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CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON THE

SANTA MARIA OIL DISTRICT

SANTA BARBARA COUNTY CALIFORNIA

BY

RALPH ARNOLD AND ROBERT ANDERSON

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PRELIMINARY REPORT ON THE SANTA MARIA OIL DISTRICT, SANTA BARBARA COUNTY, CAL.

By Ralph Arnold and Robert Anderson.

INTRODUCTION.

PURPOSE OF THIS REPORT.

During the last three years the region near the Pacific coast in the northern part of Santa Barbara County, Cal., has shown promise of becoming one of the most productive oil fields of the West, if not of the whole United States. The developed fields lie on the low, rolling hills between the Santa Maria and Lompoc valleys, and the wells are known to obtain their oil from the Monterey shale, which underlies this region. The lightness of the oil, which averages from 25° to 27° Baumé, and the great productiveness of the wells, which yield an average of 300 to 400 barrels per day, and sometimes as high as 3,000 barrels per day, are among the things for which the district has become noted. Large areas in the same general region as the productive fields were known to be analogous, as far as surface evidence went, to the proved territory. With the purpose of studying the occurrence of the oil, the extent and structure of the oil-bearing formations, and their relations to associated formations, the field work leading to the present report was carried on by the writers during the summer and autumn of 1906. This is a preliminary report, and will be followed later by a bulletin containing more detailed descriptions of the conditions and more complete maps, sections, and other illustrations. The locations of this and other oil fields of southern California are shown in fig. 1.

ACKNOWLEDGMENTS.

Mr. H. R. Johnson covered the territory northeast of the Santa Maria Valley, and the map and notes concerning that region are largely the result of his work. Dr. H. W. Fairbanks's paper on the geology of Point Sal[a] has been consulted for some of the areal geology and descriptions of this complicated promontory.

[a] Bull. Dept. Geology, Univ. California, vol. 2, 1896, pp. 1–92.

Without the assistance of the operators in the developed field that part of the report which relates to the geology of the wells, production, and other technical data would have been an impossibility, and the writers therefore wish to acknowledge their indebtedness to the officers and managers of the different oil companies for their hearty cooperation and support. Thanks are due more particularly to Mr.

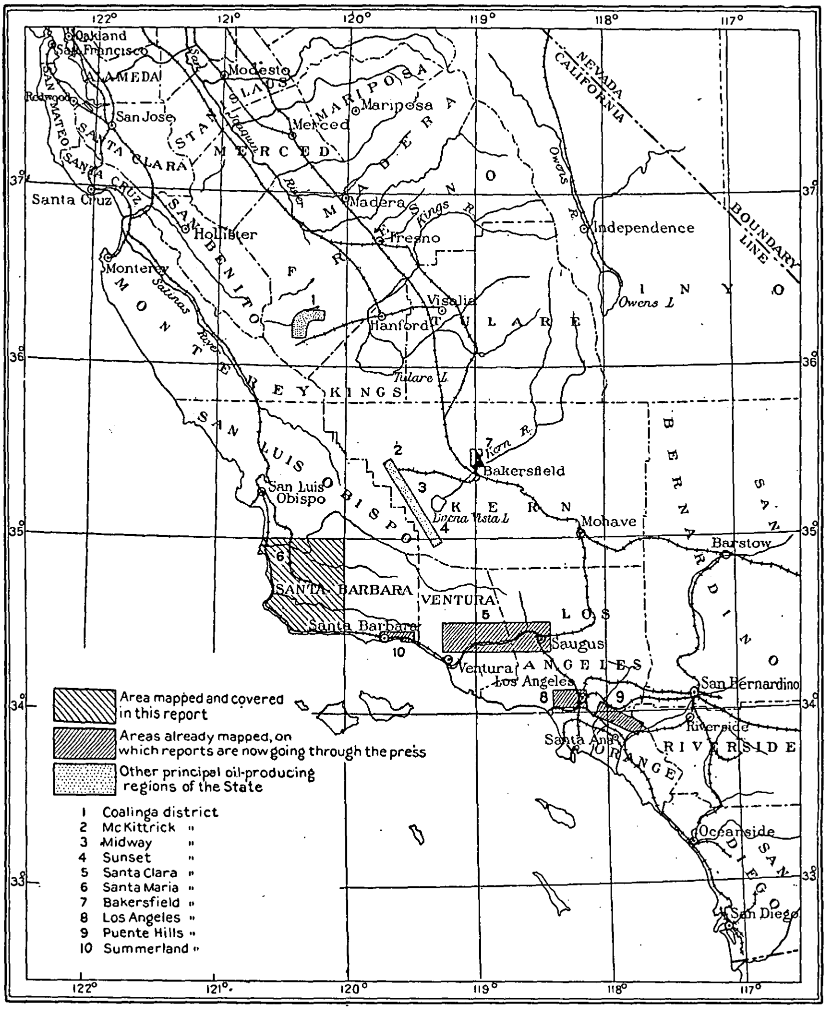

FIG. 1.—Index map of part of southern California, showing location of area discussed and of other productive oil fields of the State.

W. W. Orcutt, geologist of the Union Oil Company; Messrs. J. F. Goodwin and F. J. Burns, of the Pinal and Brookshire oil companies; Mr. Morris Albee, secretary of the Western Union Oil Company; Mr. Adolph Phillips, of the Graciosa Oil Company; Mr. W. O. Maxwell, of the Recruit Oil Company; Mr. E. E. Henderson, of the Palmer Oil Company; Mr. F. D. Hall, of the Hall & Hall Oil Company; Capt. N. P. Batchelder, of the Los Alamos Oil and Development Company; Mr. Frank M. Anderson, geologist of the Southern Pacific Company; Mr. William Vanderhurst, of the Todos Santos Oil Company; Mr. D. G. Scofield, vice-president of the Standard Oil Company; and many others whose assistance has added materially to the value of this report.

EARLY HISTORY OF THE DISTRICT.

This district was, up to 1899, entirely unknown as an oil-producing territory. To Messrs. McKay and Mulholland, of Los Angeles, is due the credit for starting operations in the Santa Maria field proper. After a favorable report had been made on certain lands of the Carreaga ranch by Mr. Mulholland the Western Union Oil Company was organized, drilled three prospect holes, and was finally rewarded, in August, 1901, by striking paying quantities of oil in the third well. In 1902 the Pinal Oil Company, of Santa Maria, began operations on the north side of Graciosa Ridge and, meeting with marked success, was followed by the many other companies that have since undertaken operations in this field.

GEOGRAPHY AND TOPOGRAPHY.

SITUATION.

The region here discussed is comprised within the Lompoc and Guadalupe quadrangles, as mapped by the United States Geological Survey, which cover an area of about 1,300 square miles in northern Santa Barbara County, Cal. (See Pl. I.) It includes portions of the San Rafael and Santa Ynez divisions of the Coast Ranges and covers the basin region between these mountains, which is occupied by the Santa Maria, Los Alamos, and Santa Ynez valleys and the intervening hill ranges. It is bordered on the west and south by the Pacific Ocean. The southwest corner of the area is marked by Point Arguello and Point Conception, where the coast bows around from a southeast to a west-east course. These headlands are among the most salient features of the whole Pacific coast. The Arroyo Grande oil field, situated in the San Luis quadrangle to the north, is briefly mentioned in this report.

DEFINITION OF PLACE NAMES.

The following paragraphs define certain place names as used on the map (Pl. I, pocket) and in this report:

The only land comprised within the Guadalupe quadrangle is the narrow strip of coast west of longitude 120° 30′ W. The Lompoc quadrangle comprises the rest of the area mapped east of that line.

The San Rafael Mountains include the whole group between Santa Ynez and Cuyama rivers.

The Santa Ynez Mountains include the whole range east of Point Arguello between Santa Ynez River and the ocean.

The Casmalia Hills include the group extending from the coast at Point Sal to Graciosa and Harris canyons and San Antonio Valley.

The Solomon Hills lie between the Santa Maria Valley, Foxen Canyon, and the Los Alamos Valley and between Divide and La Zaca Creek.

The Purisima Hills lie between Lompoc, the Santa Rita Valley, and the Santa Ynez Valley on the south and the Los Alamos Valley on the north, and between Burton Mesa on the west and Alamo Pintado Creek on the east.

The Santa Rita Hills lie between the Santa Ynez and Santa Rita valleys, extending from a point east of Lompoc nearly to the east edge of the Santa Rosa grant.

The name San Antonio terrace is applied to the wide terraced region between Casmalia and the west end of the Los Alamos Valley.

The Lompoc terrace is the plateaulike region of hills extending from the coast a distance of about 5 miles east from Honda and the same distance southeast from Surf.

GENERAL TOPOGRAPHIC FEATURES.

The San Rafael Range is a high, rugged maze of ridges divided by steep canyons that usually cut transversely across the formations regardless of the folding and structural lines. It is traversed by two well-graded streams—Sisquoc and Cuyama rivers. The range trends northwest and southeast, paralleling the main structural lines of California.

The Santa Ynez Range has an east-west course and determines the long, straight shore line between Point Conception and Santa Barbara. It includes a long, even-topped ridge rising abruptly from the sea and a hilly belt between this ridge and the Santa Ynez Valley. Its topography reflects the structure more than that of the San Rafael Mountains and deformation within it does not appear to have gone so far as in that range.

The triangular hilly basin opening out toward the coast between these two divergent ranges of mountains contains three main valleys and several lines of higher ground that radiate like the ribs of a fan from the vertex of the triangle. The point of especial interest in the topography of these interior features is their characteristic reflection of the structure of the formations. They contrast in this respect with the two boundary ranges just mentioned.

An anticline in this intermediate region is apt to be marked by a ridge, as in the long ridges of the Purisima Hills, which follow close to the axis of a broad anticline; and some of the larger valleys coincide with the synclinal axes of the broad lines of structure. The latter statement is illustrated by the Santa Ynez Valley in parts and by its structural although not actual continuation in the Santa Rita Valley. It is also exemplified by the upper portion of the Los Alamos Valley and by Harris Canyon. These topographic features may be explained by the fact that the main movements in these hill ranges have been gentle as compared with those in the older mountain masses, that the disturbances giving them form have been comparatively recent, and that deformation has not gone very far. Low areas of rolling hills are almost sure to prove that a syncline or plunging fold has given rise to structural depressions in which deposits of soft sand, producing low topographic forms, have been laid down.

GEOLOGY.

SEDIMENTARY FORMATIONS.

GENERAL STATEMENT.

The formations involved in the geology of this district include the Franciscan (Jurassic?), Knoxville (lower Cretaceous), pre-Monterey (which may include both Cretaceous and older Tertiary), Sespe (Eocene or Oligocene), Vaqueros (lower Miocene), Monterey (middle Miocene), Fernando (Miocene-Pliocene-Pleistocene), and other Quaternary deposits.

FRANCISCAN FORMATION (JURASSIC?).

The oldest rocks within the Santa Maria district belong to the formation described by Fairbanks[a] under the name San Luis, and are probably of Jurassic age. They represent the Franciscan formation, which is a very important basement formation in the Coast Ranges farther north. The small areas of these rocks occurring here consist of remnants of sandstone, shale, glaucophane schist, and jasper, associated with serpentine that has probably been intrusive in them. The sandstone is in general of a dark-green color, fairly fine grained, and considerably indurated. The jasper is banded by thin contorted beds. These sediments are so disturbed that little clue as to their structure can be obtained and so local in extent that no attempt has been made in mapping to differentiate them from the accompanying serpentine.

[a] Fairbanks, H. W., Description of the San Luis quadrangle: Geologic Atlas U. S., folio 101, U. S. Geol. Survey, 1904.

KNOXVILLE FORMATION (LOWER CRETACEOUS).

Several small areas of sedimentary rock occur, which can be definitely assigned on fossil evidence to the Knoxville formation (lower Cretaceous). The two most important are north of Mount Lospe, in the Casmalia Hills. The rock is chiefly dark-colored, unaltered argillaceous shale such as is characteristic of the Knoxville throughout its wide area of distribution in the California Coast Ranges. Sandstone and conglomerate occur in lesser amounts. Brownish-yellow sandstone, similar to that common in the Knoxville in the Coast Ranges several hundred miles farther north, occurs on the border of an irregular area of diabase on Tepusquet Creek in the San Rafael Mountains and contains Knoxville fossils. It is present only in very small patches and seems to have been brought up from below by the diabase intrusion. Knoxville rocks were recognized in one other place in the San Rafael Mountains, a few miles north of Zaca Lake, at the base of the series mapped as pre-Monterey. It is very likely that a portion of the area so mapped belongs to the lower Cretaceous, but it is not probable that the whole does. The differentiation of the formations included within these two areas has been left for later work.

PRE-MONTEREY ROCKS.

Two large areas of sedimentary rocks, whose age has not been determined otherwise than that they are older than the Monterey, occur in the San Rafael Mountains. It is probable that strata of Knoxville (lower Cretaceous) age occur at the base of the series in these areas and that the higher portions represent either the upper Cretaceous or the Eocene, or both, and possibly include some Vaqueros. Detailed work was left until another time.

The larger of these two areas occupies the northeast corner of the territory and has an extent of about 60 square miles. The other lies on the northeastern slope of the high ridge north of Zaca Lake. In these areas is exposed a great series of thin-bedded, dark-colored, locally greenish shale alternating with more massively bedded sandstone that is in places of a very granitic nature. Conglomerate, much of it plainly showing its origin from granite, occurs in minor horizons. Knoxville fossils were found in a gritty greenish sandstone near the lowest portion of these pre-Monterey rocks, about 2 miles north of Zaca Lake, and it is probable that a considerable portion of the series is lower Cretaceous. The higher portion seems to be a continuation of a formation in San Luis Obispo County that has been considered upper Cretaceous and of one in southeastern Santa Barbara County that has been ascribed to the Eocene. Its age is therefore much in doubt. It may also include at the top a part of the Vaqueros (lower Miocene), which overlies this doubtful terrane and of which the base has not been definitely determined.

Structurally the strata included in the pre-Monterey rocks lie beneath the Monterey and upper Vaqueros, but though far older they do not bear the marks of intense folding as strongly as the brittle Monterey shale. They are, however, steeply upturned, and the lines of folding, as in the other formations, have in general a northwest-southeast direction.

SESPE SANDSTONE (EOCENE OR OLIGOCENE).

The Sespe sandstone, of Eocene or Oligocene age, which is of great importance farther east, notably in the region of the Summerland oil district near Santa Barbara, appears in this territory, so far as discovered, only at a point about 4 miles south of the Santa Ynez Mission, where the deep-red sandstone characteristic of this formation outcrops very locally in the axis of the central anticline of the Santa Ynez Range, conformably underlying sandstone of the Vaqueros (lower Miocene). It is probable that this formation has a wide extent in the Santa Ynez Range under the beds of the lower Miocene, although it is not elsewhere exposed.

VAQUEROS FORMATION (LOWER MIOCENE).

GENERAL STATEMENT.

The Miocene was a period of almost, if not absolutely, continuous marine deposition in this region, and the sedimentary beds of this age predominate over all others in thickness and areal extent. The Vaqueros comprises the lower Miocene and overlies conformably the red sandstone at the top of the Sespe (Eocene or Oligocene). It seems to cover most of that part of the Santa Ynez Range which is included within the Lompoc and Guadalupe quadrangles, although it must be stated that this range was not examined in sufficient detail to warrant definite sweeping statements.[a] It also covers belts in the San Rafael Mountains, where it is exposed at the base of the Monterey (middle Miocene).

LITHOLOGIC CHARACTER.

The lower portion of the Vaqueros is made up of a thick series of greenish-gray, coarse and fine sandstone, much of it somewhat concretionary in character, interbedded with dark, fine-grained, thin-bedded

[a] Since writing this report paleontological evidence indicating the Eocene age (equivalent to the Tejon formation) of the sandstone beneath the fossiliferous Vaqueros conglomerate has been discovered. It should be borne in mind, therefore, that a considerable portion, at least, of the terrane described and mapped in this paper as Vaqueros is of Tejon (Eocene) age.

shale in lesser amount. Toward the middle of the formation the shale increases in amount, alternating with thin beds of sandstone. For considerable thicknesses the shale has a characteristic olive-gray color, and owing to its hard, gritty, brittle nature makes excellent road material for the Santa Ynez Valley. The shale and sandstone continue up to the top of the Vaqueros, giving place in large part, however, to other deposits of shallow-water character, such as coarse sandstone and a great quantity of coarse, in places greenish or reddish, gravelly conglomerate.[b] At the top of the formation there is a conformable gradation into the Monterey (middle Miocene) beds, the summit of the Vaqueros being marked in many places by a calcareous zone, as, for instance, south of Lompoc, where the two formations are divided by a very prominent bed of hard limestone. Sandstone, shale, and conglomerate that probably belong to the Vaqueros occur at the seaward end of the Casmalia Hills. They constitute a portion of a formation conformably underlying the Monterey, but separated from beds of flint and shale that can be definitely assigned to that formation by many hundred feet of soft, light-brown, clayey, alkaline shale that is almost invariably full of crystalline gypsum. The conditions which existed here during the period of transition from typical Vaqueros to typical Monterey sedimentation must have been very different from those which prevailed over the areas occupied by the Santa Ynez and San Rafael ranges.

STRUCTURE AND THICKNESS.

Like all the Tertiary and pre-Tertiary formations of this region, the Vaqueros has been subjected to folding that has left little of it in an undisturbed attitude. But owing to the character of the deposits, which are in large part soft sandstone and conglomerate with interbedded layers of sandstone and clayey shale, the strata have not been so violently fractured and disturbed as much of the brittle shale of the lower portion of the Monterey. A marked instance of the way in which the soft, coarse conglomerate has been left little affected occurs in Buckhorn Canyon, where thick beds of it, probably part of the Vaqueros, lie almost horizontal.

The high ridge of the Santa Ynez Mountains from Point Conception eastward is formed by a great monocline of sandstone of supposed Vaqueros age, that dips toward the sea on the south at an angle of about 25°. North of this ridge occurs a longitudinal depression in the range in which the folds of the Vaqueros are fairly low, and still farther north, bordering the Santa Ynez Valley, these rocks are considerably disturbed, dipping in various directions and at all angles between 20° or 30° and the vertical. In the San Rafael

[b] This conglomerate is believed to mark the base of the lower Miocene (true Vaqueros).

Mountains the strata of this age are steeply folded along northwest-southeast lines, in conformity with the overlying Monterey.

The formation that has been taken to be entirely Vaqueros in the Santa Ynez Mountains has a thickness of at least 5,000 feet,[a] and further work may allow the figures to be considerably increased.

EVIDENCE OF AGE.

Characteristic fossils are abundant in the limestone at the top of the Vaqueros, and in beds of the conglomerate and sandstone in the upper part of the formation, but occur sparingly in the lower half. Those in the conglomerate near the top include huge oysters, pectens, and turritellas that show in the size and strength of their shells remarkable adaptation to the conditions prevailing in the shallow water where the big bowlders of the conglomerate were being tumbled about and deposited. These fossils are such as are distinctive of the Vaqueros throughout the coast ranges and afford good evidence of its lower Miocene age. Only a few feet conformably below the conglomerate containing the characteristic Vaqueros lower Miocene fauna is sandstone containing typical Tejon (Eocene) fossils. So far as known, no species bridges the gap between the two faunas, either here or elsewhere in California where similar stratigraphic relations of the two formations have been observed.

MONTEREY SHALE (MIDDLE MIOCENE).

GENERAL STATEMENT.

A great series of fine shales, largely of organic origin, overlies conformably the coarse and fine sedimentary deposits of the Vaqueros. These shales make up the Monterey formation and are representative of the whole of middle Miocene time. The formation is of great thickness and is doubly important as the probable source and the present reservoir of the oil. The areal extent of the Monterey is not adequately represented on the map. It doubtless covers as one continuous sheet the whole basin between the Santa Ynez and San Rafael mountains as well as a large part of these ranges, but it is covered over considerable areas by later deposits, which are in many places very thin. The character, structure, and relations of the Monterey have been the chief subject of the present study.

The name "Monterey" was given by William P. Blake[b] in the early fifties to an organic shale formation typically developed in the vicinity of Monterey, in central California. It is very extensive in

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[a] By far the greater part of this is believed to be Tejon (Eocene).

[b] Proc. Acad. Nat. Sci. Philadelphia, vol. 7, 1855, pp. 328-331.

the California coast ranges, being the "bituminous shale" series described by Whitney in the reports of the Geological Survey of California as occurring at widely separated points north and south of the Golden Gate. Its age is generally considered to be middle Miocene. It is the source of much of the petroleum found in California. The shale that characterizes this unique formation is not similar to ordinary clay shale, but is composed largely of the remains of minute marine organisms. In its unmetamorphosed condition it resembles chalk, but is of siliceous instead of calcareous composition.

The Monterey in the part of California treated here may be divided on lithologic grounds into two parts, although there seems to be perfect conformity throughout the formation. There is no definite dividing line to be drawn, but taken as a whole the lower half, composed chiefly of hard, metamorphosed, in places flinty shales, is distinct from the upper half, in which soft shale, giving evidence to the naked eye of its organic origin, is predominant.

LOWER DIVISION.

The fossiliferous limestone at the top of the Vaqueros is overlain conformably by hard, calcareous, and flinty unfossiliferous shale characteristic of the base of the Monterey. In places the limestone stratum at the top of the Vaqueros is not well developed, but is replaced by a series of thin-bedded siliceous and calcareous shales of coarse and fine texture, in which no well-defined line of demarcation between the two formations is to be drawn. The Vaqueros and Monterey taken as wholes are distinct units, representing periods of deposition of entirely different character. As indicated by the rocks, deposition was continuous and the change in its character came suddenly, although less so in some places than in others. The general nature of the Vaqueros formation is detrital; that of the Monterey is organic. The former contains many well-preserved molluscan forms; the latter few. Close to the line between the two, beds predominantly of a gravelly or sandy nature or bearing fossil mollusks are considered part of the Vaqueros; those of a fine texture and of flinty or chalcedonic nature are regarded as part of the Monterey.

The lower half of the Monterey lying above the horizon of the transitional limestone between that formation and the Vaqueros consists of a thick series of thin-bedded, brittle, chalcedonic and calcareous shales, with here and there gradations on the one hand into beds of the hardest flint and on the other into soft diatomaceous earth. Near the base there is usually black, brownish, or wax-colored flint in heavy beds 1 foot to several feet thick and similar massive beds of peculiar brownish limestone with characteristic lamellar weathering. The greater part of the series is made up of brittle siliceous shale, in the main much fractured and some of it crumpled, in beds averaging about one-half to 1 inch in thickness, which alternate in many places with thin shaly calcareous beds or massive strata of limestone. Beds of flinty shale or of pure flint are included here and there, and there is every step in the gradation from these to soft white diatomaceous shale. This soft unaltered shale in which the constituent diatom tests are plainly to be seen occurs but sparingly, however, in the lower half of the formation. The varieties of shale are very numerous, but they show no departure from the general siliceous and calcareous types so peculiar to this formation. There is no approach to the common clay shale or the slate derived from it, and only very locally is there an appearance of a sandy texture. In the San Rafael Mountains the series has a somewhat different character, especially at the base, where a considerable amount of sandstone, in some places soft and in others quartzitic, is interbedded with the hard calcareous shale. Near the base of the Monterey, in the northwestern portion of the area occupied by that formation, hard, coarse yellow and grayish volcanic tuff is locally interbedded with the shale.

This hard series of shales is very commonly impregnated with bituminous material. The limy beds have almost universally a bituminous odor and some of them contain pockets of tarry oil. To a less extent the same is true of the flint, and in some places the great mass of the hard, brittle shale has a similar odor or is discolored with oil. This hard shale series, especially the lower portion of it, and possibly here and there the uppermost sandstone just below it, contains the principal oil-bearing beds in the developed field.

UPPER DIVISION.[a]

The line of division between the lower and upper portions of the Monterey is rather arbitrary, yet when each group is taken as a whole the lithologic distinction is marked, and the separation is made natural by the areal limitations of the outcrops of one or the other of the groups. Where they are found in contact a conformity between the two halves of the formation is evident and a gradation occurs from the porcelaneous and flinty shales of the lower half into the light-colored, earthy beds of the upper. Such is the occurrence, for instance, near the northern edge of the hills 4 miles west-southwest of Lompoc.

The greater part of the upper division is made up of white or brownish diatomaceous shale, in general of light weight, but grading

[a] A detailed description of the diatomaceous deposits found usually in the upper portion of the Monterey is included in "Contributions to economic geology for 1906" (Bull. U. S. Geol. Survey No. 315) under the title "Diatomaceous deposits of northern Santa Barbara County, California."

in places into heavier and harder, brittle, porcelainlike shale. The bedding is characteristically very thin, but where great masses of the soft white shale, which goes by the name of diatomaceous earth, occur, lines of bedding are as a rule indistinguishable, except here and there on thin projecting laminæ produced by weathering, or on the upper surface of small cavities due to the eating out of less resistant material. In general, both the softer and harder varieties of the Monterey shale, owing to their siliceous composition, do not give way readily to decomposition or weathering. Scattered chalcedonic lenses are to be found in this upper division, roughly following the bedding planes in unaltered shale, as well as strata of hard, porcelaneous, generally much-fractured shale, but such hard rock does not become predominant over the softer variety as it does in the lower division. Very local metamorphism is characteristic of the Monterey shale in both divisions. It is common to find soft unaltered shale grading directly, even in the same hand specimen, into brittle flinty shale, and the slightly altered varieties changing, in irregular lenses and beds, into the hardest flint. In the hills immediately south of Lompoc volcanic ash is interbedded with the soft shale.

The composition of the Monterey shale is of especial interest. Examination of the soft, unaltered variety with a hand lens, or sometimes even with the naked eye, shows that it is made up of small round dots from 0.25 mm. or less to 1 mm. in diameter. These are the skeletons of minute marine organisms, closely packed together to form the bulk of the deposit. In some places they are so well preserved that the details of their structure can be made out with the aid of higher magnification, but in others they appear crushed and almost unrecognizable. Where the shale has undergone alteration and hardening into the porcelaneous and flinty varieties the constituent organic remains are for the most part obscured, but even in these, on examination under the microscope, the impressions are often found well preserved. The most abundant skeletons are those of marine diatoms, a very low order of plants or algæ having a small framework of silica. These little skeletons, dropping to the ocean bottom during a long period, have built up this formation, which is very largely silica. The limy beds seem to be formed chiefly of remains of Foraminifera, small animal organisms having calcareous instead of siliceous skeletons.

The upper portion of the Monterey, like the lower, is to a large extent impregnated with bituminous material. It is apt almost anywhere in this region to give out a bituminous odor when broken or to show a brownish discoloration due to the presence of oil. In many places the shale, which is otherwise white, is specked with minute black spots of bitumen. Thin sandy layers occur sparingly interbedded with the shale, and these, in almost every case, have absorbed considerable oil and have a dark-brown color and strong odor. These beds of sand, however, are very rare and make no appreciable proportion of the great bulk of the formation.

The soft varieties of the Monterey shale are almost invariably alkaline. They contain an abundance of salts that are easily soluble in water and form characteristic woolly coatings of efflorescence on the surface of outcrops. This is especially true near the summit of the formation, where a soft, clay-like, gypsum-bearing shale locally marks the contact with the Fernando above.

STRUCTURE AND THICKNESS.

The Monterey has nowhere been left undisturbed. In some places it has been but gently folded; in others it has been thrown into folds so close and numerous that the succession of the beds and the thickness of the formation are difficult to make out. The details of its structure are discussed on pages 30–40. The thickness of the formation is at least 5,200 feet. Each of the two divisions comprises a known maximum thickness of 2,600 feet. No single complete section of the whole could be obtained.

EVIDENCE OF AGE.

A paucity of recognizable molluscan fossils is one of the prominent characteristics of the Monterey in this region, as in most others where it abounds in the coast ranges. Its age is determined by the lower Miocene fossils found just below its base in the Vaqueros and the upper Miocene fossils found at or near the base of the Fernando, which lies unconformably above it.

FERNANDO FORMATION (MIOCENE-PLIOCENE-PLEISTOCENE).

GENERAL STATEMENT.

The name Fernando was first applied by Homer Hamlin to a series of rocks overlying the Monterey in the San Fernando Valley, Los Angeles County. The formation has since been recognized by Eldridge and Arnold[a] in the region of the Puente Hills, Los Angeles and Santa Clara Valley oil districts. It is a series of unaltered sedimentary rocks lying unconformably over the Monterey, and representing the whole of Pliocene time and probably a part of both the upper Miocene and Pleistocene. Its lower portion is the equivalent of the Santa Margarita and Pismo formations and its upper portion

[a] The Santa Clara Valley, Los Angeles, and Puente Hills oil districts, southern California: Bull. U. S. Geol. Survey No. 309, 1907.

is contemporaneous with the Paso Robles formation, the three last named being described by Fairbanks in the San Luis folio, already cited.

In the Santa Maria district the name Fernando is applied to a similar formation that represents probably about the same time interval. It consists of sandstone, conglomerate, and shale, resting unconformably on the Monterey. Local unconformities are present within the Fernando. It attains a thickness of at least 3,000 feet, but no one section exposes the whole, and it is probable that the formation includes a considerably greater thickness. It is widespread in the northern part of Santa Barbara County, where it was deposited in the old basin between the Santa Ynez and San Rafael ranges. It covers the Monterey over the greater part of the basin, and as its structure in most places there conforms approximately to that of the Monterey, it is a fairly good key to the folding that has taken place in this underlying formation. The relation between the Monterey and Fernando is of a somewhat perplexing nature. An unconformity in dip between the two was not to be definitely made out on examination of the exposed contact in any part of the central basin, because of the fact that the Monterey and Fernando have practically been subjected to the same movements over a large part of the region. Lithologic similarity of parts of the Fernando to the Monterey is also an obstacle to their differentiation. But pebbles of Monterey shale and flint, some of them showing pholas borings and giving evidence of marine deposition, are very abundant in the Fernando. In fact, the greater part of the coarse detrital material of the Fernando conglomerate is derived from the Monterey, proving that its period of deposition was one of erosion in the previously deposited shale and that it followed both the uplift above sea level of a portion of the Monterey and the formation of the flint in that shale series. The importance of the break between the two is indicated by the change in character of the deposits from organic, probably deep-water sediments almost free from erosional débris, to sandy and gravelly deposits derived from the wearing away of land areas. This change was hardly as marked as that occurring in the reverse order at the close of Vaqueros time, although it probably consumed a greater time and accompanied a structural break. The apparent structural conformity between the Monterey and Fernando at most places within the Santa Maria basin region is probably due to the previously almost undisturbed attitude of the shale upon which the Fernando was laid down and the subsequent disturbance of both formations at the same time. But remnants of the Fernando left around the border exhibit less conformity with the underlying Monterey, owing doubtless to the upheaval of the shale around the edges of the basin during the period intervening between the close of Monterey time and the beginning of deposition of the Fernando.

The chief importance of the Fernando in connection with studies of this oil field is derived from the fact that it hides the oil-bearing formation over a wide area; that it affords, through its structure, however, a clew to the structure of the underlying Monterey; and that it acts as a reservoir for oil (Arroyo Grande field) and as a receptacle for escaping bituminous material. As the latter it gives origin to asphalt deposits of economic value and to cappings of hard asphalt that may be of significance as an aid in the retention of the oil within the Monterey.

LITHOLOGIC CHARACTER.

These rocks are mapped as a unit, although they certainly represent a long period during which sedimentation, while continuous in the region as a whole, was locally intermittent and carried on under differing conditions, owing to the differential elevations to which the region was subjected. The zone resting on the Monterey in one place is apt to be absent in another. The lowest recognized horizon is to be found south of Sisquoc, where the Monterey is overlain by a bed of brecciated and waterworn shale derived from it and cemented by argillaceous sand, above which lies about 200 feet of fine sand, and still higher a 50-foot layer of diatomaceous shale that is indistinguishable from that of the Monterey. Above this the formation grades up through about 600 feet of fine white and yellow sand and coarse sand, until a stratum of conglomerate is reached. At other places, as south of Waldorf and south of Harris, the lowest zone found at Sisquoc is either wanting or of minor importance, and beds of diatomaceous shale lie conformably upon the Monterey shale, making the dividing line very hard to find. West of Waldorf the contact is marked for miles by a bed of brecciated Monterey shale of coarse and fine fragments, locally cemented into a hard amalgam by a paste of bituminous material. Here the overlying beds are made up of fine shale and sand and pebbly sandstone, which, though actually separated from the Monterey by an important unconformity, as indicated by the brecciated zone and the abundance of pebbles of that formation in them, are conformable in dip with the underlying beds. A still younger series of fossiliferous shale and sand marks the base of the Fernando just northeast of Schumann, northwest of Mount Solomon, and 1½ miles northeast of Divide. On the summit of the ridge, near the head of Pine Canyon, halfway between the two latter localities, the Monterey is capped by what appears to be part of the same formation that is younger still, being upper Pliocene in age, as shown by abundant marine shells. This shows either that an overlap of the late Fernando (Pliocene portion) occurred on an old eminence of Monterey shale which was above the sea at the time of the deposition of that part of the Fernando preceding the Pliocene, causing the omission on its summit of hundreds of feet of sediments which were deposited around its base; or else that the portion of the Fernando preceding the Pliocene was removed from the Monterey at this point during a period of erosion within Fernando time, this period being followed by subsidence.

Above the soft diatomaceous or gritty shale and fine white sand that are common at or near the bottom of the Fernando in this region the bulk of the formation is composed of rather loosely consolidated fine white and yellow sand and coarser gray sand that grades here and there into thick beds of loose conglomerate. The conglomerate is made up of well-worn pebbles, mostly of flint and hard shale, embedded in a coarse sandy matrix. In places the sand and conglomerate are extremely hard, owing usually to the presence of a large number of mollusk shells, from which a calcareous cement has been derived. The most prominent bed of conglomerate and one that seems to be constant over the whole region occurs from 800 to 1,000 feet above the lowest horizon in the formation just north of Canada de los Alisos, on the La Laguna grant. What is probably the same outcrop is well exposed in cliffs west of Canada Laguna Seca, 1½ miles south of Los Alamos Valley. This loose aggregate of sand and pebbles in alternating strata of coarse and fine material is dominated by the light-colored pebbles of Monterey shale. Pebbles of other varieties occur more sparingly.

Above the conglomerate is a bed of limestone that is constant over the whole region and seems to mark a division in the Fernando. There are two or more massive layers of hard limestone interbedded with soft gray, very alkaline, earthy material, making a total thickness varying from 10 to perhaps 50 feet. Its fossils indicate that it is of brackish-water origin, and it has been taken to mark the base of a brackish or fresh water formation possibly corresponding to the fresh-water Paso Robles formation of the Salinas Valley described by Fairbanks in the San Luis folio. In some places, where the higher portions of the Fernando above the lime have not been worn away, they are found to consist of slightly consolidated beds of fine sand, gravel, and clay that look as if they might be of fresh-water origin. Such beds are well exposed in the foothills of the San Rafael Range north of Santa Ynez. There have appeared no good criteria by which these rocks may be separated from the purely marine portion of the Fernando, and they are therefore mapped as one formation.

STRUCTURE.

As has been stated, the Fernando is generally so nearly conformable with the Monterey that it is difficult to draw a line between them on the basis of a discrepancy in dip. Nevertheless, it is in general true that folding has been gentler in the Fernando than in the Monterey. It would seem that the older formation had been disturbed in varying amounts, in some places severely and in others gently, during the process of uplift that put an end to its period of deposition. As a result, the dips at the present time in the Fernando are apt to be less steep than in the Monterey, but folding has gone on largely along old lines so that conformity in strike between the two formations is the rule.

Wide, low folds are characteristic of the structure in the Fernando within the Santa Maria basin region. This is illustrated by the broad anticlines found in this formation in the Solomon Hills, the broad anticline in the Purisima Hills, and the synclines in the Los Alamos and Santa Rita valleys, in which the dips range from 5° to 25°, as a rule, for a long way on either side of the fold and in few places become steeper than 30° or 35°. Here and there, as south and west of Sisquoc and west of Canada Laguna Seca, the beds are almost if not quite horizontal, but this is not usual. Curves and plunges in the preexisting low folds in the Monterey gave rise to structural basins in which the Fernando was deposited as a filling. Such was the origin of the oval area of Fernando sand covering the eastern portion of the Todos Santos y San Antonio grant. This basin is a westward extension of a great synclinal basin that extends eastward and southeastward across the Los Alamos, La Laguna, and Corral de Quati grants and has determined the position of the Los Alamos Valley. The northern arm of this syncline slopes gradually up to the axis of the Solomon Hills and the southern arm rises abruptly into the Purisima Hills, the slope in both cases conforming with the topography. The region of low slopes covered by parts of the Mission La Purisima and Santa Rita grants is a somewhat similar wide synclinal basin filled with soft Fernando sediments. The Fernando is steeply upturned along the northeastern border of the Casmalia Hills, where it stands almost vertically in contact with much-disturbed, and in places overturned, beds of the Monterey shale. It is in similar position where it rests against the serpentine north of Alamo Pintado Creek on the La Laguna grant, and southwest of Los Alamos it seems to dip very steeply under the brow of an overturn in the Monterey. In the San Rafael Mountains patches of Fernando deposits occur as remnants, and the beds in many cases are steeply folded or turned completely on edge. They exhibit unconformity with the Monterey. In at least three places the Fernando is affected by faulting—a few miles west of Los Alamos and in the neighborhood of Cebada Canyon, in neither of which localities is the dip of the beds more than moderate or the disturbance great—and along the fault crossing Labrea Creek.

DISTRIBUTION.

An excellent idea of the distribution of the Fernando may be obtained from the map (Pl. I, pocket), as it is not covered by so many formations as the older Monterey. It is much more widespread near the surface, however, than appears on the map, since it is hidden by only thin deposits over almost the whole of the area mapped as Quaternary.

The general character of the Fernando is that of a filling. Its soft, loose, spreading sands, which poorly preserve evidence of low folds, form moundlike hills and broad valleys that convey the idea of a filled topography. But, on the other hand, harder beds, as well as surface cappings due to hardening by iron oxide, which not uncommonly produce sharp, square outlines, are marked features of the topography, as in the vicinity of Mount Solomon and at the head of Howard Canyon. On the northeast border of the Casmalia Hills, between Schumann and Graciosa Canyon, a series of lime-hardened sandstone beds predominates and forms a prominent ridge. In the Santa Rita Hills the lines of structure that there curve around from a westerly to a southeasterly direction are brought out by the resistant limestone stratum which supports the northeastern flanks of the hills. The wide stretches of foothills of the San Rafael Range north of Santa Ynez have a character all their own. They are formed of gravel, clay, and sand that has the appearance of belonging to a fresh or brackish-water series, and stand out with many bold faces that have been cut in the soft formation. Elsewhere the dominant character and topographic forms of the Fernando are due to the soft sand which forms the major portion of the formation.

EVIDENCE OF AGE.

At least five, and probably six, distinct horizons are recognizable in the Fernando by means of characteristic fossil faunas. The localities at which these different faunas occur, named in their probable relative order, beginning with the oldest, are as follows:

(*a*) South of Waldorf in soft shale, south and east of Sisquoc in fine sandstone.

(*b*) "Sea-urchin bed," Squires (Santa Maria Oil and Gas) lease, California Coast lease, south of Graciosa-Western Union wells, west of Harris Canyon, vicinity of Hill wells in the Lompoc field, and near head of Howard Canyon.

(*c*) Waldorf asphalt mine, railroad cut 1 mile northeast of Schumann, Pennsylvania asphalt mine at east end of Graciosa Ridge, all in gray shale or fine gray sandstone.

(*d*) Waldorf asphalt mine, railroad cut 1 mile northeast of Schumann, Fugler Point asphalt mine, Sisquoc (or Alcatraz) asphalt mine, and points along north flank of Casmalia Hills, in coarse sandstone or conglomerate.

(*e*) East end Folsom lease in soft sandstone.

(*f*) Fresh or brackish water beds immediately west of the mouth of Canada Laguna Seca.

Horizon *a* is of marine origin, is probably upper Miocene in age, and corresponds in a general way to Fairbanks's Santa Margarita and Pismo formations. Horizons *b*, *c*, and *d* are of marine origin, are closely related, belong at the base of the Pliocene, and are in a general way the equivalents of the middle part of the Purisima formation and the lower and upper parts of the San Diego formation. There is some doubt in the mind of the writers as to the relation existing between horizon *f*, which is of fresh or brackish water origin, and horizon *e*, which is marine Pliocene or Pleistocene. The evidence in hand, however, suggests the relationship indicated above.

QUATERNARY.

GENERAL STATEMENT.

The areas left blank on the map (Pl. I, pocket) are those covered by sediments of post-Fernando age. They are thin deposits that have been laid down unconformably on the older sediments subsequent to their disturbance and deformation. There are several different Pleistocene and Recent formations that are younger than the latest Fernando, but they have been mapped as one because of the difficulty of distinguishing between them areally. Three distinct classes of Quaternary deposits can be made out—terrace deposits, dune sand, and alluvium. It is possible that each represents more than one period of deposition.

TERRACE DEPOSITS.

The San Antonio, Burton Mesa, and Lompoc terraces, the terrace north of Schumann Canyon, those fringing the coast and Santa Maria and Santa Ynez rivers, and many smaller ones capping hilltops and hill slopes are covered with a thin coating of sand and gravel of probable marine origin. No fossils are included in these deposits, but they contain in many places pholas-bored pebbles, and the rocks on which they rest have in places been bored by these marine mollusks. The terrace coatings are horizontal, having been little disturbed by the uplift of the land that brought them to their present altitude. They are entirely unconformable with the formations below and evidently were laid down after the underlying strata had been given their present structure. Terraces and horizontal cappings of coarse sand and gravel are to be found commonly at all altitudes up to 1,200 feet in this region and here and there up to 1,400 feet. None have been definitely recognized at a higher elevation. The average thickness of the material is only about 25 feet. It hides considerable areas of the Monterey, but most of the canyons that cut into the terraces reveal the presence of this formation beneath. The thickness of the coatings is not sufficient to make a serious difference in the depth to which it is necessary to drill for oil. Where these terrace deposits overlap on the Fernando they are unrecognizable owing to the similarity of the two formations. This similarity causes in places a great deal of difficulty in determining whether the deposits belong to the Fernando or to the later epoch and whether it is necessary to go only a few feet or through a great thickness of Fernando beds to reach the Monterey below. Where fossils or distinct lines of bedding are present they are an indication that the sand belongs to the Fernando.

The terrace sands are charged with asphalt in some places where oil has seeped from the Monterey beds and been absorbed in the porous capping.

In many places sand and gravel of probable contemporaneous deposition with that on the terraces occur over low hills where terrace forms are less in evidence. Along many of the valleys—as, for instance, that of Salsipuedes Creek—occur fillings of horizontally bedded sand, gravel, and shale that are older than the recent alluvium and possibly are a part of the terrace-deposit formation. It is very difficult in most places to distinguish between these deposits and more recent alluvium.

DUNE SAND.

The prevailing winds from the ocean on the west have amassed great deposits of sand in places along the coast. The process has been going on all through the Quaternary period, and it is hard to distinguish the older deposits of this character from those partially or entirely of marine deposition. The greatest mass of dune sand occurs north of Point Sal Ridge, in the Casmalia Hills. The slopes down to the sea from an elevation of 1,100 to 1,200 feet are covered by loose yellow sand of probable eolian origin. The deposits consist of pure sand faintly showing horizontal lines of bedding. In one canyon a thickness of 300 feet is exposed. A layer of large bowlders marks the base, overlying the Monterey shale unconformably. Recent marine shells are scattered extensively over these loose sands, but in the opinion of the writers these have for the most part been carried there by Indians or birds.

ALLUVIUM.

All the valleys of this region contain a certain amount of alluvial material, which reaches in many localities a thickness of 50 feet or more. In some places it is earthy, in others sandy earth, and in still others pure sand, gravel, or clay. It is as a rule horizontally stratified. Recent deposits of this character attain considerable extent in the wide valleys, but it is not easy to distinguish them from Quaternary deposits of different age or somewhat different origin.

IGNEOUS ROCKS.

GENERAL STATEMENT.

The formations in this region are chiefly of sedimentary origin, but eruptive and intrusive igneous rocks of various ages appear. These are in all cases basic in composition. Deposits of volcanic ash high in silica are interbedded with the Monterey; these have been referred to under that heading (p. 18). The center for igneous rocks is in the region around Point Sal, of which Fairbanks has made a special study, and the statements here made in regard to the igneous rocks of that area are based on his description.[a]

PRE-MONTEREY INTRUSIONS.

Fairbanks describes a small intrusion of basalt having a laccolithic appearance in the Knoxville (lower Cretaceous) shale north of Mount Lospe, in the Casmalia Hills, and a large neighboring area of spheroidal basalt that he is certain is older than the Monterey and believes to antedate the Knoxville. It is closely associated and intermingled with masses of diabase and gabbro. This complex forms Point Sal Ridge and the rocky headland. Another complex that he believes belongs in the Knoxville forms long dikes north of Schumann Canyon. It is an exceedingly complicated intrusive mass of gabbro and peridotite that has been penetrated by later dikes of diabase, norite, gabbro, and intermediate types of rock.

The areas mapped as Franciscan (Jurassic) are largely occupied by serpentine that was originally intruded in Franciscan strata. This serpentine is older than the Tertiary, and the occurrence of gabbro and peridotite north of Schumann Canyon may be contemporaneous with it.

Diabase was struck at a depth of 1,300 feet in the Pezzoni well No. 1, southwest of Sisquoc. It is a considerably altered rock composed largely of serpentine and plagioclase feldspar, with some augite, possibly a small amount of unaltered olivine, considerable magnetite,

[a] Fairbanks, H. W., The geology of Point Sal: Bull. Dept. Geology, Univ. California, vol. 2, 1896, pp. 1-92.

and several accessory minerals. It is an occurrence of some importance as affecting the prospects for the production of oil in this neighborhood. The question arises whether this diabase has intruded the Monterey, as in the San Rafael Mountains, or whether it is a part of the older igneous formations, in which diabase occurs commonly. The fact that the rock is so much altered probably indicates that it belongs to a formerly exposed older formation on which a fairly high portion of the Monterey shale has overlapped. It is hardly conceivable that an intrusion at such a depth in the shale could have undergone so much alteration. But whether this diabase marks the base of the Monterey or the shale has been intruded by an igneous mass, the conditions are unfavorable for the accumulation of oil in the immediate vicinity.

POST-MONTEREY INTRUSIONS.

The youngest igneous rocks occurring in the Santa Maria region and those of chief interest in the present connection are intrusive in the Monterey (middle Miocene). They comprise five small areas of diabase south of Point Sal Ridge and two areas of diabase in the San Rafael Mountains. The age of the two latter is somewhat in doubt, but the metamorphic and disturbed appearance of the Monterey shale in their vicinity indicates that they are dikes intruding that formation. The shale appears hardened and baked in the immediate neighborhood, and narrow tongues of Monterey shale, certainly altered along the contact, extend into the mass on Tepusquet Creek. Along its edges appear patches of *Aucella*-bearing sandstone belonging to the Knoxville, which were probably brought up from below by the intrusion. The diabase in both cases is of dark-green color and coarse texture and exhibits sheared serpentinous facies.

STRUCTURE AND CONDITIONS AFFECTING THE PRESENCE OF OIL.

GENERAL CONSIDERATIONS.

The area comprised within the limits of the Lompoc and Guadalupe quadrangles has been subjected to two systems of forces acting obliquely to each other, the one producing structural features which trend northwest and southeast, the other producing features which trend east and west. The northeast-southwest structure system is probably the older and dominating one, as it results in the highest ranges and best developed folds. It conforms with the great system which has determined not only the Coast Ranges of California, but also the western border of the North American Continent. The forces producing the east-west features, although exceedingly effective from the west end of the Santa Ynez Range eastward to the region south of the end of the San Joaquin Valley, were not so far-reaching as the former, and probably began to exert themselves at a later date.

That portion of the area under discussion which lies to the northeast of the Santa Maria Valley is dominated almost completely by structural lines trending northwest and southeast, but in the extreme southern portion those trending east and west prevail. The region between these two well-marked systems is occupied by folds and faults some of whose component parts exhibit allegiance to one system and some to the other, but the resultant trend of which is intermediate between the two. In a general way the lines of disturbance as well as the topographic relief within this latter province radiate fanlike from the junction of the Santa Ynez and San Rafael ranges east of the town of Santa Ynez.

In the region the forces have more often found equilibrium in the production of folds than in adjustment by faulting. It is also apparent that these forces have acted intermittently along the same general lines throughout a long period of time. Several important faults are recognizable, however, and doubtless others will be revealed by detailed work, especially in the San Rafael Range.

The following paragraphs in relation to the structure of various areas should be accompanied in the reading by reference to the maps (Pls. I, II). For convenience of discussion the two quadrangles will be divided into the three naturally separated portions outlined in a preceding paragraph, viz, the region of the San Rafael Range, which includes all of the territory northeast of the Santa Maria Valley and a line extending southeastward from its head; the region of the Santa Ynez Range, and the region of low hills and shallow valleys intervening between the two mountain masses. In the field study of the structure of the formations and in the present discussion special attention has been paid to the structure of the Monterey shale, because it is the formation which has apparently given origin to the petroleum and in which the bulk of the oil is stored. For the sake of compactness the conclusions as to the possibilities of productiveness of the shale have been stated together with the following brief description of the main structural features. The chief criteria for judging as to the presence or absence of oil in appreciable quantities have been the attitudes of the beds, their position in the formation, and the surface indications. Other minor evidences of a local nature have also been taken into account.

In drawing conclusions from structural indications, the anticlinal theory has been used as a basis, because it appears to hold good in a majority of proved cases in this district. Although oil accumulation is affected by a complication of other circumstances, the anticline seems to be the chief favorable factor and affords a tangible and fairly trustworthy clue. Close folding appears to play a part in depriving beds of their oil, and excessive disturbance and fracturing is unfavorable to its retention. Furthermore, the position of the beds in the formation is regarded as of great importance, since there is less likelihood that the oil-bearing strata, which seem to lie mainly low in the Monterey, were able to retain their contents when denuded of the greater part of the overlying formation or when themselves exposed or partially removed.

The chief surface indications are seepages of oil or tarry material, asphalt deposits, bituminous shale, and burnt shale. Asphalt occurs mainly in three ways—as a mixture of bituminous material with sand due to the absorption by overlying sand deposits of seepages from the shale, as hardened fillings of asphalt in cavities along joints and as saturated shale. The burnt shale is the rose-colored or slaglike rock often observed in this and other oil-bearing regions within the Monterey shale. It is the result of the burning of the hydrocarbons that have impregnated the shale, and its presence therefore indicates where these have existed.

It must be remembered that in regions of great disturbance, such as the shales have undergone in some parts of the area, it is difficult to represent by single lines the complexity of the structure. In some cases, therefore, the lines mark zones of folding, rather than single, definitely continuous folds. The dotted lines of structure are purely suppositional.

REGION OF THE SAN RAFAEL MOUNTAINS.

AREAS OF ROCKS OLDER THAN THE MONTEREY.

Whatever succession of beds or structural conditions may once have existed in the Franciscan formation (Jurassic), they have been largely obliterated by the successive folding and crushing to which these rocks have been subjected in the long period of time since their first uplift. The shales and sandstones mapped as pre-Monterey, especially where the beds alternate, have preserved the folds well, but except on North Fork of Labrea Creek and along Sisquoc River no effort has been made to work out the structure.

AREAS OF MONTEREY AND LATER FORMATIONS.

Folds.—Considered as a whole the Monterey shale has been thrown into a series of anticlinal and synclinal folds, striking about N. 50° W. and apparently plunging in the main toward the northwest. Although great variation exists in the relative steepness of dip along these folds, it is evident that the compressive forces producing them were of much greater strength in the southeastern part of the area (between Bone Mountain and Round Corral Canyon). Here the folds become so compressed that it is difficult to trace them. In contrast with this constricted portion of the area is the broad series of folds which extend rather uniformly along the northeastern border of the area and develop toward the southeast into the syncline which crosses the lower portions of Tunnel Canyon and Horse Gulch. The high, broad ridge between Bone Mountain and Manzanita Mountain is composed of Monterey shale, which lies approximately flat, and toward the northwest becomes one arm of the great syncline which extends through Goodchilds ranch on Labrea Creek and is traceable almost to Colson Fork of Tepusquet Creek. A similar syncline, possibly the same, extends from Colson Fork northwestward across Tepusquet Creek to the margin of the quadrangle. The northeastern arm of this fold forms the high ridge extending along the southwestern side of Buckhorn Canyon.

It is possible that the pre-Monterey rocks north of Bee Rock Canyon plunge down monoclinally under the Vaqueros in a fold at right angles to the wide anticlinal fold that exposes the pre-Monterey. Such a plunge would be apt to give rise to the northeast-southwest table that interrupts the structure between Bone Mountain and Manzanita Mountain, and it would thus appear that this table may represent a buckling across an otherwise continuous structure.

Southwest of Los Coches Mountain one or more folds are overturned, but their northwestern extension has not been examined.

The region southeast of Round Corral Canyon and Asphaltum Creek is occupied by several sharp folds which strike in a general northwest-southeast direction. Overturning is not uncommon in this series of folds, one notable example being an anticline on the south flank of Zaca Peak. West of Round Corral Canyon the structure lines curve around from a northwesterly to a westerly or west-southwesterly direction, the folds at the same time becoming less compressed and the conditions for the retention of the oil in the basal sands of the hard shale correspondingly better.

Faults.—There is strong evidence of a fault zone passing north of the narrow area of intrusive rock north of Zaca Lake, and thence northwestward as far as the head of Rattlesnake Canyon. The resultant downthrow along this zone of displacement is on the southwest, probably amounting to a good many hundred feet toward the east edge of the quadrangle. Toward the northwest this fault apparently dies out or merges into a syncline.

Just east of Los Coches Mountain there may be another fault which brings up the uppermost Vaqueros on the north. A third fault between the Fernando and Monterey may extend from a point near the mouth of Round Corral Canyon to Labrea Creek.

A fault zone also occurs along the Franciscan-Fernando contact in the region northwest and southeast of Figueroa Creek, but the throw was not determined. A depositional contact is clearly exposed along this same line just northwest of Alamo Pintado Creek.

Evidence of petroleum.—Despite the great development of folds within the Monterey area only here and there do seepages of asphaltic material occur. It would seem that the fractures produced by sharp folding would give adequate channels for the escape of petroleum and it is surprising to find so few seepages. The best developed of these is on Labrea Creek at and near its junction with Rattlesnake Canyon, and is typical of the localities noted north of Sisquoc River. The oil seepage is associated with small springs of strongly saline and sulphurous water, and the oil has exuded along the bedding planes of the Monterey shale, here thrown into a pronounced anticline which has been flexed in such a manner as to open the laminæ of the shale and thus give better opportunity for the passage of oil. Two wells have been sunk here, but they are shallow and offer no additional data. The following is a brief statement of the asphalt seepages occurring in the San Rafael Mountains:

1. Branch of upper Tepusquet Creek. Slight seepage in bed of creek three-fourths mile above junction with main stream. At anticlinal axis. Has been located.

2. Colson Fork of Tepusquet Creek. Black bituminous streaks, veinlets, and pockets, associated with calcareous shale which is considerably folded on a minor scale. This has also been located.

3. Labrea Creek, at and near junction with Rattlesnake Canyon.

4. Sisquoc dairy. Seepage and asphaltic sand along sharply defined anticline, which is obscured by later material. Well sunk here, but no record available.

5. Sisquoc River, one-half mile below Round Corral Canyon. Slight seepage from steeply inclined Monterey shale.

6. Fugler Point, 1 mile north of Gary. Veins of asphaltum, parallel in a general way to the bedding, which here dips 25° SW., intrude the fossiliferous Fernando (lower Pliocene portion). A shaft has been sunk here a few feet for the removal of the asphaltum.

7. Alcatraz mine, 3½ miles east of Sisquoc post-office. Vast deposits of asphaltum, from a few feet to 200 feet or more in thickness, lie unconformably above the steeply dipping Monterey shale over large areas in the general region of the mine. These deposits have been mined on a large scale at one place, but at present the plant is idle.

8. Zaca Canyon, 5 miles southeast of Sisquoc post-office. Deposits similar to those at the Alcatraz mine are found on both sides of La Zaca Creek where it debouches from its narrow mountain canyon into the broad valley carved by it through the hilly country.

9. Sisquoc Ridge, 1¾ miles north of Sisquoc post-office. A small area significant of underlying petroliferous beds, similar in occurrence to the two preceding. This area overlies the axis of an anticline in the Monterey shale.

Conclusions regarding future development.—On account of the greater development of the folds and the lack of the thick, more or less unaltered diatomaceous deposits which are found associated with all the proved productive fields in this district, the indications are not so encouraging for good wells in the territory northeast of the head of the Santa Maria Valley as they are in certain other portions of the Lompoc and Guadalupe quadrangles. The areas which offer the most inducements for testing by the drill are as follows:

1. North and northwest of Sisquoc post-office, along the anticlines shown on the map (Pl. I, pocket). There are one or two local anticlines not shown, which might also be prospected with good results. The hard shale exposed in this region is probably lower Monterey, and consequently the conditions are not favorable for such great accumulations of oil at their base as if they were overlain by the upper part of the formation. The strata in the region above the headwaters of Round Corral Canyon and Asphaltum Creek are too sharply folded to give much hope of the retention of large deposits of petroleum. The asphaltum deposits here and to the southeast indicate that the Miocene rocks were at one time highly petroliferous, but that at least a considerable portion of the oil has escaped.

2. In the Monterey area bordering the head of the Santa Maria Valley on the northeast, both west and east of Tepusquet Creek, wherever the anticlines are not so badly fractured as to permit the loss of their petroleum content. The surface evidence of petroleum in this general Monterey area is greatest in the southeastern or more sharply folded portion, but for obvious reasons it seems likely that the chances for the accumulation of economically important deposits of petroleum are greatest in the less compressed area north of Labrea Creek.

3. The region about Fugler Point and thence southward and southeastward toward Sisquoc. This territory is doubtless underlain by the oil-bearing formation, but at what depth it is not possible to calculate owing to the fact that the Monterey and Fernando are covered by later sediments. The occurrence of asphaltum at Fugler Point is analogous to that at the east end of Graciosa Ridge, near which very productive territory has been developed. The local dip at the point (25° SW.) would indicate that the best places to drill would be east of the asphaltum deposits, but the uncertainty whether this dip is anything more than a local tilting of the Fernando is so great that conclusions regarding the best localities for exploitation in this immediate vicinity are extremely hazardous. Southwest of Fugler Point there is evidence of the existence of a low anticline which should yield good returns if penetrated deep enough. This anticline is mentioned further in connection with the Canada del Gato[a] area (pp. 42–43).

[a] Called more commonly Cat Canyon.

REGION OF SANTA YNEZ MOUNTAINS.

AREA SOUTH OF LOMPOC.

South of the Lompoc Valley the Monterey dips in general northward away from the higher portion of the hills, but south of the town of Lompoc is an area of much disturbance, and many folds have been developed on what may be thus broadly considered as a monocline. These folds trend in different directions and there is a puzzling diversity of dip and strike. There are so many local folds that it is difficult to connect the more important axes, but the general lines of disturbance are continuous for the distance mapped. The main folds south of Lompoc are an anticline near the valley and a syncline north of the Monterey-Vaqueros contact, with a minor anticline and syncline between. The attitude of the beds is extremely variable, the dip ranging in general between 15° and 60°. On either side of the main anticline, between Salsipuedes and San Miguelito creeks, the hard shale dips away at an angle of 20° to 40°. West of San Miguelito Creek the folds swing out toward the valley or die out on the monocline, which at this point is unbroken.

The greater part of the strata in the hills south of Lompoc belongs low in the Monterey shale, although higher portions remain in the synclinal folds. The disturbance has been considerable, and erosion has removed the highest parts of the formation, so that the chances have been good for the escape of any oil that may have been present. There are no surface indications of petroleum and the conclusion is that no great quantity of oil would be found on drilling.

AREA OF SANTA RITA HILLS.

East of Lompoc the lines of structure cross the Santa Ynez Valley into the Santa Rita Hills. These hills are formed of a single main ridge along the south side of which is an important anticline. The dips on either side of the broad summit of this fold range from less than 10° to about 35°. The general trend of the fold is east and west, in conformity with that of the Santa Ynez Range, but it is curved, especially at the east end, as if influenced by more than one set of forces. Other important folds occur on the flanks of the anticline, giving origin to the disturbed zone followed by Santa Ynez River.

The conditions along this anticline, especially through the eastern half of its length, favor the occurrence of some oil at least, as the axis exposes beds fairly high in the series and the folds are gentle. No surface indications of petroleum were found, except a patch of burned shale south of the road about 1 mile southwest of the highest hill (elevation 1,300 feet) and local outcrops of bituminous black flint and brown shale on the west side of the 800-foot hill about one-half mile north of the river and 1½ miles west of the east edge of the Santa Rosa grant.

MAIN PORTION OF THE SANTA YNEZ RANGE.

The Santa Ynez Range is chiefly composed of Vaqueros rocks, and its structure is therefore much less important in connection with the oil deposits. It is dominated by a great southward-dipping monocline that forms a high ridge along the coast, north of which the strata are gently folded along curving lines that reflect two different structural systems. The folds that expose the Vaqueros and the underlying Franciscan toward the west end of the range are in places sharp and complex. The anticline of the Santa Rita Hills probably crosses the Santa Ynez Valley and continues in a large fold to the southeast.

REGION BETWEEN THE SAN RAFAEL AND SANTA YNEZ MOUNTAINS.

CASMALIA HILLS AND SAN ANTONIO TERRACE.

Two dominant structure lines control this region. One is a recognizable fault starting on the coast south of the long area of igneous rocks and running southeastward. About 2 miles west of Casmalia the line is continued by an anticline, which is probably affected by faults at least as far as Schumann Canyon. This anticline plunges more and more toward the southeast and loses its character as a fold, giving place to the eastward-dipping monocline of the San Antonio terrace.

The other structure line is one of varying character, here called the Schumann anticline. Northeast of the area of igneous rock just mentioned Vaqueros and Monterey strata form a great monocline, dipping rather steeply to the northeast. In the high region of Mount Lospe and northeast of the long strike ridges extending southeastward from that peak this monocline flattens out into a structural platform of very low dip which on approaching the edge of the steep descent to the Santa Maria Valley bends abruptly and plunges under the valley. The axis along which this steepening of the dip occurs is in a way equivalent to an anticlinal axis and is the line mapped. (See Pl. I.) In places it is true anticline of gently dipping beds that form a broad syncline of the platform on its southwestern side. South of Corralillos Creek the structure curves westward and the Schumann anticline is sharply defined and overturned. It is seemingly to be correlated with a large anticline exposed in the Vaqueros formation on the coast north of Point Sal. South of Waldorf this anticline, as shown by the dotted line on the map, is not certainly continuous, but west and south of Schumann the same or a similar fold becomes well developed and the strata dip away from it on both sides. In this portion and southeast of Schumann Canyon its summit is broad, but the dips become very steep farther out on its northeastern flank. It plunges to the southeast and finally dies out.

Asphalt and other surface indications of oil, such as burnt shale and bituminous shale, occur at many places in the Casmalia Hills. The shale is especially bituminous all along and near the contact with the Fernando on the northeastern side of the part of the hills north of Schumann, and it has been burnt in a number of places in the same region. Outcrops of burnt shale are prominent on the hill just southeast of Schumann, and near the contact at the northern base of this hill the shale is extremely bituminous. Wells put down in the region about Schumann encounter heavy tar at depths below 2,000 feet, but no paying wells have been struck. It seems likely, however, that at greater depths, possibly 3,000 feet or so, the horizon of the productive flinty beds encountered in the Graciosa Ridge wells would be penetrated and yield oil in paying quantities.

The region lying north of Schumann Canyon, west of the valley that runs southward out of the hills and opens to Schumann Canyon 1 mile N. 45° W. of the Casmalia depot, and west of the road that crosses the ridge to Waldorf, will probably not yield any large quantity of petroleum, because the strata are so low in the series and because there appear to be no sufficiently well-developed folds to afford good points of accumulation. Oil might be found in small quantities in the minor folds between the lower portion of Schumann Canyon and the fault. The shale along the coast here is very bituminous. East and south of the supposedly unproductive region outlined above the plunging structure exposes higher portions of the Monterey shale, and the conditions warrant the conclusion that oil can probably be obtained in the neighborhood of the major anticline. Southeastward from the point where the road south of Waldorf crosses the ridge the territory appears promising, especially along the anticline and on its eastern side. The oil which is supposed to rise on the steep eastern flank of the fold probably is not forced far to the south and west of the axis. South of Schumann, where the fold becomes more nearly normal, both flanks will probably be found productive if penetrated deep enough. The surface structure indicates that the oil horizon plunges to a greater and greater depth under the whole region southeast of Casmalia Creek. The anticline south of Antonio is well defined, and conditions favor the presence of oil on both this and the other anticlines on the San Antonio terrace.

The main anticline already mentioned on the coast north of Point Sal is in the Vaqueros and doubtless barren of oil. North of this locality the Monterey is decidedly bituminous, but no special circumstances point to the existence of petroleum in large quantity. It is quite possible that the region north of Mussel Rock, the next point to the north, would prove promising if the surface covering allowed the examination of the underlying formations and the determination of anticlines. The formations seem to plunge toward the north from the north end of the Casmalia Hills, and a fairly high portion of the Monterey may underlie the region at the mouth of the Santa Maria Valley.

BURTON MESA.

The plateau known as Burton Mesa contains numerous low folds in the Monterey. Along the coast the flinty shale is of low dip, but folded and contorted in a complex way. The folds indicated on the map are the most important ones, but whether or not they are perfectly continuous units across the mesa can not be definitely ascertained on account of the covering of sand over the shale. The underlying structure of the mesa appears to be a continuation of that in the region near Lompoc as much as it is of that in the Purissima Hills, although topographically the mesa is a continuation of the latter. In the neighborhood of Pine Canyon and Santa Lucia Canyon there is a thick formation of shale striking far to the north of west, which apparently follows the structural lines across the Lompoc Valley as if to join those showing a tendency to curve northward there. West of Pine Canyon the strike changes. The Pine Canyon anticline shows this curving structure. It is a well-defined fold with broad summits and supports on its flanks a considerable thickness of shale. The dip varies from 10° to 30°. North of this fold occur a number of minor flexures and there is some doubt as to the continuity of the anticline mapped at the head of Oak Canyon with the well-defined fold near the coast in the vicinity of Canada Tortuga. A well-marked low anticline occurs near the coast north of Lompoc Landing and probably continues inland. It is probable that either one anticline of considerable importance or several small component flexures occur in the mesa between Tangair and San Antonio Creek. The summit of all these anticlines so far mentioned on the Burton Mesa exposes hard shale that is low down in the Monterey, and it is probable that with the removal of all of the higher portion opportunity has been offered for the escape of the greater part of the oil from the basal beds.

A low anticlinal fold occurs in the northeast corner of Burton Mesa and plunges toward the southeast. As indicated by the dotted line on the map, it is possibly a continuation of the anticline before mentioned south of Antonio and of another on the east edge of the mesa that is discussed in connection with the Purissima Hills. The evidence of folds in this northeastern portion of the mesa is scanty, but it is probable that where they occur accumulations of oil are present.

The brittle calcareous and flinty shale of the lower portion of the Monterey that is exposed along the coast edge of Burton Mesa is very bituminous. The petroleum slowly oozes out in some places and collects in tarry patches over the shale. Up Oak Canyon the shale is bituminous, pockets of tar being in places found in the flint on the surface. On the north border of the mesa, near the point where the road to Lompoc comes up the grade, a 3-inch bed of bituminous sand was found traversing the shale fairly high in the formation.

PURISIMA HILLS.

Folds.—The Purisima Hills are formed by one broad anticline which has its axis on the south side of the summit of the dominating ridge. Through the major portion of this anticline's course, from the region north of the Hill wells to a point beyond Redrock Mountain, the beds lie almost horizontal on its summit, becoming gradually steeper up to an angle of 15° or 20°, or locally even 40°, within a mile or two from the axis. The general trend of this fold is more to the north of west than that of the Los Alamos or Santa Ynez valleys, but portions of it have a more westerly course, as at the west end, where it also becomes a steeper fold. At the east end it has the dominant northwest-southeast trend characteristic of this part of the hills and likewise becomes steeper. It is a fold plunging from either end toward the region at the head of Cebada Canyon, where the axis of the depression in the anticline occurs. This depression appears like a broad syncline crossing the anticline at right angles, with the deepest portion of its trough at this point.

Conclusions regarding future development.—This anticlinal fold seems to offer a favorable location for oil wells along most of its extent. Owing to the plunging of the fold, lower and lower strata are reached as its extremities are approached. In the region mapped as Fernando, between the Hill wells and the head of Cañada Laguna Seca, the summit beds of the Monterey are overlain by later sand, and a well would have to be drilled to a great depth before reaching the oil horizon. East and west of that region the oil horizon probably approaches nearer to the surface. In the vicinity of Redrock Mountain, especially to the west of it, the conditions seem very favorable for the occurrence of oil. Farther east, near La Zaca Creek, a much lower portion of the Monterey is exposed and the rocks have been affected by considerable disturbance, so that it is less likely that large quantities of oil will be found there.

The Purisima Hills anticline can not be traced farther westward than is shown on the map, but at the east end there seems to occur a structural offset to the northwest, a poorly exposed anticline about a mile from the end of the main fold being traceable for a short distance and seeming to mark the continuation of the general structure of the hills. There is a likelihood of oil being found along this fold, as well as along the main anticline.

Faults and asphalt deposits.—A thrust fault is finely exposed in two forks of Cebada Canyon, where the Monterey is thrust southwestward up over the Fernando. The dip is toward the northeast at an angle of about 30°. The movement has amounted to a few hundred feet. The fault zone seems to continue for a considerable distance toward the northwest, and to be marked near the Wise & Dennigan oil well No. 8 by large asphalt deposits occupying fractures in the Fernando that dip at an angle similar to that of the fault plane. The asphalt back of the Wise & Dennigan well No. 1 is probably due to oil that has seeped through the same fractured zone and collected in the sandy capping.

The structure of the hills is further complicated by a prominent overturned anticline in the Monterey along the contact with the Fernando southwest of Los Alamos and by what appears to be a fault exposed near the mouth of Canada Laguna Seca. In this fault the Fernando limestone and sand are thrown down several hundred feet on the north at the edge of the Los Alamos Valley.

In addition to the deposits above noted, asphalt occurs in great abundance south and east of Redrock Mountain, surrounded by a large area of very bituminous shale and burnt shale. Undoubtedly an immense amount of petroleum has escaped here, but it is not probable that the supply is exhausted. On the contrary, the presence of this petroliferous material on the surface, coupled with the favorable structural conditions, points strongly to the existence of rich oil deposits beneath.

A large mass of asphalt occurs in the much-fractured Monterey shale west of La Zaca Creek, and very bituminous shale approaching asphalt in character occurs on the creek south of Zaca station. The shale is more or less bituminous throughout the zone of disturbance traversed by this creek south of Zaca. On account of the low position of the strata in the formation and the severe fracturing and folding that have taken place, it seems probable that the conditions have been favorable in this eastern portion of the Purisima Hills for the escape of much of the petroleum.

Small beds of bituminous sand occur in the upper portion of the Monterey, interbedded with soft shale just east of Canada de la Puenta, about three-fourths of a mile south of the Los Alamos Valley; also on the north side of the Purisima Hills ridge, about 2 miles south of Harris. A small area of shale that is saturated with bituminous material is exposed in the canyon followed by the road 1 mile south of the Los Alamos Oil and Development Company's well No. 1, and the shale is bituminous in the neighborhood of the Todos Santos well.

AREA AROUND SANTA YNEZ.

The Santa Ynez anticline is a distinct steep fold exposed southeast of the town of that name. It supports on its flanks a thickness of at least 2,500 feet of calcareous and porcelaneous shales belonging to the lower portion of the Monterey. The dips at the axis range between 50° and 80°, but become lower toward either side. This fold is seemingly a continuation of the structure of the Purisima Hills and it probably continues under the gravel of the region around Santa Ynez, its axis passing approximately under that town. But it is doubtful whether it is actually the same as either of the anticlines that are shown on Pl. I as stopping indefinitely near the east end of the Purisima Hills. The terraced stretch between La Zaca Creek and Ballard seems from the fragmentary evidence obtainable to be an undulating structural plateau formed of beds low in the oil-bearing shale, dipping at slight angles in various directions. It is probable that the structure of the Purisima Hills is here interrupted, but continued in a general way beyond by the Santa Ynez anticline. Owing to the low position of the beds in the formation, the chances for finding a considerable amount of oil along this anticline do not seem to be as good as farther west. No surface evidence of petroleum was seen. Any definite statements, however, in regard to the region between Los Olivos and Santa Ynez River and between La Zaca Creek and the east edge of the area mapped are hazardous, for the reason that the widespread terrace deposits obscure practically all of the structure.

SOLOMON HILLS AND AREA NORTH OF LOS OLIVOS.

GENERAL FEATURES.

Three anticlines dominate the structure of the Solomon Hills. These are, in order from west to east, the Mount Solomon anticline (first worked out and named by W. W. Orcutt), the Gato Ridge anticline, and the La Zaca Creek–Lisque Creek anticline. In addition to these there are at least three or four minor anticlines associated with the first named, and at least one north of that on Gato Ridge.

MOUNT SOLOMON AND ASSOCIATED ANTICLINES.

Structure.—The details of the northwest end of the Mount Solomon and associated anticlines are shown on the contour map. (Pl. II,

p. 46.) Whether or not the extension of the anticline through the Santa Maria Oil and Gas and Escolle properties should be considered the true extension of the Mount Solomon anticline, or whether the Hartnell anticline should be so considered, it is impossible to decide with the data at present available. It is the writers' opinion that the Mount Solomon and Hartnell anticlines are the result of the same set of forces and should therefore be considered as one fold, but that the data used in compiling the map favored the relations shown on Pl. II. The mapping of the Pinal, Hobbs, and Newlove anticlines is based almost entirely on evidence furnished by the drill, although certain superficial evidence strengthens the theory of their presence.

The southeastern portion of the Mount Solomon anticline gradually fades out into the south flank of the Gato Ridge anticline, losing its individuality toward the southeast end of Mount Solomon Ridge. The northeastern flank of the anticline is much the steeper, dipping from 20° to 38° in the region of Mount Solomon and gradually flattening out from that locality southeastward.

The Western Union anticline is a well-developed flexure with steep northern flank just south of the eastern group of Western Union wells, but its identity becomes more and more obscure as it fades into the southwestern flank of the Gato Ridge anticline in a similar manner to the Mount Solomon anticline, just south of the latter's southeast end.

The relations existing between the Mount Solomon and Schumann anticlines are vague, although it is certain that they are not in alignment, and therefore can not possibly be one continuous feature. If the Hartnell and Mount Solomon anticlines are considered as one, the relations which exist between this united anticline and the Schumann anticline will be exactly analogous to those which exist between the Mount Solomon and Gato Ridge and the Gato Ridge and La Zaca Creek-Lisque Creek anticlines, viz, the adjacent anticlines will be en échelon with each other, each plunging down past the end of its neighbor. Graciosa and Harris canyons, particularly the former, are the superficial reflection of the syncline between the ends of the Mount Solomon and Schumann anticlines, and Solomon Canyon and Canada de los Alisos occupy analogous positions between the Mount Solomon and Gato Ridge and the Gato Ridge and La Zaca Creek-Lisque Creek anticlines, respectively.

Asphalt deposits.—Practically the whole top of Graciosa Ridge is capped by post-Monterey sandstones and conglomerates which are heavily charged with asphaltum. Asphaltum also occurs as veins penetrating the Monterey and post-Monterey beds at the east end of the ridge, and a fine example of asphaltum veins and veinlets filling the joint cracks in the Monterey is to be seen beside the road leading up to the Santa Maria Oil and Gas (Squires) well No. 4. This occurrence of asphaltum in the joint cracks of the shale gives a clue to the probable channels through which the oil migrated from the depths to the surface, and leads to the general conclusion that joint cracks are the reservoirs and channels of migration of the oil in many of the productive strata of this field.

Conclusions regarding future development.—It is obvious from a glance at the contour map (Pl. II) and a perusal of the detailed description of the developed areas that practically all of the territory covered by contour lines is productive. The only part of the region about which the compiler of the map has any misgivings as to productiveness is that occupying a general syncline south of the great bend in the Mount Solomon anticline. These misgivings are partially alleviated, however, by the idea that probably the position of the territory in question on the flanks of the Graciosa Ridge, which is, broadly, a quaquaversal or dome, may exert enough control on the oil to cause its collection there at least in paying quantities, if not in the remarkable measure found in other parts of this field. The region adjacent to the southeast end of the axis of the Mount Solomon anticline ought to be productive. The beds on the northeastern flank dip more steeply than those on the southwestern flank, and the first productive stratum is thought to be at a lower horizon in the shale on the former than on the latter, so it is probable that the upper oil zone will be struck at a greater depth northeast of the anticline than southwest of it.

GATO RIDGE ANTICLINE.

Structure.—The Gato Ridge anticline extends from the top of the ridge just east of the north end of Solomon Canyon to a point somewhere near the middle of the triangle formed by Canada de los Alisos, Cuaslui Creek, and Foxen Canyon. It follows very closely the crest of the ridge between Canada del Gato and Solomon Canyon, and for a considerable distance to the east is coincident with the highest topographic features. In general the anticline plunges from the southeast toward the southwest, the lowest beds along its axis being exposed in the region of Canada Arena. The Fernando is the only formation exposed along the entire length of the anticline. With the exception of some diatomaceous beds which closely resemble and were at first mistaken for Monterey shale, the rocks exposed are sandstone and conglomerate.

The northwestern portion of the fold from the head of Howard Canyon northwestward is a gentle arch with dips on the flanks rarely more than 5°, except in the region to the northwest of the town of Los Alamos, where the dips of some of the youngest beds exposed change abruptly from 3° or 4° to 40°. The northwestern extremity of the fold fades off into the low slopes toward the Santa Maria Valley. From Howard Canyon eastward the southward dip increases rapidly in steepness, until in the region of Canada de los Coches it attains a slope of 25° to 35°, the steepest dip being at the junction of the canyon last named and Canada Arena. While the southern dip increases to the east along the anticline, the northern slope becomes less, varying from 12° or 15° in the region of Howard Canyon to 3° or 4° just west of Canada Arena, and finally changing to a gentle southward slope in the region of Cuaslui Creek, thus fading into the southern flank of one of the folds emanating from the region at the head of Round Corral Canyon and Asphaltum Creek. The flexure in the region of Cuaslui Creek is therefore not a typical anticline in the regularly accepted sense, with the dip away from the axis on both sides, but in every other way it conforms to the characters of such a structure.

On the ridge north of the central portion of Canada del Gato and extending indefinitely northwestward out into the Santa Maria Valley a mile or so southwest of Gary, is a low anticline, the southeast end of which merges into the almost horizontal northern flank of the Gato Ridge anticline. At no place along its course is this fold well developed, although it appears to be fairly persistent for a considerable distance.

Evidence of petroleum.—Very little surface evidence of the existence of petroleum in the Gato Ridge anticline is to be had along its course. Near its axis in Cuaslui Creek and north of the head of Howard Canyon, however, the Fernando shale is slightly bituminous. The Pezzoni well, in Canada Arena; the Williams well, near Canada del Gato, 1½ miles west of the Howard Canyon road; and the Palmer Oil Company's well No. 1, 1 mile west of the lower part of Canada del Gato, all approximately a mile north of the anticline, offer indisputable evidence of the presence of the oil-bearing formation along a considerable extent of its northern flank. In the region of the Pezzoni well an unproductive oil and gas bed is encountered at about 1,200 feet below the surface, immediately followed by a diabase or lava rock in which the ferromagnesian minerals have been weathered to serpentine. In the Williams well the same or a similar oil and gas bed occurs much lower. The well was abandoned owing to the terrific gas pressure, which heaved heavy tar up into the hole and stopped operations. The Palmer well is productive, yielding oil of 16° or 17° gravity. Although not directly associated with the minor anticline northeast of Canada del Gato, the asphaltum occurring at Fugler Point, 1 mile north of Gary, is important as indicating the probable presence of petroleum in the upper end of the Santa Maria Valley.

Conclusions regarding future development.—The region north of the Gato Ridge anticline, from the vicinity of Cuaslui Creek westward to a point at least a mile beyond the Howard Canyon road, is underlain by strata so nearly horizontal as to preclude their containing very productive accumulations of petroleum. Northwest of this region, however, especially near the axes of the two anticlines shown on the map (Pl. I, pocket), the indications are good for productive wells. The conditions for the accumulation of petroleum are also good along and just south of the axis of the Gato Ridge anticline in the vicinity of Cuaslui Creek and from this point westward to the upper portions of Canada de los Coches. The same might be said of the immediate vicinity of the row of prominent knobs which extend in a straight line northwestward for 5 miles from a point about a mile north of Los Alamos, and possibly also, but in a less degree, for the territory between these knobs and the axis of the anticline. These knobs mark an abrupt change in the attitude of the beds from dips of 3° to 12° SW. to those of 35° or 40°, or possibly more, in the same direction. Wells would have to be sunk to a great depth along this last-mentioned line to reach the oil horizons, but if oil was encountered at all it would probably be in such quantities as to pay for the deep holes.

LA ZACA CREEK-LISQUE CREEK ANTICLINE.

Structure.—The La Zaca Creek-Lisque Creek anticline extends from the ridge southeast of Canada del Comasa southeastward at least as far as the edge of the Lompoc quadrangle east of Santa Agueda Creek. Its course is practically straight except at the northwestern extremity, which bows around toward the southwest and is en échelon with the east end of the Gato Ridge anticline. The dips along the axis are low in both directions, but distant from it they are much steeper, being as high as 30° or more to the northeast on the second ridge east of Figueroa Creek, and 30° SW. at the junction of Figueroa and Lisque creeks.

Conclusions regarding future development.—No indications of petroleum were noticed along this anticline, and it is almost certain that no productive wells will be developed on that part of it which lies within the Lompoc quadrangle, with the possible exception of a small area at its west end. There are good reasons for believing that the oil-bearing beds are absent from most of its northern flank, and if present under certain portions of its southern flank they lie at such a depth as to preclude their successful exploitation.

SUMMARY OF CONCLUSIONS REGARDING FUTURE DEVELOPMENT.

There can be no doubt that the region treated in this report is one of great promise. The structural and other conditions favor not only much more extensive development of the territory that has already been tested, but also the development of new fields. It must be borne in mind, however, that absolute determination, by work on the surface, of the occurrence or nonoccurrence of oil in any one locality is not possible. The best that can be done is to calculate the degree of probability on the basis of surface indications and structural conditions.

The following is a list of the tracts that appear especially to invite exploitation. Most of them have been discussed in the foregoing pages.

North and northwest of Sisquoc post-office, along anticlines.
General region east and west of Tepusquet Creek.
Indefinite area west of Gary, about Fugler Point.
Santa Rita Hills anticline.
Near the coast north of Schumann Canyon.
Schumann anticline in southeastern part of Casmalia Hills.
Two anticlines on San Antonio terrace.
Questionable region at mouth of Santa Maria Valley.
Northeastern portion of Burton Mesa.
Purisima Hills anticline.
Anticline at head of Santa Lucia Canyon.
Region about Mount Solomon and related anticlines.
Along Gato Ridge anticline and south of it, between Cañada de los Alisos and Cañada de los Coches.
Row of knobs extending 5 miles northwestward from a point about 1 mile north of Los Alamos, and the territory between these and the Gato Ridge anticline.
Wide region northwest of the head of Howard Canyon, especially along the axis of the two anticlines shown.
Arroyo Grande field.

DETAILS OF THE DEVELOPED TERRITORY.

DEFINITION OF FIELDS.

In the following paragraphs are discussed the more important details regarding the structure, geology, oil zones, oil, and production in the areas in which development is well under way. These areas within the Lompoc and Guadalupe quadrangles fall naturally into two fields—the Santa Maria field and the Lompoc field. The former covers the whole territory between the Los Alamos and Santa Maria valleys, and the latter is used to designate the region south of the Los Alamos Valley. A third, the Arroyo Grande field, covering the territory north and northwest of the town of that name in San Luis Obispo County, lies to the north of the region mapped, but is briefly discussed.

SANTA MARIA FIELD.

CONTOUR MAP.

WHAT IT SHOWS.

The contour map of the Santa Maria field (Pl. II) shows the boundaries of the different properties, the approximate location of all the wells, and the general structure of the field. The structure is indicated by contours showing the distance below sea level of a hypothetical horizon, zone, or bed, which just reaches sea level at the highest part of the axis of the Mount Solomon anticline. The contour interval is 100 feet.

By means of this map the direction and amount of dip of the strata in the oil-bearing or Monterey shale may be calculated for any point in the field, as the contour lines show the direction of strike (to which the dip is at right angles), and the horizontal distance between any two contours is the distance through which the beds dip 100 feet at that particular point.

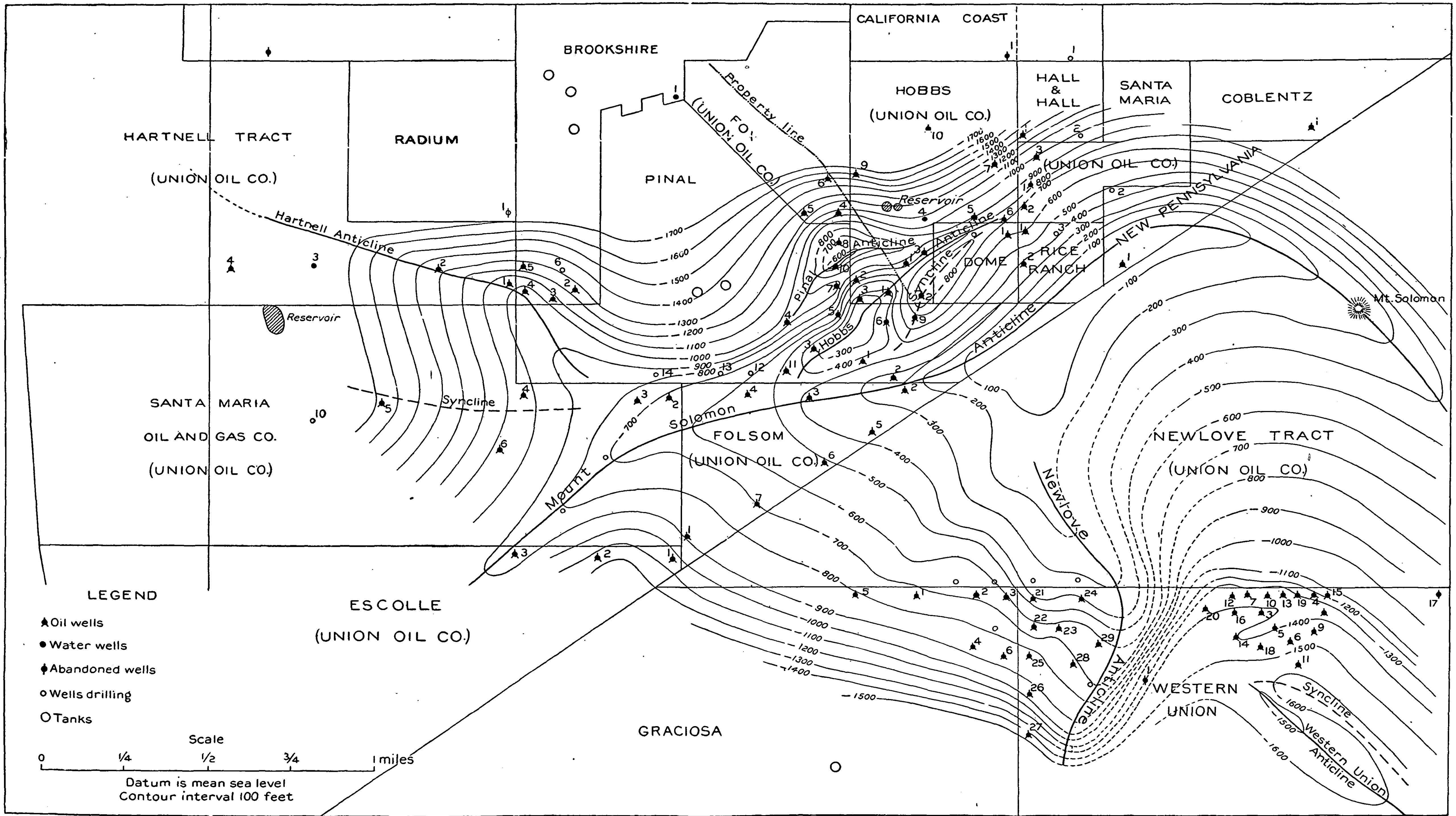
BASIS OF CONTOUR MAP.

The property lines were sketched from a map kindly furnished by Frank M. Anderson; the wells were located in the field by the eye, supplemented by pacing and in some instances by information furnished by the managers of properties. The log of every well in the area either finished or down any considerable distance in August, 1906, was used in the determination of the structure and the compilation of the data concerning the oil zones. All additional information available up to January 15, 1907, has been used in a revision of the contouring.

All of the obtainable surface evidence of dip and strike of the beds was also used in the preparation of the map. In every case where the surface and well-log evidence were at variance the latter was followed. In the Fernando formation, which unconformably overlies the Monterey shale, it was natural to expect variance with the structure of the Monterey, but even here the surface evidence more often supported than contradicted the evidence obtained by the drill.

DIFFICULTIES OF PREPARATION.

After carefully plotting all the logs on a uniform scale it was found that the greatest obstacle to overcome in the preparation of the contour map was the correlation of strata from one well to another and from one part of the field to another. The difficulties of such correlations are doubtless familiar to anyone who has tried to work out the underground structure of any of the California fields. The Santa Maria field offers as much encouragement to a



Compiled by Ralph Arnold

STRUCTURAL MAP OF THE LOCAL SANTA MARIA OIL FIELD.

Showing by contours the distance below sea level of a hypothetical horizon which just reaches sea level at the highest part of the axis of the Mount Solomon anticline.

successful study and mapping of the underlying oil-bearing formations as any so far examined by the senior author, and so the effort has been made to delineate on the map all the details of structure furnished by the data mentioned above and to supplement these details by showing for the untested areas what seems to be the most likely underground structure. It is very easy to make an ambiguous statement which will apply, no matter which way things turn out, on future development, but it is impossible to make an ambiguous map. It is deemed advisable, however, to show the information in hand, incomplete as it is, on a map. Future development will doubtless add much to our knowledge of this field and will show inaccuracies of the contouring as here presented, but it is hoped that the benefits which may accrue to the operators from a knowledge of the general structure of the field will compensate in a measure for the errors in detail which are to be expected in a map based on data so incomplete.

THE WELLS.

AREAS DISCUSSED.

For convenience of discussion the proved portion of the Santa Maria field has been roughly divided into six areas, based largely on the geographic position of the wells. The following are the areas discussed: Hall-Hobbs-Rice ranch, Pinal-Fox-Hobbs, Pinal-Folsom-Santa Maria Oil and Gas-Escolle, Hartnell-Brookshire, Graciosa-Western Union, and eastern Western Union.

OIL ZONES.

Four fairly well-defined oil-bearing zones are believed to be recognizable in the Santa Maria field. Of these at least two are found in practically every part of the field, although all vary more or less in thickness, composition, and yield from well to well. The most persistent zone in that part of the field which is best developed at the present time is the second, or B, zone. Above this in many of the wells is zone A; in others zone C is penetrated below it. The upper zone in the eastern group of Western Union wells, although above what is supposed to be the horizon of B, is probably considerably above the A zone of the northern part of the field, where it appears to have no correlative.

HALL-HOBBS-RICE RANCH AREA.

Location and structure.—The area here discussed comprises the California Coast, Meridian, Coblentz, Santa Maria Oil Company (Keyser), Hall & Hall, New Pennsylvania, Rice ranch, and Dome properties and the northeastern part of the Hobbs lease, and occupies the ridges and canyons which extend northward from the east end of the main Graciosa Ridge. The wells are located on the northwestern flank of the Mount Solomon anticline, at or immediately northwest of the point at which it changes from a northeastward to a southeastward trend. In addition to the main anticline there appear to be one or more local flexures, the Hobbs anticline and the syncline between it and the Mount Solomon anticline being the most prominent. The characteristics and extent of these features, as they are believed to exist, are portrayed on the contour map. (Pl. II).

Geology of the wells.—Nearly all the wells in this area, with the exception of the Hall, Meridian, and Coblentz, start in the Monterey shale. Those farthest from the top of the ridge, other things being equal, have to penetrate farthest through the Fernando clay, sand, and conglomerate. Up to the present time the greatest thickness of the Fernando penetrated before reaching the shale is 650 feet, and much trouble is experienced in going through this formation, which is mostly sand. From the top of the Monterey to the bottom of the wells the rocks are largely blue and brown shales, with only here and there interbedded hard "shell" layers. In fact, one log reports "no shell" until the first oil zone was reached. Wherever "shell" is penetrated accumulations of gas or oil or both are generally encountered. The shale seems to be somewhat more sandy in this area than farther west or in the Graciosa-Western Union region.

Three oil zones are recognizable in the area under discussion, although practically all of the strata from the top of the uppermost zone to the bottom of the lowest are more or less petroliferous at one point or another.

The first productive zone (A) is penetrated at a depth of 1,600 feet or more, varying according to the position of the well topographically and relative to the axis of the anticline. Its top is from 550 to 700 feet above the top of zone B in this area. Zone A is productive for a distance of 20 to more than 500 feet. Of course this does not mean that the beds are productive in any one well for the whole distance of 500 feet, but that throughout the zone alternating barren and productive beds occur at such close and as a rule irregular intervals as to preclude their practical differentiation. The productive measures in this first zone consist both of hard fractured shale or "shell" layers and more or less porous sandy beds. In at least one of the wells the oil accumulates only under the hard "shell" layers. This is the only zone penetrated by some of the wells farthest away from the anticlinal axis. In these wells it appears to be much more petroliferous than in wells higher up on the fold.

The second oil zone (B) is from 550 to 700 feet below the top of zone A, and its upper limit is about 300 or 400 feet above the top of zone C, although it can hardly be said to be distinct from C in all the wells, so rich in oil are some of the intervening strata between them. True sands of medium grain, in addition to the productive hard-shale zones, yield the oil in zone B.

The third oil zone (C) is encountered in some of the deeper wells nearest the axis of the main anticline. This zone has been penetrated for as much as 150 feet, the whole being very rich in petroleum. It is overlain by a considerable thickness of black shale, also more or less petroliferous, between which and the rich zone is a thin, hard, "shell" layer. The oil-yielding rock is a true sand, coarse in places, and even becoming pebbly toward its base in certain portions of the area. To the coarseness of the material is doubtless due the great productiveness of the zone.

Product.—The oil in the Hall-Hobbs-Rice ranch area runs from 26° to 29° Baumé, and is dark brown in color. Gas accompanies the oil and also occurs isolated under some of the more impervious "shell" layers in the shale. No water is reported in any of the wells.

The production of the wells varies from 300 to something over 2,000 barrels per day. Those wells which penetrate the lowest or C zone are the best producers. It is said that where a number of wells are located comparatively near together the production of each well is largely dependent on whether or not the adjacent wells are producing, a fluctuation of 50 per cent resulting from this cause in some instances.

PINAL-FOX-HOBBS AREA.

Location and structure.—The area comprising the Fox lease, the southwestern part of the Hobbs lease, and the northeastern portion of the Pinal property occupies the ridge and two adjacent canyons which extend northward from the central portion of Graciosa Ridge. The wells are located in an area of considerable structural disturbance caused by the development of two local anticlines on the northwestern flank of the main Mount Solomon anticline. These two minor flexures have been named after the companies under whose property they are best developed. Although the position assigned to them on the map is more or less hypothetical, the evidence in favor of it is fairly complete, and they explain some of the variations in production of adjacent wells.

Geology of the wells.—Practically all the wells within this area start in the Monterey shale, and this is the prevailing formation to their bottoms. Certain portions of the shale are burnt to a brick-red color by the combustion of their hydrocarbon contents, the burnt shale being encountered as low as 330 feet in one of the wells. The burning has so hardened the shale in places as to render drilling in them more difficult. A hard limestone "shell" layer was encountered in one of the wells just above the second, or B, oil zone. Tar or asphaltum occurs in some of the wells at a depth of about 600 feet; in others at various depths from 200 to 1,200 feet. The tar is often associated with black shale. Gas accumulations under "shell" and other impervious layers are of common occurrence both in the oil zones and locally in the barren overlying shale. Water is encountered in some of the wells at depths varying from 150 to 270 feet. This occurrence is noteworthy, as the wells in the group to the east are, so far as known, quite free from water in the shale. Its occurrence in the Fernando sands and conglomerates is to be expected, but its presence in sands interbedded with the Monterey shale is unusual for this field.

The first oil zone (A) is penetrated in the wells in this area at depths ranging from a little more than 1,600 feet down, or between 400 and 600 feet above zone B. Petroliferous strata occur in some of the wells above this horizon, but they are of little consequence as regards production. The thickness of zone A in the wells varies from 8 or 10 to nearly 150 feet, with several more or less important oil-bearing beds between this and the next lower, or B, zone. The productive measures of zone A consist largely of brown shale, probably seamed or jointed in such a way as to afford a reservoir for the oil, although certain of the wells may obtain their product from fine-grained sands interstratified with the shale.

The second oil zone (B) is the most important one in this area, although it is underlain over at least a part of the area by zone C, which is apparently even more productive. The thickness of zone B is variable, but most of the wells penetrate from 50 to 150 feet of productive strata at this horizon. The oil-bearing beds are similar to those of zone A and consist largely of hard shale, with some fine sands, although excellent examples of a true siliceous sand are obtained in many of the wells. A hard limestone "shell" overlies zone B in one of the wells.

The third oil zone (C) is penetrated by some of the deeper wells at a depth of about 300 or 400 feet below zone B. In one of the wells this C zone appears to be missing, although a good flow of oil is reported from the same hole about 500 feet below the point where it should occur.

Water underlies oil zone B in one of the wells and C in another. This occurrence of water below the oil, so common in most fields, is very rare in this one. It may be that in the course of time water will follow up and displace the oil in the productive zones, and the determination of this point will be awaited with a great deal of interest. Some of the wells in the Santa Maria field have been stopped in the midst of productive strata for fear of encountering water farther down, but whether or not these fears were well founded has never been established.

Product.—The oil from this group of wells is of a dark-brown color and varies in gravity from 24° to 28° Baumé, the lighter oil usually occurring in the wells nearest the main anticline; the average gravity is between 25° and 26°. Much gas is associated with the oil in all of the wells.

The production of the individual wells varies from 60 to 1,000 barrels per day, the latter amount coming from a hole very eccentric in its behavior, as shown by its yield of 200 barrels on some days and as high as 1,000 on others; the average daily production for this well is 300 barrels. With the eccentric well omitted, the maximum production is about 500 barrels per day. One well which produced 150 barrels from zones A and B added 350 barrels to its output when deepened to zone C.

PINAL-FOLSOM-SANTA MARIA OIL AND GAS-ESCOLLE AREA.

Location and structure.—The area here discussed comprises the Folsom lease, the southern part of the Pinal property, the central and southern portions of the Santa Maria Oil and Gas lease, and the Escolle property of the Union Oil Company. The wells are located on the west end of Graciosa Ridge and in the canyons on its sides. The region is largely covered by the Fernando sandstone and conglomerate "cap rock," although the Monterey shale is exposed in the side canyons. The structure underlying this part of the field is comparatively simple so far as known, the main Mount Solomon anticline plunging northwestward through its center and being the only fold of consequence immediately affecting the area. The location of the anticline near Escolle well No. 3 is based entirely on the well logs, which are at variance with the northwesterly dips in the Fernando in the vicinity of Escolle wells Nos. 2 and 3.

Geology of the wells.—Those wells which start in the Fernando remain in this formation for distances ranging from a few feet to nearly 300 feet, the strata penetrated being sand and conglomerate. In the region of Escolle well No. 1 and Folsom well No. 1 the Fernando appears to be exceptionally deep, extending nearly 300 feet below the surface, and to consist largely of conglomerate. One of the wells reports red conglomerate at 30 to 90 feet below the surface; whether this is burnt shale so hardened as to come out of the well in fragments of considerable size or whether it is true waterworn material is not known. Asphaltum is reported to occur at the base of the Fernando in some of the wells, and may also be seen at the contact between the Monterey shale and overlying beds at many places in this area. The channels through which this material has escaped from the shale are undoubtedly joint cracks, as veins of the hardened asphaltum may be seen in the shale beside the road leading up to Santa Maria Oil and Gas (Squires) well No. 4, and at other points in the field. From the base of the Fernando to the bottom of the wells the strata penetrated are practically all shale with a few hard "shell" layers, under which accumulations of gas and locally oil occur. A zone in which "shells" appear to be particularly abundant immediately overlies the first oil zone. Traces of tar and asphaltum are also reported in the shale at various depths. Two zones in which many hard limestone "shell" layers are encountered are reported from some of the wells; one of these zones is about 500 feet above the second oil zone (B), and the other immediately underlies it.

The first oil zone (A), which lies from 250 to 500 feet above zone B, is struck at depths ranging from 1,400 feet down. Its thickness varies from a few feet to about 50 feet; according to the logs it is lacking in some of the wells, the first oil being encountered in zone B. The oil-bearing strata in zone A are largely shale, but fine sand may also contain some of the petroleum.

The second oil zone (B) is penetrated by all the wells in this area. It varies in thickness from nearly 50 to about 250 feet; one of the wells, however, is said to encounter petroliferous beds intermittently from the top of zone B for a distance of 550 feet downward. The oil-bearing strata consist of alternating hard shale and fine sandstone layers.

The third oil zone (C) occurs from 500 to 600 feet lower in the wells than zone B and consists of two parts, each from 25 to 50 feet thick, separated by a layer of shale of variable thickness; in one of the wells, however, the intervening shale is missing and the strata are richly impregnated with oil from the top of the zone for a distance of 250 feet, to a point where a 3-foot layer of water sand limits the productive measures. In practically all the wells in the field zone C is very rich. and nearly all the wells tapping it are fine producers.

Product.—The oil obtained in the area under discussion averages somewhat better than that in the area to the east, and has a gravity of 26° to 28° Baumé, with an average somewhere between 26° and 27°. As is common in other portions of the field, the gas pressure in most of the wells is high.

The production of the individual wells varies from 100 to 2,700 barrels per day, the well yielding the latter amount being said to have had an initial daily output of 5,000 barrels for a short time. In one series of wells those down the dip are more productive than those nearer the axis of the anticline, the variation being at least partially accounted for by a thickening of the oil-bearing zone away from the axis.

HARTNELL-BROOKSHIRE AREA.

Location and structure.—The area comprising the southern portion of the Hartnell tract and Brookshire property and the southeastern portion of the Radium lease is located on or adjacent to and in the broad valley south of the ridge running northwestward from a point near the west end of Graciosa Ridge. The major structural feature is a northwestward-plunging anticline which is here called the "Hartnell." There is both surface and underground evidence of its presence, but its exact location is, of course, only conjectural. As will be noticed by an examination of the map (Pl. II, p. 46), the northern flank of the anticline is much steeper than the southwestern, this fact apparently having a direct bearing on the productiveness of the wells penetrating this flank.

Geology of the wells.—The surface distribution of the formations in the immediate vicinity of the little swale on the ridge in which Brookshire wells Nos. 3 and 4 are situated is very interesting. The bottom of the swale is Monterey (Miocene) shale; unconformably overlying this on the south is fossiliferous Fernando (Pliocene) sandstone and conglomerate; immediately north of the swale is terrace-deposit (Pleistocene) sandstone. It has been suggested that such a condition is most easily explained by a fault through the swale, the downthrow being on the north. The logs of the wells in the immediate vicinity, however, offer evidence that such is not the case, but that the underlying Monterey strata, followed almost immediately north of the swale by fossiliferous Fernando beds, plunge steeply northward and are overlain unconformably by the low-dipping or practically horizontal terrace beds which are exposed on the ridge north of the swale. The wells starting in the post-Monterey formations penetrate, in some places, sand and gravel for a distance of more than 600 feet before entering the Monterey. Limestone, probably corresponding to the limy layers associated with fossiliferous beds at the base of the Fernando in the railroad cut north of Schumann, is reported as occurring next to the Monterey shale in one of the wells. Water is encountered in gravel at various horizons in the Fernando between the depths of 150 and 600 feet. Hartnell well No. 3 and Brookshire well No. 1 (the latter about one-half mile northeast of the area under discussion), which penetrate the water-bearing Fernando, are used as water wells. From the base of the Fernando to their bottoms the wells penetrate blue and brown shales, and very rarely fine sandy layers. Here and there "shell" strata, many of them underlain by gas and some by oil and gas, are encountered throughout the shale.

The first oil zone (A) occurs about 400 feet above zone B, is struck at depths from 2,150 feet down, and is said to vary from 2 to 5 feet in thickness. From an examination of the material from this and the underlying productive zones it is thought that the oil must come from the joint cracks or interstices between the fragments of more or less fractured shale, as no true sand of sufficient coarseness to allow the rapid transmission of oil has been encountered in the productive zones in the wells of this group. Between the first zone and the one that has been recognized as the second, or B, are one or more productive zones 2 to 15 feet in thickness. No two wells show the same sequence of these zones, and they probably represent places of local fracturing.

The second oil zone (B) is thought to be fairly constant throughout the area. It consists of alternating barren and productive layers of shale, some of the productive layers being from a few feet to as much as 20 feet in thickness. Below the main or upper part of this zone are others, some at least 200 feet below B. The oil-bearing measures in these zones, as in A, are probably nothing more or less than fractured portions of the shale.

Product.—The oil from the wells in this area runs from 24° to 26° Baumé and is dark brown in color, with the exception of that from one of the wells, which is said to be a reddish emulsion of oil and water. All the wells show much gas, the best producers being under heavy pressure.

The production of the individual wells in this group varies from an initial output of 12,000 barrels in one well to a daily average of 150 barrels in another. The following statement concerning the production of Hartnell well No. 1, the greatest producer in the California oil fields, has been kindly furnished by Mr. Orcutt, of the Union Oil Company:

Well (Hartnell No. 1) started to flow over derrick through 8¼-inch and between this and 10-inch casing December 3, 1904. Gas pressure was very heavy, estimated at 400 pounds per square inch—was probably much higher, however. Oil was measured in an open ditch by use of a miner's inch measuring box, and showed about 12,000 barrels per day. The flow continued for about sixty days and gradually weakened. September 1, 1905, the well was doing 3,069 barrels per day.

The oil was stored in earthen reservoirs, and the production to the above date is estimated at 1,500,000 barrels from this well alone. Up to August 15, 1906, the total production for the well was something over 2,000,000 barrels.

The gas accompanying the initial flow of oil was estimated at 4,000,000 cubic feet per day. After the well had been gotten under control it furnished gas for running 20 boilers for well-drilling rigs, and in addition supplied the town of Orcutt (population about 200) with gas for domestic purposes. At the present time it is still yielding a constant flow, which is used for many purposes in Orcutt.

GRACIOSA-WESTERN UNION AREA.

Location and structure.—The wells at the northeast corner of the Graciosa and northwest corner of the Western Union properties are located on the point of the ridge which runs southward for more than a mile from the main Graciosa Ridge. The structure is apparently simple, being the southwestern flank of the hypothetical Newlove anticline. At least two minor folds occur on this flank, one apparently passing through Western Union wells Nos. 21 and 22 and the other occurring from three-eighths to five-eighths of a mile northwest of the first. The Newlove anticline as shown on the map is wholly hypothetical. It is the expression of the most plausible explanation of the relationship which is supposed to exist between the known Graciosa-Western Union and the eastern Western Union well areas. The surface evidence of the structure consists of a 10° SE. dip in the Fernando beds just north of the Graciosa wells, together with some more or less uncertain dips in the Monterey toward the head of the ridge, approximately parallel with which the anticline is supposed to run.

Geology of the wells.—The wells all start in the sand of the Fernando, penetrating this formation for 70 to 300 feet. No water is reported from this sand, but in one of the wells asphaltum is said to have been found at its base. From the base of the Fernando to the top of the main productive horizon the formation consists of blue and brown shales, with many hard "shell" layers, some sticky shale beds, and rarely a little sandy material. In some of the wells streaks of asphaltum are reported as occurring in the shale and in others gas is present under some of the "shells."

The first oil zone (zone B of the northern part of the field) is reported from only one well. It is nearly 200 feet thick and is encountered at a depth of about 2,075 feet. Gas is associated with the oil in this zone.

The second and important oil zone of this area (C) is struck at depths of 2,670 feet or more and lies about 600 feet lower in the wells than zone B, which is apparently unproductive in most of the wells. According to the data in hand the productive zone varies in thickness from 18 to about 240 feet, and consists of alternating light and dark-colored flinty shales interbedded with varying amounts of sandy shale. No true sand, as ordinarily implied by the name, occurs in the productive zone of this area, so far as the writers were able to learn.

Product.—The oil from zone C runs from 25° to 27° Baumé, averaging well up between 26° and 27°, and has a brownish color. It comes from the wells at a temperature of about 95° F. and is usually accompanied by much gas. Some of the wells, however, are said to show a comparatively low gas pressure.

The production of the individual wells varies from 300 to 3,000 barrels per day, the flow often being unusually strong. None of the wells have been allowed to produce up to their full capacity, owing to the lack of storage and transportation facilities, so that even had they been down long enough for a thorough test (which is hardly the case, since nearly all have been finished since 1904), no definite conclusions could be drawn concerning their lasting properties.

EASTERN GROUP OF WESTERN UNION WELLS.

Location and structure.—The eastern wells of the Western Union Company are located near the head of one of the branches of the broad valley which extends east-northeastward from Harris Canyon at Blake and are about 5 miles southeast of Orcutt. They are from one-half to three-fourths of a mile east of the west property line of the company and close to the northern line. Slightly more than half a mile northeast of the wells is the axis of the Mount Solomon anticline, from the southwestern flank of which the wells derive their oil. The structure in the immediate vicinity of wells, as indicated by the logs (see Pl. II, p. 46), is more or less complicated, the general strike of the beds apparently changing suddenly from northwest to southwest immediately northwest of the group. Furthermore, a local flexure with northeast-southwest strike immediately underlies the developed territory, and a pronounced anticline (here named the "Western Union") with a steep northeastern flank lies just to the south. There is no surface evidence of the northeast-southwest disturbance, but the Western Union anticline is plainly seen in the Fernando beds. The dip of the beds on the southwestern flank of this fold at the surface varies from 15° at the west end of the hill south of the wells to 10°, and possibly much less, one-half mile to the southeast. The maximum northeasterly dip of 45° is seen south of well No. 18, but the slope rapidly decreases both to the northwest and southeast. As nearly as could be ascertained from the available data, the production of the wells in this group supports the anticlinal theory of the accumulation of petroleum—that is, for an equal thickness of productive zone the wells near the axis of the anticline in the local flexure are more productive than those farther away from it.

Geology of the wells.—The wells start in soil, but soon enter the clay, sand, and conglomerate layers of the Fernando, which is the surface formation in this part of the field. The Fernando beds are penetrated for 100 to 250 feet, varying with the location of the well, the wells on the north passing through it in the shortest distance. Water and quicksand were encountered in at least two of the wells in the lower portion of the Fernando; in another asphaltum occurs at the base of the formation. From the base of the Fernando to the first oil-bearing zone the wells penetrate blue and brown shales, largely the latter, interstratified with hard "shell" layers, under some of which are accumulations of gas.

The first oil zone is struck at a depth of 1,200 feet down and varies in thickness from 12 to 75 feet, although in some of the wells sands are encountered at intervals for at least 250 feet below the top of the first sand. The oil sand is for the most part rather fine grained and is accompanied both above and below by shale and in a few places by shell. In some of the wells the oil zone appears to be a practically continuous sand for its entire thickness; in others alternating sand and shale layers furnish the oil.

A second oil zone occurs about 1,200 feet below the first, the entire distance between the two being occupied by shale, with a few hard "shell" layers. Very little oil occurs at this horizon.

A third oil zone about 150 feet thick is penetrated at a considerable depth below the second, the formation between the second and third horizons being practically all shale. Comparatively little oil was obtained from this zone, although it is thought to be the same as the one which is so productive in the Graciosa-Western Union area only half a mile to the west. This may be accounted for by the general synclinal position of the eastern group between the Mount Solomon and the hypothetical Newlove anticlines.

Product.—The oil in the first productive zone has an average gravity of about 19° Baumé and is very dark colored. Gas is associated with the oil, but no water has so far been reported from any of the wells.

The production of the wells in this group varies from 5 to over 150 barrels per day. The yield of some of the wells is fairly constant, showing only a small decrease in average daily output over a considerable number of months; in others, however, the yield is fluctuating.

LOMPOC FIELD.

LOCATION.

The developed territory within the Lompoc field, on which the following discussion is based, lies on the flanks of the Purisima Hills between the Cebada Canyon and Santa Lucia Canyon roads. Within it are located the Logan well of the Los Alamos Oil and Development Company; the Hill, Wise & Denigan, and Eefson wells of the Union Oil Company; and the abandoned wells of the Todos Santos, Coast Line, and Barca oil companies.

STRUCTURE.

The dominant structural feature of the field is the main anticline of the Purisima Hills. From surface evidence the location of the anticline is believed to be that shown on the map (Pl. I, pocket). From the evidence offered by the logs of the Hill and Logan wells, the axis of the anticline, in so far as it affects the oil-bearing beds of this part of the field, might better be drawn through Hill well No. 1, extending westward and eastward (swinging to the north in both directions) to the points where the "surface" anticline passes from the Fernando to the Monterey. In either location, however, the anticline has a steeply dipping northern flank and a low-dipping and probably undulating southern flank.

A fault, clearly seen on the east side of Cebada Canyon and traced by deposits of asphaltum over portions of the rest of its course, extends from a point a short distance east of Cebada Canyon northwestward at least as far as the brea deposits near Wise & Denigan well No. 1. The fault is clearly a thrust fault in the Cebada Canyon region, supposed Monterey diatomaceous shale being thrust up on the north over Fernando sandstone which lies south of the line, the dip of the fault plane being about 30° toward the north. Mr. Orcutt suggests that this fault probably causes the difference in yield between Hill wells Nos. 2 and 3. The sand is struck about 700 feet lower in No. 3 than in No. 2, and is barren in the former, but productive in the latter. The dip of the strata (if the anticline affecting the oil sands passes south of No. 2) might account for the difference in distance of the oil sand below the surface in the two wells, but it alone would hardly account for the difference in saturation of the sands. It is quite possible that the fault (which theoretically emerges somewhere near Hill well No. 4) passes downward at such an angle as to cut the oil sand between Hill wells Nos. 2 and 3, throws the sand down on the north, and, while acting as an outlet for the oil in the sand for some distance on its northern or upper side, effectively seals up the truncated end of the same sand on its southern or lower side. This hypothesis assumes a downthrow on the north, a condition exactly opposite to that shown at the surface in Cebada Canyon. Alternate upthrow and downthrow on the same side of a single fault, occurring at different times, are not unusual in the Coast Ranges, so that such an explanation is not only possible, but probable. To conform to the prevailing conditions the downthrow must have been on the north in pre-Fernando and on the south in Fernando or post-Fernando time.

The logs of the Wise & Denigan wells indicate a more or less local anticline in the Monterey. Its axis passes near well No. 2 of this group and probably extends in an east-west direction parallel to the major lines of structure in the hills immediately to the north. This suggests the probable gentle folding of the Monterey in the region south of the Purisima Hills in a manner similar to that which takes place under Burton Mesa farther west.

GEOLOGY.

GENERAL STATEMENT.

All the productive wells in the area start in the Fernando formation and penetrate its clays, sandstones, and conglomerates for depths ranging from 45 to 800 feet. The great variation in the thickness of the Fernando in adjacent wells (the beds over much of the territory being nearly horizontal) implies great inequalities in the surface of the underlying Monterey shale, and this in turn signifies a profound unconformity between the two formations. Water is encountered in the Fernando at various depths in the different wells.

From the base of the Fernando to the top of the oil sand the wells pass through shale (largely " brown," according to the logs). A few hard siliceous " shell " layers are encountered in this shale, and in one well hard limy " shells " were struck at only 1,180 feet from the surface. These limy layers are abundant in the formation just above the oil-bearing zone, but are not found in most of the wells above this horizon.

Oil and gas are found in minor quantities in the shale at various depths from 500 feet down in some of the wells in the northern part of the developed area, although such occurrences are not recorded for the wells in the southern part.

BURNT SHALE.

One of the most interesting features of the geology of the Monterey shale in this area is the evidence that combustion has taken place at certain points more than 1,000 feet below the surface. Mr. Orcutt, of the Union Oil Company, exhibited samples of red shale coming from depths of 950 and 1,040 feet below the surface in Hill well No. 1, which are identical in appearance and texture with the burnt shale found so abundantly in the bituminous areas of the Monterey on the north side of the Santa Maria field and in other fields in the State. Traces of petroleum were associated with the upper stratum of burnt shale in Hill well No. 1.

OIL ZONES.

The principal productive oil zone in the region under discussion is struck at depths below the surface ranging from more than 2,000 feet down. In nearly all the wells the productive strata are overlain by limy " shell " layers, which apparently act as barriers to the upward migration of the oil at the present time. The beds beneath these limy " shells " are true sands in most places, although in some of the wells these sands are interstratified with various quantities of shale and limestone "shells." The thickness of the oil-yielding zone varies from about 160 to 700 feet, and in one well a productive series of sands, shales, and "shells" is said to be penetrated for a depth of 1,100 feet. Either water sand, dry oil sand, or limy "shell" usually defines the base of the productive zone.

THE OIL.

Two grades of oil are struck in this field, one a black oil with a gravity of 18° to 24°, the other a brown to greenish oil of about 35° Baumé. The black oil is produced by most of the wells, the lighter variety coming only from the Logan well of the Los Alamos Oil and Development Company and one other well in the Wise & Denigan lease of the Union Oil Company. One of the wells yields an emulsion of water and 20° oil, which is reddish brown in color as it comes from the well. The oil turns to the usual black color on separation of the water by settling.

PRODUCTION.

The production of the individual wells varies from 100 to 1,000 barrels per day, the best producers averaging from 300 to 500 barrels. One of the wells which gave an initial output of 200 to 300 barrels suddenly began flowing 1,000 barrels a day. This continued for a few days and then gradually fell off to 300 barrels, which it is still yielding. It is said that the wells, as a rule, are exceptionally steady producers, falling off but little in the two years since the field was first opened. Very few of the wells have been tried to their full capacity, so that it is probable that yields greater than those mentioned will be recorded when the field is fully tested.

ARROYO GRANDE FIELD.

LOCATION.

Drilling has recently shown that at least certain portions of the region north and northwest of Arroyo Grande, San Luis Obispo County, a short distance north of the area mapped in Pl. I, are underlain by productive oil formations. The successful wells belong to the Tiber Oil Company and are located on the western side of Price Canyon, about 3 miles northeast of Pismo and 7 miles slightly east of south of San Luis Obispo. Although outside of the immediate area covered by this report, the occurrence is so important in showing an extension of the Santa Maria district toward the northwest as to merit mention here.

GEOLOGY.

The geology of the San Luis quadrangle has been mapped and described by H. W. Fairbanks in the San Luis folio.[a] According to this work nearly all of the territory of the hills between San Luis Obispo Creek and the Arroyo Grande Valley, with the exception of a rather limited area of Monterey volcanic ash, shale, and diatomaceous earth north of Pismo, is composed of sandstone, covered by the Pismo formation. This formation is composed of sandstone, some of which is asphaltic, and cherty diatomaceous beds, and is the equivalent of the lower part of the Fernando as described for the hills adjacent to the south side of the Santa Maria Valley. The Pismo is unconformably underlain by the Monterey shale, which outcrops on either side of it.

STRUCTURE.

According to Fairbanks, the Pismo area forms a low syncline, striking northwest and southeast, its flanks resting against the upturned Monterey.

OCCURRENCE OF THE OIL.

The oil is derived from a great thickness of productive sands which probably represent the base of the Pismo and which rest on the upturned and more or less contorted shale of the Monterey. Its occurrence in a syncline is worthy of note, as, ordinarily, synclines are not highly productive. The Monterey is the oil-bearing formation in the Santa Maria district, and it is the ultimate source of the oil in this field also. The migration of the oil probably took place along the joint cracks in the shale, as was the case with the asphaltum in the Santa Maria and other fields. The oil on reaching the upper limit of the shale passed across the plane of unconformity and accumulated beneath an impervious shale in the porous sand at the base of the Pismo. Where this porous layer approaches the surface the more volatile parts of the oil have escaped and there remains nothing but the bitumen while the more deeply covered sand retains the oil in its lighter and liquid state. The migration of the oil, as in every similar case coming under the notice of the writers, has been accompanied by a loss of its volatile constituents and a consequent lowering of the gravity. This is shown by the fact that while the gravity of the oil from the Monterey shale in the Santa Maria field averages about 25° that from the Pismo formation in the Arroyo Grande field is only 14°.

[a] Copies of this folio, which is No. 101 in the series making up the geologic atlas of the United States, should be in the hands of every oil man or other person interested in the natural resources of this region. It may be obtained for 25 cents from the Director of the United States Geological Survey, Washington, D. C.

CONCLUSIONS REGARDING FUTURE DEVELOPMENT.

It seems almost certain that considerable portions of the Pismo formation toward the middle of the area northwest and north of Arroyo Grande will be found to be oil producing. This conclusion is based on the assumption that the Pismo of this region is underlain by the oil-yielding Monterey. The surface evidence of such a condition is most conclusive. What effect local flexures, either in the Monterey below the Pismo or in the Pismo itself, will have on the production only drilling will determine. According to the structure of the area, as mapped by Fairbanks, the depth at which the oil may be struck ought to decrease from the middle of the area toward both the northeast and southwest. The only wells fully tested in the region yield from 500 to 600 barrels of 14° oil per day, so that the prospects for the development of a good field are unusually bright.

As the Monterey shale underlying the Pismo of the Arroyo Grande field is continuous with the Monterey mapped in the Lompoc quadrangle northeast of the Santa Maria Valley, it is reasonable to suppose that there are considerable portions of this great belt of Monterey that will prove productive. The local structure is usually the determining factor in the accumulation of petroleum, so that a thorough knowledge of this is essential to economical test drilling. It is to be regretted that no maps adequate for showing the structure of the formations in the region east of the San Luis and north of the Lompoc quadrangle are available. Without these it will be impossible to do for this region such detailed geologic and structural mapping as that already done for the two quadrangles mentioned.

HUASNA FIELD.

The Huasna field lies east of the Arroyo Grande field and north of the Lompoc quadrangle. Prospect drilling is now going on in this region, but with what results the writers are not able to say. During a very hasty trip through this region in the summer of 1905 the senior writer noted great areas of Monterey shale, with some interbedded coarse granitic sandstones, in many places of considerable thickness. Such conditions are ideal for the accumulation of petroleum if the beds are not too sharply folded. This is probably the continuation of the Monterey area exposed in the northeastern part of the Lompoc quadrangle and may connect the latter with both the Monterey area east of Arroyo Grande and that covering the summit of the Santa Lucia Range a few miles east of San Luis Obispo.

PRODUCTION.

The production of oil in the Santa Maria district has been increasing rapidly in the last four or five years, but the increase as shown by the figures of actual production does not fully indicate the increase of the capacity of the field. Lack of storage capacity, inadequate transportation facilities, and the low price of crude petroleum are factors which have kept down the total produced and marketed. Well drilling has been going on steadily ever since the field was opened, but only in a few instances have the companies pushed their production up to the limit for any length of time.

The production of the district, including the Santa Maria, Lompoc, and Arroyo Grande fields, for the last five years is as follows:

Production of crude petroleum in Santa Maria oil district, 1902–1906.[a]

	Barrels.
1902	99, 283
1903	178, 140
1904	1, 367, 174
1905	2, 565, 966
1906	4, 906, 513
	9, 117, 076

The estimated maximum capacity of field, January 1, 1907, is 40,400 barrels per day.

STORAGE CAPACITY.

The storage facilities of the district consist of steel and wooden tanks and open earthen reservoirs. The last are found only in the field and are used only temporarily or in cases of emergency. The total storage capacity of the district, not including the open reservoirs, is 1,464,000 barrels.

TRANSPORTATION FACILITIES.

The oil from the Santa Maria field is distributed by means of pipe lines, tank cars, and, in some instances, eventually by tank steamers. The principal pipe lines of the district are the four connecting the field with Port Harford and the one running from the Western Union wells at Gaviota. The rail lines available are the Southern Pacific at Gaviota, Casmalia, and Betteravia and the Pacific Coast at Carreaga and Orcutt. Tank steamers of the Associated, Standard, and Union oil companies take the product from Port Harford or Gaviota.

The following is a summary of the principal pipe lines in the district:

[a] Compiled from data furnished by the different operating companies. Barrels of 42 gallons each.

Pipe lines in Santa Maria oil district.

Company.	From—	To—	Distance.
			Miles.
Coast Oil Transport Company	Wells	Oil Port	34
Do	do	Casmalia	8
Los Alamos Oil and Development.	do	Carreaga	
Pacific Oil and Transportation	Orcutt	Gaviota	51
Pinal-Brookshire	Wells	Graciosa station	2
Do	do	Betteravia	7
Standard	Orcutt	Port Harford	32
Do	Western Union wells	Orcutt	7
Do	Hall, Dome, Pinal, and Brookshire wells.	do	3
Standard (2 lines)	Pacific Coast Oil Co.'s tanks	Port Harford	
Union	Orcutt	do	32
Do	do	do	32
Do	Lompoc field	Orcutt	16
Do	Escolle and Santa Maria oil and gas wells.	do	3
Do	Fox, Hobbs, Folsom, and other wells.	do	3
Do	Reservoirs 1, 2, and 3	do	4
Western Union	Wells	Carreaga	4

OIL COMPANIES.

The following table gives the names of the oil companies working in this district, together with the field of operations and number of wells, where known:

Oil companies of the Santa Maria district.

Companies.	Field.	Oil wells.			
		Productive.	Abandoned.	Drilling.	Total.
Anglo-Californian Oil Syndicate	Lompoc			1	1
Barca Oil Co	do		1		1
Brookshire Oil Co	Santa Maria	4	*a* 1	1	6
California Coast Oil Co	do		1		1
California Coast Oil Co. (Union Oil Co.)	do	3			3
Casmalia Ranch Oil and Development Co	do		1		1
Claremont Oil Co	do		*a* 1	1	2
Coast Line Oil Co	Lompoc		1		1
Coblentz Oil Co.	Santa Maria			1	1
Diamond Oil Co	do				
Dome Oil Co	do	1		1	2
Graciosa Oil Co	do	6		2	8
Hall & Hall Oil Co	do	1		1	2
Laguna Land Co	Arroyo Grande			1	1
Las Flores Land and Oil Co	Santa Maria				
Lompoc Oil Developing Co	Lompoc				
Los Alamos Oil and Development Co	do	1	2		3
Meridian Oil Co	Santa Maria			1	1
National Oil and Transportation Co. (Associated Oil Co.).	do			1	1
New Pennsylvania Oil Co	do		1	1	2
Perpetual Oil Co	Arroyo Grande			1	1
Pacific Oil and Transportation Co. (Associated Oil Co.)	Santo Maria		1		1
Palmer Oil Co	do	1			1
Pinal Oil Co	do	11		3	14
Radium Oil Co	do		1		1
Recruit Oil Co. (Escolle & Newhall)	do		2	2	4
Rice Ranch Oil Co	do	2		1	3
Santa Barbara Oil Co	Santa Ynez			1	1
Santa Maria Oil Co. (Union Oil Co.)	Santa Maria	1		2	3
Santa Maria Oil and Gas Co. (Union Oil Co.)	do	4	1	3	8
Santa Ynez Valley Development Co	Santa Ynez				
Southern Pacific Co	Santa Maria			1	1
Standard Oil Co. (pipe lines, storage, etc.)	do				
Stillwell Oil Co	do				

a Water well.

Oil companies of the Santa Maria district—Continued.

Companies.	Field.	Oil wells.			
		Productive.	Abandoned.	Drilling.	Total.
Syndicate Oil Co. (Union Oil Co.)	Santa Maria			1	1
The Oil Co	....do		1		1
Tiber Oil Co	Arroyo Grande	1		2	3
Todos Santos Oil Co	Lompoc		1		1
Traders Union Oil Co	Santa Maria		1		1
Union Oil Co.:					
Burton lease	Lompoc			1	1
Eefson lease	....do	2	1	1	4
Folsom lease	Santa Maria	5		3	8
Fox lease	....do	5		1	6
Hartnell lease	....do	2	[a]1	1	4
Hill lease	Lompoc	2	1	1	4
Hobbs lease	Santa Maria	8		2	10
Newlove lease	....do			5	5
Wise & Denigan	Lompoc	8			8
Waldorf well	Santa Maria		1		1
Western Union Oil Co	....do	26	3	2	31
Yakima Oil Co. (Lucas) (Associated Oil Co	....do		1		1
Total		86	25	45	156

[a] Water well.

RÉSUMÉ.

The Santa Maria oil district, comprising the Santa Maria, Lompoc, and Arroyo Grande fields, occupies the central and northern portions of the Lompoc and Guadalupe quadrangles in northern Santa Barbara County and the southern part of the San Luis quadrangle in southern San Luis Obispo County, Cal.

The formations involved in the geology of the district include the Franciscan (Jurassic) sandstone, shale, glaucophane schist, jasper, and intruded serpentine; Knoxville (lower Cretaceous) conglomerate, sandstone, and shale; pre-Monterey (which may include both Cretaceous and older Tertiary) conglomerate, sandstone, and shale; Sespe (Eocene or Oligocene) sandstone; Vaqueros[a] (lower Miocene) conglomerate, sandstone, shale, and limestone; Monterey (middle Miocene) diatomaceous and clay shale, limestone, and volcanic ash; Fernando (Miocene-Pliocene-Pleistocene) conglomerate, sandstone, and shale; and Quaternary gravel, sand, clay, and alluvium.

Two structural systems prevail in the district, that of the northeastern portion trending northwest and southeast, and that of the southern portion trending east and west; while in the intervening region are features trending in a direction intermediate between the two. Few faults of importance were noted in the field. The productive territory lies in a region of more or less gentle folds in the central part of the area, most of the wells being located along or near anticlines.

[a] As mapped and described in this report the Vaqueros includes much Tejon (Eocene).

The wells vary in depth from 1,500 to over 4,000 feet. In the Santa Maria and Lompoc fields they obtain their oil from zones of fractured shale or sandy layers in the lower portion of the Monterey (middle Miocene) shale. The production of the individual wells varies from 5 to 3,000 barrels per day, being on an average between 300 and 400 barrels. The gravity of the oil ranges from 19° to 35° Baumé, the yield from the greater part of the field being about 25° to 27°. In the Arroyo Grande field the oil comes from sandstone at the base of the Fernando and has a gravity of 14°. There is much undeveloped territory in all these fields which promises to be highly productive.

Forty-three oil companies are listed as being interested in the district; 12 of these own all the producing wells. The estimated maximum daily capacity of the field January 1, 1907, was 40,400 barrels. The storage capacity for the field is 1,464,000 barrels, not including earthen reservoirs. The oil is transported by pipe line and rail, and finally by tank steamer.

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