposited against a fault scarp, the displacement along the fault occurring during the period of deposition of the conglomerate, thus keeping the scarp constantly renewed and allowing the deposition of a great thickness of beds against it without any of the material being deposited on the uplifted side of the fault. This is similar to the explanation given for the overlap of the lower shale of the Puente southwest of Pomona; the faulting postulated is of the same type of block faulting which took place in the post-Fernando period of deformation.

The Shell Co.'s Sentous well, a few miles west of San Jose Peak, on the axis of the main anticline, failed to get any trace of the conglomerate beneath the shale. The well penetrated only shale to a depth of slightly less than 4,000 feet, where igneous rocks were encountered. Evidently all of the lower Puente is absent here, unless the lower part of the shale in the well should be classed as lower Puente, with the horizon of the conglomerate at the base of the upper Puente and the middle sandstone not represented.

South of the main anticline of the San Jose Hills there is a well-defined and easily traceable syncline. South of this fold is an area where the structure is probably anticlinal but within which the dips in the shale are so discordant that it is uncertain whether there is a single large fold obscured by small superficial structural features or several small folds. It is difficult to work out the structure satisfactorily in shale areas, because of the unreliability of dips measured on small outcrops of shale. Where shale is exposed to a depth of several feet, as in road cuts and other excavations, it is seen that surface creep and minor crumpling are very common in shale beds close to the surface. The presence of so many small crumples may easily result in noncharacteristic dips being observed in areas of few outcrops.

The nearly detached group of hills east of the town of Puente is traversed by a steep westward-plunging anticline. In the eastern half of the hills this fold is shoved to the south, and the beds on the south flank are overturned. A cross fault separates the beds that are overturned from those along the western part of the fold that dip to the south. This anticline is in line with the irregular anticlinal area to the east, and it may be that at a depth of a few thousand feet there is a single fold extending eastward as far as a point directly south of San Jose Peak.

*Santa Monica Mountains, Repetto and Verdugo hills.*—A detailed report on the area including the variously named groups of hills south of the San Gabriel Mountains and west of the Puente Hills, by W. S. W. Kew, is to be issued by the Geological Survey, but as some time will elapse before it is completed a few points of general structure that have a bearing on the probable structure beneath the San Gabriel Valley will be mentioned here.[35] Along the south side of the Santa Monica Mountains there is a fault, or rather a series of faults, along which the range was uplifted and tilted toward the north. The northern half of the range is formed of Tertiary formations dipping mostly to the north, the type of structure being in a general way similar to that of the Santa Ana Mountains, though the orientation is different. The Verdugo Hills and their southeastward continuation as far as the Arroyo Seco at Garvanza are made up of granite. Thence eastward halfway to the Paso de Bartolo the surface beds are closely folded and faulted beds of the Puente formation, followed to the east by the Fernando, which forms the Merced group of hills, in which the Montebello oil field is situated. Most of the folds within this area trend east.

*San Gabriel Valley.*—The possible presence of oil deposits within San Gabriel Valley lends interest to speculations as to the occurrence of certain formations and types of structure in the valley area, even though nothing very definite can be said. It seems likely that the Puente and Fernando formations are thicker toward the south side of the valley than toward the north, as they are in the hills that bound the valley to both the east and west. In the Puente Hills successively younger formations appear southwestward from the north end of the hills. The granite near Pomona is followed in turn by pre-Puente volcanic rocks, the Puente formation, and the Fernando group, the last nearly a mile thick in the western part of the Whittier Hills. On the opposite side of the San Gabriel Valley are the granitic Verdugo Hills to the north, then appear beds corresponding to the Puente, and in the hills east of Los Angeles most of the outcrops are of the Fernando. It therefore seems probable that the valley fill in the northern part of San Gabriel Valley is underlain by pre-Puente volcanic rocks and granite and that the structure is rather complicated. The central part of the valley should have the

[35] The geology of part of this area in the vicinity of Los Angeles is shown in a report by Ralph Arnold (The Los Angeles oil district: U. S. Geol. Survey Bull. 309, pp. 138–198, 1907), and that of a slightly larger area in California State Min. Bur. Bull. 69, map folio, 1915.

Puente formation beneath the valley fill, and toward the south the Fernando should be present in considerable thickness.

The only suggestions as to possible anticlines beneath the valley are obtained from the position of three anticlines that trend toward the valley. In the San Jose Hills are the San Jose anticline and one near the town of Puente, both of which plunge steeply westward toward the valley. There might possibly be structural features out in the valley in line with these folds. The east-west anticline of the Montebello field [36] may be traced eastward as far as the edge of Paso de Bartolo, on the other side of which is the monocline of northwestward-dipping Fernando beds that forms the flank of the Whittier Hills. It seems natural to postulate a syncline in the area between. (See Pl. I.) If there is any eastward continuation of the Montebello line of folding it probably swings around to a northeasterly trend paralled to the structure of the flank of the Whittier Hills, from which it is separated by a parallel syncline.

*Santa Ana coastal plain.*—Because of its importance as an oil-producing area and the possible existence of undiscovered fields within this area the Santa Ana Plain is of peculiar interest. The part of the plain here discussed lies in the block between the Whittier and Inglewood faults. To the northwest it ends at San Gabriel River, which has been arbitrarily taken as dividing the Santa Ana Plain from the Los Angeles Plain. To the east and southeast are the Santa Ana Mountains and San Joaquin Hills. The structure of the Santa Ana Mountains shows that they have been tilted so as to slope toward the southwest. The coastal-plain block is probably to be regarded as the lower end of this tilted block—at least, there is no clear-cut geologic boundary between the two. Most of the structure lines within the Santa Ana Mountains and San Joaquin Hills have a northwesterly trend, and the indications therefore point to a similar trend of the structure beneath the plain opposite these hills. An exception to this trend is the prominent irregular anticline in the northern part of the Santa Ana Mountains. This fold trends nearly west and plunges strongly to the west. Possibly this structural trend continues beneath the plains west of Burruel Point.

On the northeast side of the plain is the steeply dipping monocline of Fernando beds, which is almost exactly parallel to the Whittier fault. A series of outlying anticlinal folds from 3½ to 4 miles south of the fault are known both from surface structure and from information obtained in the course of oil development. These folds trend almost west and are low domes in which a thickness of 3,000 to 6,000 feet of Fernando beds is present over the crest.

[36] Augur, I. V., Report on Montebello oil field: California State Min. Bur. Monthly Summ., vol. 7, No. 11, 1921.

The structure of two of these domes is known only from the data gained from oil wells. Each of the known folds in this area is the seat of a productive oil field.

Between Burruel Ridge and the Whittier fault there is a synclinal reentrant of the coastal-plain block. Possibly this structure continues to the west beneath the alluvium. If so, it is necessary to postulate a buried structural ridge trending west or slightly south of west as a continuation of the anticline present at the mouth of Santiago Creek in the Santa Ana Mountains. If this ridge is present the westerly trend of the outlying series of folds south of the Whittier fault can be explained as the resultant of stresses normal to the trend of Burruel Ridge and the Whittier fault, for the east-west line almost exactly bisects the angle between the trends of these two structural features. This would place the series of folds to the south of the Whittier fault nearly in the center of a broad syncline of Fernando beds. South of this basin area the structural lines should normally trend northwest, parallel to the structure in the Santa Ana Mountains and San Joaquin Hills and to the Inglewood fault. Such a trend is by no means certain, however, as is shown by the various trends of structural lines in the central part of the Puente Hills block, where the structure is not parallel to that on any of the sides of the block. The steep southwestward tilting of the Santa Ana Mountains suggests that if the same tilting took place in the Tertiary formations beneath the valley alluvium the Fernando should be present in considerable thickness not very far southwest of the edge of the mountains.

*South side of Whittier fault.*—The monocline of Fernando beds on the south side of the Whittier fault belongs to the coastal-plain block, but because of its importance in relation to some of the principal oil fields of the district and its position within the area of the Puente Hills it is described separately. Through most of its length the Whittier fault is flanked on the south by a simple monocline of the Fernando, in which the beds strike nearly parallel to the fault. Slight departures from this simplicity are found to the north of the town of Whittier, near the Brea oil field, and northeast of Yorba Linda.

In the area north of Whittier for a distance of half a mile west of Turnbull Canyon the fault is flanked on the south by shale of the upper member of the Puente. This shale is believed to be the core of an irregular anticline that plunges sharply to the west and is cut off on the east by the Whittier fault. On the south side of the Puente, just south of the mouth of Turnbull Canyon, the Fernando, which directly overlies the Puente, strikes slightly south of west and dips 45°–75° S. Half a mile to the northwest, where the

Fernando overlies the Puente on the other flank of the supposed anticline, the strike is N. 30° E. and the dip 45°–60° NW. This dip is fairly uniform as far as the west line of sec. 16, T. 2 S., R. 11 W., beyond which the only outcrops found to the south of the fault consist of crushed conglomerate in which the attitude of the bedding could not be determined. This anticline may be at the east end of a line of folding that extends to the west beneath the valley alluvium, though there does not appear to be any topographic evidence of a continuation of the fold in that direction. North of the west end of the fault, in the ridge south of the mouth of Sycamore Canyon, the beds that should form part of the northwestward-dipping monocline of the Fernando are overturned, dipping 70° S. Some geologists have mistaken these overturned beds for part of an anticline.

Eastward from the south side of Turnbull Canyon the Fernando strikes almost exactly toward the east. This causes the beds to be truncated toward the east by the Whittier fault, and Fernando beds of successively higher horizons abut against the fault as far as the eastern limit of the old Whittier field. From that point eastward there is very little departure in strike from parallelism with the fault as far as the Fernando extends, though the dips gradually steepen toward the east. In the neighborhood of La Habra Canyon the average dip to the southwest is 30°. East of Olinda the dip increases to 60° and 70°, and even overturned beds occur at several points.

In the neighborhood of Brea Canyon there is a closely folded anticline, which lies south of the main fault and traverses the central part of the Brea Canyon oil field. This anticline leaves the main fault opposite the old Puente oil field and gradually diverges, reaching a maximum distance from the Whittier fault of 1,500 feet.

Northeast of Yorba Linda there is some complication in the structure of the Fernando in the last half mile of its outcrop along the fault. The normal steep dip of over 60° is replaced by dips of 15° and 20° S., with no noticeable change in strike. Obviously some sort of cross structure is required to account for this abrupt change in amount of dip. Some observers have mapped an anticline plunging steeply to the southwest in this area.

## PHYSIOGRAPHY

The surface features of the land, their relation to underlying rock structure, and the history of their development fall within the province of physiography. A study of strata deposited during successive periods gives the history of the basins of deposition, but there is no direct evidence of the character of the land areas from which the sediments were derived, except that which is preserved in the present land forms. Because the physiographic record of one period is likely to be completely obliterated in a subsequent period of extensive erosion, this type of geologic record is usually very fragmentary, except for the comparatively recent periods of geologic time. A study of the development of land forms within this area brings out important features of structure of which there is no other evidence.

The physiographic history of southern California of which there is good record dates from a time near the end of the Fernando epoch. During Fernando time an extensive surface of low relief was developed over nearly all of the southern part of the State. For the country east of Los Angeles this old surface is known as the Perris peneplain, from the fact that a large area of it is preserved in the vicinity of Perris. Most of the peneplain remaining near Perris consists either of a nearly level plain of granitic rocks, covered with a thin surface soil, or of low rolling granite hills. Above this level rise scattered groups of steeper hills, some of which reach heights of 1,000 feet above the plain. The topography is less subdued toward the southeast, though this same belt of low relief continues southeastward as far as the Mexican border, forming the central part of the Peninsula Range of San Diego County.[37]

Remnants of the Perris peneplain, or at least of a similar plain of low relief, are found in the Bear Valley region of the San Bernardino Mountains. The surface altitude there averages about 6,500 feet, as compared with 1,000 to 1,500 feet for the Perris block. Between the two areas of low relief is the rugged southwest front of the San Bernardino Mountains—in fact, the Perris block is flanked on three sides by rugged mountain fronts. This topographic discordance is the result of the post-Fernando faulting. The character and location of the faults and the amount of displacement are discussed on pages 54–55.

In the area southwest of the San Gabriel and Chino-Elsinore faults the peneplain was represented by the plain of aggradation of the top of the Fernando group as originally deposited. At the time of the breaking up of the Perris peneplain the Fernando beds were severely folded. Subsequent erosion has been sufficient to remove all trace of the original surface formed by the deposition of the Fernando sediments.

The Puente Hills have been subject to a large amount of erosion since the post-Fernando folding and probably bear little resemblance to the hills as originally uplifted. Many of the drainage and other

[37] Waring, G. A., Ground waters in San Jacinto and Temecula basins, Calif.; U. S. Geol. Survey Water-Supply Paper 429, 1919. Contains maps and views that illustrate the character of the Perris peneplain.

topographic features are of the subsequent rather than the consequent type—that is, they were produced by erosion acting on hard and soft strata in such a way that the stream valleys were made to follow the softer strata and the hard beds came to stand out as ridges.

Several valleys have been determined by the structure along the Whittier fault, notably parts of Brea Canyon, the small canyon to the west of Brea Canyon, and Olinda Canyon. Each valley follows the trend of the fault on the inside of the ridge of Fernando before breaking through to the coastal plain. There are also a number of places where small swales and saddles have developed along this fault, notably in the vicinity of La Habra Creek. These features are believed to have been caused, not by recent movement along the fault, but by the greater ease with which the crushed beds close to the fault were attacked by erosion.

Santa Ana Canyon is the valley of an antecedent river whose course was maintained during the post-Fernando uplift. The river has its source in the San Bernardino Mountains, flows across the south side of the broad San Bernardino Valley, and, after passing through the narrow canyon that separates the Puente Hills and the Santa Ana Mountains, emerges on the coastal plain, across which it flows to the ocean. This river has maintained its middle course during the uplift of a mountain range across its path. The position of its canyon, at the north end of the core of hard metamorphic rocks of the Santa Ana Mountains, is significant. No stream was able to maintain its course across the central core of hard rocks.

About 40 miles to the south of Santa Ana River is Temecula River, the next stream to the south to cross the crest line of the mountains. Temecula River marks the south end of the Santa Ana Mountains. At this point the post-Fernando uplift along the Elsinore fault was very much less than it was farther north. The crest of the range has an altitude of only 1,500 feet, as compared to 5,000 feet at the highest point in the range, and is only 500 feet higher than Temecula Valley, east of the Elsinore fault.

The physiographic development of the coastal plain is of great economic interest, as it affords the only direct evidence available for predicting the possible position of domes other than those already known. The coastal plain (see Pl. IV) includes two divisions. One, which will be called the La Habra terrace, occupies a crescent-shaped area about 5 miles in width, lying south of the Puente Hills, between San Gabriel River and Olinda Creek. A line passing through Los Nietos, Santa Fe Springs, La Mirada, Fullerton, Placentia, and Richfields lies along the southern boundary of this terrace. The other division, to the south of this line, is a low slope toward the coast occupied by alluvial fans of Santa Ana and San

Gabriel rivers. Coyote Creek follows the trough between the fans of these two rivers.

Where the La Habra terrace joins the hills it has an altitude of 400 to 500 feet. The lower side of the terrace is only 100 feet above sea level close to Mirada, but it becomes higher toward the east. Several groups of low hills occupy the central and southern parts of the terrace for most of its length. Of these the most prominent are the East Coyote and West Coyote hills. The former reach an altitude of 531 feet, and the latter of 610 feet, both being from 150 to 200 feet above the level of adjacent parts of the terrace. During the formation of the La Habra terrace these hills acted as dams and caused the streams flowing southward from the Puente Hills to build up an alluvial apron on La Habra Valley. As the alluvial slope was built up it extended tongues between gaps in the hills and may even have buried some hills completely. Recently the La Habra terrace has been dissected by the principal streams to a maximum depth of about 100 feet. This erosion was probably caused by a climatic change to greater humidity, as evidence of similar recent cutting is found all over southern and central California. The most prominent of the streams that cut La Habra terrace are La Brea and Coyote creeks, along both of which good exposures of the La Habra terrace deposits may be found.

The position of the East and West Coyote hills was determined by geologic structure. In each group there is an eastward-trending anticlinal axis passing almost exactly through the highest point. The Fernando beds, which are present at the surface over most of the hills, dip at considerably steeper angles than the present surface slope. In the West Coyote Hills the San Pedro (?) formation arches over the crest of the hills in almost exact conformity with their present form, if the recent gullies are disregarded. Evidently these hills owe their present height largely to uplift after San Pedro time. Their present form, however, departs considerably from that of the dome produced by this uplift. Most of the erosion that affected the hills probably took place very soon after the uplift and before the formation of the La Habra terrace was very far advanced, for the La Habra epoch must have been one of deposition rather than of erosion. The East Coyote Hills, particularly, were modified in form. Almost the whole of the eastern dome of these hills was cut down below the level of the present terrace, and of the western dome only the southeastern part remains. In the West Coyote Hills the north side was considerably cut away, and Coyote Creek evidently followed its present course prior to the post-San Pedro uplift, as it cuts off a small hill to the west of the main range of hills.

West of the West Coyote Hills the uplift along the southern edge of La Habra terrace was much less pronounced than it was farther east. A topographic nose extends west into the southern part of sec. 3, T. 3 S., R. 11 W., and is separated from a low ridge to the west by a small gulch through which Whittier Creek flows. To the west lies the Santa Fe Springs ridge, which marks the approximate location of the oil field of the same name. The records of wells in this field show that a dome is present. In view of the conditions found farther east, it seems fairly certain that this ridge is the topographic expression of the anticlinal structure, even though it is not directly over the crest of the dome. It seems hardly possible that this ridge was produced in the post-San Pedro epoch of folding and remained as a topographic feature during the subsequent periods of erosion. The form of this ridge is quite different from that of the much more prominent Coyote Hills. Its top is flat, and it was probably once a part of the upper surface of the La Habra terrace. Very recently it was slightly uplifted, and since that time only a comparatively small amount of erosion has taken place. Very likely this area was uplifted during the post-Fernando and post-San Pedro epochs, but the hills were completely cut down, so that the present low dome owes its existence entirely to a very recent uplift, probably one at the end of La Habra time.

The character of Whittier Creek gives evidence that the Santa Fe Springs ridge is of structural origin. The valley followed by this creek to the north of the ridge (Pl. I) is wide, with low sloping sides; but east of the ridge, where the creek flows directly south, it follows a narrow gulch. As the surface rocks in both parts of its course are of approximately the same hardness this is not a normal condition, for valleys ordinarily widen out as distance from the source of the stream increases. The simplest and most logical explanation is that the stream antedates a recent uplift of the ridge. During the period of uplift the stream was able to maintain its course by cutting a narrow gulch across the ridge. This stream is thus similar to Santa Ana River, described above, but on a very much smaller scale.

The conditions present on Brea and Coyote creeks might suggest that Whittier Creek crosses the ridge at a structural saddle. However, the earlier post-San Pedro hills were completely eroded and covered by the La Habra terrace at the time the most recent uplift began. Whittier Creek probably swung back and forth across the terrace, and its present position was determined by the position it happened to occupy at the time the uplift began. Once the uplift had begun, the stream would tend to become intrenched, and its position would be made permanent.

When the uplift of the Santa Fe Springs ridge began San Gabriel River probably occupied a position a mile farther east than at present. During the early part of the uplift it held its position, and it was large enough to erode the west end of the ridge as fast as it was uplifted. Later the river became slightly intrenched and then shifted its position a mile to the west. Its former channel is occupied at present by the low swampy area formerly called Little Lake.

The writer is unable to agree with those geologists who believe they have found topographic proof of the presence of the Richfields dome. Any hills that may have marked the site of this fold in times past seem to have been completely worn down and overridden by the La Habra terrace, and there does not seem to have been any uplift such as occurred at Santa Fe Springs after the formation of this terrace.

The fan of Santa Ana River spreads out to the west from a width of less than 2 miles north of Burruel Point to include all of the plain south of La Habra terrace as far west as Coyote Creek. The slope of the fan is 20 feet to the mile to the southwest. South of Burruel Point is the smaller fan formed by Santiago Creek, which extends as far west as the town of Santa Ana. The grade in this fan is greater than that of the Santa Ana fan, averaging 50 feet to the mile. Southwest of La Habra terrace and northwest of Coyote Creek the low fan of San Gabriel River slopes to the south at 10 to 15 feet to the mile. The form of the southern part of this fan is modified by the low ridge that constitutes the surface expression of the Inglewood fault, but that area is beyond the scope of the present study.

The gradual building up of the fans of San Gabriel and Santa Ana rivers forced the streams draining south across La Habra terrace to flow along the line of junction between the terrace and the adjacent fans, westward or eastward as the case might be, to the trough that marks the line of separation between these two fans. This trough is followed by Coyote Creek, which carries the drainage from all the streams of the central part of La Habra terrace. Thus Brea Creek, which reaches the southern edge of La Habra terrace directly north of Fullerton, flows slightly north of west for 5 miles, joining Coyote Creek at Northam. Whittier Creek reaches the south side of La Habra terrace between Norwalk and Mirada and thence flows southeast to Coyote Creek.

The San Gabriel and Santa Ana River fans have covered up all ridges or other surface expression which may have existed in the plains area in the past as a result of the post-Fernando and post-San Pedro periods of folding; but in view of the fact that slight movements of recent date are known to have affected areas near by it seems possible that even these recent fan deposits may have been slightly warped by recent folding. If such a condition could be recognized it would give indications of great value with regard to the probable position of buried folds. But as any folding of this time would be very slight it could be recognized only from accurate topographic maps of the plains or possibly from a series of accurate profiles. With such data available great care would have to be exercised not to mistake minor irregularities produced in the normal course of fan building for the results of folding.

In the triangle between Fullerton, Olinda, and the Santa Ana Canyon oil field lies the east end of the La Habra terrace, which was formed by the combined action of Olinda Creek, the small creeks to the east of Olinda Creek, and Santa Ana River. At the time this terrace was formed Santa Ana River was from 50 to 75 feet higher where it left the gorge than it is at the present time. During the erosion period that followed the building of the La Habra terrace Santa Ana River lowered the eastern part of its fan and in swinging to the north cut a scarp along the south edge of La Habra terrace between Placentia and Fullerton. At the same time the smaller streams draining south across the terrace dissected it to the same depth as Santa Ana River had cut below its previous level.

## OIL RESOURCES

### OCCURRENCE OF OIL

There are three points of chief geologic interest with regard to the occurrence of oil in any field—(1) the original source of the oil and the character of the material from which it was derived; (2) the structural conditions that have served as a trap and determined the location of the pools; (3) the process by which the oil was made to migrate from its original position to the one in which it is now found.

According to the most popular current theory, the larger part of the oil in the California fields originated in diatomaceous shale formations of Miocene age. Within the area considered here the Puente formation is the diatomaceous shale in which the oil is supposed to have had its original source. The diatomaceous shale theory became widely current as the result of its publication in a number of United States Geological Survey bulletins on California fields, which were issued beginning about 1907 and extending over a period of 10 years. This theory has been widely accepted by California geologists, though in the last few years a number of facts have come to light which raise considerable doubt as to its application in all or even most of the fields of the Los Angeles basin. According to newer theories the oil originated in younger formations, closer to the horizon in which it is now found. A source is postulated in the clay shale beds of the lower part of the Fernando group.

The arguments in favor of the diatomaceous shale theory may be placed under three main heads. (1) The presence of diatom skeletons in the shale in considerable abundance indicates that the formation probably once contained considerable organic matter consisting of the soft parts of the diatoms. (2) Chemical treatment and retorting recently formed diatomaceous ooze shows that an oil very similar to California petroleum may be derived from it. (3) Diatomaceous shale is closely associated with the oil-bearing formations in most of the fields, and in some the oil is produced from sands interbedded with the shale.

Against these arguments the following considerations may be urged:

1. It is admitted that diatomaceous shales were probably an original source of oil, and in some of the commercial fields they were probably the chief source. On the other hand, direct evidence of original content of organic matter (the evidence being presence of diatom skeletons) is not necessary in order to believe that a formation may at one time have contained an abundance of oil-forming material. It is in fact decidedly misleading to use the abundance of fossil remains as a basis for judging of the abundance of the original organic content of a formation. We know that at the present time there are many nonskeleton-forming rhizopods as well as other forms of life which contribute to the organic material deposited in oceanic sediments. In neither the Rocky Mountain nor the eastern oil fields is there an abundance of preserved hard parts of organisms in the supposed source formations of the oil. The tremendous amount of potential oil-forming material present in the Tertiary "oil shales" of Colorado, Wyoming, and Utah is not associated with any skeletons of organisms. If the oil were removed from these shales there would be little to show that they had ever contained so much organic material. For these reasons it is felt that the presence of diatom skeletons in the Miocene shales does not raise a presumption that these shales rather than other nondiatomaceous shales were the original source of the oil.

2. The argument here is much the same as under the previous heading. Although diatomaceous material may be capable of forming petroleum when distilled artificially, so also may most other organic material found in sediments. "Oil shales," black shales, cannel coals, and even peat are capable of forming oil similar to petroleum on distillation. There has been a general tendency in recent years for geolgists to consider kerogen (also called sapropel)

rather than diatom oozes and similar marine organic sediments as probably the most important original source of oil.

3. In some places, such as parts of San Joaquin Valley and in the Santa Maria fields, the association of the oil-bearing beds is such as to indicate that the oil probably originated in diatomaceous shales. In at least one of the fields of the Los Angeles basin and in the Elk Hills field of San Joaquin Valley such does not appear to be the case.

In most of the fields in the Los Angeles basin the known oil sands are confined to the Fernando (Pliocene) group, but in many of them the depth to the underlying Puente formation and its relation to the oil-bearing beds have not been determined. Only a few wells have been drilled very far below the known producing beds. This applies to the Whittier, Olinda, Richfields, East and West Coyote hills, Montebello, Dominguez, Athens, and Inglewood fields. In the Huntington Beach and Torrance-Redondo fields the greater part of the oil is found in beds of Fernando age, but the oil-bearing series appears to extend down into the underlying Puente formation. The stratigraphic position of the lowest oil-bearing beds in the Signal Hill and Brea Canyon fields is not definitely known by the writer. In the Los Angeles city field, the Salt Lake field, and the old Puente field the oil occurs in the Puente formation.

The Sante Fe Springs field furnished the evidence on which a question is raised as to the origin of all the oil in the fields of the Los Angeles basin in the Puente formation. In Santa Fe Springs there is definite evidence that the oil-bearing beds belong to the Fernando group, and that they are not immediately underlain by the Puente formation. The Standard Oil Co.'s Brownrigg-Keller well No. 1 was drilled to 7,215 feet, which carried it roughly 2,500 feet below the top of the oil-bearing series. At practically the bottom of this well sea shells characteristic of the Fernando group were found. This was an edge well, and the fact that the lower 2,000 feet or more of beds penetrated were barren of oil might be ascribed to structural conditions. However, the deep well drilled by the Shell Co. on the Slusher lease, near the crest of the anticline, has shown that there is a barren zone of Fernando beds at least 1,000 feet thick below the Fernando oil sands. It is argued that it would be unlikely for such a thickness of barren beds to be present in the lower part of the Fernando if the oil had originated in the underlying Puente. With such an origin we would expect the oil sands to be successively richer as the Puente was approached.

In the Elk Hills district of the Midway field in San Joaquin Valley there is beneath the productive sands a zone barren of oil at least 2,000 feet thick, separating the oil-bearing part of the Etchegoin formation from the underlying diatomaceous Maricopa shale. Not only is this zone barren of oil but sands within it contain artesian water and dry gas under very high pressure. It therefore seems very unlikely that in this district the oil has migrated up from the diatomaceous shales. In other parts of the Midway field the oil-bearing beds are directly associated with and even interbedded with diatomaceous shale, so that it seems likely that part of the oil originated in diatomaceous shale formations and part did not.

The writer believes that the same condition may hold true in many of the fields of the Los Angeles basin. Even in those fields where the productive beds extend from the Fernando down into the Puente it is not unlikely that oil originated in both formations, being found in beds of about the same stratigraphic position as those of its origin.

The structural conditions governing the occurrence of oil in the Whittier-Fullerton fields are among the most interesting in California. The fields that lie along the Whittier fault are probably the largest fields in the world whose structural trap is entirely due to a fault. These fields may be regarded as a series of half anticlines cut off along the crest by a strike fault and sealed by an impervious bed on the opposite side of the fault. In Brea Canyon a narrow steep-sided anticline close to the fault determines the location of some extremely productive territory. A remarkable feature of the narrow steep fold is the fact that at a depth of 4,000 feet its crest is almost exactly under the surface trace.

In the old Puente field, to the northwest of Brea Canyon, the surface beds are much contorted Puente shale. The writer was unable to find the anticline that is generally supposed to exist in this field. The chief point of interest regarding this field is the rather novel suggestion, which seems to be borne out by the character of the oil, that the oil has migrated north across the Whittier fault to its present position. The writer is indebted to Mr. Wallace Gordon, formerly of the Union Oil Co., for this interpretation. Mr. Prutzman came independently to the conclusion that the oil had unusual characteristics, and he called it a "migrated oil."

The group of fields south of the fields along the Whittier fault consists of a series of closed domes, which are successively less intensely folded and more regular from east to west. In all these fields the area of closed structure is greater than the areal extent of the oil pools, the limits of the pools being determined by the occurrence of edge water in the sands.

The fields along the Whittier fault present an interesting problem of oil migration. It is believed that in most closed-structure domal fields the oil was trapped in the dome as a result of the migration of the oil and water originally contained in the strata of the central part of the basin to an outlet beyond the dome, at the edge of the basin. This migration of fluid was probably caused by the consolidation of the formations and the consequent squeezing out of a large part of the original fluid contained in the sediments. In other fields it has been suggested that the concentration of the oil in the structural traps was accomplished by the action of currents of meteoric water, which entered the beds at a relatively high point along the edge of the basin and either migrated across the basin or flowed laterally to a lower point of egress. In the fields along the Whittier fault the fault trap is open to circulation of fluid only from one side, and it would seem that any flow must have been parallel to the trend of the fault. It seems probable that the course of migration of oil and water was either east or west parallel to the fault, and that the oil tended to work to the up-dip side as far as possible.

## HISTORY OF PRODUCING FIELDS

Oil has been produced in the fields east of Los Angeles for about 40 years, several of the fields being among the oldest in the State. In fact, the old Puente field is, next to the Pico Canyon field, the oldest commercially productive field in California, and before the discovery of the Los Angeles city field in 1892 this was the most productive field but one in the State.

As may be seen from the accompanying graph (fig. 2), the production of the Whittier-Fullerton district has yet to reach its peak. At the present writing (July, 1923) the district is attracting national attention because of the great yield of the newly discovered Santa Fe Springs field. Not only has the total production of the district increased from year to year, but the average production per well per day has increased nearly every year. This is a truly remarkable record for a small district in which oil has been produced for over 40 years. The record is due to the gradual shifting of development to deeper sands in the old fields, and to development of new fields on more deeply buried folds. This progress has been the result of improvements in drilling methods more than anything else. In the Brea Canyon field there are a few wells about 4,000 feet deep which are 20 years old, but they were extremely costly to drill and were justified only by the enormous yields obtained. Up to a dozen years ago it was considered that commercially profitable wells rarely exceeded 3,000 feet in depth, and most operators were much better satisfied with less yields in 2,000-foot territory. Deep drilling was so costly that few operators cared to drill exceptionally deep wildcat wells, and so the prominent fields of the present day remained undiscovered. The dependence on seepages solely rather than on geologic structure in selecting territory for test wells was another factor that held back development of the deep fields. It was not till several extremely productive wells were drilled in the West Coyote field that the majority of the operators would consider the possibility of fields present elsewhere than close to the lines of seepage.

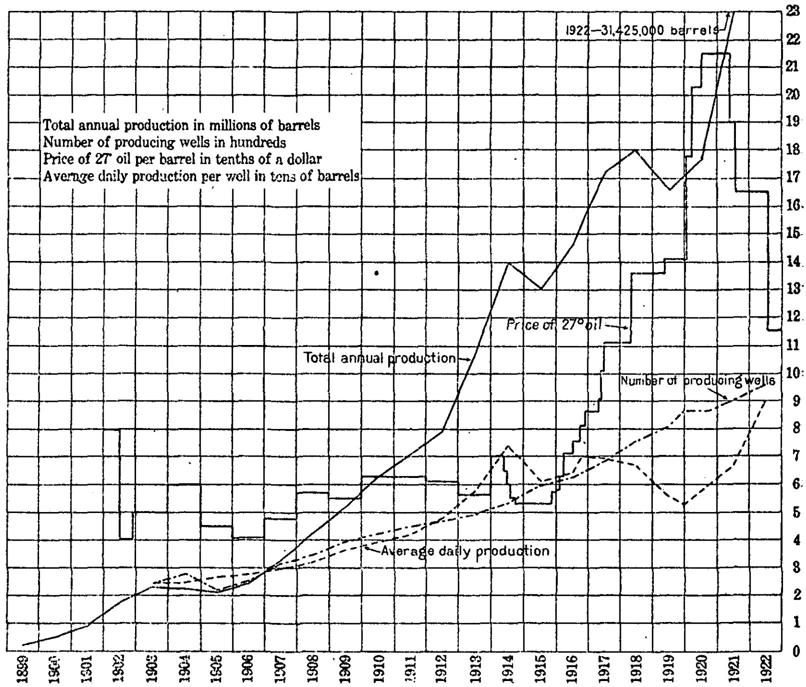



FIGURE 2.—Production statistics of the Whittier-Fullerton district. These statistics apply to the Whittier, Brea Canyon, Olinda, Santa Fe Springs, West Coyote Hills, East Coyote Hills, Richfields, Santa Ana Canyon, and old Puente fields

The following notes on the early history of the old Puente field are quoted from McLaughlin and Waring:[88]

The earliest producing wells (east of Los Angeles) seem to have been in the Puente field, secs. 34 and 35, T. 2 S., R. 10 W., where Lacy & Rowland drilled two wells prior to 1882 and by 1887 had six producers. * * *

Two grades of oil were obtained at Puente—20° B. from the wells less than 300 feet deep, and 30° to 32° B. from those 800 feet to 1,000 feet deep. In 1887 the three deep wells were together producing about 100 barrels of light oil per day, and the three shallow wells about 40 or 50 barrels per month. The price of the light oil was $1.50 per barrel, and the heavy oil sold for $5 per barrel. It is not stated whether these prices were at the well or in Los Angeles. The cost of drilling the deeper wells (800 to 1,000 feet) averaged $11.54 per foot. In 1893 there were 25 wells in the Puente field, yielding 100,000 barrels (for the year) (11 barrels per well per day).

Near Olinda, secs. 5, 8, and 9, T. 3 S., R. 9 W., eight wells had been drilled near the brea outcrop along the fault line but were idle in 1887.

[88] McLaughlin, R. P., and Waring, C. A., Petroleum industry of California: California State Min. Bur. Bull. 69, p. 308, 1915.

Statistics and maps published in 1904[39] show that at that time the Whittier, Brea Canyon, and Olinda fields were well established, and most of the productive territory was outlined. The Brea Canyon and Olinda fields were at that time known as the Fullerton field. In the Whittier field there was a group of about 35 wells extending across the central part of sec. 22 and the southwest corner of sec. 23, T. 2 S., R. 11 W., also a row of wells along the north line of sec. 26. The only later enlargement of the field has been by deeper drilling over sec. 26, now the Standard Oil Co.'s Murphy-Whittier property. About 75 producing wells are shown on the 1904 map of the old Puente field, which even then was declining in output. At Brea Canyon development was confined to the Brea Canyon Oil Co.'s property, which was pretty well drilled up in its northern part, and the Union Oil Co.'s Stearns lease, on which there was a row of wells following the bottom of Brea Canyon. The full length of the Olinda field was outlined, but the field was not completely drilled up, and development did not extend quite as far south as at the present time.

By 1913, according to Prutzman,[40] the condition of the Whittier field was as follows:

> The Whittier field, reading from the west end of the field to the west line of the Rancho Puente and from the north line of developments to the south line of T. 2, R. 11, contains 244 wells, of which 134, or 55 per cent, are now producing; 94 wells, or 38 per cent, are abandoned; and 16 wells are drilling [April, 1912].
>
> Of the abandoned wells, 32 were drilled to the depth desired and found no oil whatever; 26 were drilled to depth and found a little oil, but not a profitable quantity; 12 were brought to production and afterward lost through accident or mechanical defects; and 24 were lost in drilling and abandoned at less than the depth desired.

In regard to the old Puente field Prutzman[41] says:

> There are at present on this property, including the Menges wells[42] noted below, 53 probably producing wells and 35 abandoned holes. Of the latter, 25 were dry holes or showed only traces of oil, while 10 were pumped for periods varying from one year to twenty years.
>
> The average depth of the producing wells is 1,324 feet, with a maximum of 2,340 feet and a minimum of 1,210 feet. Of these wells, 14 are less than 1,000 feet in depth and 26 more than 1,500 feet.
>
> The average age of all the producing wells on the property is approximately 15½ years. The present output (year 1911) is reported at 33,000 barrels, or an average of 1.7 barrels per well per day.

At that time the Brea Canyon and Olinda fields were the principal producers in southern California. In both fields nearly the

[39] Prutzman, P. W., Production and use of petroleum in California: California State Min. Bur. Bull. 32, 1904.

[40] Prutzman, P. W., Petroleum in southern California: California State Min. Bur. Bull. 63, pp. 259–260, 1913.

[41] Idem, p. 285.

[42] On the Grazide tract, which is now held by the Shell Union Oil Co.—W. A. E.

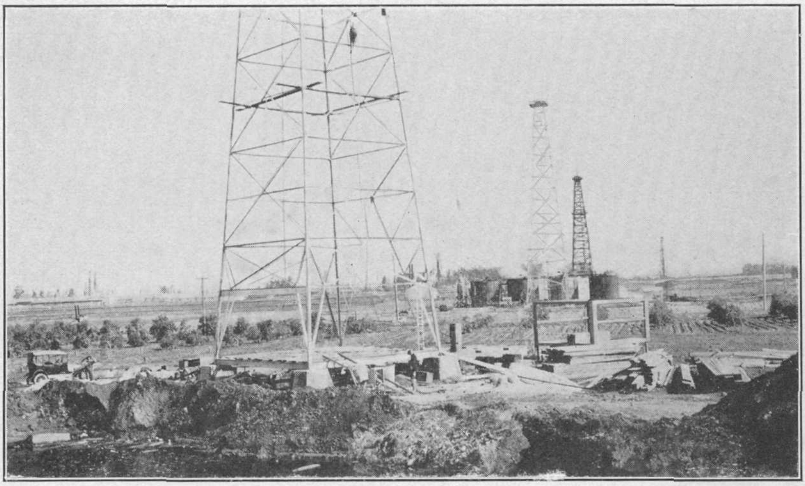
full extent of the productive territory had been outlined, and several of the leases were completely drilled up. The gap had been bridged between the two fields, and there was a continuous line of producing wells from Brea Canyon to Olinda Creek.

Development of the fields in the outlying anticlines south of the edge of the Puente Hills came at a later date than that of the fields along the Whittier fault. The first of these outlying fields to be discovered was the West Coyote Hills field, where some drilling was done as early as 1904, but the first commercial production was that obtained by the Murphy Oil Co. in its well No. 1, completed in 1908. In 1909 several wells of large production were completed in this field, and the value of the field was fully proved. This resulted in a wave of wildcatting, during which the East Coyote Hills field was proved. The discovery well in that field was drilled by the Amalgamated Oil Co. in 1911 on its Anaheim Union Water Co. lease.

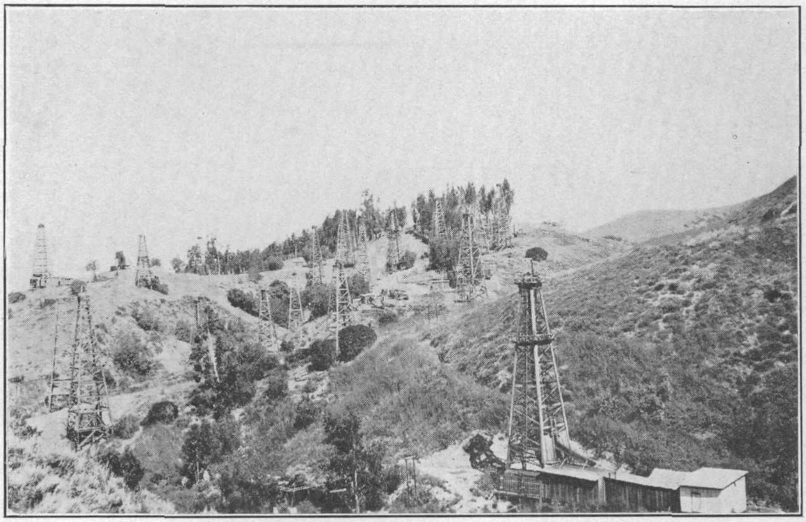
Several other very productive fields are of recent discovery, and it is due largely to them that this district is now producing much more oil than it did a decade ago, when many believed that the principal fields had already been discovered. The Santa Ana Canyon field was discovered in 1918, followed by Richfields in 1919, and recently by the Santa Fe Springs field, which came into prominence with the completion of the Union Oil Co.'s Bell No. 1, in October, 1921, though the same company's well on the Meyers lease had obtained oil two years earlier.

These recent discoveries of new fields, together with an active drilling campaign and the adoption of greatly improved drilling methods, have resulted in a continuous increase in production up to the present time, and the total production of these fields is now considerably larger than it was a few years ago. The production is shown graphically in Figure 2, which also shows fluctuations in the price of oil, as that has been an important factor in determining the amount of drilling carried on and hence the volume of production.

Other recently discovered fields in southern California not far from this district are Montebello, a few miles west of the town of Whittier, discovered late in 1916; Huntington Beach, discovered in 1919; and Signal Hill, discovered in 1920. During 1922 and 1923 much drilling has been done in the last two fields and in the Santa Fe Springs field. Owing both to the abundant yield and to the rapid bringing in of wells these fields have together produced a flood of oil greater than the previous normal total production for the entire State. The Santa Fe Springs field alone has reached a peak daily production of over 300,000 barrels, by far the largest ever reached by any single field in the State.

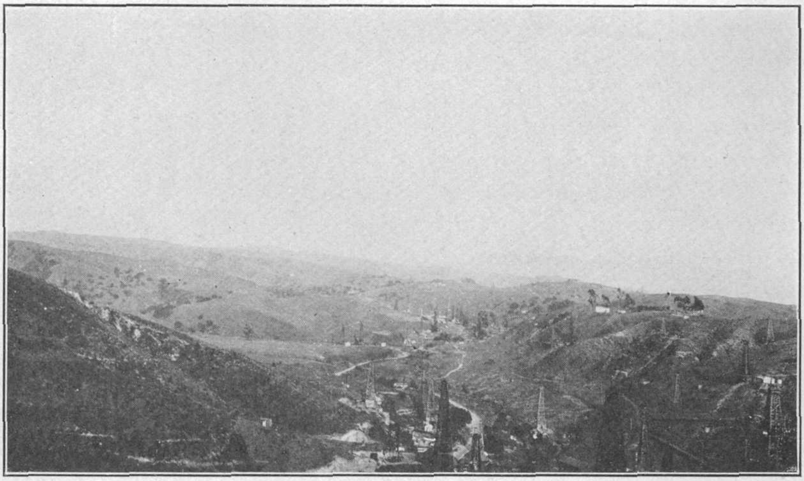


*A*. VIEW IN SANTA FE SPRINGS OIL FIELD, WITH PART OF WELL CRATER IN EXTREME FOREGROUND



*B*. OLD WELLS IN WHITTIER OIL FIELD

*A.* OLINDA OIL FIELD



*B.* BREA CANYON OIL FIELD

## PROVED FIELDS

### WHITTIER FIELD

The Whittier field lies close to the southern edge of the Puente Hills, directly east of the town of Whittier. Development began about 25 years ago in the west end of the field (see Pl. V, *B*) and gradually extended to the south and east. Except properties acquired by the Standard Oil Co., most of the field is in the hands of companies that were incorporated when the field was opened and have confined their operations to this area.

The Whittier field has the simplest structure of all the fields along the Whittier fault. (See Pl. VI.) A steep monocline of Fernando beds is truncated by the fault on the northeast. In a zone a few hundred feet wide, close to the fault, the dip in the Fernando steepens to nearly 90°, but to the south of this zone the dip is very uniformly from 30° to 45°; the lower dips are found in the eastern part of the Murphy-Whittier property of the Standard Oil Co.

The oil occurs throughout a thickness of 3,000 feet of the lower part of the Fernando, the lowest sands being very close to the base of the Fernando, if not in the Puente. Five productive zones have been recognized. The lowest, which lies in the west end of the field, is the thickest, but because of the poor records available for that part of the field it is impossible to correlate individual sands within the zone from one well to another. Possibly this lowest zone is less regular than the others because of the fact that it lies in steeply dipping beds close to the fault. This zone must have a thickness of about 1,000 feet. The deepest zone was the one to be first developed, and the development of the upper zones came later with the extension of the field to the southeast of the original area. This is a reversal of the common order of discovery.

The first (highest) zone, which is relatively thin and only slightly productive, is found only in the eastern part of the field. The second zone lies from 500 to 600 feet below the top of the first and is in most wells not over 300 feet thick; only part of this thickness is oil sand. The third zone lies from 600 to 700 feet below the second zone and has a thickness of 100 to 250 feet. Intermediate water sands are found separating these zones. The third zone lies nearly 1,000 feet above the irregular top of the fourth zone. It must be understood that the division into zones is arbitrary, as there is a nearly continuous series of alternating sandstone and shale beds in which most of the sandstones contain some oil. The water sands make it necessary to set casing between the zones as outlined, so that wells ordinarily produce from only one of the zones. Because of the steep dip the productive sands crop out within the field only a short distance from points where they are productive.

There is considerable water trouble in this field, as would naturally be expected in an old field in which most of the wells were drilled before present methods of controlling water were being used. The natural conditions, however, make the control of the water comparatively easy, and if it were not for the fact that extensive repair work is not justified by the present production, the field could be freed of most of the water, even at this late date.

This field has been extremely long lived, and it is often pointed out as an example of the life that may be expected of the California fields. The figures showing production per well for the field as a whole, however, are likely to be misleading. The original development was in the part of the field where wells were shallow and initial production was comparatively small. Later development has extended to more deeply buried sands from which large initial yields have been obtained. For this reason the average daily production per well dropped only from 26 barrels in 1903 to 19 barrels in 1921. Many of the original wells now produce not much more than a barrel a day, and most of even the later wells yield less than 100 barrels a day. All the wells are now pumped, and the field never had many flowing wells. The gravity of the oil ranges from 14° to 24° Baumé.

A number of wells have been drilled north of the Whittier fault along the northeast edge of the field. Some of these wells yielded considerable oil that was on the average of lighter gravity than the oil obtained south of the fault, but most of these have not been commercially successful. It is the writer's opinion that the oil found north of the fault has migrated across the fault plane and that the difference in character is due to the straining out of part of the oil during the migration. To the south the field is limited by the increased depth of the sands and the greater number of intermediate water sands, which make it difficult to drill wells free from water trouble. To the west the field now extends to the town of Whittier. A number of old wells failed to get much oil in the western part of the field. There does not seem to be any structural reason for the present western limit of the field, and possibly if lots were not so valuable commercial production would be developed by modern drilling methods west of the present field. To the southeast the field is limited by truncation of the oil-bearing sands by the Whittier fault.

### BREA CANYON AND OLINDA FIELD

The original development of what is now a single field took place in 1900 in two disconnected areas in Brea and Olinda canyons (Pl. VII), and for that reason both names are applied to the field. Nine companies control all the proved land in this field. Most of the properties have been in the same hands for many years, and there is none of the hurried development which is seen in the more recently discovered fields.

The structure that controls the field is the steeply dipping zone of Fernando beds truncated on the north by the Whittier fault. From 1,000 to 1,500 feet south of the fault there is a sharp steep anticline in the Fernando, which is well marked in Brea Canyon and which may extend east to the Olinda field, though in that area the evidence available to the writer is not sufficient to determine definitely the nature of the structure close to the fault. In Brea Canyon a line of many seepages marks the crest of the anticline, and it was from these seepages that the canyon got its name. At the east end of the Olinda field there is a narrow strip of productive territory in which the wells start in steeply dipping Puente beds on the northeast side of the Whittier fault.

During the preparation of the accompanying structure map of the field (Pl. VIII) it was found difficult to make accurate correlations of the different sands except for the southern part of the Olinda field. The difficulty was particularly great in the western half of the Stearns property, the group of wells around the Tonner development, the Brea Canyon Oil Co.'s property, and the northern part of the Olinda field. In most of these areas the wells are old and the records imperfect, and the dips are so steep and the geology so complicated that the oil zones probably do not in all places conform to the structure. Because of the questionable nature of the correlations over much of the field it was thought worth while to show the surface structure by means of dip symbols for comparison with the subsurface structure contours. The dotted structure contours for the Brea Canyon area are based almost wholly on the surface structure. In the south-central part of the Stearns property the surface beds strike more to the east than the subsurface contours. Other geologists in mapping this area have shown an embayment to the north in the structure contours, to conform more nearly with the strike of the surface beds. In the northern part of the Olinda field the outcropping beds are much crushed, and at a number of places the strike is almost at right angles to the general structural trend of the field. The well logs show that oil sands are present in different wells from the surface down to 2,500 feet. The only suggestion as to the possible structure of this area that has come to the writer was obtained a number of years ago from looking at a peg model of the field prepared by Harry R. Johnson. The oil sands, which according to many of the logs made up half the total thickness of the formation, were colored black on the pegs. By looking at the model along the strike of the structure (parallel to the

Whittier fault) the writer got the impression that the oil sands were most abundant in a zone several hundred feet thick, which seemed to arch over an anticline a few hundred feet south of the Whittier fault. This peg model disappeared a number of years ago, and the writer was not able to confirm this impression during the course of the present study. No attempt is made here to show the subsurface crest of the Brea Canyon anticline. Other geologists who have studied the area believe that the anticline in the third oil zone lies almost exactly beneath the south property line of the Shell Co.'s Orange and Pico leases.

In the Brea Canyon-Olinda field oil is obtained from three main zones. The upper two are in the Fernando, and the very productive third zone may be either in the Fernando or in the upper part of the Puente formation. The divisions are by no means clear-cut throughout the field, as there is a nearly continuous succession of alternating oil sands and shaly beds through a thickness of 2,500 feet of strata. Very little water is present, especially on the higher parts of the fold, so that wells can produce from more than one zone, and the divisions are therefore of less importance than in the Whittier field.

Most of the wells along the south edge of the field produce from the upper zone. Though this zone is not as productive as the second zone, initial yields of several hundred barrels a day are commonly obtained. The oil ranges from 16° to 20° Baumé in gravity. Nearly all the wells obtain oil from more than one sand, and the oil from wells that produce from sands close to the base of the zone is lighter that that from other wells. The best yield from the first zone comes from the upper half. This zone extends down to the top of the second zone, 1,500 feet below. The second zone yields most of the oil produced in all but the deep wells on the crest of the Brea Canyon anticline and is probably the source of most of the oil obtained in the northern part of the Olinda field also. The oil ranges from 20° to 24° Baumé in gravity. Some of the wells had an initial daily production of over a thousand barrels. The third zone is 900 feet below the top of the second and is the most productive of all. This zone is reached only in rather deep wells close to the axis of the anticline. The initial production of these deep wells is as much as several thousand barrels a day. Some of the best wells ever drilled in the State draw their oil from this zone in the neighborhood of the west end of the anticline, where it crosses the north side of the Birch property. Of these wells Birch No. 5 is the best known. This well has produced about 5,000,000 barrels of oil, and though 12 years old it is still (1923) producing between 200 and 300 barrels daily. Several other wells in the same area have produced from 1,000,000 to 3,000,000 barrels of oil each. Very good wells have been obtained farther east on the same anticline on the General Petroleum Corporation's Tonner lease and the Union Stearns lease. The oil from this lower zone ranges from 29° to 32° Baumé. Most of the wells flowed when they were drilled in, and recently the Shell Co. has completed several flowing wells on its Pico and Fisher leases that yield 1,000 to 2,000 barrels daily from the third sand.

The wells in the narrow strip close to the fault at the extreme east end of the Olinda field produce an oil of 32° to 35° Baumé. The high gravity of the oil has caused some to believe that the oil sands are north of the fault and that the gravity has been raised by migration from the south.

Throughout the early history of the field there was very little water trouble, and that only in wells along the south edge of the field. As the pressure became reduced water made its appearance. Most of this water is edge water, but as edge water extends farther up the dip in some sands than in others, by careful work wells can be obtained even where part of the productive zone contains water sands.

The northern limit of possible production is the Whittier fault. Wells in the Brea Canyon area may not be productive even that far north, owing to the almost vertical attitude of the beds on the north side of the anticline. To the west the field is limited by a slight change in the strike to north of west. This has the effect of giving a strong plunge to the west end of the Brea Canyon anticline. However, a similar swing close to the west line of the Stearns property does not limit the productive area on the east. The field ends abruptly toward the east at the valley of Olinda Creek. The writer suspects that there is a cross fault down this valley, as the beds on the east side of the valley dip 60° or more, whereas those just west of the valley have a dip of only half that amount. To the south the field is limited by practicable drilling depth and by the appearance of edge water. The field is still being extended southward, and its limits will probably be found to be southwest of the present edge wells.

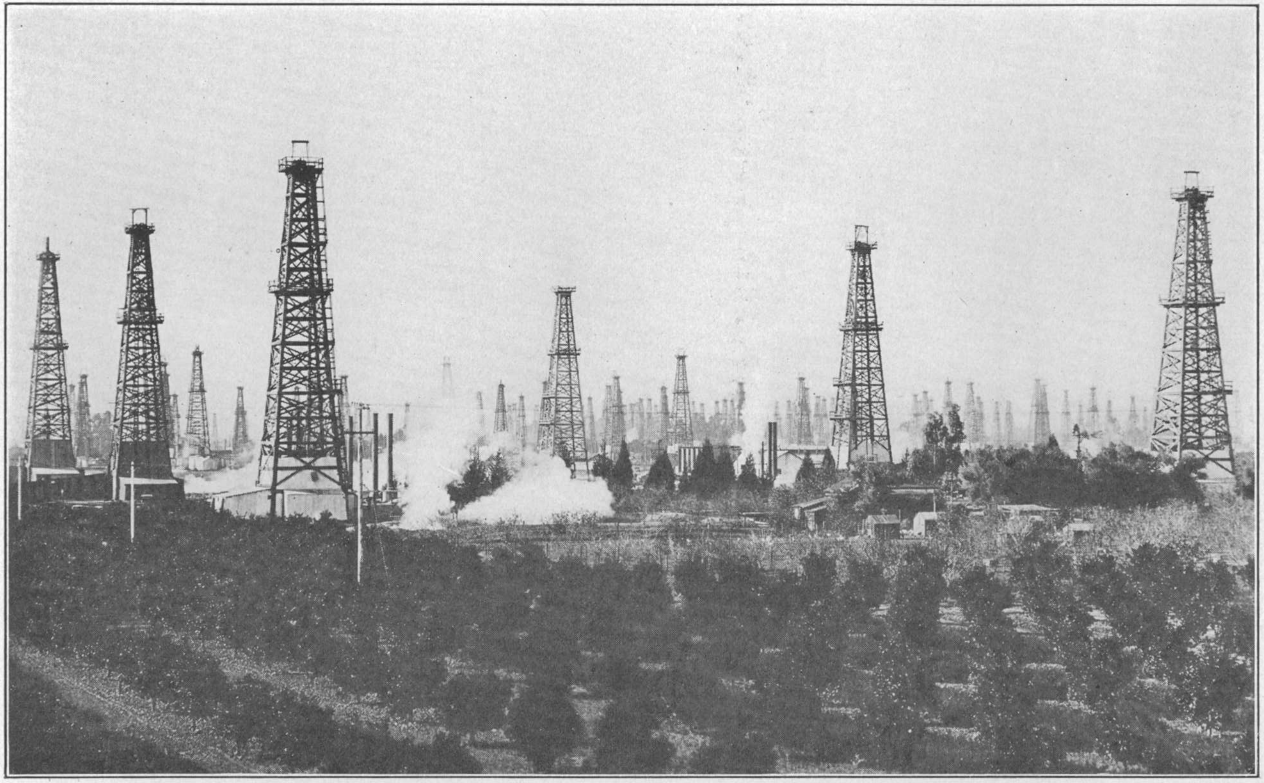
### SANTA FE SPRINGS FIELD

The most recent and most remarkably productive of all the southern California fields is that at Santa Fe Springs, which came into prominence with the bringing in of the Bell No. 1 well of the Union Oil Co. in October, 1921. The initial yield of 4,000 barrels a day of this well caused a rush for leases and speedy development beyond anything previously seen in the State. The fact that about 80 acres in the central part of the field was divided into small lots brought in many small operators and caused a very rapid development. (See

Pl. IX.) At the present writing (July, 1923) the field is less than two years old, yet the production has risen to more than 300,000 barrels a day. Exclusive of the town-lot area, most of the leases are held by six or seven of the large companies, and when the flush production has been obtained from the central area a more deliberate development program will probably be followed.

The oil comes from three zones—the Foix sand, Bell sand, and Meyer zone, named from the discovery well in each zone. The Foix sand is present only in the central part of the field and covers slightly less area than is included within the 3,550-foot contour on the Bell sand as shown on the accompanying map (Pl. X). At 200 feet below the top of the Foix sand is the Bell sand, which is productive over the area included within the 3,750-foot contour. At 200 feet below the top of the Bell sand is the top of the Meyer zone, which has been proved to be at least 600 feet thick. The best yield is obtained from the lower half of the proved zone. The limit of production in this zone is now fairly well defined and reaches the 4,100-foot contour (Pl. X). The production from the Foix sand has been comparatively small, and the Bell sand, though tapped by many wells with initial yields of 3,000 to 6,000 barrels a day, gives smaller initial yields than the Meyer zone, in which good wells come in at 6,000 to 15,000 barrels. An idea of the relative importance of each zone may be gained from the figures for production at the end of April, 1923, when the Foix sand yielded 2,000 barrels daily, the Bell sand 35,000 barrels, and the Meyer zone 168,000 barrels. The oil from the Foix has a gravity of about 29° Baumé, the Bell 30° to 32°, and the Meyer 34° to 35°. The limit of production in each sand is determined by the replacement of oil by edge water. The change from good wells to those in which only water is encountered is more abrupt than in most fields. The fact that the edge water is found in each sand at about the same altitude all around the field is also an unusual feature for southern California and is probably due to the very regular character of the structure.

The upper two oil zones at Santa Fe Springs are certainly in the Fernando group, and the writer believes that the Meyer zone is also in the Fernando, though other geologists believe that it is in the Puente formation. The upper zones contain medium-grained sandstone, but the Meyer zone is almost entirely hard gray clay shale in which sandy shale carries the oil. No very deep wells have been drilled in the central part of the field, but an edge well (the Standard Oil Co.'s Brownrigg-Keller No. 2) failed to get oil in the upper sands and has been drilled to a depth of more than 6,900 feet, and drilling is still being continued as this is written. The depth of 6,900 feet carried the well 2,300 feet below the top of the Meyer zone.



AREA OF TOWN-LOT DRILLING IN SANTA FE SPRINGS OIL FIELD

CRATERS CAUSED BY GAS BLOW-OUTS IN SANTA FE SPRINGS OIL FIELD

Most of the material encountered in the Meyer zone was hard gray shale, but toward the bottom of the hole it penetrated some sandstone that carries fossils, of which a few fragments have been recovered. These shell fragments, though not really diagnostic, appear to be of the type found in the Fernando.

At a depth of about 2,000 feet in the central part of the field the top of a shaly formation carrying gas is encountered. This shale extends down to the top of the Foix sand, 1,500 feet deeper. The gas in some parts of this shaly zone is under very high pressure and has caused spectacular and destructive blowouts in a number of wells, particularly in an area on the northwest side of the crest of the dome. (See Pl. XI.) The beds above the gas zone are softer than those lower down, a fact which has led some geologists familiar with the field to conclude that the gas zone is within the Fernando group and that the overlying beds belong to the San Pedro formation.

## WEST COYOTE HILLS FIELD

Practically the entire productive area of the West Coyote Hills field has been controlled by the Standard Oil Co. since a short time after the field was discovered. As a consequence of the single ownership many of the wastes of competitive drilling have been avoided in the development of the field. The wells are all spaced adequate distances apart, and there has not been the race seen in some other fields to produce the most oil possible in the shortest length of time, often to the neglect of proper drilling precautions and in defiance of market conditions. The first commercial well was completed in 1909, and since then a gradual development has taken place, until the field is at present almost completely drilled up and most of the wells have ceased to flow.

The structure of this field is that of a fairly regular dome. The subsurface structure shown on the accompanying structure map (Pl. XII) departs somewhat from that of the eastward-trending surface anticline. The axis of the higher part of the dome trends considerably to the south of west, and the long eastward-plunging nose trends to the south of east, thus giving the fold an arcuate shape, with the convexity toward the north.

The oil comes from two sands, one 300 feet above the other and both in the Fernando group. The upper sand is much less productive than the lower and is comparable in productive area and yield to the Foix sand of the Santa Fe Springs field. The production from the second sand makes this field rank with the best in the State. The initial production of a number of the early wells was in excess of 10,000 barrels a day, and because of the wide spacing of the wells the rate of decline has been low, so that large ultimate yields have been obtained. Several of the wells have already produced between 2,000,000 and 3,000,000 barrels of oil each.

The depth to the second sand ranges from 3,500 to 4,500 feet according to its position on the dome. This was the first deep field to be developed in the southern part of the State, and its success turned the attention of operators to the possibilities of deep drilling, which up to that time had been considered of doubtful commercial feasibility. Although water conditions in this field are not as good as they might be, they are not menacing, even now that the gas pressure is much depleted and more than half of the probable total yield of the field has been obtained.

The factors that determine the limits of the field are edge water in the producing sands and lessened productivity combined with greater depth of wells, making edge wells unprofitable. The limits of this as well as of most other California fields are not clear-cut. Edge water makes its appearance in thin strata of water sand within the productive zone, so that some edge wells in which the water is shut off at just the right depths make fairly good producers, though offset wells no lower on the dome are never satisfactorily completed. Another character of edge wells is that they yield oil of slightly lower gravity than wells producing from the same sand in the center of the field. This difference in gravity may be from 1° to 3° Baumé, though it is not shown at all in some of the edge wells. In this field the edge water is not found at the same depth on all sides of the field, the oil extending much farther down on the eastern plunge of the dome than elsewhere. On the west end, too, the oil extends to structurally lower points than on the flanks of the fold, and some of the wells far down on the western plunge were among the most productive of the field.

The gravity of the oil from the upper zone is 24° Baumé, and that of the oil from the lower zone 27° to 30° Baumé.

## EAST COYOTE HILLS FIELD

The discovery well in the East Coyote Hills field was drilled in the north-central part of the field and was completed in 1911. The eastern third of the field was developed mainly by about a dozen companies, each of which controlled about 20 acres. Most of the rest of the field was developed by the Amalgamated and Union oil companies.

Structurally this field consists of two domes with easterly trend separated by a saddle in the northwestern part of sec. 24, T. 3 S., R. 10 W. (See Pl. XIII.) The western dome is known as the Hualde dome and the eastern as the Anaheim dome. The western dome is flat-topped but shows an abrupt change to steep dips on the flanks, particularly on the south and southeast sides. The most productive wells are on the top part of the dome. The Anaheim dome is somewhat larger and has several small domes along the crest of the main one. The structure along the flanks of the east half of the dome is not known, because producing wells were not obtained there.

Two producing zones are known in this field. The upper is productive only in the eastern part of the Hualde dome, where it yields an oil of 17° to 20° Baumé gravity. The main producing zone is about 800 feet below the top of the upper zone. The lower oil ranges in gravity from 17° to 25°. Oil is obtained from an intermediate zone 230 feet above the lower zone in one well in the area occupied by the upper zone. The gravity of this intermediate oil is 21°.

Production in this field has not been as great as in the West Coyote Hills, though most of the wells came in at several hundred barrels a day. The rate of decline has been fairly rapid and was possibly hastened by water flooding from defectively drilled wells. Top, intermediate, and bottom water are all present in this field.

## RICHFIELDS FIELD

The Richfields field is named from the town near by, which, however, is just beyond the limit of production, so that there was no town-lot drilling in this field. The discovery well was the Union Oil Co.'s Chapman No. 1, which was completed in 1919 with an initial yield of 5,000 barrels a day. The field was quickly drilled up, and at present the production is declining.

Structurally, like the East Coyote Hills field, this field consists of two domes with their axes slightly offset. (See Pl. XIV.) The western dome is much the larger of the two, and the sands on it are more productive. Some geologists believe that there has been faulting along the remarkably straight northeastward-trending syncline between the two domes.

The oil comes from two main zones separated by about 250 feet of barren shale. The upper or Chapman zone was the first developed and gave many good wells, though they were not the equal of those in the lower zone. The oil from this upper sand has a gravity of 19° to 22° Baumé; that from the lower sand ranges from 25° to 29°, the gravity probably depending on the depth of sand penetrated. The lower zone has been proved to be at least 400 feet thick. There is top water above the Chapman sand, but no intermediate water, though a shut-off must be made below the upper sand near the edge of the field, to keep edge water in the upper sand from flooding the productive lower sand.

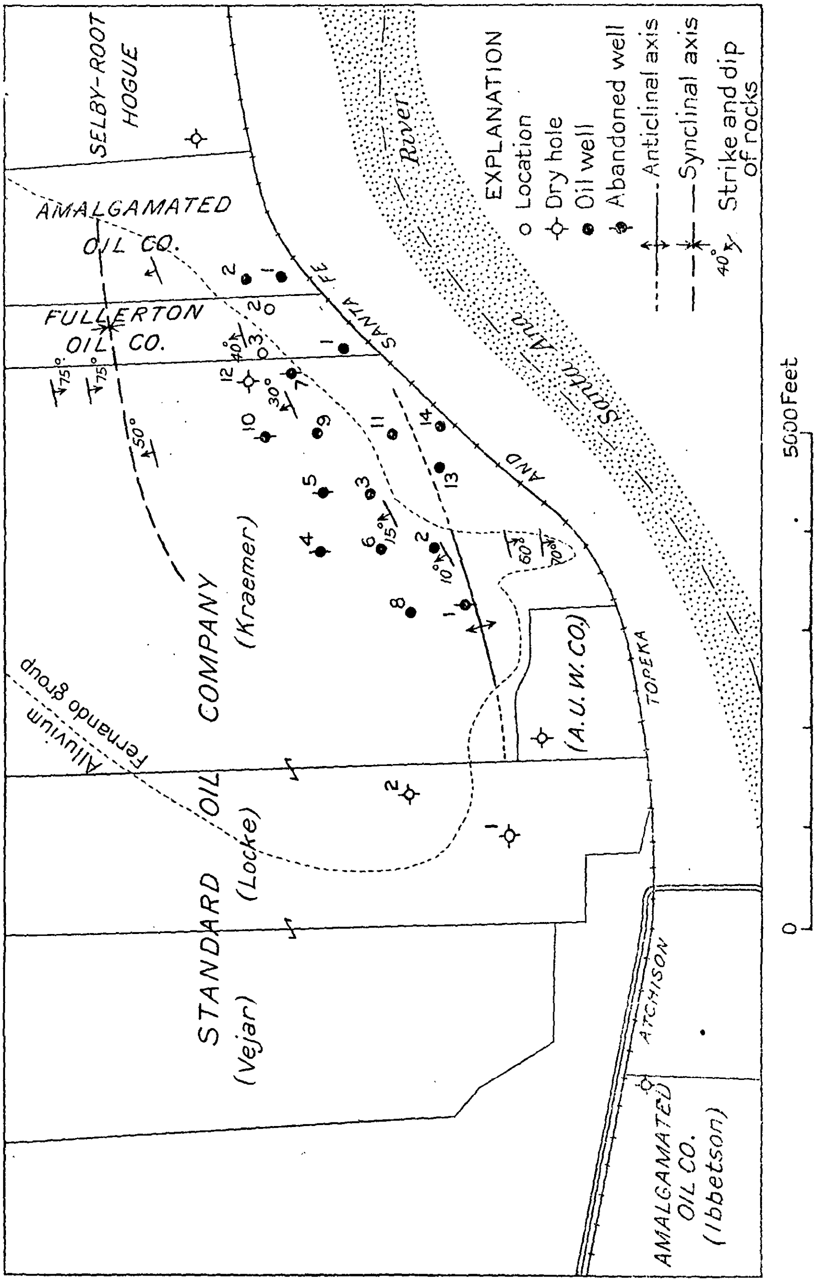



FIGURE 3.—Map showing structure of Santa Ana Canyon field

### SANTA ANA CANYON FIELD

The Santa Ana Canyon field was discovered by the Standard Oil Co., which brought in the Kraemer No. 1 well late in 1918, a short time before the discovery of the neighboring Richfields field. This field proved to be very small, and the only other companies that got any oil here were the Amalgamated and Fullerton. The field has declined rapidly and at the present time is of little importance.

The structure is that of a steep asymmetric anticline in the Fernando group. As shown on the accompanying map (fig. 3), all the productive wells start down north of the surface trace of the axis. The oil-sand zone is encountered at depths of 1,900 to 2,500 feet. The subsurface axis is north of the surface axis, coming between the Kraemer No. 2 and No. 6 wells. The best wells had initial yields of 150 to 300 barrels a day of 18° oil. Several deep tests failed to disclose deeper oil zones.

### OLD PUENTE FIELD

The old Puente field was discovered in the early eighties and was the first commercially important field in the State outside of Ventura County. Its production has been small, however, in comparison to that of newer fields. The chief point of interest in this field is the fact that the oil occurs far down in the Puente formation. In most of the other southern California fields the oil is in the lower part of the Fernando or the top of the Puente. Practically all geologists who have written about this field describe the structure as anticlinal. With this conclusion the present writer is unable to agree. The structure is very irregular and seems to be simply that of a distorted zone in the northward-dipping monocline which is characteristic of the Puente for most of the distance along the north side of the Whittier fault. The irregularity in structure may be connected with the intrusion of the diabase sills in this area, but at all events the oil reservoir is probably crushed shale and the accumulation was caused by the porosity of this crushed zone. It seems to the writer not unlikely that the oil in this field migrated northward across the Whittier fault from the area west of the Brea Canyon field. The wells in the Puente field are mostly from 1,000 to 2,000 feet deep and encountered the oil at such irregular depths that even were the records of all wells available and accurate it is doubtful if any subsurface structure could be worked out from them. The daily production was never large and is now only a very few barrels in those wells that are still pumped.

## POSSIBLE PRODUCTIVE AREAS OUTSIDE OF PROVED TERRITORY

### SOUTH SIDE OF WHITTIER FAULT

As there are two highly productive fields along the Whittier fault, the territory similarly situated with reference to the fault deserves careful consideration. This territory may be divided into three areas—that at the extreme west end of the hills, known as the Rideau Heights field; the area between the Whittier and Brea Canyon fields, known as the La Habra Canyon district; and the hills southeast of the Olinda field.

Within the last five years 14 wells have been drilled in the Rideau Heights field; besides these there are several old wells that were drilled shortly after 1900, during the time of the active development of the Whittier field. All the recently drilled wells are fairly close to the fault. As much as 200 barrels a day was obtained in two or three of the wells, but trouble with water has caused the abandonment of the field. The beds dip so steeply and the structure is so complicated that it is nearly impossible to correlate sands between wells. Here, as in the zone close to the fault in the Whittier field, the boundaries of the oil zones do not seem to follow the bedding planes. Instead there are irregular bodies of impregnated sand, and for this reason the field is very spotted, dry holes and producers being close together.

About 2 miles east of the Whittier field, in La Habra Canyon, there is a group of five wells drilled by the Union Oil Co. of California between 1903 and 1906. These wells were from 2,000 to 3,000 feet deep, and each produced from 10 to 50 barrels of oil a day for a few months after completion, but trouble with water eventually forced the abandonment of all of them. Since that time there has been no more drilling, though eventually this area will undoubtedly receive a more thorough test.

East of the Olinda field the dip steepens abruptly so that the Fernando along the south side of the fault dips 60°–90° S. and is in places overturned. The western part of this monocline has been tested by several wells in the valleys of Telegraph and Carbon canyons, but no tests have been drilled in the eastern 3 miles of the Fernando monocline. The absence of any oil seepages in the beds east of the Olinda field, however, makes the area look unfavorable.

### PUENTE HILLS NORTH OF WHITTIER FAULT

Although numerous test wells have been drilled over the Puente Hills north of the Whittier fault, nothing of importance has been discovered outside of the old Puente field. Many of the early wells were located without competent geologic investigation, but during the last five years deep test holes have been drilled on what appear to be some of the best available locations, without encountering notable amounts of oil. In the following discussion of possibilities the Puente Hills will be divided into western, central, eastern, and northern parts.

The western part of the Puente Hills, often known as the Whittier Hills, includes the only area north of the fault in which the Fernando is present in any considerable thickness. The northwest flank of the hills is a monocline of Fernando beds more than a mile thick. The structure is more regular close to the Whittier fault than to the north and east of the head of Turnbull Canyon, where there are several folds and faults. Both the regular monocline and the area to the north have been tested by wells reaching the horizons at which oil is found on the south side of the Whittier fault. The northern part of the Whittier Hills was carefully investigated by the Shell Oil Co., and the three dry holes that it drilled go far toward proving the lack of oil in this area.

Closer to the Whittier fault, in a strip about a mile wide and extending from Turnbull Canyon to the eastern edge of R. 11 W., there have been far more test wells drilled than the territory justifies. Most of these holes were drilled shortly after the opening of the Whittier field. The structure is extremely complicated, and the beds are so much faulted that it is not at all remarkable that many of the wells obtained small amounts of oil. Within a region of oil fields there are usually seepages in areas of faulting or crushed rock; but wells in such localities, though they get numerous showings, seldom get oil in profitable quantities.

Eastward for several miles from the north end of the Turnbull Canyon grade the edge of the hills is flanked by a monocline of Fernando beds dipping north. The Fernando rests with normal contact on several phases of the Puente; and toward the west, in sec. 24, T. 2 S., R. 11 W., the basal part of the Fernando is impregnated with oil. Several wells have been drilled to the northeast of these oil-impregnated beds, but without favorable result. East of sec. 24 the base of the Fernando does not show evidence of oil. The structure of the Fernando is regular from the base of the group north to the fault several miles long that parallels the Whittier fault. Both ends of this fault may be traced in the hills, but between the ends the fault is covered by a southward extension of Puente Valley. To the northeast of the fault the structure is difficult to determine, as the hills are low near the valley and outcrops are not numerous. Toward its east end the fault cuts more into the hills, and a small northeastward-trending anticline is present in the Fernando. Very little is known of the structure to the west of this area, and this is one of the few places in the Puente Hills that might repay further study.

Most of the surface in the central part of the Puente Hills is formed of the middle sandstone member of the Puente formation. Wells drilled within this area test zones in the lower shale of the Puente that are productive in the old Puente field. However, the Gold Seal and Copa d'Oro wells, in the upper part of Rodeo Canyon, and the Currier well, in Puente Valley southeast of Walnut, failed to get oil. The northeast slope of the Puente Hills on both sides of the Carbon Canyon road has been tested by a number of wells. Wells here start at the horizon of the outcropping oil sands in the middle sandstone member of the Puente. This zone of oil sands can be traced for several miles on the surface and across several folds, so that it would appear to be more closely connected with the beds in which it occurs than with any particular local structural feature over which the oil sands crop out. Several of the wells have obtained small yields of heavy oil in both shallow and deep sands. Possibly the location of this oil is determined by the structure that has produced the overlap of the lower shale. The structure possibly present beneath the middle sandstone in the central part of the hills is discussed on page 58. Southeast from these wells the structure is synclinal, and the dips steepen as the block narrows between the Whittier and Corona faults, to the southeast. To the writer the area most likely to yield oil within this part of the hills appear to be close to the Corona fault on its southwest side. The beds dip very steeply, but it is possible that in the narrow zone close to the fault oil might occur, as the structure is similar to that in the fields south of the Whittier fault. There are, however, no seepages or other surface evidences of oil in this area.

In the northern part of the Puente Hills, known as the San Jose Hills, several test wells have been drilled recently on two anticlines in the western part of the hills. The more northern of the two folds is the large anticline that trends southwestward from San Jose Peak. The Sentous well of the Shell Co. reached a depth of nearly 4,000 feet and probably gave this fold an adequate test. The other fold, which lies directly east of the town of Puente, has been tested by two wells west of the cross fault, both getting a small quantity of 18° oil at a depth of slightly less than 2,000 feet. This oil came from about the horizon of oil-stained sands that crop out on the north flank of the larger anticline. If these tests are considered conclusive, nothing now remains to be tested but beds at higher horizons in the Puente or possibly in the Fernando down the western plunge of these two anticlines. The steepness of the plunge of both folds where they leave the hills does not make this area appear particularly favorable.

### SANTA ANA MOUNTAINS

Largely because of the prevalence of older formations and the lack of favorable structure there is little chance of any oil fields being developed within the northern part of the Santa Ana Mountains. The Puente is present only on the north side of Burruel Ridge, where it forms a faulted monocline dipping north, toward Santa Ana River. Half a dozen wells have tested this area without getting any oil. Toward the west end of the ridge the Puente is overlapped by the Fernando and San Pedro (?) formations. About a mile east of Olive a small anticline breaks the monotony of the prevailing northerly monoclinal dip. A well on this small fold failed to get oil, though another well a slight distance to the south, on a small syncline, is reported to have encountered good showings of oil at a depth of about 3,000 feet. These showings of oil must have been within the Puente formation.

The chief interest in the Santa Ana Mountains lies in the clue they afford to favorable structure which may be present beneath the alluvium of the Santa Ana Plain to the west. A large irregular anticline plunging steeply toward the west reaches the edge of the plain at the mouth of Santiago Creek. Within the area of Cretaceous and Eocene rocks the fold is much complicated by faulting and is indicated only by the fact that the apex of a triangular area of outcrop of these rocks extends farther west than these rocks do in the rest of the mountains. The fold becomes more regular in the Sespe formation, the contact between which and the Topanga, if projected beneath the terrace gravel, gives a good indication of the character of the western part of the fold. Its continuance beyond the point where the Sespe swings around the axis is hypothetical, and the discussion of it belongs in the consideration of buried structural features in the Santa Ana Plain.

### SANTA ANA PLAIN

During the last few years seekers after new oil fields in this region have almost entirely abandoned the hills and have turned to the search for possible buried structural features beneath the coastal plain. This has been due largely to the recent discovery of Richfields, with no surface evidence of oil, and Santa Fe Springs, with only a very low ridge. It is argued that other folds may exist of which there is little or no surface evidence, and this argument is responsible for several million dollars' worth of wildcat wells that are being drilled. In considering the possibilities of the Santa Ana Plain the northern, southern, central, and eastern parts of the plain will be discussed separately.

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Along the northern part of the Santa Ana Plain are the four highly productive fields that lie from 4 to 5 miles south of the Whittier fault, the general trend of this line of folds being parallel to the trend of the fault. If other fields remain to be discovered along this same line it appears, on a basis of spacing, that they must lie either between Santa Fe Springs and the West Coyote Hills or northwest of Santa Fe Springs. The Standard Oil Co. has already drilled several unsuccessful deep holes northwest of the West Coyote Hills, which have disclosed most of the possibilities of that area. In the other area mentioned most of the interest has centered in the Bandini tract, 5 miles northwest of Santa Fe Springs, where two deep test holes are now being drilled. In one of these wells showings of oil have been encountered at a depth of slightly more than 4,000 feet. Several other wells have been drilled close to Telegraph Road between the Bandini tract and Santa Fe Springs.

The southern part of the Santa Ana Plain is beyond the edge of the area mapped in this report but is discussed as it throws some light on conditions farther north. The southwest edge of the Santa Ana Plain is marked by the low intermittent ridge of hills that forms the surface expression of the supposed Inglewood fault. This ridge lies between 1 and 2 miles back from the coast within the area of the Santa Ana Plain, from San Gabriel River to the east side of Newport Bay. It is thought that the Inglewood fault line marks an important structural line for the oil-bearing formations, though it has not affected the surface beds to any great extent. Because there are two productive oil fields (Signal Hill and Huntington Beach) along this line, something is known of the geology of the rocks present beneath the surface from the records of wells in these fields. In both fields the northeast flank of the anticline dips steeply toward the northeast, and a short distance to the north of these fields the oil measures are a mile or more beneath the surface.

That the Fernando is very thick over the central coastal plain has been proved by several very deep wells. Wells at Buena Park, at Garden Grove, and north of La Mirada, all more than a mile deep, have encountered only Fernando beds, as have wells more than 4,500 feet deep at Los Alamitos, 7 miles south of Norwalk, and at Westminster, 8 miles south of Northam. Whether there are upfolds within the central part of the coastal plain on which the productive zones may be reached by present drilling methods can be definitely decided only by future drilling, but the results thus far have been discouraging. This statement applies only to the area some distance out from the southeast edge of the plain, as the Fernando thins in that direction.

Only the northern part of the eastern edge of the Santa Ana Plain is within the area mapped. Opposite this part of the plain the

Topanga formation crops out in the hills next to the plain, both the Puente and the Fernando being absent. Much the same condition exists all along the eastern edge of the plain from Burruel Point to the coast at Newport Bay, where the plain is flanked by the San Joaquin Hills, which like the northwest end of the Santa Ana Mountains are formed mostly of beds of Topanga age. Somewhere between the edge of the hills and the central part of the plain, where the oil measures are too deeply buried to be reached, there should be a strip in which the Fernando and Puente are present at favorable drilling depths, and if anticlines can be located within this strip they should be productive. One point at which a productive fold might be sought is opposite the anticline that trends west in the northern part of the Santa Ana Mountains and reaches the edge of the plain at the mouth of Santiago Canyon. Except at this point drilling will have to be done pretty much at random unless a study of water wells will yield some significant information on the structure. When a few wells have been drilled later locations might be made more intelligently, provided an accurate record of the formations encountered in all wells is kept and is available to later operators. At present the opportunity to gain highly valuable information on the structure beneath the central and eastern parts of the coastal plain is being lost, because of the inadequate record that is kept of formations encountered in wells now being drilled. The driller's log, even though accurately kept within the limits of nomenclature used by drillers for beds of different lithologic types, is entirely inadequate and useless for correlations involving distances greater than those between wells in a developed field.

If the writer's view of possible conditions beneath the alluvium of the coastal plain is correct the most favorable place in which to prospect is a few miles out from the eastern border of the plain. It is not impossible that several new fields may be discovered in this area, though their discovery may be a very costly undertaking.

### SAN GABRIEL VALLEY

Up to the present time there has been very little attention paid to the possibility of buried structural features beneath San Gabriel Valley. Most geologists feel that if the conditions present along the west side of this valley, between the Montebello field and the Verdugo Hills, are an index of conditions present beneath the valley the folds are too steep and broken and the beds older than Fernando are too prominent for the area to be worth testing. On the other hand, it is the writer's belief, as outlined in the discussion of structure on page 60, that the Fernando may be present in considerable thickness under the southern part of the valley, and it is by no means impossible that favorable structure is present in that part of the valley. This area does not, however, take rank with parts of the Santa Ana Plain which are yet untested, and it is deserving of a thorough test only when conditions in the oil industry have changed very much from the present conditions of overproduction and comparatively low prices.

### SAN BERNARDINO VALLEY

The area mapped for this report includes a part of San Bernardino Valley east and southeast of Pomona. The following discussion, however, applies to most of the valley. A few wells have been drilled here, but among the oil companies that follow the advice of geologists no enthusiasm has ever been manifested for the prospects of this valley. As pointed out in the discussion of structure the valley is the down-tilted end of a granitic block on which there are probably very few sedimentary beds of any kind. Of course conjectures of this kind as to what is present beneath large areas of alluvium may prove to be entirely wrong and even ludicrous in the light of later information, but at present the writer can only say that the evidence available is unfavorable to all parts of San Bernardino Valley.

## PROBABLE FUTURE PRODUCTION OF THE DISTRICT

In estimating the future production of a property or district there is room for endless refinement. During the last few years much attention has been devoted to such estimates, largely for purposes of taxation. Where properties are nearly drilled up, with wells regularly spaced and with production data for individual wells available, the problem resolves itself into a comparatively simple extrapolation of the decline curve of the wells to conform to their previous rate of decline and to that of similar wells for which more complete data are at hand. In most of the southern California fields the development has been irregular, and wells have been rejuvenated by drilling to deeper sands, so that a large amount of study would be necessary in order to make a really accurate estimate of the future production of even the fully developed territory. Such a study could not be undertaken by the writer, but the following rough estimate is given in the hope that it will be of value to those desiring to form some idea of the future of these fields.

Exclusive of the Santa Fe Springs field, which will be discussed separately, about 210,000,000 barrels of oil was produced by the fields of the Whittier-Fullerton district up to the end of 1922. Their production for the year 1922 was about 21,000,000 barrels.

In the "Manual for the oil and gas industry" published by the Treasury Department, edition of 1921, are given figures for the future expectation of wells of various sizes in each of the fields of the Whittier-Fullerton district. If these figures are applied to the figures of production for 1922 for each field, they indicate a total expectation for all the wells now producing of 50,000,000 barrels. This, added to the 210,000,000 barrels already produced, gives an ultimate total production of 260,000,000 barrels for all the wells now in existence in these fields.

R. E. Collom, of the California State Mining Bureau, recently published figures on the areas of developed and undeveloped proved lands in the southern California fields.[43] According to his figures there are 2,482 acres of fully developed and 2,197 acres of undeveloped proved oil land in the fields under discussion. His classification of developed and undeveloped land is based on the assumption that the number of acres per well in each field when fully drilled up will be the same as that on some of the completely drilled-up properties that he takes to be characteristic of the field in which they are located. Accepting his figure for developed acreage would give an average of 105,000 barrels of oil to the acre to be ultimately extracted from the land now developed. The writer would make a more liberal inclusion of land adjacent to producing wells in determining the area classed as developed. A rough estimate was made that the present wells will drain 4,500 acres. This gives an average ultimate production of 58,000 barrels to the acre.

The figures given by Collom show 47 per cent of the proved land as being still undeveloped. This might lead to the conclusion that when the undeveloped lands are fully drilled they will ultimately yield nearly as much oil as the lands now classed as developed. Such a conclusion would be far from true. The development has invariably begun in the best parts of each pool, and the land on which only a few or no wells have been drilled is of less potential productivity than the developed lands. Furthermore, the allowance of only 2 to 5 acres to the well in determining how much land is classed as developed allows land very close to existing wells to be classed as undeveloped. When such "undeveloped" land is drilled it will be found to have been depleted to a considerable extent by neighboring wells. For these reasons the writer believes that the total production of existing wells will be not less than 80 per cent of the total to be recovered from the fields. On this basis future wells in this district should produce a total of 52,000,000 barrels of oil. The total ultimate production of the district should therefore be about

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[43] California State Oil and Gas Supervisor Monthly Repts., vol. 8, No. 2, Sacramento, August, 1922.

312,000,000 barrels, of which 210,000,000 barrels had been produced up to the end of 1922.

The development in the Santa Fe Springs field is not yet far enough advanced to admit of an accurate estimate of the total production of the field. It appears probable that 1,500 acres will be productive, and an average production of 75,000 barrels to the acre seems not unlikely to the writer. This estimate would give a total production for the field of 110,000,000 barrels, of which slightly more than 10,000,000 barrels had been produced up to the end of 1922.

## TECHNOLOGY OF PRODUCTION

### DRILLING METHODS

The science of drilling deep wells is so complicated that a complete description of the equipment and methods employed is entirely beyond the scope of the present report. The following few notes are designed to give those not familiar with the California fields an idea of some of the local problems. Descriptions of drilling methods may be found in the bulletins of the United States Bureau of Mines, and special articles in the monthly reports of the California oil and gas supervisor give notes on new equipment and methods.

#### CABLE-TOOL DRILLING

At the present time the cable-tool method of drilling has been almost entirely superseded in the Whittier-Fullerton district by the rotary method, though until a few years ago a large proportion of the wells were drilled with cable tools. The chief disadvantage of the cable-tool method, apart from its slowness, is the difficulty of keeping the casing free because of caving formations which have a tendency to "freeze" the casing. It is necessary to keep nearly all the hole cased during drilling, and the casing must be watched constantly and moved up and down at frequent intervals in order to keep it free. In spite of these precautions deep wells drilled with cable tools generally require a much larger number of strings of casing than are necessary with wells drilled by the rotary method, and there is always the danger of "running out of hole" before the desired depth is reached. The advantage that this system formerly possessed over the rotary method was the ability of cable tools to drill a straight hole through hard and steeply tilted formations. Recent improvements in rotary tools enable them to meet such conditions successfully, and they have therefore replaced the cable tools for all but shallow wells and a few wildcat wells. Some operators believe that cable tools are preferable for wildcat wells because it is not necessary to maintain so high a fluid pressure at the bottom of the hole as is required in rotary drilling. One of the chief defects of the rotary has been the fact that the fluid pressure may be great enough to keep all but a very small amount of oil or gas from entering the well, even when strata capable of large production are being drilled. Productive oil and gas sands might thus be passed without their presence being detected. This advantage of cable tools is being rapidly lost, however, owing to the general introduction of core drilling for rotary wells.

#### ROTARY METHOD

Progress in rotary equipment has been almost entirely toward the use of heavier equipment, with very few changes in basic design, though numerous improvements in the detailed design of equipment have been made. The one thing that has not been increased is the diameter of the hole drilled, and the equipment is thus considerably heavier relative to the size of the hole than it was a few years ago. This allows hard formations and conglomerate to be drilled without the twist offs and crooked hole that were formerly likely to result when the rotary was used in this territory. The rotary now far surpasses the cable-tool system in ability to drill deep holes in the California Tertiary formations. The Standard Oil Co. recently drilled with rotary tools two wildcat wells in southern California more than 6,500 feet deep, and it seems likely that before long there will be profitable rotary wells 6,000 feet deep in the Long Beach field.

The adoption of core drilling is one of the recent developments that makes the rotary method much more effective than formerly. Sands that may be highly productive give only very slight showings of oil in the mud returns when they are encountered at depths of more than 4,000 feet. In drilling wells where the oil sands lie at such depths cores are taken at frequent intervals to locate the sands, as well as to locate suitable formations in which to land casing for cementing off top water. Both single-barrel and double-barrel core drills are used, though the double-barrel drills are gaining in favor because of their ability to take longer cores than the single-barrel drill. With the latter there is a tendency for the core to be "burned," especially in hard rock, as the circulating mud does not reach the bottom of the hole, and the heat generated in drilling may be sufficient to melt the iron of the drill pipe and turn the cored formation into a slag.

The fishtail bit is the one most used, though disk bits are used for sandy shale by some drillers. Cone and roller bits are used for very hard formations. Despite its inability to make a hole rapidly through hard material the fishtail bit is used because of its safety. In case of a twist off the fishtail bit can be more easily pulled out than bits of other designs, because the small cross-sectional area of the fishtail is no greater than that of the drill pipe. This allows it to be pulled up through the sand that immediately packs around the bottom of the drill pipe when the mud circulation is stopped.

## GEOLOGY AS AN AID IN DEVELOPMENT OF PROVED FIELDS

In most of the southern California fields a company that is drilling several wells employs a resident geologist or petroleum engineer, who is expected to give advice on operations that depend for their success on knowledge of geologic conditions. The resident geologist therefore makes such studies and collects such data as will enable him to predict the depths at which strata containing oil, water, and gas and strata suitable for landing and cementing casing will be encountered in drilling wells and to recognize such strata when they are reached. This information should lead to the proper setting of casing to protect the oil measures from infiltrating water and prevent passing without recognition oil or gas sands that have been encountered in other wells. The following paragraphs are designed to give readers not familiar with the methods of subsurface geologic study an idea as to the way in which it is done in this area.

Prediction of depths to particular strata involves sufficient correlation of strata between neighboring wells to get the general dip of the beds in the vicinity, and then interpolation or extrapolation of figures for depth to the desired strata in the well that is being drilled. For correlation the chief reliance of the geologist is of necessity placed on the record of formations as given in the drillers' logs. Whenever possible this record is supplemented by his own examination of drill cuttings and cores. Analyses of oil, water, and gas may also be useful, and occasionally fossils from wells may be studied with advantage.

The work of correlation is nearly all done graphically. The record of formations and other data for each well are compiled on a graphic log. These logs are correlated by comparison of a group of adjacent wells or of several wells lying along a straight line. The correlations thus made may be combined in a structure section or in a contour map from which the depth to the contoured horizon may be determined for any point within the area contoured. Perhaps the clearest method of showing subsurface conditions is by the peg model. Models for each of the principal fields in the area covered by this report have been made by the State Mining Bureau, and several companies have models of their own. Strings are run from peg to peg indicating the position of strata of oil or water bearing sand.

The logs of most groups of wells show considerable differences in the formations logged, even for wells close together. The skill of the geologist is required in correlating these rather dissimilar records. It is known that many of the beds in the oil-bearing series are lenticular, and the geologist must be able to judge when the differences in the recorded logs denote real differences in the strata encountered and when they are due to faulty observation by the drillers or to dissimilar drilling conditions that cause the same bed to appear to be different in adjacent wells. Where more than one correlation appears to be possible, the geologist must be guided by his knowledge of the general structure of the field. In this connection it is of advantage to have data on the surface geology of the field available for comparison.

It is usually possible to pick out some marker recognized by the drillers in the majority of wells and make it the basis of most of the correlations, ignoring the fact that the rest of the beds logged may appear entirely dissimilar. The choice of a marker to be used depends on whether the well is drilled with cable or rotary tools. In both methods oil showings are looked for by the drillers, and with the rotary they are the most common marker used. Wherever there are other possible bases of correlation they should be considered, and the final correlation should be a compromise that seems to give best results for all features.

With the rotary method the mud masks slight changes in color as well as many changes in the lithology of the material that is being drilled, so that the changes may not be noted by the driller from examination of the returns. The driller is likely to rely on the action of his machinery during the process of drilling, rather than on direct observation of the cuttings, in forming his conclusion that the formation being drilled is sand, shale, gumbo, or conglomerate.[44] His conclusions are generally correct, but the limitations of his classification are such that the log is not of much value for correlating any but closely spaced wells. It is the writer's belief that with proper collection and examination of drill cuttings a formation record superior to that possible with cable tools might be made. However, practically nothing along this line is being done by most of the large companies that operate in California at present.

When cores are taken, as is now the general custom with rotary wells, they give an excellent idea of the material being penetrated, though because of the small amount of core relative to the depth of the hole it is difficult to make correlations on the basis of cores alone. If several cores are taken close together in adjacent wells they may furnish data for very accurate correlations.

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[44] In these fields the term conglomerate is used by the drillers in its geologic sense more often than to denote a mixture of formations, though both usages are current.

With cable tools the character of the cuttings is not masked by mud, and changes in color and hardness of the beds are shown with sufficient clearness to make correlation easy if the well log has been accurately and carefully kept. The powdering action of the bit may cause an incorrect determination of the bed drilled if only fine cuttings are available. Thus it is difficult to distinguish débris derived from an arkose sandstone from that derived from granite. A hard sand will require more pounding than a soft one, and consequently the cuttings from it will appear to be of finer grain, irrespective of its original coarseness. The amount of water standing in the hole while any stratum is being drilled should be considered when judging the importance of oil showings, as the greater the water pressure at the bottom of the hole, the less tendency there is for oil to enter the well. In the same way water sands may not be recognized if there is already a considerable column of water standing in the hole.

In both cable and rotary methods of drilling there is a tendency for material from a considerable distance above the point at which drilling is progressing to fall into the hole and appear in the returns or bailings. For this reason it is well to know where strings of casing were landed, as these fix an upper limit to material that can have dropped to the bottom of the hole.

The use of the microscope in examining well cuttings and cores has come into prominence recently, chiefly through studies of Foraminifera, which are found abundantly in the shales of the Fernando. It has been possible to make correlations on the basis of Foraminifera, though thus far only zones several hundred feet thick are recognizable from well to well. For the more exact correlations necessary to guide work in developed fields reliance must still be placed on other methods.

The water found in different strata varies considerably in the concentration and chemical character of dissolved minerals. Water analyses may be used to advantage in correlating water sands, though in practice it is usually difficult to get uncontaminated water samples from any particular stratum. This method has not been used much in southern California. The chief value of water analyses would be in the later history of the field. If water made its appearance in a well a considerable time after completion of the well, analyses of the water passed through during drilling might make it very easy to locate the stratum from which the water was coming.

Some attempts have been made to treat well cuttings with chemical reagents and by characteristic reactions render certain strata readily identifiable. Thus far this method has not produced significant results, and it is not yet beyond the experimental stage.

The resident geologist is often assigned to the duty of watching wells that are being drilled, to detect showings of oil or gas. In rotary wells these showings may not be recognized from the returns, even when the drill is passing through strata capable of a large yield. Rainbow colors and gas bubbles are usually seen on the ditch, but the most usual test is to treat washed samples of sand with chloroform or ether. This will dissolve out oil from fine crevices in the sand and give a color test, even when on casual inspection the sand does not appear to contain any oil.

## CHARACTER OF THE OIL

By Paul W. Prutzman

### GENERAL FEATURES OF SOUTHERN CALIFORNIA OILS

The oils produced in the fields of the Puente Hills region vary widely in character. They range in gravity from 14° to 36° Baumé, in color from black to greenish brown, in viscosity from glutinous tars to oils as fluid as water, and in gasoline content from none to 35 per cent or even higher. Variations are found between one field and another, between different sands in the same field, and between different parts of the same sand. Some of these variations are definitely related to geologic conditions, and certain generalizations can be drawn as to the relation between character of oil and structural and stratigraphic conditions of occurrence.

In nearly all the fields there is a range of several hundred feet in the stratigraphic position of the productive sands, and in the fields along the Whittier fault there is a maximum range of 3,000 feet. The oil almost invariably becomes higher in gravity in successively lower strata in each field. Correlation between fields is not established with sufficient accuracy to determine whether oils of the same gravity in different fields come from the same stratigraphic position. However, in several of the fields there is a change toward the bottom of the sequence of known sands, from coarse, rather soft sand and conglomerate with interbedded clay and sandy clay to finer-grained hard dark clay and fine sandy shale. The oil from these lower finer and harder beds is mostly of 30° to 35° gravity and has a much higher gasoline content than oil of only a few degrees lower gravity from overlying coarser beds. This is suggestive that the light oil comes from approximately the same horizon in each of the fields.

There is a general tendency for oil from deeply buried parts of a productive sand to be higher in gravity than oil from the same sand at localities where it approaches closer to the surface. There is an even more pronounced tendency for the gravity of the oil to decrease where it is close to edge water. Thus in the fields with dome structure the lightest oil in any sand is near the center of the field, and the oil from a greater depth around the edge of the field is heavier and has a notably smaller gasoline content.

As compared with oils from the San Joaquin Valley fields, the southern California oils average higher in gravity (Baumé), the proportion of gasoline is greater for oils of the same gravity, the proportion of amorphous wax in the heavy distillates is greater, and the sulphur content is higher.

In the following descriptions and tables the character of the oil from each of the fields of the Puente Hills district is shown, and a few notes on their value for refining are given.

### WHITTIER FIELD

The oils from the Whittier field are distributed through 3,000 feet of Fernando beds in a steeply dipping monocline bounded by the Whittier fault. The gravity increases with stratigraphic depth and to a lesser extent with well depth. Most of the wells produce oil from several sands, and the wells close to the fault get their oil from irregular bodies of impregnated sand, the boundaries of which do not appear to follow bedding planes.

*Analyses of oil from the Whittier field*

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Gravity (° Baumé) | 24.0 | 14.2 | 21.0 | 21.5 |
| Gasoline at 61° | 6 | 0 | 1 | 0 |
| Engine distillate at 52° | 9 | 3 | 2 | 4 |
| Kerosene at 42° | 8 | 8 | 13 | 12 |
| Middlings | 23 | 31 | 25 | 27 |
| Lubricants | 39 | 40 | 36 | 33 |
| Asphalt | 15 | 18 | 23 | 24 |

1. Whittier Crude No. 8, at the northwest extremity of the field.
2. Home No. 7, at the center of sec. 7, T. 2 S., R. 11 W.
3. Murphy No. 4, at the center of the south line of sec. 23.
4. Murphy No. 25, near the center of sec. 26.

The oils from this field, despite their variation of 10° in gravity, have certain features in common. They are characterized by low sulphur content, low acidity, a small proportion of asphalt relative to other constituents, and a high percentage of viscous cold-test lubricants. The sulphur content ranges from 0.9 per cent on oil of 15° Baumé to 0.6 or 0.7 per cent on the lightest samples. These oils are relatively free from basic and acidic bodies and in distillation give unusually sweet and stable products. The gasoline yield is too small to be of much value, and the yield of most value on refining is the lubricating stock. The lubricants do not run into very high viscosities but are readily refined, show a low cold test, and have a viscosity curve better than the average.

### PUENTE FIELD

In the group of old wells lying on the Rancho Puente northwest of the Brea Canyon field shale of the Puente formation crops out, and the oil is supposed to come from reservoir space between fragments of crushed shale. The productive horizon differs widely from that of all the other fields of this region.

*Analyses of tank samples of oil from Puente field*

| | | |
|---|---|---|
| Gravity (° Baumé) | 23.3 | 26.9 |
| Gasoline at 56.5° | 2 | 4 |
| Engine distillate at 49.5°–48° | 12 | 10 |
| Kerosene distillate at 40° | 8 | 10 |
| Middlings | 35 | 24 |
| Lubricants at 474–232 viscosity | 22 | 18 |
| Asphalt | 21 | 34 |

These two analyses of tank samples cover the range of quality of the oil as actually run from the field. The four analyses below represent samples taken direct from the wells and indicate that the tank samples had lost much of their volatile constituents.

*Analyses of well samples of oil from Puente field*

| Well No. | 61 | 50 | 34 | 66 |
|---|---|---|---|---|
| Gravity (° Baumé) | 23.1 | 26.8 | 32.5 | 29.5 |
| Gasoline at 61° | 20.0 | 6.0 | 15.0 | 11.8 |
| Engine distillate at 52° | .0 | 6.0 | 12.5 | 8.0 |
| Kerosene at 42° | 22.0 | 26.5 | 13.5 | 14.0 |
| Middlings and lubricants | 35.9 | 35.5 | 46.5 | 53.1 |
| Asphalt | 22.1 | 26.0 | 12.5 | 13.1 |

61. Extreme northwest edge of field.
50. About center of north line of field.
34. At east end of present productive area.
66. On south edge of field.

These oils run very low in sulphur, about 0.4 per cent, and are rich in amorphous paraffin. Probably because of the low sulphur content the distillation products are unusually sweet and clean.

### BREA CANYON AND OLINDA FIELD

The prevailing structural feature of the territory included in the Brea Canyon and Olinda field is a steeply dipping monocline of Fernando beds in which productive sands are found through a stratigraphic range of 3,000 feet. Sharp small folds and faults modify the structure in some of the most productive territory close to the Whittier fault, and in these areas the structure is so complicated that the exact stratigraphic position of the productive sands is uncertain. As might be expected under such conditions, the oils vary considerably for different depths and for different parts of the field. The analyses have been arranged in three groups—for wells in the vicinity of Brea Canyon, for the main part of the Olinda field, and for the extreme east end of the Olinda field.

The territory covered by the analyses of the first group extends from the central part of the Union Oil Co.'s Stearns property westward to the edge of the field. The gravity of the oil increases with stratigraphic depth and to a lesser extent with depth of productive sand beneath the surface. The oil of highest gravity comes from sands close to the Whittier fault, which bounds the field on the north, and some geologists believe that these deep sands are in the top of the Puente formation. The analyses of oil from the north line of the field (Nos. 6 and 7, below) represent samples from wells that probably produce from upper sands as well as the deepest sand, for wells that produce only from the deepest sand give a product of about 30° gravity.

*Analyses of oil from Brea Canyon field*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Gravity (° Baumé) | 17.7 | 18.6 | 20.5 | 22.5 | 25.1 | 27.5 | 27.9 |
| Gasoline at 61° | 0.0 | 0.0 | 0.0 | 0.0 | 8.0 | 11.7 | 10.5 |
| Engine distillate at 52° | .0 | 5.0 | 8.0 | 14.0 | 7.0 | 6.0 | 6.3 |
| Kerosene at 42° | 11.0 | 14.0 | 9.5 | 9.0 | 7.0 | 19.0 | 10.5 |
| Middlings | 35.6 | 35.0 | 29.5 | 31.1 | 31.1 | -------- | 32.6 |
| Lubricants | 30.9 | 22.5 | 26.5 | 26.4 | 25.1 | 48.1 | 26.6 |
| Asphalt | 22.5 | 22.5 | 26.5 | 19.5 | 21.8 | 14.2 | 13.5 |
| Paraffin | None. | Low. | High. | -------- | None. | -------- | High. |

1. At southwest curve of the group.
2, 3. West of center.
4. East of center.
5. At northeast curve.
6, 7. On north line near center.

The next group of wells extends from Brea Canyon over the ridge to the town of Olinda. In the southern part of the field there is a monocline dipping to the south, but in the north half of the field the structure is so complicated that the stratigraphic position of the oil sands has not been worked out. The following analyses represent wells in different parts of the field:

*Anayses of oil from main Olinda field*

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Gravity (° Baumé) | 15.0 | 16.4 | 15.9 | 20.1 | 21.8 | 21.2 |
| Gasoline at 61° | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Engine distillate at 52° | .0 | .0 | .0 | 6.5 | 9.5 | 12.0 |
| Kerosene at 42° | 4.0 | .0 | 5.0 | 6.0 | 10.0 | 7.0 |
| Middlings } Lubricants | 67.6 | 41.4 | 61.4 | 35.8 | 44.0 | 30.7 |
| Lubricants | | 18.3 | | 32.4 | 11.5 | 37.3 |
| Asphalt | 28.4 | 40.3 | 33.6 | 19.3 | 25.0 | 13.0 |
| Paraffin | -------- | None. | -------- | High. | Low. | High. |

1. In sec. 1, at west end of group.
2. Near center of sec. 7, on southwest edge.
3-5. Near center of group.
6. On northeast edge.

The small group of closely spaced wells in the east end of the Olinda field differ in both geologic conditions and character of the oil from those in the rest of the Brea-Olinda field. The surface trace of the Whittier fault lies south of the wells, the beds that crop out in the field being steeply dipping sandstone and sandy shale of the Puente formation. The relation of the productive sands to the geologic structure has not been determined.

*Analyses of oil from east end of Olinda field*

| | 1 | 2 | 3 |
|---|---|---|---|
| Gravity (° Baumé) | 34.5 | 32.2 | 32.4 |
| Gasoline at 61° | 24.5 | 14.9 | 20.0 |
| Engine distillate at 52° | .0 | 11.5 | .0 |
| Kerosene at 42° | 27.4 | 22.5 | 29.1 |
| Middlings | 12.5 | 23.7 | 14.9 |
| Lubricants | 21.2 | 17.6 | 25.8 |
| Asphalt | 14.4 | 9.8 | 10.2 |
| Paraffin | High. | Low. | High. |

1. Petroleum Development No. 39, near west end.
2. Fullerton No. 10, on southwest margin.
3. Puente Oil Co. well, in southeast extension.

If these analyses are compared with those of the rest of the Brea Canyon-Olinda field it becomes clear that they form a distinct group. The oils from most of the Brea-Olinda field are similar to one another and belong to the class of waxy sulphurous oils. They contain from 0.8 to 1.2 per cent of sulphur and large proportions of naphthenic acids. Such oils are difficult to refine except as they are topped to obtain the small gasoline yield. Some of them are characteristic cold-test oils, similar to the heavy oils of San Joaquin Valley, but others of only slightly higher gravity are distinctly in the waxy-oil class. The waxy and nonwaxy oils probably come from beds at different horizons.

The wells at the east end of the Olinda field produce a uniform very clean oil, running about 0.4 per cent of sulphur, with low asphalt content and much wax. This is not a typical wax oil, which normally is high in asphalt. The quality of the oil and the drilling records indicate that this small pool contains a migrated oil, from which certain constituents have been absorbed. The oil bears a much closer relation to the oils from the Puente field than to those of the rest of the Brea-Olinda field.

## WEST COYOTE HILLS FIELD

The single analysis available from the West Coyote Hills field represents oil from a well in the SE. ¼ sec. 18, T. 3 S., R. 10 W., and is typical of the oil obtained from the single main producing zone of this field. In this and the East Coyote Hills fields the oil comes from deeply buried sands on a dome.

*Analysis of oil from West Coyote Hills field*

| | | |
|---|---|---|
| Gravity | ° Baumé | 30.0 |
| Gasoline at 61° | per cent | 9.0 |
| Engine distillate at 52° | do | 5.0 |
| Kerosene at 42° | do | 17.0 |
| Middlings and lubricants | do | 42.8 |
| Asphalt | do | 26.2 |

In this analysis the stated percentage of asphalt is probably too high, though there is no doubt that the asphalt content is high for the gravity, as the gasoline and disillate are low. This oil is high in paraffin.

On the west line of sec. 16, which is now the easterly limit of the productive area, a 21° oil containing no gasoline was found at a considerable depth. This oil is high in paraffin and low in asphalt.

EAST COYOTE HILLS FIELD

A sample from the discovery well in the East Coyote Hills field, the Anaheim Union Water Co.'s No. 1, about half a mile east of the center of sec. 13, T. 3 S., R. 10 W., gave the analysis shown in column 1 below. The analyses in columns 2 and 3 represent oil from Amalgamated Hualde Nos. 9 and 16. Sample 1 was taken in 1911; the others in 1922. Samples 2 and 3 came from different sands, but they have the same gravity.

*Analyses of oil from East Coyote Hills field*

| | 1 | 2 | 3 |
|---|---|---|---|
| Gravity (° Baumé) | 16.4 | 24.6 | 24.6 |
| Gasoline at 65° | .0 | 6.0 | 9.0 |
| Engine distillate at 48° | 2.5 | | 9.0 |
| Kerosene at 42° | 13.6 | 3.0 | 9.0 |
| Middlings | 31.4 | 30.2 | 24.6 |
| Lubricants | 24.5 | 34.2 | 20.8 |
| Asphalt | 28.0 | 26.6 | 27.6 |
| Paraffin | High. | Low. | High. |

These are typical waxy oils, high in asphalt and light ends and carrying much amorphous wax.

RICHFIELDS FIELD

The following table gives analyses of oils from different parts of the Richfields field:

*Analyses of oil from Richfields field*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Gravity (° Baumé) | 19.8 | 15.3 | 16.2 | 17.9 | 16.9 | 18.5 | 21.0 |
| Gasoline at 60° | 6.00 | 0.00 | 0.00 | 3.24 | 1.38 | 3.14 | 5.86 |
| Gas tops at 52° | 11.82 | 1.75 | 1.20 | 6.80 | 3.74 | 7.08 | 12.22 |
| Kerosene at 37° | 7.85 | 8.85 | 6.23 | 10.87 | 9.06 | 8.17 | 7.78 |

| | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|
| Gravity (° Baumé) | 22.1 | 22.6 | 21.9 | 22.0 | 24.3 | 25.2 |
| Gasoline at 60° | 9.57 | 9.92 | 6.00 | 4.00 | 13.38 | 11.00 |
| Gas tops at 52° | 17.25 | 18.50 | 9.00 | 14.00 | 24.33 | 21.10 |
| Kerosene at 37° | 1.31 | 11.91 | 11.00 | 12.00 | .00 | 10.00 |
| Middlings | -------- | -------- | 31.80 | 23.40 | -------- | 28.60 |
| Lubricants | -------- | -------- | 25.70 | 25.00 | -------- | 18.00 |
| Asphalt | -------- | -------- | 22.50 | 25.60 | -------- | 22.30 |

1. General Petroleum Group 4, northeastern part.
2. General Petroleum Brown, east center.
3. General Petroleum Osman, east center.
4. General Petroleum McCracken, east center.
5. General Petroleum Carpenter, southeastern part.
6. Selby, Root & Hogue, southeastern part.
7–9. General Petroleum Thompson, center.
10. Standard Oil Co., Kraemer 2, southwestern part.
11. Standard Oil Co., Kraemer 14, southwestern part.
12. Wonder Oil Co., southwestern part.
13. Standard Oil Co., Kraemer 15, southern part.
1 to 10 from Chapman sand (upper); 11 to 13 from Kraemer sand.

In the above analyses the figure given for gas tops at 52° includes the figure for gasoline at 60°. These are typical wax oils with a relatively high content of asphalt and volatile products.

The Brown, Osman, McCracken, and Carpenter wells all approach edge conditions in the Chapman sand, and the oil is not characteristic of the greater part of the oil produced from this sand.

## SANTA ANA CANYON FIELD

Only one analysis of oil from the Santa Ana Canyon field is available, as below:

*Analysis of oil from Standard Oil Co.'s Kraemer No. 1, well 3, Santa Ana Canyon field*

| | | |
|---|---|---|
| Gravity | ° Baumé | 20.5 |
| Gasoline at 63.7° | per cent | 3.0 |
| Engine at 49.1° | do | 9.2 |
| Kerosene at 37.4° | do | 9.0 |
| Middlings | do | 33.1 |
| Lubricants | do | 17.7 |
| Asphalt at 40 penetration | do | 28.0 |

This oil is rich in paraffin and asphalt and is a typical waxy crude oil, closely resembling the oils of Richfields.

## SANTA FE SPRINGS FIELD

Santa Fe Springs oils are typically low in sulphur, very waxy, and high in asphalt. As will be seen by the following analyses, those whose gravity is above 30° (which apparently excludes oil from edge wells) run excessively high in light ends. These oils do not exactly correspond in characteristics to any other oils in this State, though they belong in the general class of wax oils. The oil from Dallugge No. 1 represents edge conditions in the Bell sand. The entire lack of gasoline in this oil is a peculiar feature in some way related to the position of the well at the edge of the field.

*Analyses of oil from Santa Fe Springs field*

| Company | Well | Date | Zone | Depth (feet) | Gravity (°Baumé) | Gasoline | Gas tops | Kerosene |
|---|---|---|---|---|---|---|---|---|
| Amalgamated | Dallugge No. 1 | Apr. 14, 1922 | Bell | 3,950 | 25.1 | 0.00 | 3.50 | 28.50 |
| Union | Alexander No. 2 | June 12, 1922 | Foix | 3,525 | 25.8 | 2.10 | 7.00 | 22.50 |
| Twin Bell | Grohs No. 1 | Aug. 14, 1922 | do | 3,511 | 27.8 | 3.00 | 10.33 | 27.17 |
| Union | Bell No. 1 | Nov. 30, 1921 | Bell | 3,788 | 31.1 | 13.78 | 27.50 | 14.50 |
| General Petroleum. | Santa Fe No. 1 | Apr. 24, 1922 | do | 3,911 | 31.9 | 18.33 | 35.00 | 6.00 |
| Do | Santa Fe No. 4 | Nov. 30, 1922 | Meyer | 4,629 | 33.4 | 22.83 | 40.25 | .00 |
| Union | Meyer No. 3 | Dec. 12, 1922 | do | 4,595 | 34.2 | 22.75 | 42.50 | 1.83 |
| Amalgamated | Butterworth No. 1 | Dec. 12, 1921 | do | 4,682 | 35.1 | 29.20 | 49.25 | .00 |

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