GEOLOGY AND OIL PROSPECTS OF THE SALINAS VALLEY-PARKFIELD AREA, CALIFORNIA.

By Walter A. English.

INTRODUCTION AND ACKNOWLEDGMENTS.

The region discussed in this report lies in the southern Coast Ranges of California, extending from the country west of Salinas River eastward to the crest of the Diablo Range. East of this range is the San Joaquin Valley, along the west edge of which lie the largest productive oil fields of the State,[1] though there are fields within the Coast Ranges farther south. In the area examined no productive wells have been drilled, but numerous seeps of oil occur and a number of wildcat wells have been drilled, so the region has been looked upon by many as presenting possibilities of future development. The present investigation was undertaken partly to procure data for the classification of public lands withdrawn from entry pending classification, and partly to determine areas in which the geologic conditions are favorable for prospecting so as to prevent useless expenditures in drilling dry holes in unfavorable areas. The field work on which the report is based was done during the field seasons of 1915 and 1916; about three months was spent within the area mapped.

Throughout the field work the writer was assisted by Mr. William S. W. Kew, whose excellent aid is gratefully acknowledged. Thanks are due to the many ranchers, whose hospitality was a considerable factor in carrying on work in a thinly settled region. Acknowledgment is due particularly to Messrs. A. Pinkerton, Jean Garrissere, G. E. Huston, John Noreen, and Louis and Al Patriquin for information regarding wells that have been drilled.

CONCLUSIONS.

Though by far the larger part of the area examined has little to recommend it for wildcat drilling, certain areas appear to be well worth testing. The chief of these is the low anticline that extends southeastward from a point north of Bradley to a point east of San

[1] The region along the edge of San Joaquin Valley east of the area here described has already been mapped by the Geological Survey and the results published in Bulletins 398 and 406.

Miguel. A much smaller anticline in the Pleyto oil district and an area west of San Ardo, near the zone of oil-impregnated shale, also have possibilities, though these areas are deemed less favorably situated than the first mentioned. The Parkfield district and the anticline that crosses Vineyard Canyon near its head have received notice from oil prospectors, but the writer believes them to be barren of oil. A description of each of these areas and the reasons for the above conclusions are given under the heading "Petroleum."

PREVIOUS PUBLICATIONS.

Although many geologists have visited this part of the Coast Ranges no accurate description of either the geology or the oil possibilities of the Salinas Valley region has been published. The following chronologic review includes the principal papers.

Among the earliest work done in the Coast Ranges was that of the geologists of the Pacific railroad surveys. Antisell[1] describes the geology of Salinas Valley and the San Jose Range and the outcrops of bituminous rock in the Coast Ranges. At the present time this work has only a historical interest.

Whitney,[2] who was State geologist in early days, describes the geology of the Coast Ranges south of Monterey Bay and devotes several pages to oil possibilities. The trend of his statements was calculated to throw cold water on an oil boom which was flourishing in California at the time he wrote. His conclusion that the beds dip too steeply and the structure is too broken for the development of a successful oil field, if applied to the mountainous part of the Coast Ranges, still holds with considerable force.

In a report on petroleum by Goodyear[3] in 1888 the asphalt occurrence on San Antonio River and the oil seepage near Parkfield are described.

A summary of field notes by Fairbanks[4] published in 1894 gives an interesting description of the geology of the Santa Lucia Range and a few notes on the area to the east. Notes on a well drilled near Table Mountain are given in the same volume.

In a report published in 1901 Fairbanks and Watts[5] describe briefly the geology of and oil developments in the Salinas Valley region.

Eldridge during his work on the asphalt deposits of the United States visited the areas of asphalt-impregnated sandstones and

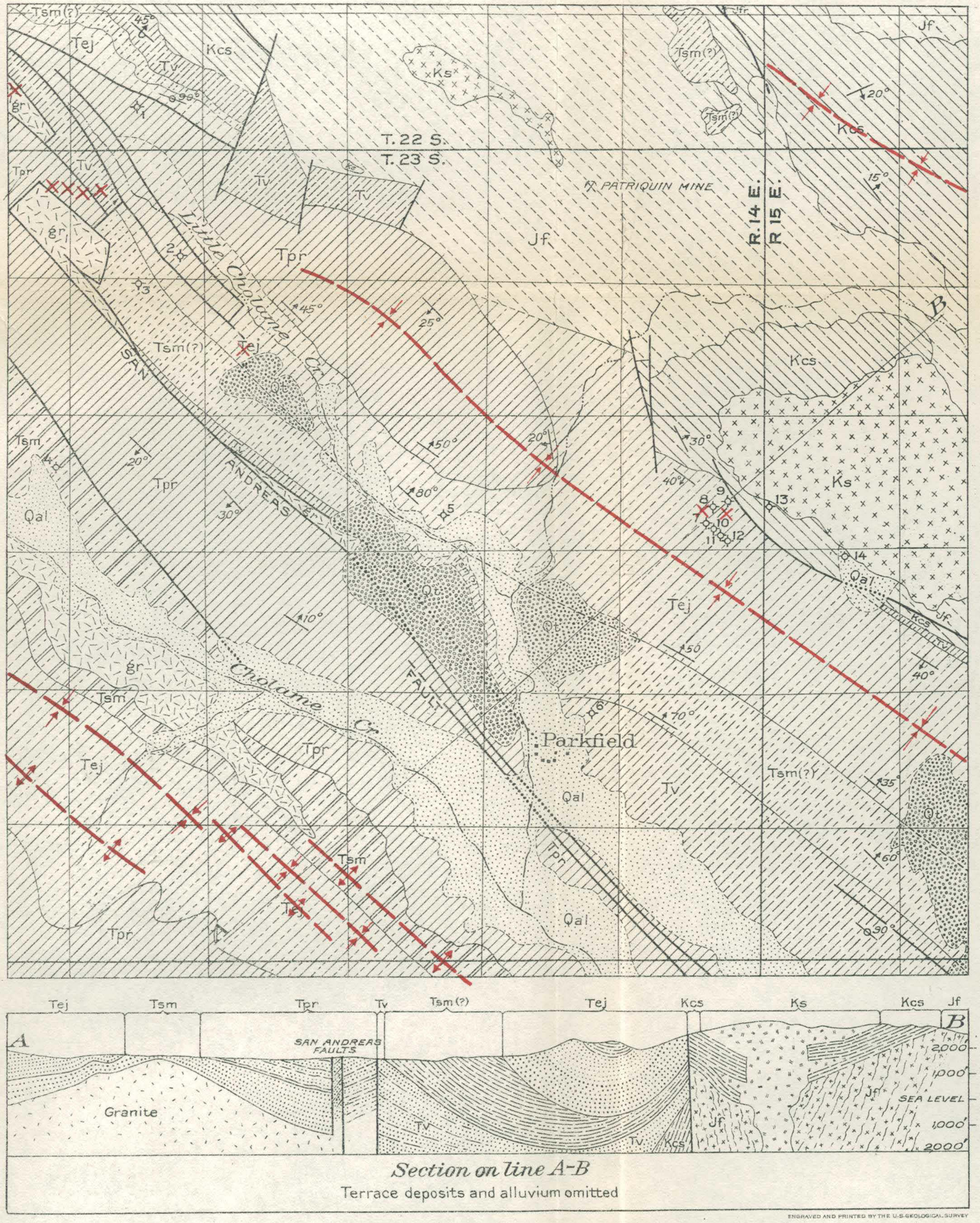
[1] Antisell, Thomas, U. S. Pacific R. R. Expl., vol. 7, pt. 2, chs. 4, 6, 16, 1857.

[2] Whitney, J. D., California Second Geol. Survey, Geology, vol. 1, ch. 5, secs. 1–2, 1865.

[3] Goodyear, W. A., California State Mineralogist Seventh Ann. Rept. pp. 85–89, 1888.

[4] Fairbanks, H. W., California State Mineralogist Twelfth Ann. Rept., pp. 356, 519–521, 1894.

[5] Watts, W. L., Oil and gas yielding formations of California: California State Min. Bur. Bull. 19, pp. 143–145, 1901.



GEOLOGIC MAP OF PARKFIELD DISTRICT, CAL.

GEOLOGY BY W. A. ENGLISH AND W. S. W. KEW

Scale $\frac{1}{62,500}$

0 1 2 3 4 Miles

1918

LEGEND

SEDIMENTARY ROCKS

QUATERNARY

- Qal — Alluvium and slide
- Qt — Terrace gravel

TERTIARY

Pliocene

- Tpr — Paso Robles formation (Fresh-water sands, clays, and conglomeratic beds)

(?)

- Tej — Etchegoin and Jacalitos formations (Massive blue and buff sandstone in lower part; shaly sandstone and brown clay near top; white sandstone southwest of Cholame Valley)

Miocene

- Tsm — Santa Margarita formation (Chiefly sandstone with some shale)
- Tsm(?) — Santa Margarita(?) formation (Diatomaceous shale)
- Tv — Vaqueros sandstone (Brown-weathering sandstone and sandy shale)

Upper and Lower Cretaceous — CRETACEOUS

- Kcs — Chico and Shasta rocks (Dark-gray shale with minor amounts of sandstone)

JURASSIC (?)

- Jf — Franciscan formation and basic intrusive rocks (Sandstone, shale, chert, and schist intruded by various basic rocks)

JURASSIC OR OLDER

- gr — Pre-Franciscan rocks (Complex of granitic and metamorphic rocks)

IGNEOUS ROCKS

CRETACEOUS

- Ks — Peridotite, largely altered to serpentine (Intrusive into Shasta series)

Anticline

Syncline

Fault
Full line accurate, broken lines approximate, dotted lines concealed

35° Strike and dip of bed

45° Overturned dip

90° Vertical dip

Oil seep or tar sand

Well drilled for oil

shales west of San Ardo, and in the Pleyto district. His report[1] gives a short description of the geology and character of the deposits.

A paper by Nutter,[2] devoted largely to the water resources of the Salinas Valley, describes the low-dipping Tertiary beds in that valley.

In 1904 Hamlin[3] described the formations present in the Salinas Valley and outlined its larger structural features. He devoted two pages to petroleum possibilities and recorded the test wells which had been drilled up to that time. No geologic map was published with this report, but through the courtesy of Mr. Hamlin the present writer has had access to a manuscript map prepared by him, which has proved very useful; and some data from it were used in the preparation of Plate XXVII.

In 1914 McLaughlin and Waring[4] described the Salinas Valley and adjacent territory, and the map folio accompanying their report contains a geologic map of this region.

Besides these publications other papers[5] that describe immediately adjacent areas are of value in a study of the Salinas Valley region.

LOCATION, TOPOGRAPHY, AND CULTURE.

As is shown on the index map (fig. 35) the area investigated, all of which is within the drainage basin of Salinas River, lies in the Coast Ranges, west of San Joaquin Valley, about midway between San Francisco and Los Angeles. The geologic maps (Pls. XXVII, XXVIII; fig. 36) show parts of the Priest Valley, Cholame, and San Miguel quadrangles. The Priest Valley and Cholame maps have been published, and topographic field work is now being done in the San Miguel quadrangle. All these maps are on a scale of approximately half an inch to the mile, with 100-foot contours. A 5-foot contour map of the area adjacent to Salinas River as far south as Bradley is also available.

The area is mainly mountainous. The Diablo Range, the crest of which rises from 4,000 to 4,500 feet above sea level, forms the divide

[1] Eldridge, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, pp. 410–411, 1901.

[2] Nutter. E. H., Sketch of the geology of Salinas Valley, Cal.: Jour. Geology, vol. 9, pp. 330–336, 1901.

[3] Hamlin, Homer, Water resources of Salinas Valley, Cal.: U. S. Geol. Suvrey Water-Supply Paper 89, 1904.

[4] McLaughlin, R. P., and Waring, C. A., Petroleum industry of California: California State Min. Bur. Bull. 69 and map folio, 1914.

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

Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Kern and San Luis Obispo counties, Cal.: U. S. Geol. Survey Bull. 406, 1910.

Pack, R. W., and English, W. A., Geology and oil prospects of Waltham, Priest, Bitterwater, and Peachtree valleys, Cal.: U. S. Geol. Survey Bull. 581, pp. 119–160, 1915.

Anderson, F. M., and Martin, Bruce, Neocene record in the Temblor Basin, Cal., and Neocene deposits of the San Juan district, San Luis Obispo County, Cal.: California Acad. Sci. Proc., 4th ser., vol. 4, pp. 15–112, 1914.

between the Salinas and San Joaquin valleys. West of the Salinas Valley are a number of ranges, known collectively as the Santa Lucia Range, which separate the valley from the ocean. Parts of the Santa Lucia Range reach an altitude of over 5,000 feet a few miles from the ocean and are extremely rugged. The main ridges all

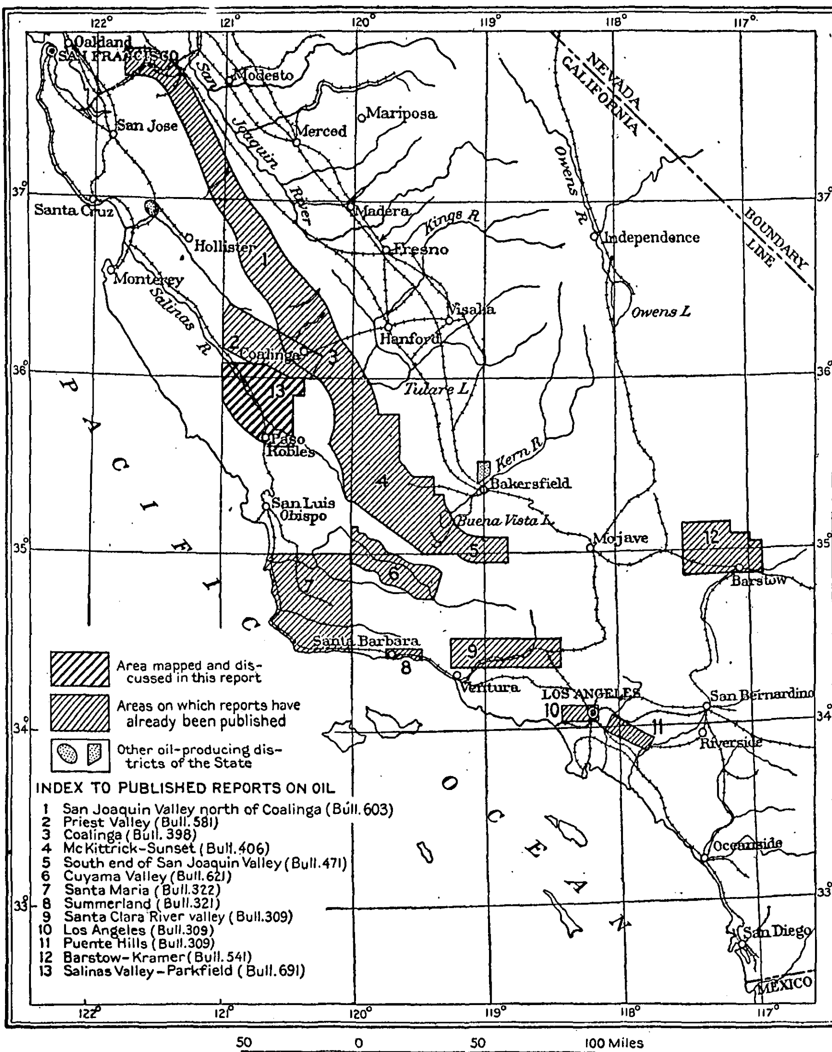


FIGURE 35.—Index map showing location of the Salinas Valley-Parkfield area, Cal.

have a marked northwesterly trend, determining a like course for the principal streams; and many of the smaller streams also trend in a northwesterly direction. A different type of topography, and one rather unusual in the Coast Ranges, is that between Salinas River and the San Andreas fault, to the east. In this area long, nearly parallel ridges slope southwestward toward Salinas River, and the ruggedness of their topography decreases as the river is approached. The ridge crests have an even slope, and there is little difference in altitude between adjacent ridges, so that as seen from a distance this area presents no prominent features to catch the eye, such as the rugged buttes and uneven crest lines seen in the higher parts of the Coast Ranges.

The region is semiarid and is progressively hotter and has less rainfall from the coast eastward.[1] The rainfall at Paso Robles averages about 15 inches a year, at San Miguel 10 inches, and at Parkfield 12 inches. The higher parts of the Diablo Range get considerably more rain and the San Joaquin Valley slope somewhat less than the places mentioned above. The streams, though of considerable size directly after a rain, are normally small, and in summer and fall most of them are dry. Good water for domestic use is scarce, as much of the water contains a considerable amount of alkaline salts.

The higher ridges are partly brush-covered, but the growth is in few places thick enough to be impassable, and the lower hills and valleys are grass-covered or bare. The vegetation is of different character on the different formations. Areas of Franciscan rocks are almost always bare of brush but are covered by a good growth of grass and wild oats. Areas of diatomaceous shale and serpentine are as a rule nearly devoid of vegetation, though on the north slopes of the higher ridges they are covered with scrub oak. The Cretaceous areas are usually brush-covered on the higher slopes, with grass on the lower hills. In the high valley west of The Dark Hole there is a good growth of pine, and scattered oaks occur in the Cholame Valley and on the hills sloping toward Salinas River, but for the most part trees are lacking. The level land along Cholame Creek and considerable areas of rolling hills on the Salinas Valley slope produce good crops of hay in wet years. There are a number of bearing almond orchards in the vicinity of Paso Robles, and many new orchards have been planted recently. The larger part of this region, however, is devoted to stock raising, which is still the most important industry.

The Coast Line of the Southern Pacific Railroad follows Salinas River. Along it are situated Paso Robles (population in 1915, 1,441), San Miguel (population, 830), Bradley (population, 207), and San Ardo. Coalinga (population, 4,200), the nearest town along the west edge of San Joaquin Valley, has railroad connection with the San Joaquin Valley lines. Stage lines are run (1916) from Paso Robles to Shandon and Annette, San Miguel to Parkfield, and Coalinga to

[1] Hamlin, Homer, op. cit., pp. 34–46. This paper describes climate and rainfall in considerable detail.

Paso Robles by way of Parkfield. The railroad from a point near San Miguel to the Stone Canyon coal mine is not in operation at present.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES AND RELATION TO PETROLEUM.

The rocks of this part of the Coast Ranges are divisible on the basis of their lithologic character and structural relations into four major units. The oldest includes the pre-Franciscan rocks (Jurassic or earlier), largely granitic rocks and schists. The second is the Franciscan formation (Jurassic?), with associated basic igneous rocks. The third division consists of Cretaceous dark-colored marine shale and sandstone, which have a thickness of over 20,000 feet west of Coalinga. The youngest division includes all the Tertiary beds, consisting of buff to brown weathering marine shale, sandstone, conglomerate, and fresh-water and subaerial deposits, of variable lithology and thickness.

On the basis of their importance with relation to petroleum a somewhat different grouping is more significant. The pre-Franciscan, Franciscan, and Cretaceous are older than any rocks known to be oil bearing in this region, and any area over which they crop out may at once be condemned as not oil bearing. The Tertiary is divided into the diatomaceous shale group (Salinas shale and shale of the Santa Margarita formation) and the underlying and overlying beds. The diatomaceous shales are the probable sources of any oil which may be found in this region, and the oil is to be looked for in beds close to the shales, especially those overlying them. In the Coalinga region and along Reef Ridge south of Coalinga is the diatomaceous Kreyenhagen shale, which is older than the shales present in the Salinas Valley; and this lower shale is the source of the oil in the Coalinga field. In the Salinas Valley region the Tertiary beds below the Salinas shale are mostly clastic rocks (sandstone and clay shale) and probably were not the original source of any oil, though they may possibly contain oil that has migrated downward from the overlying shales. The beds above the diatomaceous shales (later Miocene to Recent) are those most likely to contain oil.

PRE-TERTIARY ROCKS.

PRE-FRANCISCAN ROCKS (JURASSIC OR OLDER).

The oldest rocks that crop out in the Coast Ranges consist of various metamorphic rocks intruded by one or more granites. These were termed by Willis the Santa Lucia series[1] and also the Coast

[1] Willis, Bailey, Science, new ser., vol. 11, p. 221, 1900.

complex;[1] and a granite of the complex was named by Lawson[2] the Santa Lucia granite. The pre-Franciscan rocks crop out in considerable areas in the Coast Ranges, notably in the San Jose Range, southeast of Paso Robles; in the Santa Lucia Range, west of the area here described; and in the Gabilan Range, east of the lower part of Salinas River.

In the area shown on the geologic map of the Parkfield district (Pl. XXVIII) these rocks form a number of small outcrops. Along the San Andreas fault zone northwest of Parkfield are blocks and long, narrow belts of granite, schists, and limestone; and west of Parkfield is an area which includes rhyolite and other volcanic rocks. Very little is known as to the age of these rocks, and the components of the complex may differ widely in age. Although they have not been found in other than fault contact with the Franciscan rocks, it is almost certain that these rocks are entirely pre-Franciscan and therefore not younger than Jurassic.

No considerable quantity of petroleum can be expected in these rocks, though there are numerous oil seeps from an outcrop of granite northwest of Parkfield.

FRANCISCAN FORMATION AND ASSOCIATED IGNEOUS ROCKS (JURASSIC?).

The Franciscan formation consists of dark sandstone, shale, chert, and small bodies of schist which have been produced by contact metamorphism. Intrusive basic rocks of pre-Shasta age are for convenience mapped with the Franciscan. The Franciscan formation crops out extensively in the Coast Ranges and is easily recognized by its complicated structure and the presence of so many diverse types of rock intimately associated. The component types of rock are well described by Fairbanks,[3] who made a detailed study of them in the San Luis Obispo region, south of Paso Robles. The most abundant sedimentary rock is a green sandstone or graywacke, containing angular grains of quartz, feldspar, and hornblende, with some clay in the interspaces. The shale in the Franciscan is nearly black clay shale, without prominent bedding planes, and breaks up on partly weathered surfaces into lenticular fragments. The chert in most places occurs only in small outcrops, which because of their resistance to erosion form prominent hillocks. Individual beds of chert are usually only an inch or two thick and are separated by a softer shale parting. The chert makes good road metal, as it is easily broken into fragments of suitable size and because of its

[1] Willis, Bailey, Some coast migrations, Santa Lucia Range, Cal.: Geol. Soc. America Bull., vol. 11, p. 419, 1900.

[2] Lawson, A. C., The geology of Carmelo Bay: California Univ. Dept. Geology Bull., vol. 1, pp. 1–59, 1893.

[3] Fairbanks, H. W., U. S. Geol. Survey Geol. Atlas, San Luis folio (No. 101), 1904. In this folio the Franciscan is given a local name ("San Luis formation"), and the igneous rocks are mapped separately from the Franciscan.

hardness forms a very durable surface. Pre-Shasta basic igneous rocks are intruded into the sedimentary rocks in many small irregular masses, and it is largely due to these intrusions that the structure of the Franciscan is so complicated.

SHASTA AND CHICO ROCKS (CRETACEOUS).

Overlying the Franciscan with marked unconformity are the Cretaceous rocks, consisting of dark marine shale and sandstone. Their uniformity in lithologic character from base to top in this region is in contrast to the many variations in the Tertiary formations. The Cretaceous rocks occupy considerable areas in the central part of the Diablo Range and are well exposed on the San Joaquin Valley slope and west of San Miguel in the Santa Lucia Range. Though consisting predominantly of clay shale they also contain sandstone lenses of considerable thickness and locally a conglomerate made up of well-rounded boulders. On fresh surfaces the shale is dark gray to black, but on weathering it changes to dark green and yellowish green, and where maturely weathered it forms a light-yellow clay soil. The sandstone is blue-gray when fresh and changes to green and yellow on weathering. Though subject to variation the commonest type of sandstone is one in which the sand grains are subangular, feldspar grains being abundant; a large amount of chloritic (?) material is present and almost completely fills the interspaces between the sand grains. The Cretaceous within the area mapped includes rocks belonging to both the Shasta series (Lower Cretaceous) and the Chico group (Upper Cretaceous). The rocks associated with the serpentine are probably of Shasta age, as the Cretaceous serpentine in the San Luis region near by is proved by Fairbanks[1] to be post-Shasta but pre-Chico in age. Elsewhere within the area mapped Chico fossils were found in similar shales and sandstones.

TERTIARY ROCKS BELOW DIATOMACEOUS SHALE FORMATIONS.

GENERAL FEATURES AND RELATIONS TO PETROLEUM.

In a general geologic section for the central part of the Coast Ranges the Tertiary rocks below the diatomaceous shale would include the Tejon (Eocene), Kreyenhagen (Oligocene?), and Vaqueros (Miocene) formations. Within the area mapped neither the Tejon nor the Kreyenhagen formation crops out, nor are they believed to be present below the surface. It is believed that in this area the Vaqueros rocks are not likely to contain much petroleum, despite the fact that in the Coalinga oil field most of the oil comes from the Vaqueros. In that field the oil probably originated in the diatoma-

[1] Fairbanks, H. W., op. cit.

ceous Kreyenhagen shale, which underlies the Vaqueros and from which oil migrated upward into the Vaqueros; but in the part of the Salinas Valley here described and probably throughout that valley the Kreyenhagen shale is lacking and no diatomaceous shale is present below the Vaqueros formation. Small quantities of oil may have collected locally in the top of the Vaqueros as the result of downward migration from the overlying diatomaceous shale, but in general the Vaqueros is unlikely to contain oil in the area under discussion.

VAQUEROS SANDSTONE (MIOCENE).

The Vaqueros formation, consisting of marine sandstone and shale, rests unconformably on the Cretaceous and older formations. Together with the overlying Salinas shale it forms the Monterey group. Though these two formations are in many places conformable the change from sandstone to diatomaceous shale is important with relation to petroleum.

The Vaqueros sediments were derived largely from granitic material and give evidence of rapid deposition of detritus from areas of considerable relief. The sand grains are rarely well rounded or sorted, variations in material are common, and a granitic conglomerate is locally present at the base.

In the region here described the Vaqueros crops out in an area extending southeast, north, and west of Parkfield and west of the Pleyto oil district. Its thickness ranges from 200 to over 3,000 feet. The difference in thickness is due in part to progressive overlap and probably in part to local unconformities at the top and possibly within the formation.

DIATOMACEOUS SHALE FORMATIONS.

GENERAL FEATURES RELATIVE TO PETROLEUM.

The Salinas shale (the upper formation of the Monterey group, commonly known as the "Monterey shale") and the shale of the overlying Santa Margarita formation are well developed in this region. Each is economically important as having been the original source of at least some oil. The direct evidence of origin of oil in these shales is the presence of seeps or tar sands in the shales or adjacent rocks. The oil and tar in the Pleyto district and west of San Ardo originated in the Salinas shale. Oil from the shale of the Santa Margarita (?) formation forms the seeps in the Parkfield district. The Mylar asphalt quarry, east of King City (about 10 miles north of San Ardo), contains oil derived from this shale. Indirect evidence that oil originated in these shales is the fact that they are lithologically similar to the shales from which the large amount of oil in the productive fields is believed to have come. It would therefore seem probable that comparable amounts of oil originated in the shales away from the proved productive areas.

SALINAS SHALE (MIOCENE).

Probably the best known of the California Tertiary formations is the marine diatomaceous shale which extends from Monterey southward. This shale was known as "bituminous shale" by the early California geologists but is now commonly called the "Monterey shale." For over 50 years it has been recognized as the probable source of the oil present in localities where it occurs. The name Monterey has been adopted as a group name by the United States Geological Survey to include the so-called "Monterey shale" and the underlying Vaqueros sandstone. The name "Monterey shale" is therefore no longer applicable as a formation name. The name Maricopa shale was used in the writer's report on the Cuyama Valley[1] on the mistaken assumption that the shale previously called "Monterey shale" was essentially contemporaneous with the shale exposed in the vicinity of Maricopa, but the latter has since been found to include representatives not only of the shale previously called "Monterey" in the area under consideration but also of the Santa Margarita formation. The name Maricopa shale is therefore not appropriate as a substitute for "Monterey shale." The name Salinas shale is here proposed for the diatomaceous shale which is well developed on the west side of the Salinas Valley within the area mapped and which is believed to extend as a single formation northward along the west side of the valley to the town of Monterey. The light-pink to nearly white color of the outcrops of this shale and the light weight (low specific gravity) of much of the material have caused it to be commonly known as "chalk rock," and although this shale consists largely of silica, whereas chalk is a form of limestone, the two rocks are similar in that they are both made up, at least in part, of minute to microscopic shells, and the lightness of both is due to the large open spaces present in an aggregate composed of shells. Most of the shale is made up of hard layers 1 or 2 inches thick, separated by partings of softer material. The hard layers break up into rectangular blocks with smooth surfaces that can not be scratched with a knife. Various gradations into softer shale are present, and beds 5 to 10 feet thick consisting of soft white earthy, nearly pure diatomaceous remains are interstratified with the harder varieties of shale.

Within the area mapped the Salinas shale crops out only west of Salinas River. The beds are considerably folded, and owing to the

[1] English, W. A., Geology and oil prospects of Cuyama Valley, Cal.: U. S. Geol. Survey Bull. 621, pp. 191–215, 1916.

crushing of the shale its thickness can not be determined by measurements across the strike of the outcrops. Thus the Pleyto well, situated on the axis of an anticline, is reported to have penetrated diatomaceous shale for at least 3,100 feet, though the original thickness of the beds penetrated may have been considerably less.

SANTA MARGARITA FORMATION (MIOCENE).

At the type locality near Santa Margarita, about 15 miles south of Paso Robles, the Santa Margarita formation consists of white quartzose sandstone, which overlies the Salinas shale with marked unconformity. It carries a small but characteristic fauna of marine shells of which a large oyster (*Ostrea titan*), a barnacle (*Tamiosoma gregaria*), a scallop (*Pecten estrellanus*), and two kinds of sand dollars are the most characteristic species. Beds made up of the same material and containing the same kinds of shells are present in the anticline near the head of Vineyard Canyon and also southwest of Salinas River. In the latter area they overlie the Salinas shale with marked unconformity. In the Salinas Valley region and in the hills bordering San Joaquin Valley a thick diatomaceous shale member overlies the sandstone of the Santa Margarita formation and forms the upper part of that formation.

The lower sandstone portion of the Santa Margarita formation in T. 23 S., R. 13 E., near the head of Vineyard Canyon, consists of sandstone and shaly sandstone underlain by coarse arkosic conglomerate. The upper 400 to 500 feet of the sandstone zone contains resistant "reef beds," which weather to strike ridges. These beds are underlain by several hundred feet of buff shaly sandstone, which weathers easily and forms few visible outcrops. The lower part of the succession is made up of light-colored, poorly sorted arkosic sandstone and conglomerate, containing boulders as much as 8 inches in diameter. This boulder bed is considerably thicker than the overlying sandstone, though its base is not exposed and no accurate estimate of its thickness was made. Only the upper two lithologic zones contain Santa Margarita fossils, and the lower beds may possibly belong to an older formation. In this area a shale member of the Santa Margarita rests conformably on the lower sandstone, in some places with a sharp line of contact but elsewhere grading downward and also laterally into the sandstone.

West of Salinas River, south of Bradley, the Santa Margarita is a nearly white quartzose sandstone, in many places only slightly indurated. Fossils are abundant, especially echinoderms and large pectens. West of San Ardo the basal beds of the formation are shaly and are overlain by the typical sandstone, followed by more shale and interbedded sandstone. These beds are shown on Plate XXVII as sandstone.

Within the Parkfield area, northeast of the San Andreas fault, the name Santa Margarita (?) is applied to a shale believed to be equivalent to the shale within the Coalinga region mapped by Arnold and Anderson[1] as Santa Margarita (?). The lower sandstone phase of the Santa Margarita is absent within this area, the shale resting directly on the Vaqueros sandstone. Although the upper part of this shale is believed to be of Santa Margarita age, there is some doubt as to the age of the lower part, but for the present the name used by Arnold is retained. The Santa Margarita (?) within this area is lithologically similar to the shale of the Santa Margarita formation southwest of the San Andreas fault.

The shale member of the Santa Margarita consists of pink to white thin-bedded and locally "chalky" shale, made up in part of diatom shells. The purer diatomaceous material is rare, clay and very fine quartz sand being the most abundant constituents of the shale. The flinty varieties of shale are also uncommon; most of the shale is rather porous, breaks with an irregular fracture, has a dull surface, and is easily scratched with a knife. The maximum thickness of the shale within the area mapped is probably about 800 feet.

The shale is in most areas conformably overlain by sandstone, the basal beds of which contain a Jacalitos fauna. North of the San Lorenzo grant (Peachtree ranch), in the northwest corner of the area shown on Plate XXVIII, the shale grades up into Jacalitos sandstone beds the fauna of which is closely related to that of the Santa Margarita. It is thus seen that the Santa Margarita is closely related to the overlying upper Miocene both faunally and structurally.

FORMATIONS OVERLYING THE DIATOMACEOUS SHALES.

GENERAL FEATURES AND RELATION TO PETROLEUM.

The beds present above the Santa Margarita belong to the Jacalitos, Etchegoin, and Paso Robles formations. The Jacalitos and Etchegoin are represented in the Salinas Valley-Parkfield area, but no attempt was made to differentiate the two, as where they are both present the difference seems to be one of faunal zones, and no unconformity is apparent.

These formations and the sandstone of the Santa Margarita are the ones most likely to contain oil, because of their position above the shales that are presumed to have been the source of any petroleum present. The exact age of the bed overlying the diatomaceous shale in any area is not so important as its position above the shale, and any one of the later formations may prove to be oil bearing where it overlies the shale in an area of favorable structure.

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

JACALITOS AND ETCHEGOIN FORMATIONS (MIOCENE AND POSSIBLY PLIOCENE).

Marine deposits of upper Miocene and possibly Pliocene age, consisting chiefly of sandstone with some clay shale, corresponding to the Jacalitos and Etchegoin formations, rest with apparent conformity on the Santa Margarita formation. These deposits vary greatly in character, thickness, and faunal content in different parts of the Salinas Valley area. In the Parkfield syncline a maximum thickness of about 2,000 feet is exposed. The lower part is a massive-weathering buff quartzose sandstone. Overlying this is a similar massive blue sandstone. The upper 500 feet consists largely of soft buff shaly sandstone and siltstone in which are interbedded lenticular strata of brown clay. Southwest of the San Andreas fault zone the upper Miocene varies considerably in thickness, apparently thinning toward the southwest. On the northeast flank of the Vineyard Canyon anticline considerably over 1,000 feet of beds are exposed, made up of three divisions—a lower white sandstone, a zone of cross-bedded white, buff, and yellow massive sandstone, and an upper zone of granitic conglomerate and coarse sand. On the southwest flank of the anticline 400 to 600 feet of beds are exposed. These are mostly yellow sandstone, shaly sandstone, and gravels. Close to Salinas River, near the mouth of Poncho Rico Creek, and along the anticline northwest of Bradley the upper Miocene is only 200 to 250 feet thick. The smaller thickness here is probably due at least in part to erosion prior to the deposition of the Paso Robles. West and southwest of Bradley the upper Miocene is entirely overlapped by the Paso Robles.

PASO ROBLES FORMATION (PLIOCENE).

In the Salinas Valley are extensive outcrops of a formation consisting of incoherent sand, gravel, and clay of fresh-water origin. These beds were named Paso Robles formation by Fairbanks[1] and Hamlin,[2] who published papers on areas in the Salinas Valley region at about the same time. They occupy the same stratigraphic position and correspond to the fresh-water deposits mapped and described as Tulare formation in the report on the adjoining Coalinga district.[3] The older name, Paso Robles formation, is retained for them, and the name "Tulare" formation is therefore abandoned by the United States Geological Survey.

The Paso Robles ("Tulare") in this area rests with apparent conformity on the Etchegoin formation, but elsewhere it rests uncon-

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[1] Fairbanks, H. W., U. S. Geol. Survey Geol. Atlas, San Luis folio (No. 101), 1904.

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

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

formably on that formation or overlaps older formations with marked unconformity. Where the Paso Robles rests on the Etchegoin in this area there is no definite line of separation. Beds carrying marine Etchegoin fossils are interbedded with what appear to be nonmarine deposits, and the line of contact as drawn separates the prevailingly marine beds from those largely of nonmarine origin. On the basis of a scanty marine fauna locally present at its base and of its position overlying the fossiliferous marine upper Miocene, the Paso Robles is believed to be of Pliocene age.

The Paso Robles ranges from coarse gravel to fine-grained shaly sandstone and clay and includes in the upper part a number of thin beds of hard white chert. Over most of its area of outcrop in the Salinas Valley it is practically flat-lying, so that good sections are exposed only near the basal contact, both east and west of Salinas River, where the beds dip at angles of 10° to 60°. As a rule the lower beds are conglomeratic, and the upper beds consist of fine-grained sand and sandy clay. The total thickness is probably nowhere much over 1,500 feet.

The Paso Robles beds that crop out in Middle Mountain, northwest of Parkfield, and those in the axis of the Parkfield syncline are made up of brown to gray clay interbedded with light-gray to buff-weathering arkosic sand, gravel, and sandy shale. Pebbles of diatomaceous shale are abundant in the coarser beds.

TERRACE GRAVEL.

Along both sides of Little Cholame Creek north of Parkfield there are terraces as much as a quarter of a mile wide and from 100 to 150 feet above the level of the creek. Terrace gravels which reach a thickness of 100 feet are exposed on the faces of these terraces.

In Turkey Flat the terraces are prominent features, and the gravel is considerably indurated at many places, owing to the fact that the streams flowing from the serpentine ridge to the north were heavily laden with minerals in solution, which they deposited as a cementing material in the gravels. A similar cementation of Quaternary beds is described by Arnold and Anderson[1] as occurring west of Coalinga.

IGNEOUS ROCKS.

Besides the igneous rocks mapped with the Franciscan and pre-Franciscan formations, there are extensive outcrops of serpentine, a rock altered largely by the action of percolating water from peridotite, the form in which the rock was originally intruded. The least-altered specimens obtainable contain as much as 50 per cent of

[1] Arnold, Ralph, and Anderson, Robert, Conglomerate formed by a mineral-laden stream in California: Geol. Soc. America Bull., vol. 19, pp. 147–154, 1908.

olivine, but in almost all surface outcrops the olivine is altered to the mineral serpentine, and the rock is known as serpentine. The peridotite was intruded into the Cretaceous shale, forming nearly horizontal sills and irregular dikes. From his studies in the San Luis Obispo region Fairbanks determined that the serpentine intrusive into the Cretaceous is of post-Shasta but pre-Chico age, so that its age is approximately middle Cretaceous. An older pre-Cretaceous serpentine is intrusive in the Franciscan in this and other areas in the Coast Ranges.

The serpentine has a marked tendency to slide and cover adjacent areas of other formations, and unless considerable care is exercised the areas covered by slide may be mistaken for bodies of serpentine in place, a mistake that has been made by a number of geologists who have studied the area west of Table Mountain.

STRUCTURE.

Although most of the sedimentary formations in this area were originally deposited on the ocean bottom as practically flat-lying beds, the uplifts that brought them to their present altitude above sea level were accompanied by lateral pressure, which caused the beds to buckle and slope (dip) at various angles, and in some places they were practically turned on edge. The present attitude of these originally flat-lying beds is known as their geologic structure. The structure in any area is an important factor in determining whether or not the oil originally disseminated through the beds finally collected or concentrated in sufficient amount to form an oil pool.

Although preceded by other movements in Tertiary time a pronounced folding near the end of the Pliocene epoch (after the deposition of the Paso Robles) produced much of the tilting and faulting which the beds show. Long anticlinal ridges and synclinal valleys were formed at this time; and these features, modified by erosion, constitute the larger ridges and valleys as they now exist. The Diablo Range and the ranges southwest of Salinas River were formed chiefly at this time.

The San Andreas fault is the dominating structural feature of this region. It extends in a southeasterly direction diagonally across the area shown in Plate XXVIII and has been traced for several hundred miles to the northwest and southeast. Movements have taken place on this fault recently, the most noted being that of 1906, which produced the San Francisco earthquake. The recent movements have formed rift features, such as long troughs, ridges, and sinks occupied by lakes, and these are the most easily recognized features of the fault. Geologic mapping shows that there are other faults which are parallel to the main rift line and belong to the same zone of faulting but which show no evidences of such recent movement, though geologic evidence proves that profound movement has taken place along these faults during several epochs in the past. The San Andreas fault zone ranges from a few hundred feet or less to a mile in width, and in this zone the structure is extremely complicated. Rocks of widely different age have been brought into contact, each cropping out in a narrow belt whose length is parallel to the fault zone.

The areas on the two sides of the San Andreas fault zone differ considerably in structure and stratigraphy. In the area to the northeast the rocks are intricately folded, in general steeply dipping, and cut by numerous faults, whereas to the southwest, as far as the west side of Salinas River, the beds have a prevailingly low dip. Farther southwest, in the Santa Lucia Range, there is a region of complicated structure and older formations similar to that of the Diablo Range.

In the area northeast of the San Andreas fault the structure is a complicated resultant of many periods of folding. The wide belt of older rocks that marks the crest of the Diablo Range probably formed a region of uplift during recent movements, though the structure is so complicated that it can hardly be called anticlinal. In fact, the Stone Canyon and Castle Mountain synclines are on the crest of the ridge, and near the west corner of Kings County the ridge splits in two parts separated by the synclinal McClure Valley. Another interesting feature is the fact that the Parkfield syncline, in which a considerable thickness of Tertiary beds is infolded, trends obliquely to the San Andreas fault and on the northwest is entirely truncated by that fault.

The gently dipping Paso Robles beds southwest of the San Andreas fault form part of a broad, shallow synclinal trough. Nearly through the center of the trough extends a low anticline which trends southeastward through Bradley, but this fold is to be regarded as within the larger syncline. The beds in this area were little affected by the movement at the close of the Paso Robles epoch. However, this area, especially its southern part, appears not to have been equally immune at the times of earlier movements. The older formations show steep dips, and the Paso Robles may be thought of as a nearly horizontal covering over beds of complicated structure. The formations older than the Paso Robles come to the surface locally within the general area of Paso Robles beds. The largest of these areas is that in which the Santa Margarita formation crops out in the Vineyard Canyon anticline, extending from a point north of Indian Valley southeastward to Ranchita Canyon. Most of the upper or shale member of the Santa Margarita dips at a low angle, but in the area of the sandstone division of the Santa Margarita the dips are steeper. Southeast of Shandon (south of the area shown in Pl. XXVII), in secs. 4, 5, and 9, T. 27 S., R. 16 E., are the Red Hills, in which the pre-Franciscan rocks crop out beneath the Paso Robles. The absence of intermediate formations here illustrates the magnitude of the unconformity at the base of the Paso Robles in the southern part of the Salinas Valley region. Along the southwest side of Salinas River the Paso Robles bends up rather abruptly close to its contact with the older formations, its dip reaching 60°. The two en échelon anticlines, one at Bradley and a smaller one near the bend of San Antonio River, are described in the discussion of the oil possibilities of the region (p. 237).

PETROLEUM.

CONDITIONS IN ADJACENT PRODUCTIVE OIL FIELDS.

The most satisfactory method of arriving at the possibilities of finding oil in an untested area is to compare it with productive areas, to determine whether or not the geologic features believed to have caused the known concentrations in those areas are duplicated in the area under consideration. A brief outline of salient features of the productive fields near the Salinas Valley-Parkfield area will therefore be given.[1]

In most of the San Joaquin Valley fields the oil is derived from sands overlying diatomaceous shale, and it is now generally believed that the oil originated in the diatomaceous shale and migrated into adjacent porous sandy beds.[2] In the Coalinga field the oil is supposed to have originated in the Moreno (Cretaceous) shale and Kreyenhagen (Oligocene?) shale and is now found chiefly in sandy beds overlying these shales. In the Temblor Range fields, to the south, the oil originated in the diatomaceous shales of the Monterey group. Beds of the same age and of much the same lithologic character are present in the Salinas Valley-Parkfield area.

The fields on the west side of San Joaquin Valley also have certain structural features in common. They are all situated in a zone of low folds which lies between the steeply dipping and faulted beds of the mountainous area to the west and the broad San Joaquin Valley, in which at least the later Tertiary formations dip at a low angle over a large area and form a complete cover for the diatomaceous shale. It is supposed that the oil in these fields originated in

[1] For a full discussion of conditions in the productive California fields see U. S. Geol. Survey Bulls. 309, 321, 322, 398. 406, and 603.

[2] The origin of the oil found in California and the reasons for its accumulation at certain places are discussed in detail by Robert Anderson and R. W. Pack in a recent publication (Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Cal.: U. S. Geol. Survey Bull. 603, pp. 116–120, 1915).

the shale and migrated upward and laterally into the overlying sandy beds, there being an especially wide zone lying to the east, under San Joaquin Valley, from which oil may have come. The general tendency has apparently been for the oil to migrate up the rise and accumulate in the beds overlying the diatomaceous shales in the low folds that occur in the foothill area. The oil has thus collected in the anticlines and also in synclines west of productive anticlines.

GENERAL FEATURES OF AREAS DISCUSSED.

Most of the area shown on Plate XXVII lies within the broad, shallow syncline of late Tertiary rocks between the Santa Lucia Range on the west and the Diablo Range on the east. The existence of a large area of gently dipping Tertiary beds which overlie one and perhaps two diatomaceous shales over most of their extent is a condition favorable for the occurrence of oil, which would be most likely to accumulate in a local anticline. The anticlinal folds within this area are the one trending southwestward through Bradley to a point east of San Miguel, which will be called the Bradley anticline; the one which crosses San Antonio River in sec. 26, T. 24 S., R. 10 E., called the Pleyto anticline; and the one which crosses Vineyard Canyon near its head, called the Vineyard Canyon anticline. West of San Ardo the Santa Margarita lies in a monocline upon the Salinas shale, but as the outcropping sands are saturated with oil and tar, it is possible that they contain commercial amounts of oil below the surface. About 15 miles southeast of the southeast corner of the area mapped on Plate XXVII is a local uplift within the area of low-dipping beds, known as the Red Hills. Each of these areas, as well as the Parkfield district (Pl. XXVIII), which lies within the Diablo Range, will be discussed in the following paragraphs.

It is possible that oil may also be found in the San Antonio Hills, west of Salinas River, where the Salinas shale is well developed. Any oil present here would be in sandy lenses or crushed zones within the shale, as there is no covering of later formations overlying the shale.

According to Arnold and Anderson,[1] the diatomaceous shale in the Santa Maria field is a reservoir in which a large quantity of oil has accumulated. In that field hard flinty beds of shale have been crushed by close folding, forming a porous reservoir of angular fragments, and the spaces between these fragments, together with the pores in lenticular sandy beds, were filled with oil by downward migration from the softer unfractured shale in the upper part of the formation. Though similar accumulations of oil may possibly

[1] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Cal.: U. S. Geol. Survey Bull. 322, p. 1907.

exist in the San Antonio Hills, the field work done in that area was not sufficient to warrant any discussion or predictions as to this possibility.

LOCAL FEATURES.

BRADLEY ANTICLINE.

The anticline which extends from a point north of the mouth of Swains Canyon southeastward through Bradley to a point east of San Miguel is in the writer's opinion the most promising structural feature of this region and should be tested by several wildcat wells. The plunging anticline extending from a well-developed diatomaceous shale formation into gently dipping overlying beds is similar to productive folds in the fields on the west side of San Joaquin Valley, and the conditions of stratigraphy, structures, and evidence of oil are all fairly favorable.

Stratigraphy.—It is important to know what formations are likely to be present beneath the Paso Robles along the anticline, because if this fold is to be considered favorable a diatomaceous shale which may have been the original source of oil should be present, and the thickness and character of the formations overlying it should be known so as to calculate the probable depth necessary to drill. The diatomaceous Salinas shale crops out along the northern part of the axis of the fold and is well developed on the west side of Salinas River. However, it does not crop out anywhere along the San Andreas fault zone east of the wide synclinal belt of the Santa Margarita and later formations, though older Tertiary rocks are brought to the surface in the fault zone; and if the log of the Eureka well is to be relied upon the Salinas shale is absent beneath the Santa Margarita where the Vineyard Canyon anticline crosses Big Sandy Creek. The northeastern limit of the shale is therefore somewhere beneath the synclinal area of later beds. If a straight line were drawn from the shale where it crops out northwest of Bradley to the southern part of T. 29 S., R. 17 E., where what is probably the same shale is exposed along the southern edge of the broad synclinal area of later Tertiary beds, the line would be nearly parallel to and slightly east of the axis of the Bradley anticline. There is little reason to believe that this line actually marks the northeastern limit of the shale, but the limit is as likely to be east of this line as west of it. It may therefore be said that the shale is pretty certainly present along the fold in its northern part, say as far to the southeast as Bradley, beyond which there is a fairly good chance that the shale is present. The Santa Margarita formation, the next younger, consists of sandstone overlain by shale. The sandstone is present on both sides of the wide synclinal trough and is probably present beneath the surface along most of the anticline, though it is overlapped by the upper Miocene beds along the axis of the fold north of Bradley. West of San Ardo the lower part of the Santa Margarita is 700 feet thick. West of San Miguel, in the syncline which crosses the southwest corner of T. 25 S., R. 11 E., a section incomplete at the top includes 250 feet of white sandstone. In the Vineyard Canyon anticline a section incomplete at the base includes 1,200 feet of sandstone belonging to the Santa Margarita formation. The data available therefore indicate that this sandstone may be 1,200 feet or more thick along the Bradley anticline, but if this fold was an axis of uplift and subject to erosion before Paso Robles time the sandstone may be much thinner or even lacking. The shale member of the Santa Margarita is from 200 to 600 feet thick along the Vineyard Canyon anticline, thinning toward the southeast. This shale also shows a tendency to thin and grade laterally into sandstone toward the southwest, along and north of Poncho Rico Creek. If the same tendency is maintained between the Vineyard Canyon anticline and the Bradley anticline there is probably not over 200 to 300 feet of shale present below the surface along the latter fold, or the shale may be entirely lacking. The upper Miocene formations are 400 to 500 feet thick on the west flank of the Vineyard Canyon anticline. These beds thin southwestward from the northern part of this anticline and are only 200 to 250 feet thick near the mouth of Poncho Rico Creek and northwest of Bradley. The upper Miocene is therefore probably from 200 to 500 feet thick along the Bradley anticline, and the lower figure is more likely the true one. The Paso Robles, though reaching a thickness of 1,500 feet elsewhere, is probably not very thick along this fold. In Vineyard Canyon the uppermost beds of the upper Miocene are exposed, and a well starting at the same altitude elsewhere along this anticline would encounter not over a few hundred feet of Paso Robles beds.

Structure.—The Bradley anticline is a low fold in a large shallow syncline of nearly flat-lying beds. The synclines that parallel the anticline on either side have no well-defined synclinal axes, as the beds dip at less than 3° for a width of a mile or two. Within the area of shale at the north end of the anticline the axis is sharp, the shale on both flanks dipping at 45° to 60°. This dip lessens on the northeast flank to 40° in the upper Miocene and 30° in the Paso Robles west of Salinas River. Where the axis lies within the upper Miocene the fold is lower, with dips of 20° to 25° on the flanks and a plunge to the southeast of 5°. Within the area of Paso Robles the fold is still lower, especially between Bradley and Indian Valley, where the dips on the flanks are only 2° to 4° and extend from a mile to a mile and a half out from the axis. South of Indian Valley the gentle dips are maintained on the northeast side of the axis, but on the southwest side the dips steepen to 40° and even 60°. These remarkably steep dips within a general area of low dips suggest that there is a fault parallel to and about a mile southwest of the anticlinal axis. Farther southwest, on the other side of Salinas River, the exposures are poor, but the beds appear to be nearly flat lying.

Indications of oil.—There are no seepages or other direct evidence of the presence of oil in the beds that crop out along the Bradley anticline. Where the Salinas shale and the overlying Santa Margarita formation crop out in the northern part of the fold neither contains enough oil to stain the beds, but as no extraction tests were made a small amount of oil if present might have passed unnoticed. Not far away there is abundant evidence of the presence of oil. West and southwest of San Ardo the basal Santa Margarita beds are oil stained for a number of miles along the strike and locally for a thickness of several hundred feet. Tar sands are also present in the Pleyto district, southwest of Bradley.

Economic possibilities.—The four general conditions necessary for the formation of a valuable oil pool are (1) a competent original source of oil; (2) structure permitting the oil to be gathered in a pool; (3) a porous reservoir in which the oil is retained by impermeable overlying beds; and (4) the oil sands at a depth accessible to the drill. The Bradley anticline appears to satisfy these conditions. The Salinas shale is probably present beneath the surface, and the occurrence of oil in beds overlying the shale in this vicinity indicates that if the Salinas is present it was probably an original source of oil. The anticline is as broad as many of the proved productive folds and should present like possibilities for concentration of oil along the crest. The alternate sandy and shaly beds in the Santa Margarita are competent to hold and retain a large amount of oil. The oil is to be looked for in beds overlying the diatomaceous shale, and even if maximum thicknesses of the overlying beds are present the shale would be within easy drilling depth. As explained in the discussion of the stratigraphy of this fold not even an approximate drilling depth can be given. If the 5° plunge of the anticlinal axis in the upper Miocene beds continues southward beneath the Paso Robles then the diatomaceous shale should be reached at depths of about 1,000 feet at Bradley. South of Bradley there is very little if any plunge in the Paso Robles beds, but this is of little significance, as the unconformities between the Paso Robles and the beds in which the oil is sought would allow their thickening or thinning greatly within a short distance.

Wells drilled for oil.—An old well in sec. 4, T. 25 S., R. 12 E., is said to have been drilled about 1904-5 and to have reached a depth of 1,340 feet, getting a small amount of gas but no oil. The lower part of the well is said to have been drilled in shale, but whether this was the Salinas shale or not is uncertain. If the well reached the Salinas shale and was properly tested it goes far toward proving the lack of oil in the southern part of the anticline.

PLEYTO OIL DISTRICT.

The Pleyto district (see fig. 36) lies near the bend in San Antonio River, about 6 miles southwest of Bradley and 8 miles southeast of Pleyto. Attention of oil men was early attracted to this area by the outcrops of asphalt rock, and a number of wells have been drilled, but they did not encounter enough oil to justify pumping.

Structure.—The anticline that crosses the SW. ¼ sec. 36, T. 24 S., R. 10 E., constitutes a structural spur extending out into the area of gently dipping beds of the Paso Robles formation, very much like the productive anticlines in San Joaquin Valley, though on a much smaller scale. Owing to this similarity it has been thought that oil may have accumulated in this anticline.

Indications of oil.—The basal 150 feet of beds of the Paso Robles formation along the contact just south of San Antonio River are impregnated with asphalt. The quality of the asphalt rock is variable, the best being confined to a bed of fine sandstone about 20 feet thick. An open cut has been made in this bed, and what probably amounts to several hundred wagon loads of asphalt rock has been removed for local use in road making. To the southeast there are stringers of rich asphalt rock in the basal Paso Robles beds where they cross the Nacimiento River, and small pockets of sand that has been squeezed into the underlying Salinas shale are heavily impregnated with asphalt. The Salinas shale adjacent to the Paso Robles is hard and broken into angular fragments, between which a tar cementing material is locally present. The tar occurs only on the surfaces of the shale fragments and seems to have migrated to this locality from elsewhere in the shale.

Economic possibilities.—The Salinas shale is the probable source of any oil present in this district, and the most likely collecting place of the oil would be in the overlying Paso Robles or in the Santa Margarita sandy beds where they are present. The asphalt along the outcrop of the Paso Robles on the west side of the syncline furnishes direct evidence of the presence now or formerly of oil in the district. Against these favorable features may be urged the following: (1) The bed of asphalt rock is 150 feet thick just south of San Antonio River but thins out to a few feet within a quarter of a mile in each direction, and there is no asphalt in sec. 26 in the sandy beds on the flank of the anticline. The accumulation of asphalt appears to be due to fractures in the shale caused by movement along a fault that continues eastward from sec. 33, where it forms the contact between the Salinas shale and the Vaqueros formation. These fractures ap-

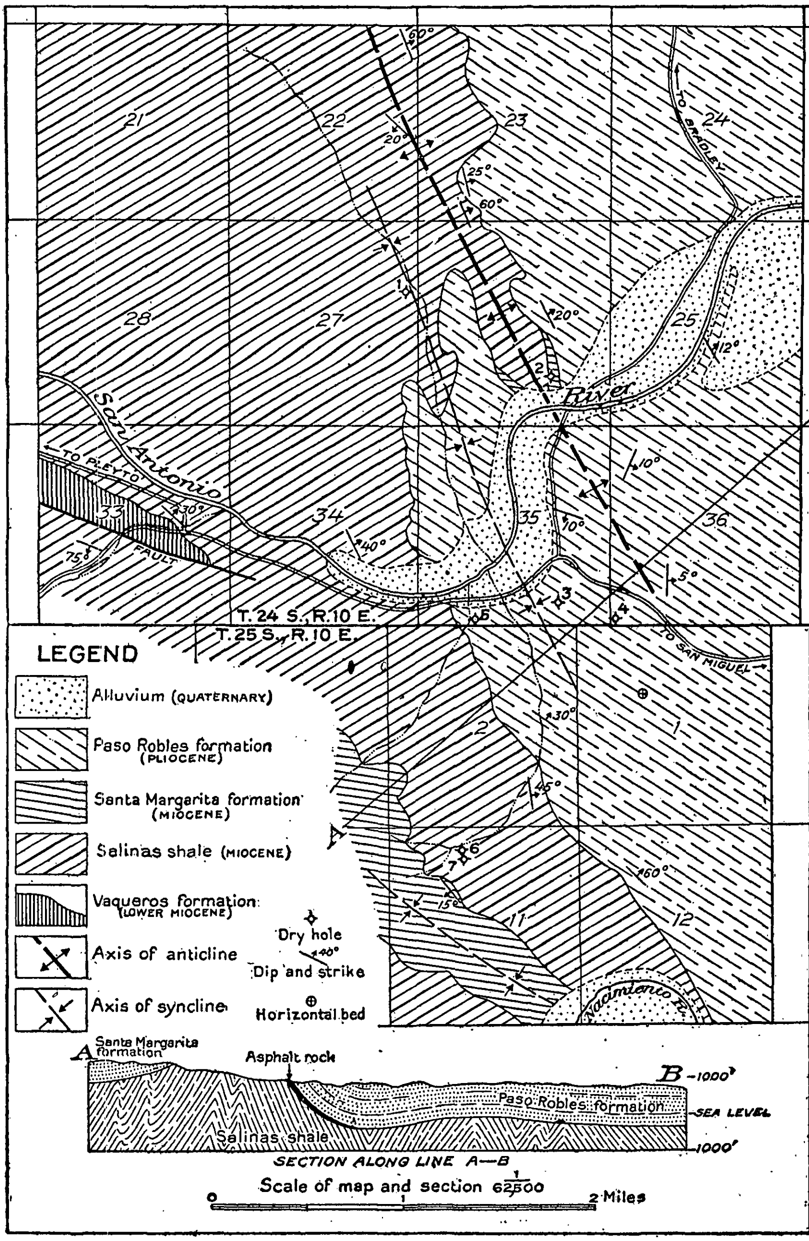

FIGURE 36.—Geologic map of Pleyto oil district, Cal. Geology by W. A. English and W. S. W. Kew.

parently allowed a ready migration from the shale into the overlying Paso Robles. Thus the presence of asphalt here is apparently not due to the anticlinal structure to the east and is not very good evidence of a concentration of oil in the anticline. (2) The four wells that tested the beds overlying the shale got negative results. The Metropolis well, which passed through the Paso Robles into the underlying shale without encountering either oil or tar sand, furnishes the best test. Two shallow wells close to the outcrop near the south line of sec. 35 got tar sands but no oil. The King well of the Bradley Oil Co. is said not to have reached the Salinas shale, so its results are inconclusive. The Metropolis well went far toward proving the absence of oil in this anticline. However, the King well should be depended to reach the shale. If after reaching the shale it proves a failure also, more drilling in the field would seem inadvisable, though a well a quarter to half a mile east of the King well would give the most conclusive test of the anticline.[1]

Wells drilled for oil.—The wells drilled in the Pleyto district are here listed and numbered to correspond with numbers on the geologic map (fig. 36):

Well No. 1, in sec. 27, drilled by the Monterey Oil Co. (?), is said to have reached a depth of 1,100 feet and struck flowing water.

Well No. 2, in the SE. ¼ sec. 26, drilled by the Pleyto Oil Co. and successors, is said to have reached a depth of 3,300 feet, getting a small quantity of tarry oil near the bottom. It is in the Salinas shale for at least the upper 3,100 feet. Drilling was started about 1909 and finished in 1912.

Well No. 3, the Metropolis well, in sec. 35, drilled by the Hames Valley Oil Co. in 1911–1913, is 3,100 feet deep and obtained only a small quantity of heavy oil. The drill entered the shale at a depth of about 1,000 feet without having passed through any tar sands.

Well No. 4, in the southwest corner of sec. 36, drilled by the Bradley Oil Co. (King well), is said to have reached a depth of not more than 800 to 900 feet.[1]

Well No. 5 (location approximate) was drilled about 1900 by the White Oaks Oil Co. Another well, drilled by the Great American Oil Co., is a few hundred feet to the south. Both are close to the outcrop and are said to have penetrated the asphalt sands.

Well No. 6, the Cavanaugh well, drilled with a standard rig, is said to have reached a depth of 800 feet in the Salinas shale.

Well No. 7, the other Cavanaugh well, drilled with a portable rig, is said to have reached a depth of 2,500 feet without getting any appreciable quantity of oil.

[1] After the above was written the King well was taken over by the Associated Oil Co. and deepened to 2,035 feet, when it was abandoned. Through the courtesy of the company the writer has been furnished with the log. According to the writer's interpretation, the drill reached the Salinas shale at 1,445 feet. Seven feet of tar sand was passed through at a depth of 1,320 to 1,327 feet, but no other oil or tar sands were encountered.

The Veratina well, on the south bank of San Antonio River about a quarter of a mile east of the west line of sec. 35, is said to have been drilled shortly after 1900 and to have encountered considerable salt water and some gas.

VINEYARD CANYON ANTICLINE.

The anticline that crosses the head of Vineyard Canyon is a well-marked fold of considerable size and is structurally favorable for the collection of any oil originally present in the rocks. Despite the favorable structure, it appears unlikely that oil will be found beneath this fold, as there are no seeps or other surface evidence of the presence of oil, and it is unlikely that the Salinas shale is present beneath the fold.

Stratigraphy.—Along the middle part of the fold a maximum thickness of 1,200 feet of sandstone belonging to the Santa Margarita formation is exposed. Conformably above this sandstone is the shale member of the Santa Margarita, which is well developed along Indian Valley and to the northwest, where the thickness is about 600 feet. The shale thins toward the east, being entirely absent in the northeastern part of T. 23 S., R. 13 E., and along the southern part of the Vineyard Canyon anticline it has a thickness of only 200 feet. The upper Miocene is from 500 to 600 feet thick, thinning slightly toward the north and west.

Structure.—The part of the anticline within the area of outcrop of the sandstone member of the Santa Margarita is structurally the highest part of the fold, and there is a well-marked plunge of 5° to 8° at both the northwest and southeast limits of the outcrop of the sandstone. At the southeast end the fold passes beneath the Paso Robles only a short distance beyond the point where it leaves the sandstone. Within the Paso Roblés beds the anticline is very low if it is present at all, but it probably continues as a well-marked fold in the older beds beneath the Paso Robles cover. Beyond the sandstone member of the Santa Margarita, to the northwest, the fold flattens out greatly, dips of 20° and 25° giving place to dips of 3° to 6° along the flanks of the anticline.

Economic possibilities.—Any oil present along this anticline probably originated in and is to be sought in beds stratigraphically below those that crop out. Even along the northern part of the fold the shale member of the Santa Margarita, which might be looked to as a possible source of oil, is not overlain by beds thick enough to retain any oil that might have originated in this shale, and the total absence of seeps in the top of the sandstone member of the Santa Margarita where it crops out along the anticline makes it seem unlikely that farther north this sandstone contains oil that has migrated downward from the shale of the Santa Margarita. Toward its southeast end, where the fold passes beneath the Paso Robles, only a slight thickness of the shale is present, probably not sufficient to have been the source of any considerable amount of oil.

In the writer's opinion the only chance of the occurrence of oil along this fold is the fact that the Salinas shale may be present beneath the surface, and in that case the oil would probably be found in the base of the sandstone member of the Santa Margarita. The best place to drill would therefore be close to the axis of the fold, within the area of outcrop of this sandstone, as such a well would be situated on the structurally most favorable part of the fold and would have the least thickness of beds to penetrate before reaching the horizon to be tested. However, the surface evidence is against the supposition that the Salinas shale is present beneath the surface and that oil from it has collected along the anticline. In the first place, some seepages or oil stains would likely be present if there were much oil present at depth. Second, the Salinas shale is absent only a few miles east of the anticline, where older rocks crop out, and it is also absent in the Red Hills, to the southeast and east of King City, to the north of the area shown on Plate XXVII, where small areas of granite crop out beneath the gently dipping Santa Margarita rocks of the Salinas Valley syncline. It therefore seems likely that the shale is not present beneath the Vineyard Canyon anticline, though such a conclusion is by no means certainly correct, as the geology of the California Tertiary formations is so irregular that guesses as to the presence or thickness of formations beneath the surface several miles from their nearest outcrop are extremely risky.

Wells drilled for oil.—The Baker well, in the western part of sec. 16, T. 24 S., R. 14 E., is said to have been drilled about 1910 and to have reached a depth of 1,610 feet without getting any oil. The lower part was mostly in blue clay; sea shells were reported at 1,030, 1,090, and 1,500 feet. The well probably reaches the shale member of the Santa Margarita, but would have to go much deeper to reach the horizon at which the Salinas shale might be present. As this well is not favorably situated structurally, being on the west flank of the fold, where it is plunging to the southeast at a considerable angle, it would seem better to drill along the fold somewhere within the area of the outcrop of the sandstone member of the Santa Margarita rather than deepen this well to test the beds at lower horizons.

A well on Big Sandy Creek, in the northwest corner of sec. 31, T. 22 S., R. 13 E., is said to have reached a depth of about 1,000 feet and encountered either granite or a coarse arkosic sandstone in its lower part. The Powell well of the Standard Oil Co., in sec. 36, T. 22 S., R. 11 E., was drilled to a depth between 1,300 and 1,800 feet without encountering oil.

AREA WEST OF SAN ARDO.

Geology.—The San Antonio Hills, along the west side of Salinas River, consist entirely of the Salinas shale, except for a belt of the sandstone and shale of the Santa Margarita formation about half a mile wide close to the edge of the valley. The Santa Margarita beds in this belt overlie the Salinas shale with marked unconformity. They dip 40° to 60° NE., in marked contrast to the gently dipping beds of the same age on the east side of the river. There must be a syncline or a faulted syncline somewhere beneath the valley alluvium and terrace formation, but there is no surface evidence to indicate where the syncline shown on Plate XXVII really lies beneath the Quaternary cover. The Santa Margarita is here markedly unconformable on the Salinas shale.

Evidence of oil.—In Garrissere Gulch, west of San Ardo, tar sands in the Santa Margarita extend through a thickness of several hundred feet; farther south, in sec. 19, T. 22 S., R. 10 E., the lower beds of the Santa Margarita are richly impregnated with oil and tar; and other oil sands are exposed close to the base of the sandstone as far south as the southern limit of this belt of Santa Margarita in sec. 33.

Economic possibilities.—Surface evidence indicates that the oil migrated from the underlying shale into the Santa Margarita, and that it is confined to the west side of the syncline, which lies somewhere out in the valley. The abundance of oil sands at the surface suggests that oil might be obtained by wells that would reach the lower part of the Santa Margarita at a considerable depth. The best place for a test is opposite the best outcropping oil sands, which occur between the north line of sec. 13, T. 22 S., R. 9 E., and the south line of sec. 19, T. 22 S., R. 10 E. The well should be far enough east of the outcrop to reach the base of the Santa Margarita at a depth between 1,000 and 1,500 feet.

Wells drilled for oil.—The wells drilled in this area are described below in order from north to south. They were all drilled some time ago, and the information obtained about them is fragmentary.

The Newell well, east of sec. 12, T. 22 S., R. 9 E., is said to have reached a depth of 1,310 feet. It probably entered the oil sands at about 600 feet and continued in them to the bottom. It furnishes a fair but incomplete test of this area, as it should have been drilled to the underlying shale, which is here probably several hundred feet deeper.

The Capt. Barrett well, near the north line of sec. 19, T. 22 S., R. 10 E., is said to have reached a depth of 800 to 1,000 feet. It is located too close to the basal contact to test the Santa Margarita.

The Tomboy well, about 1,800 feet southeast of the Barrett well, is said to have reached about the same depth. It probably entered the Salinas shale at from 500 to 600 feet and proves that at that depth the overlying Santa Margarita does not contain oil.

The Doheny well, in the southwest corner of sec. 20, T. 22 S., R. 10 E., is practically on the basal contact of the Santa Margarita. Its depth was not learned.

The well of the Norman Oil Co., in the northeastern part of sec. 4, T. 23 S., R. 10 E., starts down in the Salinas shale on the north flank of a well-marked anticline. Its depth and history were not learned.

RED HILLS UPLIFT.

The Red Hills, from which the Paso Robles formation dips in all directions, constitute a local uplift that brings the pre-Franciscan rocks to the surface in secs. 4, 5, 8, and 9, T. 27 S., R. 16 E. (south of the area shown on Pl. XXVII). It would seem at first sight that this area, in which no shale is exposed between the Paso Robles and the granitic rocks, should be condemned as presenting no chance for the accumulation of oil. However, when the magnitude of the unconformity at the base of the Paso Robles is considered it may easily be conceived that areas of diatomaceous shale may underlie the Paso Robles within the margin of the Red Hills uplift, which extends from 1 to 2 miles out from the central mass of older rocks; and if so, oil may have collected in the basal conglomeratic beds of the Paso Robles. On the other hand, the absence of any seeps or other evidence of petroleum in the basal Paso Robles beds is an unfavorable indication, and this, together with the likelihood that there may not be any shale present, would make drilling in the Red Hills a very risky undertaking.

PARKFIELD DISTRICT.

The Parkfield district (fig. 35, Pl. XXVIII) lies in an elevated part of the Diablo Range about 28 miles from Coalinga, in San Joaquin Valley, and 22 miles from San Miguel, in the Salinas Valley, the two nearest railroad points. Despite the poor transportation facilities the presence of numerous oil seepages here has led to the drilling of a number of wildcat wells, though without any distinctly favorable results. Nevertheless, there are many people who still believe that the district will ultimately prove productive.

Stratigraphy and structure.—Though most of the formations common to the Coast Range crop out within this area, the only one present in which oil is likely to have originated is the Santa Margarita (?) formation, which is exposed on the southwest flank of the syncline east of Parkfield. Oil is therefore to be looked for only in beds adjacent to this formation and particularly those overlying it, in areas of favorable structure.

The beds throughout the Parkfield district dip steeply, and the structure is complicated. Toward the north, where the Parkfield syncline approaches the San Andreas fault, beds of widely different ages have been brought close together by the extensive faulting. East of Parkfield the syncline is less faulted but presents a remarkable disparity in the succession of formations outcropping on the two sides of the axis. It may be seen from Plate XXVIII that the Vaqueros formation and the Santa Margarita (?) formation, which are well developed on the southwest side of the fold, are absent on the northeast side, along the flank of Table Mountain. The absence of these beds is accounted for partly by faulting along the Tertiary-Cretaceous contact but is due also to an unconformable overlap by the upper Miocene formations upon the older formations. Some time before the deposition of the upper Miocene sediments the Table Mountain area was uplifted and the Vaqueros and Santa Margarita (?) formations were entirely eroded away. At the same time the beds which now crop out on the southwest flank of the fold were not eroded to any great extent. The Santa Margarita (?) formation is believed to underlie the upper Miocene to a point considerably east of the synclinal axis, as the shale crops out on the northeast flank of the fold only a short distance southeast of the area shown on Plate XXVIII.

Indications of oil.—Numerous seeps occur in this district and are important as giving direct evidence that oil is present. The seeps are on both flanks of the Parkfield syncline, some near the Table Mountain group of wells and others northwest of Parkfield, close to and within the San Andreas fault zone.

On the slope of Table Mountain from the east boundary of the upper Miocene sandstone down to the lower group of wells there are numerous seeps of tarry oil in each of the small gulches, and small pools of nearly solid tar have collected below the seeps. Down the canyon from the Table Mountain wells, in the eastern part of sec. 13, are accumulations of tar, indicating a former seep.

The Parkfield syncline is truncated northwest of Parkfield by the San Andreas fault, and the diatomaceous shale comes close to the fault. In this zone oil seeps are numerous and occur in all the formations, even in the granitic rocks. The following are the principal ones seen:

Near the center of the north line of the SW. ¼ sec. 9, T. 23 S., R. 14 E., a small pit has been dug in sandstone immediately overlying the diatomaceous shale, and a small quantity of oil has collected in the pit.

An almost continuous line of small seeps occurs in the Paso Robles and Vaqueros formations in the bed of the small creek which drains eastward across the center of the NW. ¼ sec. 5, T. 23 S., R. 14 E.

Seeps of heavy oil occur every few feet in a fault block of crushed granite where it is crossed by the bed of a small gulch that trends eastward and joins Little Cholame Creek about 1,000 feet northeast of the center of sec. 31, T. 22 S., R. 14 E. Seeps of oil in granite are of course very unusual, though in the present case no unusual explanation is necessary to account for the facts. The granite is a fault block which was crushed and jointed by movements along the San Andreas fault zone. Thus the normally impervious granite became sufficiently porous for oil to enter it from adjacent bodies of shale, in exactly the same way that the oil which now seeps from the Paso Robles and Vaqueros entered those formations.

Economic possibilities.—The Parkfield syncline is the only fold in this area in which any great amount of the Santa Margarita (?) formation is present and in which it is overlain by a sufficient covering to retain any oil originally derived from the shale. About 2,500 feet of upper Miocene beds are included in the syncline, and oil might be expected to occur at their base on one or both flanks of the fold. This syncline could not safely be condemned as barren of oil by reason of the surface evidence, though the flanks of an isolated syncline of this type are not the most favorable structure imaginable.

The Tricounty well and the Table Mountain group of wells have given actual proof that only small quantities of oil are present, and as these wells penetrate the beds most likely to contain oil if it were present at all, further drilling upon this syncline would appear inadvisable.

Unfavorable results were also obtained by test wells in The Vallecitos,[1] an area northwest of Coalinga, in which the structure is essentially similar to that of the Parkfield syncline. The tests of these two areas go far toward proving that isolated synclines of the oil-bearing series, surrounded by older rocks, will not prove productive in California. There are three factors which may account for the lack of oil. First, there may be an insufficient amount of shale present to have originally furnished any large quantity of oil. Second, the oil originally present could not be greatly concentrated at certain points, as migration could take place only along the comparatively short distance between the axis of the syncline and the outcrops of the oil sands on the flanks of the fold. In contrast are the productive San Joaquin Valley fields, where the oil in the productive folds may have come from areas far out in the valley syncline and also have migrated up the rise in anticlines. The third factor is the probable loss of oil at the outcrop of the oil sands. In an isolated syncline there is nothing to prevent the oil migrating up the dip and escaping at the outcrop.

[1] Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Cal.: U. S. Geol. Survey Bull. 603, pp. 167–177, 1915.

Wells drilled for oil.—In the following descriptions of wells the numbers correspond to those on the geologic map of the Parkfield area (Pl. XXVIII):

At the localities numbered 1 and 2 remnants of rig timbers, etc., probably represent old holes drilled by Captain Barrett and associates before year 1900. The locations are unfavorable.[1]

Well No. 3, the Oakshade well, owned by the Monterey Oil Co., is said to have been drilled to a depth of 1,910 feet and to have encountered some oil and gas. This well is situated in the zone of complicated structure along the San Andreas fault. Such wells generally produce showings of oil but not enough to make them successful.

Well No. 4 indicates the location of the Middle Ridge Oil Co.'s derrick. No drilling has been done here and there is little chance of obtaining oil at this locality.

Well No. 5, the Tricounty well, is said to have reached a depth of 4,160 feet and found showings of oil at several depths. The well starts in upper Miocene sandstone and reaches the underlying Santa Margarita (?) formation near the bottom. Although there was some water trouble, which might account partly for the failure to obtain much oil, this well furnishes a pretty fair test of the west flank of the Parkfield syncline.

Well No. 6, the Parkfield Syndicate well, was drilled with a portable rig to a depth of 500 feet and got a small amount of gas. It was drilled entirely in the Vaqueros sandstone.

Well No. 7, the Miller or Raymond well, was the first of the Table Mountain group of wells, as drilling is said to have been started in 1888. The drill is said to have reached a depth between 640 and 800 feet without passing through any oil or tar sands. Sulphur water is now flowing from the casing. Of the wells of the Table Mountain Oil Co., Nos. 8 and 9 are 270 and 600 feet deep, respectively. They are said to be in oil or tar sand for most of this depth. Wells Nos. 10, 11, and 12 are shallow, ranging from 100 to 200 feet in depth; they are now abandoned, and when the writer visited them water and a small quantity of oil stood within 25 to 50 feet of the top of the casing in each well. The Table Mountain wells are said to have produced a few barrels of oil per day at the time of their completion. The oil doubtless originated in the Santa Margarita (?) formation and migrated up along the fault which lies east of these wells, saturating the sands for a few hundred feet out from the fault. The base of the upper Miocene sandstone also probably contains some oil which has migrated directly up from the underlying shale, in addition to that which came up along the fault plane.

[1] Notes on the location and depths of these and other old wells may be found in California State Min. Bur. Bull. 19, p. 145, 1901.

Well No. 13, sometimes called the Livermore well, was drilled by the Future Success Oil Co. in 1913–14. It reached a depth of 1,810 feet, mostly in Cretaceous shale, but also apparently passing through intrusive sheets of serpentine and possibly reaching Franciscan rocks near the bottom. This well is separated from those on the west by a fault, and the light-gravity oil, showings of which are said to have been encountered, originated in the Cretaceous shale. Wells drilled in the dark Cretaceous shale generally get showings of a light-gravity oil but only a very small quantity.

Well No. 14, the Dominion well, was drilled in 1912 and is said to be between 150 and 300 feet deep. It is located in an area of serpentine slide, near the contact between the serpentine and the Cretaceous rocks. The bailer dump (consisting of the drill cuttings) appears to be made up entirely of serpentine, but some Cretaceous shale may have been encountered. The location is unfavorable.