Bulletin No. 322

Series { A, Economic Geology, 103
{ B, Descriptive Geology, 127

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGY AND OIL RESOURCES
OF THE
SANTA MARIA OIL DISTRICT
SANTA BARBARA COUNTY
CALIFORNIA

BY

RALPH ARNOLD AND ROBERT ANDERSON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1907

Bulletin No. 322

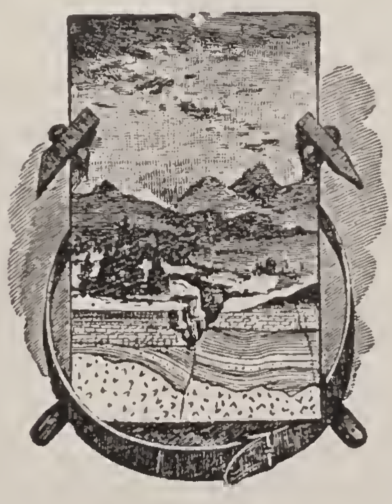
Series { A, Economic Geology, 103
B, Descriptive Geology, 127 }

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGY AND OIL RESOURCES
OF THE
SANTA MARIA OIL DISTRICT
SANTA BARBARA COUNTY CALIFORNIA

BY

RALPH ARNOLD AND ROBERT ANDERSON



WASHINGTON
GOVERNMENT PRINTING OFFICE
1907

CONTENTS.

Details of the developed territory—Continued. Page.

Santa Maria field—Continued.

The wells—Continued.

ILLUSTRATIONS.

GEOLOGY AND OIL RESOURCES OF 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, where the oil has accumulated in great abundance in the Monterey shale, of middle Tertiary age, 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 as high as 3,000 barrels a day, with an average of 300 to 400 barrels, are among the features for which the district has become noted. Large areas in the same general region as the productive fields have been known for some time to be analogous, so far as surface evidence went, to the proved territory, and it was thought that geologic investigations of the region might furnish valuable information and aid in the extension of developments. Accordingly, 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 writers carried on the field work leading to the present report during the summer and autumn of 1906. The geology of the region covered by the accompanying geologic map (Pl. I, in pocket) has not been completely studied in all parts. Between the San Rafael and Santa Ynez ranges it has been worked with considerable detail, but the mapping of the mountainous regions has been more in the nature of a reconnaissance outside of the areas of the Monterey formation.

A preliminary paper containing the features of this report most immediately pertinent to the oil developments and an outline map has been published as Bulletin No. 317 of the United States Geological Survey.

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[a] is quoted on the geology of Point Sal.

The writers are greatly indebted to Mr. F. J. Keeley and Prof. C. S. Boyer, of Philadelphia, and to Dr. Albert Mann, of the United States Department of Agriculture, for information concerning diatoms and their relation to the origin of the oil. Acknowledgments are also due to Messrs. E. C. Sullivan, W. T. Schaller, and George Steiger for making analyses of the Monterey shale. The analyses of oil on pages 115–117 were made by H. N. Cooper and published by the California State Mining Bureau in its Bulletins Nos. 31 and 32. The indebtedness of the writers to Mr. Cooper and to the mining bureau for this information is hereby acknowledged.

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. W. W. Orcutt, geologist of the Union Oil Company; Messrs. J. F. Goodwin and F. J. Burns, of the Pinal and Brookshire oil companies; Judge John D. Bicknell and Mr. Morris Albee, president and secretary, respectively, of the Western Union Oil Company; Mr. Adolph Phillips, of the Graciosa Oil Company; Mr. W. O. Maxwell, of the Recruit Oil Company; Mr. Charles Off, of the Rice Ranch Oil Company; Mr. E. E. Henderson, of the Palmer Oil Company; Mr. F. D. Hall, of the Hall & Hall Oil Company; Mr. W. A. Irwin, of the Claremont 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.

PREVIOUS KNOWLEDGE OF THE GEOLOGY.

Little attention has been given heretofore to the geology of the Santa Maria district. The earliest work was done by Thomas Antisell, with the assistance of observations by Albert H. Campbell, in the course of the explorations and surveys for the Pacific Railroad

---

[a] The geology of Point Sal: Bull. Dept. Geol., Univ. California, vol. 2, 1896, pp. 1–92.

in the early fifties.[a] In the report on this work the larger topographic features were well described, the presence of asphaltic rocks was briefly noted, and the Tertiary age of most of the sedimentary rocks was recognized, but the structural features and the relations of the rocks were in the main misinterpreted.

During the course of the geological survey of California by J. D. Whitney a hasty reconnaissance was made of a part of this region.[b] He says in his report:

> The region to the west of the San Rafael Range, between the Santa Ynez and Cuyamas rivers, was cursorily examined by our party. * * * The region is occupied by hills of moderate height. No metamorphic rock was seen; but pebbles of serpentine and metamorphic sandstone were noticed, especially for 3 or 4 miles north of Alamo Pintado. * * * These hills were covered with gravel derived from the bituminous slates. At times, especially near the Santa Maria River, the hills were capped by a modern horizontal deposit (post-Pliocene?). The underlying rock, when seen, was the bituminous slate, sometimes dipping to the north and sometimes to the south.
>
> Near Foxen's, on the south side of the valley, there were hills of nearly horizontal strata from 200 to 300 feet high, the north slopes of which were very steep, usually about 35°. Beneath the soft sandstone, which made up the principal part of these hills, was a stratum of infusorial rock resembling chalk in appearance, exceedingly light, its specific gravity not being more than 0.6 or 0.7; the thickness of this stratum was over 20 feet. The age of this formation is not yet definitely ascertained.
>
> North of the valley, at Foxen's, the bituminous slate occurs with a high dip to the north, and asphaltum is found in several localities near. In places the slates are altered and silicified, sometimes resembling semiopal in appearance, the finest laminæ of the original structure being preserved.

So far as the writers are aware no further investigation of the geology of the region was made until H. W. Fairbanks made examinations of portions of the Coast Ranges and reported on them for the State mining bureau in 1894. In his paper on the "Geology of northern Ventura, Santa Barbara, San Luis Obispo, Monterey, and San Benito counties" reference is made[c] to the region under discussion, especially to the Santa Ynez Mountains. Regarding the Santa Ynez Range he says: "It is formed, so far as is known, of Miocene rocks exclusively." And again:

> There can be no doubt that the main portion of the Santa Ynez Range is Miocene with a general anticlinal structure, well shown in the San Marcos Pass. The center of the anticlinal is not generally the highest portion of the range, but lies on the eastern slope. The normal type of anticlinal structure is also marked by an east and west compression, producing features, however, of secondary importance.
>
> As viewed from the south at various points the range consists of heavy-bedded sandstone, dipping at a high angle to the south. * * * At the western end, in the vicinity of Point Arguello, no anticlinal structure is apparent, but steeply inclined and broken strata. Asphaltum is found in many places near the sea from Point Arguello to Ventura County.

---

[a] Pacific R. R. Repts., vol. 7, 1857, Chaps. VIII, IX, and X.

[b] Geological Survey of California, Geology, vol. 1, 1865, pp. 135-138.

[c] Twelfth Ann. Rept. California State Mining Bureau, 1894, pp. 498-506.

The present writers are in agreement with these statements except as regards the exclusively Miocene age of the rocks, a large part of which are here considered as Eocene. On page 505 of Fairbanks's article he speaks of "shales and sandstones of undoubted Cretaceous age" between Gaviota Pass and Santa Ynez River, in the hills which in the present paper are considered as part of the Santa Ynez Range. In the very short time spent in this locality the present writers found no evidence of the presence of Cretaceous rocks.

A number of asphalt deposits in northern Santa Barbara County are described on pages 30 to 33 of the twelfth annual report of the State mineralogist, cited above. The localities mentioned are on the Los Alamos grant, 4½ miles north of Harris station; along the northern slope of the hills bordering the Santa Maria Valley, 10 miles southeast of Santa Maria; about 2 miles northeast of the Purisima Mission; along the southern slope of the hills between the Los Alamos and Santa Ynez valleys (Purisima Hills), especially on the San Carlos de Jonata grant; and in poorer and less known deposits at Gaviota Landing, at Point Arguello, near the mouth of Canada Honda, and at other points toward Lompoc Landing. Seepages out of the bituminous "slate" (shale) series are mentioned as occurring in the canyon of the Sisquoc, about in the center of the Sisquoc grant, along Labrea Creek, and near the west end of the Tinaquaic grant.

By far the best observations recorded up to 1896 regarding the geology of this region were those of H. W. Fairbanks, published in his paper on the "Geology of Point Sal."[a] He gives a detailed description of the igneous and sedimentary formations occurring at the seaward end of the hills, termed in the present report the Casmalia Hills. In speaking of the even summit line of the Point Sal Ridge he says:

> The regularity is due, in part at least, to the fact that the strata on the summit are nearly flat and composed of the resistant Miocene flints, while on the southern slope the bituminous shales are followed in descending order by a great thickness of gypsiferous clays, in which broad valleys have been eroded. Lower down toward the ocean the clays are replaced by strata of volcanic ash, sandstone, and conglomerate, in which, because of their greater resistance, canyons have been eroded. The strata of volcanic ash form very striking features in the landscape on the lower slopes of the ridge; being interbedded with soft clays they weather out in cliffs and projecting ridges.

In outlining the geology of the region of Point Sal Ridge, Fairbanks says:

> The region about the point itself has been the scene of many violent disturbances and repeated eruptions of basic magmas. A part of these consolidated as surface flows, while others have the characters of deep-seated rocks.
>
> The sedimentary strata comprise only the Pleistocene, Miocene, and Knoxville. * * * The Miocene is the most extensive formation represented. * * * It is

---

[a] Bull. Dept. Geology Univ. California, vol. 2, No. 1, 1896, pp. 1-92.

> divisible into two distinct parts—the upper, the bituminous shales, and the lower, the gypsiferous clays. Below the clays are sandstone, shales, and conglomerates resting on the gabbro and serpentine. * * * The strata of volcanic ash appear in the lower Miocene beds. There are three distinct horizons, the lowest resting on the gabbro.

The igneous rocks are treated in especial detail in this paper and a very good description is given of the bituminous shales. The conclusions of the present writers are in agreement with the statements above quoted and the others contained in Fairbanks's paper.

In 1901 George H. Eldridge gave an admirable general outline of the topography and geology of the country surrounding the Santa Maria field in his treatise on "The asphalt and bituminous-rock deposits of the United States," and discussed in detail its asphalt deposits.[a] He says:

> The geology of the region embraces an underlying series of folded Monterey shale of both the soft and more organic material and that which is hard and siliceous, but the former predominates. So far as observed by the writer this series of beds was not exposed at any point in its entirety. Overlying the Monterey unconformably, and especially developed in La Graciosa Hills, is the heavy and extensive deposit of Pliocene sands, grits, and conglomerate already referred to. The composition of the later deposit is chiefly quartzose.

Eldridge "observed a prevailing central fold somewhat to the north of the topographic axis of the ridge" south of Waldorf, in the Casmalia Hills, this being no doubt the fold described in the present report as the Schumann anticline. He says further:

> The Pliocene * * * shows a less degree of folding than the underlying Monterey, yet the movement that produced the pre-Pliocene ridge has apparently been continued subsequent to the deposition of the materials of this age, for gentle dips of from 2° to 10° are to be observed in the later formation.

In discussing the country east of Los Alamos, between the San Rafael Range and the Santa Ynez Valley, which he calls the Los Alamos region, Eldridge says:

> In structure the Los Alamos region presents a series of folds which are in general coincident with the topographic ridges and valleys. * * * It is worthy of note that the valleys of the region under consideration for the most part occupy the synclinal troughs. It is possible that some of them also occupy fault lines. * * * The general trend of the folds for the Los Alamos district, and indeed for a great stretch of country beyond, is N. 70° to 80° W., the dips being north and south. Excepting in their trend, however, there is but little regularity in the disposition of the folds, and their axes, both longitudinal and transverse, vary greatly in length. In addition to the main and conspicuous folding that has been described, there are frequent crumples of minor importance.

In another place Eldridge mentions a lens of limestone included in the serpentine in a high bluff just north of Alamo Pintado Creek, along the old beach line where the Fernando was deposited upon the Franciscan at the base of the San Rafael Mountains. This lime-

---

[a] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 1, 1901, pp. 424-441.

stone was composed largely of Pliocene shells, as determined by Doctor Dall. Eldridge remarks: "In view of the supposed age of the serpentine, it is thought that the deposit was formed by the accumulation of sediment and shells in a crevice of the older rocks at the time they perhaps formed the sea bluffs."

The same writer published a brief summary of his knowledge concerning the Santa Maria district in 1903.[a]

The San Luis folio,[b] by H. W. Fairbanks, issued in 1904, contains much that relates to the district in general, although it pertains directly only to the part containing the Arroyo Grande field. It is the most comprehensive report concerning the northwestern part of the Santa Maria district yet published.

The present writers have published two papers concerning the geology and economic resources of the Santa Maria district. The first is entitled "Diatomaceous deposits of northern Santa Barbara County, Cal.,"[c] and the second "Preliminary report on the Santa Maria oil district, Santa Barbara County, Cal."[d] A third paper treating more in detail the burning of the shale is "Metamorphism by combustion of the hydrocarbons in the oil-bearing shale of California," to be published in the Journal of Geology.

EARLY HISTORY OF THE DISTRICT.

The Santa Maria 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 by Mr. Mulholland on certain lands of the Careaga ranch, 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.

Successful wells were drilled in the Lompoc field in 1904, and since that time the further development of this part of the district has been assured. A later field to attract attention is that adjacent to the town of Arroyo Grande, where development is well under way, being stimulated by the completion of the successful Tiber well No. 1 late in 1905. Prospecting is now (January, 1907) going forward in the Huasna field east of the Arroyo Grande field, and the operators there confidently expect to develop productive wells.

---

[a] Contributions to economic geology, 1902: Bull. U. S. Geol. Survey No. 213, 1903, p. 313.

[b] Geologic Atlas U. S., folio 101, U. S. Geol. Survey, 1904.

[c] Bull. U. S. Geol Survey No. 315, 1907, pp. 438-447.

[d] Bull. U. S. Geol. Survey No. 317, 1907, pp. 1-69, 2 pls., 1 fig.

GEOGRAPHY AND TOPOGRAPHY.

LOCATION.

The region discussed in this paper is situated on the California coast in Santa Barbara County, between 120° and 120° 40′ west longitude and 34° 30′ and 35° north latitude. In areal extent it is about 1,300 square miles and it practically covers the Lompoc and Guadalupe quadrangles as topographically mapped by the United States Geological Survey. It includes portions of the San Rafael and Santa Ynez divisions of the Coast Ranges and the basin region lying between them, which is occupied by the Santa Maria, Los Alamos, and Santa Ynez valleys and the intervening hill ranges. It is bordered on the north by the San Luis Obispo County line, on the west and south by the Pacific Ocean, and on the east by the Santa Ynez quadrangle, which covers the high, wild mountains north of Santa Barbara. On its west coast are Point Sal and Point Arguello, and the south coast includes Point Conception and part of the long, straight shore line that runs due east from that point toward Santa Barbara. These are among the most prominent coastal features of California.

The region is thoroughly intersected by roads, except in some of the uninhabited portions. The Southern Pacific Railroad coast line, part of the transcontinental system, extends close to the ocean entirely around two sides of the area, and the Pacific Coast Railroad, a local line from Port Harford and San Luis Obispo, runs into the region as far as Los Olivos via Santa Maria. A rough estimate would place the number of inhabitants of this region between 5,000 and 10,000.

The Arroyo Grande and Huasna oil fields, in the San Luis quadrangle, San Luis Obispo County, are also briefly mentioned, although not a part of the region whose general features are described in this report.

DEFINITIONS OF PLACE NAMES.

The following list defines certain place names as used on the map and in this report. The two main mountain ranges have heretofore been indefinitely designated The other names are newly applied.

The only land comprised within the Guadalupe quadrangle is the narrow strip of coast west of longitude 120° 30′ W. The Lompoc quadrangle covers the rest of the area shown on the map 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 plateau-like region of hills extending from the coast a distance of about 5 miles east from Honda and the same distance southeast from Surf.

In 1896 H. W. Fairbanks used the names "Point Sal Ridge" for the axis of the hills between Mount Lospe and Point Sal, and "Lions Head" for a high, rugged mass of serpentine on the coast south of Point Sal. These features are so named here.

RELIEF.

GENERAL STATEMENT.

The general character of the region covered by the Lompoc and Guadalupe quadrangles is that of a triangular hilly basin opening out toward the coast between two divergent ranges of mountains—the San Rafael Range in the northeast portion of the area and the Santa Ynez Range bordering it on the south. At the east edge of the area mapped these ranges are divided only by the valley of Santa Ynez River and the foothills north of it. Farther west the distance between them grows to 30 miles or more. The region situated in this angle is primarily a basin, owing its character and the details of its structure to its position between these ranges. This basin region, its structure, and its oil deposits form the principal subjects of discussion in the present paper.

Two lines of hills and three valleys occupy this trough between the two main ranges, radiating like the intermediate ribs of a fan between the lines that bound them. The more northerly of the two lines of hills is that of the Solomon and Casmalia hills, which are separated from the San Rafael Mountains by the wide valley of Santa Maria River. The more southerly is the range of the Purisima Hills, which is separated from the Santa Ynez Mountains by Santa Ynez River. These two lines of hills are themselves divided by Los Alamos Valley.

They are topographically and structurally young ranges, except the Casmalia Hills, at the extremity of the northern line, which have the character of a separate and old range.

SAN RAFAEL MOUNTAINS.

The most prominent topographic feature is the great mass of the San Rafael Mountains on the northeast and east, 25 to 30 miles back from the ocean. The structural trend of the range is N. 50° W., approximately parallel with the general course of the lines of structure in California, although on the whole more westerly. The range runs obliquely to the north-south coast line west of it, but farther north, where the Santa Lucia Range, its northward continuation, approaches the ocean the coast curves to the northwest under the control of the mountains.

Although the portion of the San Rafael Range included within the area shown on Pl. I (pocket) composes a high, rugged maze of ridges reaching elevations that range between 2,000 and 4,300 feet, this portion is in the larger aspect, but subsidary to the main mountain group farther east, in which altitudes approaching 9,000 feet are attained. The ridges are divided by steep canyons, most of which cut transversely across the formations regardless of the folding and structural lines. Rounded soil-covered slopes form a considerable portion of the part of this range included in the Lompoc quadrangle, but rough, rocky slopes are likewise abundant. The range is traversed centrally by the well-graded canyon of Sisquoc River, which divides it into two mountain groups. On the south and north the range is bounded by wider graded valleys—those of Santa Ynez and Cuyama rivers. The Santa Ynez divides two distinct ranges. The Cuyama forms a more arbitrary division in the Coast Ranges. Near its mouth, at the point where it reaches the area included in the accompanying map, it veers to the south and cuts a narrow gorge across the San Rafael Mountains without regard to the structure. The range may be regarded as continuous across this portion of the river.

Within the triangular area mapped the high ridges and mountains around Zaca Lake, Bone Mountain, Tepusquet Peak, and Los Coches Mountain are boldly defined, with steep side slopes descending into narrow canyons, and as a rule rounded summits. The broad ridge originating north of Los Coches Mountain and extending southeastward to North Fork of Labrea Creek, where its character is temporarily lost until it appears again in Manzanita Mountain, is a striking feature with its long southwestern and abrupt northeastern slopes. The seaward flanks of the range terminate rather abruptly in the terraces bordering the Santa Maria Valley.

SANTA YNEZ MOUNTAINS.

The Santa Ynez Mountains form a long, narrow range bordering the Santa Barbara Channel and bounded on the north by the westward flowing Santa Ynez River. The trend of the range is east and west and has determined the unusual direction taken by the coast south of it. The range is about 9 miles in average width and contains two lengthwise zones. The southern zone comprises a ridge with remarkably even sky line, which rises directly from the sea. This ridge increases in height toward the east from an elevation of 1,000 feet at Point Conception to 3,800 feet east of Refugio Pass and more beyond the boundary of the area mapped. At Point Conception the coast bends abruptly to the northwest around the end of this ridge, but north of Jalama Creek a similar ridge, that of the mountain El Tranquillon, follows the coast as far as Point Arguello, where the shore bends again abruptly and assumes a northward course. The second zone lies between these two coast ridges and Santa Ynez River. It has more the nature of a foothill region, forming a partly individual range of hills and ridges separated from the coastal ridge by longitudinal valleys. The average slope from the summit of the range down to the sea is at an angle of 20° to 30°. In places the angle is less, but on some individual slopes it is greater. The width of the range on the north of the summit ridge is greater and the slope more gentle and more broken than on the southern abrupt slope to the sea. Viewed from the ocean on the south the range has the appearance of a steep, even-topped breastwork; from the north it appears as a belt of discontinuous hills and ridges grouped in front of and almost hiding the long culminating ridge. The Santa Ynez Range forms the most prominent elbow on the California coast.

The topography of this range reflects the structure more than does that of the San Rafael Mountains, and deformation within it does not appear to have gone so far.

In the high mountainous region east of the area mapped, north of Santa Barbara and south of the south end of the great central valley of California, centering at Mount Pinos, lies the point of convergence of all the ranges of mountains in this part of California—the Santa Ynez Range coming in from the west; the San Rafael Range from the northwest; the Santa Lucia and San Jose ranges from the country north of Cuyama River; the Mount Diablo Range, or easternmost member of the Coast Ranges, from still farther north of west; the Tehachapi Range, running southwestward from the south end of the Sierra Nevada; and the San Gabriel Range, which comes from the southeast as the continuation of the Coast Ranges in southern California. Here the northwest-southeast lines of structure, dominant throughout the major part of the State, are met and opposed by the east-west structure of the Santa Ynez Range, and the result is this convergence of ranges with the consequent formation of a high, structurally complex region. The Lompoc quadrangle is on the western outskirts of this region, and the lines of relief corresponding to the two lines of structure are here beginning to diverge and show their individuality in the two bounding ranges.

SANTA MARIA VALLEY.

Santa Maria River, which takes its rise in two profound valleys within the San Rafael Range, flows along the foot of this range at the north edge of the Santa Maria Valley. This valley is a wide flood plain with an even cultivated floor, surrounded by low terraces that fringe the base of the mountains on the northeast and rise into the Solomon Hills on the south. It opens out to the sea and forms the southern part of the low region lying between Pismo Beach in San Luis Obispo County and the Casmalia Hills.

CASMALIA HILLS.

The most prominent feature of the landscape south of the Santa Maria Valley is a long ridge with a level sky line running northwestward out to the ocean at Point Sal. This is the high ridge of the Casmalia Hills, which rises abruptly from the Santa Maria Valley. Its highest point is Mount Lospe, 1,624 feet above the sea. The slope up to this ridge from the valley on the northeast is steep, but on the north the rise is more gradual over wide slopes of dune sand. On the southeast the ridge declines as it approaches Schumann Pass, the low divide over which the railroad crosses from the Santa Maria Valley to Schumann Canyon; on the south it forks into successive ridges which slope gradually into terraced hilltops bordering Schumann Canyon; on the west it drops off abruptly into steep, rocky declivities that fringe the sea in the neighborhood of Point Sal. The ridges continue southeastward opposite Schumann Pass as far as Graciosa Canyon, where they sink under more recent sand formations and lose their character. South of Schumann Canyon the terraced slope continues in the San Antonio terrace as a wide plateau locally intersected by sharply defined U-shaped canyons. The Casmalia Hills, particularly that portion north of Schumann Canyon, have a distinct individuality among the topographic features of the basin region, and may be regarded as a separate although small range allied in age and character with the bounding ranges. It is conformable in trend with the San Rafael Mountains and forms a prominent headland jutting out to sea.

Most of the ridges in these hills follow the strike of the beds. Their summits are characteristically of gentle incline; the side slopes range from gentle to fairly steep, being in many places determined by the dip. Pl. IX, *A* (p. 80) shows excellent examples of the strike ridges, dip slopes, and even sky lines of these hills. The ridges diverging from Mount Lospe are given prominence by the hard flint of which they are formed, and the sharp outlines of the slopes along the coast southward from Point Sal are caused by the resistant igneous rocks there exposed.

South of the Casmalia Hills the sea has cut into soft formations and along structural lines, so as to leave the Point Sal Ridge jutting out as a promontory. The same is true on a smaller scale south of Purisima Point, the seaward extension of Burton Mesa, and south of the west end of the Santa Ynez Range. The coast north of each of these headlands runs northward, with only a gentle curve away from the point, until the indentation south of the next range is reached. The east-west coast lines follow structural features; the north-south lines truncate them. Faults are not concerned in any of the north-south features along this part of the coast.

North of the Casmalia Hills the coast forms a straight north-south line bordering the lowland that opens out at the mouth of the Santa Maria Valley as far as the deep indentation at the base of the San Luis Range, which exhibits the best example of this type of coastal structure. The latter range lies in the San Luis quadrangle and has been described in the folio covering that region.[a]

SOLOMON HILLS.

Although the Casmalia Hills drop into insignificance in the vicinity of Graciosa and Harris canyons, their general line of topographic relief continues with a more easterly course toward the San Rafael Mountains, the whole being in fact a spur of this range. The Solomon Hills are a group of low, rolling hills covering a wide area between the Santa Maria and Los Alamos valleys. From a distance the area looks like an undulating plateau sloping away on all sides except the east to wide, slightly inclined or flat valleys.

The features of the topography of the Solomon Hills are shown in Pl. XI (p. 98). From a point near at hand the individual hills and valleys of irregular round and square forms assume bold outlines. The angular slope of hills capped with low-dipping beds of sand and having steep, squarish flanks is very characteristic of the region. Many ridges have fairly flat summits, which slope gently, with a long, even sky line, and are due to surface cappings of sand hardened by iron oxide. Such a capping has in places the appearance of a resistant bed forming the ridge top and determining the slope by its low dip.

Mount Solomon has an elevation of 1,338 feet and other peaks rise

---

[a] Geologic Atlas U. S., folio 101, U. S. Geol. Survey, 1904.

as high as 1,600 feet. A common height for summits in these hills is 1,200 feet.

Wide, shallow, filled valleys between the rolling summits are characteristic of the Solomon Hills, the soft valley filling being as a rule sharply cut along a meandering course by a miniature stream gorge that has been rapidly eroded. Many of these recent channels are deeper than they are wide. In the vicinity of La Zaca Creek on the east the Solomon Hills merge with these foothills, and the general topographic features are continued in them. The Solomon Hills owe their low outlines largely to their structural development rather than to their topographic maturity. It has been an area of building up as well as of wearing away, and the original topography, which reflected characteristically the folds of the sedimentary formations, has been obscured by further deposition and by the filling of valleys, in addition to alteration by erosion.

LOS ALAMOS VALLEY.

The incline of the Solomon Hills on the south is gradual down to the Los Alamos Valley. This valley extends from the region where the Solomon and Purisima hills coalesce in the foothills of the San Rafael Range a distance of about 27 miles to the coast, in a direction about N. 75° W. This, it will be noted, is much more westerly than the trend of the Santa Maria Valley. The Los Alamos Valley separates the two basin ranges—the Solomon and Purisima hills—and is a drainage feature of them alone. The average altitude at the summit of its watershed is from 1,000 to 1,300 feet; and the highest elevation that the watershed reaches anywhere is less than 2,000 feet. All the water from the higher surrounding regions that drains into the Santa Maria basin region escapes either into the Santa Maria Valley on the north or the Santa Ynez Valley on the south.

PURISIMA HILLS.

The second of the two hill ranges is that of the Purisima Hills, which forms a definitely outlined structural and topographic unit springing from the plateau region about Santa Ynez and the foothills of the San Rafael Range in the vertex of the triangular basin. It rises at that point in the shape of a number of strike ridges which run northwestward and then curve around to the west, coming together. For most of the distance to the ocean beyond this junction the range consists of a single ridge running parallel to the Los Alamos Valley. On the north it sends out lateral ridges that drop off rather abruptly into the Los Alamos Valley. These ridges are separated by fairly sharp V-shaped valleys, although some of the valleys have sides of more gentle slope and filled bottoms. A striking topographic feature is a longitudinal trough running for miles parallel with this range and the Los Alamos Valley and cutting across the ends of the above-mentioned ridges at right angles to them, at a distance of one-half to 1 mile from the valley. It notches all the ridges and leaves an individual row of knobs 100 to 200 feet in relief bordering the valley. This depression is not a continuous drainage feature, but is stratigraphically of importance as approximately marking the contact between the Monterey shale and the loose Fernando sand. On the south side of the summit of the Purisima Hills the lateral ridges extend a long way with a uniform gentle slope, like remnants of an eroded inclined plateau. At their base, some miles from the summit, and usually from 500 to 1,000 feet below, these southern slopes merge into an undulating hilly plateau that has the appearance of being buried under soft recent sand. The range is broadest at the east end, where it consists of a number of parallel ridges. The point of convergence of some of these is Redrock Mountain, which is 1,968 feet high and the highest summit in these hills. Thence westward the hilly zone narrows into a single central ridge and its offshoots, and gradually pinches out, finally giving place on the south and west to a broad terrace in which its hilly character is lost. The summit of the main ridge of the Purisima Hills west of Redrock Mountain gradually declines in height and for most of the way it is remarkably even, the elevation varying between 1,200 and 1,000 feet. At the elevation of 1,000 feet it grades into the smooth terrace called Burton Mesa.

BURTON MESA.

Burton Mesa is a marine terrace covering more than 50 square miles, which slopes, with an average gradient of 2½ per cent, away from the west end of the Purisima Hills, reaching the sea within 7½ miles. It is composed of Monterey shale, in the main rather gently folded, which has been planed off and covered with a thickness of about 25 feet of horizontal gravel and loose sand. From the elevation of 1,000 feet, where the continuous sheet of sand overlaps on the end of the Purisima ridge, down to the 600-foot level the distance in a west-southwest direction is three-fourths of a mile and the slope 10 per cent. Within the next three-fourths of a mile a drop of 100 feet occurs, the slope being 2½ per cent. Beyond lies the main level stretch of the plateau for a distance of 5 miles, with no greater slope than three-fourths of 1 per cent until the elevation of 300 feet is reached, in the southwest corner of the mesa, where there is an abrupt change to a 10 per cent slope, the distance down to elevation 100 feet being only one-third of a mile. Below the 100-foot level there is a bench with a 3 per cent grade as far as the edge of the cliff which faces the sea, and which is in most places about 25 feet above the water. North of Canada Tortuga the steeper portion above the coastal bench is only 100 feet high, and in the northwest corner of the mesa the main terrace and the coastal bench grade into each other and become practically one.

SANTA YNEZ VALLEY AND SANTA RITA HILLS.

Santa Ynez River is the second of the two main drainage lines of the area, Los Alamos Creek, the next in size, being much subordinate to these two. The Santa Ynez rises in the high region north of Santa Barbara and flows westward between the Santa Ynez and San Rafael ranges. From the east edge of the Lompoc quadrangle, where these two ranges diverge, it flows slightly to the north of west, at the foot of the Santa Ynez Mountains. Its course is even more westerly than that of the Los Alamos Valley until it approaches the ocean, where the nose of the Santa Ynez Range, as in the two ranges farther north, shows a tendency to change its orientation into greater conformity with the northwesterly course of the San Rafael Range.

This stream has a low gradient of only one-fourth of 1 per cent. Its valley has a steep side on the south formed by the hills of the Santa Ynez Range, but it is widened on the north by the easy slopes of terraces and sand hills, except at the Santa Rita Hills, which rise midway in the river's course.

The Santa Rita Hills form a small separate range reaching a height of 1,300 feet and resembling in miniature the Purisima Hills. The range starts from the valley in several strike ridges running northwest, which join in the highest part of the range and then continue due west as a single ridge. The river follows a tortuous course between this and the Santa Ynez Range and has cut cliffs in many places. On the north the Santa Rita Hills are divided from the Purisima Hills by the Santa Rita Valley, a low basin similar to some portions of the Santa Ynez Valley.

The level floor of the river valley, including the stream bed and the somewhat higher terrace-like flats on either side, ranges in width from a few hundred feet to about a mile until within 10 miles of the ocean, where it opens out into the Lompoc Valley, an alluvial flat several miles wide.

TERRACED COAST.

Pleistocene terraces border the coast for the greater part of the distance around the Guadalupe and Lompoc quadrangles. The great Burton Mesa terrace has already been mentioned. Beyond the valleys to the north and south of this mesa similar terraced areas extend widely and in places to a considerable distance inland, but nowhere else with so gentle a slope as is exhibited on the Burton Mesa.

Where steep hills descend toward the coast there is almost without exception a coastal terrace starting at the top of the sea cliff, which, as a rule, ranges in height from a few feet to more than 50 feet above the water. Most of these terraces extend up to an elevation greater than 200 feet. Some of them have left traces at a height of 300 feet or more, and others continue perfect to this altitude or even higher.

GENERAL TOPOGRAPHIC FEATURES.

The point of especial interest in the topography of the central region between the two bounding ranges is its characteristic reflection of the structure of the formations, whereas in the mountains, as has been noted, the topographic development has been less in accordance with the lines of structure. An anticline in the central region is apt to be coincident with a ridge, as, for example, in the long ridge of the Purisima Hills, which lies close to the axis of a broad anticline. Moreover, some of the larger valleys mark the synclinal axes of the broad lines of structure—a statement 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 accounted for by the facts 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 so very far. Wherever there are low areas of rolling hills it is almost sure to be found 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.

The character of the different formations shows its influence on the topography. The areas of serpentine with associated Franciscan rocks have irregular broken surfaces with many outcrops and usually an old, well-worn appearance. The dominantly sandstone and shale terranes described under the headings "pre-Monterey rocks" and "Vaqueros, Sespe, and Tejon formations, undifferentiated," do not give rise to a very distinctive topography. They form a succession of ridges and V-shaped canyons of moderate relief and comparative regularity. In many places the truncated edges of the tilted strata form steep, rough strike slopes. The Monterey shale produces the forms of highest relief in this region, as well as forms of low relief, according to the amount of folding that has taken place in it and to its hardness. The brittle shale closely folded gives rise to sharp ridges, many of them serrate, with steep, rocky flanks. Ridges of highly tilted shale are shown in Pl. VI, *B* (p. 46). The lower folds produce hills of gentle incline and long unbroken ridges, in places parallel with the strike and having a dip slope, as shown in Pl. IX, *A* (p. 80). Characteristic of the soft shale are hills having the form of mounds with symmetrical rounded contours and with few prominent outcrops except pavements of shale forming the surface. The soft Fernando sands form small hills that look like irregular sand piles, and long slopes with shallow erosion features. Some of these slopes reflect the dip of the strata on the flanks of low folds and are structurally inclined plateaus in a typical state of youthful dissection. The valleys are, in many places, filled with sand that has shifted down from the hills faster than it could be carried away by agencies of transportation. Great cliffs of soft sand are common as the result of the rapid undermining and removal of portions of hills. Thus walled cirques are formed. Harder materials in the Fernando cause squarish forms, such as that of Mount Solomon. The terraces of the Quaternary give a strong individuality to the topography of this region. They are widely in evidence along the coast, in valleys, at all levels up to 1,200 or 1,400 feet on slopes, on hilltops, and along horizon lines.

DRAINAGE AND RAINFALL.

The three principal streams have received mention under the previous headings. A small amount of water runs in them all the year round, but the quantity is only rarely sufficient in either of the two main streams to warrant their being called rivers. This name is applied to them on the ground of the importance of their drainage areas. Almost all the drainage of the two quadrangles flows into these three streams. In the main they run parallel to the strike of the formations. In addition to those already mentioned, others that run independently into the sea are Casmalia Creek, in Schumann Canyon, which first cuts obliquely across the end of the Casmalia Hills and then assumes a longitudinal course; Canada Honda Creek and Jalama Creek, the two last having deeply cut courses parallel with the structural lines at the west end of the Santa Ynez Mountains. The steep seaward slope of these mountains is cut into by a great number of short, steep, transverse gorges.

The portion of the San Rafael Range lying within the area covered by the map is drained principally by Sisquoc and Cuyama rivers, which flow along well-graded courses, and by the minor streams, Labrea and Tepusquet creeks. With the exception of the Cuyama, these watercourses and the majority of the others in the mountains have cut transverse canyons across the formations regardless of the folding and the structural lines. In this respect they differ from the streams farther south.

On the whole, it is rather a dry region. An average of only 12 or 15 inches of rain falls annually, during the winter rainy season. During the long dry season almost complete evaporation of surface moisture takes place, and there is little erosion through the aid of water. Throughout the latter part of the Quaternary period the rate of erosion has probably been slow.

CLIMATE AND VEGETATION.

The climate of this area is that of the coastal region of California. It is equable the whole year round, excessive heat or cold being very rare. The days are mild, the nights chilly. The region is subject to the inroads of heavy fogs and driving winds from the open ocean, but this is true to a lesser degree in the eastern angle of the basin, where there are protecting hills on all sides. The winds blow very strongly from the west and northwest up the radiating valleys that open to the coast. The region is subject to earthquakes, some of which would seem to be of local origin.

The vegetation in the northern part of Santa Barbara County is open, as in the neighboring portions of California. There are almost no dense groves of trees, most of the hills being sparsely clothed with a scattering growth of small trees, usually live and white oaks, and bushes, or else entirely bare, except for sagebrush and grass. The wide terraces and hills of soft sand are commonly overgrown with so-called tarweed and are otherwise almost bare. In the valleys near the coast grow many willows; in the more protected valleys farther inland thrive large sycamores, cottonwoods, and live and white oaks. The steep slopes of the San Rafael Range are sparsely set with small oaks, pines, and yuccas, and, like those of the Santa Ynez Range, are covered in parts by dense thickets of undergrowth.

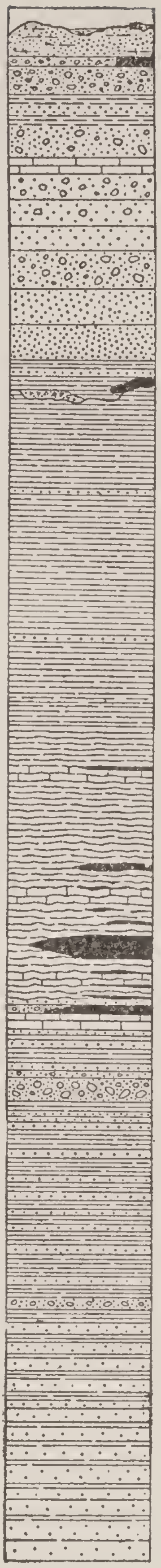
The vegetation of the hill ranges of the basin region is typically illustrated by Pl. IX (p. 80) and of the San Rafael Mountain region by Pl. VI (p. 46).

GEOLOGY.

SEDIMENTARY FORMATIONS.

GENERAL STATEMENT.

The formations involved in the geology of this district (see Pl. II) include the Franciscan (Jurassic?); Knoxville (lower Cretaceous); pre-Monterey rocks (which may include both Cretaceous and older Tertiary); Tejon, Sespe, and Vaqueros, undifferentiated (Eocene-Miocene); Monterey (middle Miocene); Fernando (Miocene-Pliocene-Pleistocene); and Quaternary. The maximum known thickness of the Tertiary and early Quaternary formations combined is 13,200 feet. The following table shows the correlation of these formations with the



Alluvium (1′—100′+) .... Sand, clay, gravel, and earth.

Sand dunes (10′—300′+) .... Marine sand, loosely aggregated and slightly horizontally bedded.

Terrace deposits (30′+) .... Sand, gravel, and clay, often hardened by iron oxide. Seepage from Monterey often causes asphalt deposits.

Unconformity.

Fernando formation (3,000′+).

- Slightly consolidated gravel, sand, and clay.
- Brackish-water limestone and alkaline sand.
- Fine, soft, yellow sand near bottom, grading upward into coarser white and gray sand and gravelly conglomerate.
- Fine, white, diatomaceous shale and fine, white and greenish sand. Local breccia and asphalt deposits (shown in black).

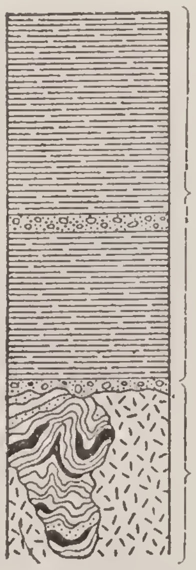
Unconformity.

Monterey shale (5,400′+)

- Soft, white, thin-bedded, diatomaceous earth or shale, with intercalated beds and lenses of concretionary lime and hard, brittle, siliceous shale due to metamorphism. Occasional fine sand beds. Shale locally bituminous; gypsiferous near top.
- Western Union. Zone A. Zone B. Zone C. Thinly stratified and much-contorted hard, brittle, and siliceous shale, often flinty, with some soft, unmetamorphosed diatomaceous shale and frequent beds of limestone and flint. Tuff and volcanic ash occur locally; Shale bituminous. Four principal petroleum zones shown in black and auxiliary zones indicated.

Vaqueros, Sespe, and Tejon formations, undifferentiated (5,000′+). .... Alternating beds of dark clay shale, sandy shale, and sandstone; frequent massive limestones near top. Thick beds of fine and very coarse conglomerate in upper portion. Shale and sandstone thin-bedded; sandstone becoming more massive toward top.

The relation of the formations above to those below is not known. The rocks mapped as pre-Monterey may fill this gap and lap over onto the formations above and below.



Knoxville formation (3,000′±). Not extensively recognized. Thickness and character as described by Fairbanks in adjacent San Luis quadrangle. .... Dark, thin-bedded clay shale, with thin irregular layers of conglomerate at bottom and near middle.

Unconformity.

Franciscan formation (1,000′±). .... Largely intrusive serpentine, associated with much-contorted banded jasper, dark, greenish hard sandstone and shale, and with some glaucophane schist.

COLUMNAR SECTION OF THE SEDIMENTARY ROCKS OF THE LOMPOC AND GUADALUPE QUADRANGLES.

standard California section and with that of Santa Clara Valley, Ventura County:

Tentative correlation of formations of Santa Maria district with the standard California Coast Range section and with that of the Santa Clara Valley.

Era.	System.	Period.	Standard Coast Range section.	Santa Maria district section.	Santa Clara Valley section.
Cenozoic.	Quaternary.	Recent.	Alluvium.	Alluvium.	Alluvium.
		Pleistocene.	San Pedro. —— Unconformity ——	Terrace deposits and dune sand. —— Unconformity ——	Sand and gravel. —— Unconformity ——
	Tertiary.	Pliocene.	Merced.	Fernando.	Fernando.
			Purisima.		
		Miocene.	San Pablo. —— Unconformity ——	—— Unconformity ——	—— Unconformity ——
			Monterey.	Monterey.	Modelo. Shale. Upper sandstone. Shale. Lower sandstone.
			Vaqueros.	Vaqueros, Sespe, and Tejon, undifferentiated (including some Monterey in Santa Ynez Range).	Vaqueros.
		Oligocene.	San Lorenzo. —— Unconformity? ——		Sespe. Upper. Red beds. Lower.
		Eocene.	Tejon.		Topatopa.
			Martinez. —— Unconformity? ——		
Mesozoic.	Cretaceous.		Chico. —— Unconformity ——	(?)	(?)
			Horsetown. —— Unconformity ——		
			Knoxville. —— Unconformity ——	Knoxville.	
	Jurassic (?).		Franciscan. —— Unconformity ——	Franciscan.	—— Unconformity ——
			Granite, schist, etc.		Granite, gneiss, etc.

FRANCISCAN FORMATION (JURASSIC?).

The oldest rocks within the Santa Maria district belong to the Franciscan formation, which is probably of Jurassic age. H. W. Fairbanks described the same formation under the name San Luis in the San Luis folio. The Franciscan is a very important basement formation in the Coast Ranges farther north. The small areas of these rocks occurring here consist of remnants of beds of sandstone, shale, glaucophane schist, and jasper associated with serpentine that has probably been intrusive in them. The sandstone is usually 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 clew 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.

KNOXVILLE FORMATION (LOWER CRETACEOUS).

Several small areas of sedimentary rock occur which can be definitely assigned on fossil evidence to the Knoxville, or 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 the characteristic Knoxville fossil *Aucella piochii* Gabb (Pl. XIII, figs. 1, 2, 3a, 3b, p. 128). The rock is present only in very small patches, and seems to have been brought up from below by the diabase intrusion. The Knoxville was 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, where also it contains *Aucella piochii.* It is very likely that a portion of the areas mapped as pre-Monterey belongs to the lower Cretaceous, but it is not probable that the whole does.

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. They are mapped as pre-Monterey rocks. It is probable that strata of Knoxville (lower Cretaceous) age occur at the base of the series in those areas and that the higher portions represent either the upper Cretaceous or the Eocene, or both. Detailed work was left until another time.

The larger of these two areas occupies the northeast corner of the region shown on the map, and is about 60 square miles in extent. The other lies on the northeastern slope of the high ridge north of Zaca Lake. In these areas are exposed a great series of thin-bedded, dark-colored, locally greenish shale alternating with more massively bedded sandstone, which is in places of a very granitic nature. Conglomerate, much of it plainly evidencing its origin from granite, occurs in minor horizons. Knoxville fossils were found in a gritty greenish sandstone near the lowest portion of this pre-Monterey terrane, about 2 miles north of Zaca Lake. The higher portion seems to be the 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 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 this pre-Monterey group lie beneath the Monterey and upper Vaqueros, but though far older they do not bear so strongly the marks of intense folding as do the brittle Monterey shales. They are, however, steeply upturned, and the lines of folding, as in the case of the other formations, are in general in a northwest-southeast direction.

TEJON, SESPE, AND VAQUEROS FORMATIONS, UNDIFFERENTIATED (EOCENE-MIOCENE).

GENERAL STATEMENT.

The Santa Ynez Range is mostly composed of a thick terrane of marine sediments equivalent to a part or all of the Tejon formation and the Vaqueros formation. The former is Eocene and the latter lower Miocene in age. This terrane comprises a continuous succession of marine sediments of detrital origin, seeming to present no point at which an angular unconformity exists, although the line at the base of the coarse conglomerate containing the Vaqueros fossils doubtless marks a long time interval.

In the preliminary report on the Santa Maria district[a] mention is made of the Sespe formation as being represented here, and a small area of it is shown on the map accompanying that report. The Sespe formation belongs to the Eocene or Oligocene and is a distinct formation above the Tejon and below the Vaqueros. It occurs extensively in the Santa Ynez Mountains north of Santa Barbara, and an outcrop of blood-red sandstone in this range 3½ miles south of the Santa Ynez Mission was indicated on the outline map as belonging to the Sespe because of its lithologic resemblance to the typical rocks of this formation. This small area has, however, not been separately shown on the present map, as there is no good proof of its age. It is quite possible that the Sespe formation is represented in parts of this western portion of the range by rocks not recognizable on the lithologic grounds which are deemed sufficient for the determination of this formation in the vicinity of Santa Barbara or the Ojai Valley, to the east; or it may be that sedimentation was not operative in the western part of the range during Sespe time, and therefore that rocks of that age are lacking from the geologic section in this region. The amount of work done in the Santa Ynez Range does not warrant a full discussion of the structure and relations of

---

[a] Bull. U. S. Geol. Survey No. 317, 1907, pp. 1-69.

its rocks stratigraphically below the base of the Monterey (middle Miocene) shale.

Strata corresponding to the upper portion of the Tejon-Sespe-Vaqueros terrane have been recognized also in the San Rafael Mountains, where they are exposed at the base of the Monterey (middle Miocene), and it may be that the pre-Monterey rocks are in part equivalent to the lower portion of this terrane. The Vaqueros and possibly part of the Tejon are present also in the Casmalia Hills.

LITHOLOGIC CHARACTER.

The lower portion of the terrane is made up of a thick series of greenish-gray coarse and fine sandstones, many of them concretionary in character, interbedded with dark, fine-grained, thin-bedded shales in lesser amount. Toward the middle of the terrane the shale increases in amount, alternating with thin beds of sandstone. Much of the shale has a characteristic olive-gray color, and owing to its hard, gritty, brittle nature it makes excellent road material for the Santa Ynez Valley. The shales and sandstones give place above the middle of the terrane to deposits of shallow-water character—coarse sandstone and a great quantity of coarse, in many places greenish or reddish, gravelly conglomerate. This conglomerate contains abundant Vaqueros fossils and probably represents the base of that formation and a period of shallow-water conditions with which the Vaqueros began. The conglomerate gives place in turn to more shale and sandstone, which continue to the summit of the terrane. At the top there is a conformable gradation into the Monterey (middle Miocene) beds, the summit of the Vaqueros being marked by a calcareous zone in many places—as, for instance, southwest of Lompoc, where the two formations are divided by a very prominent exposure of hard limestone. This limestone is quarried and used in the refining of beet sugar. Sandstone, shale, and conglomerate belonging to the Tejon-Sespe-Vaqueros terrane occur at the seaward end of the Casmalia Hills. They form a series conformably underlying the Monterey (middle Miocene); but they are separated from beds of flint and shale that can be definitely assigned to the latter formation by an intervening horizon many hundred feet thick of soft, light-brown, clayey, alkaline shale that is almost invariably full of crystalline gypsum. Here the conditions existing during the period of transition from typical Vaqueros to typical Monterey sedimentation must have been very different from those prevalent over the areas occupied by the Santa Ynez and San Rafael ranges. Acidic volcanic ash is interbedded with the Tejon-Sespe-Vaqueros strata in the Casmalia Hills. The occurrence of the ash and the alkaline shale is mentioned by H. W. Fairbanks in the two quotations given under the heading "Previous knowledge of the geology," pages 12–13, and this author discusses them further in his paper there cited.

STRUCTURE AND THICKNESS.

Like all the Tertiary and pre-Tertiary formations of this region the deposits under discussion have been subjected to folding that has left none of them in an undisturbed attitude. But as they consist in large part of soft sandstone and conglomerate with interbedded layers of sandstone and clayey shale, they have not been so violently fractured and disturbed as much of the brittle shale of the lower portion of the Monterey (middle Miocene). The high ridge of the Santa Ynez Mountains from Point Conception eastward is formed by a great monocline in the sandstone of this terrane, dipping toward the sea on the south at an angle of about 30°. North of this ridge occurs a longitudinal depression in the range in which the folds of the beds are rather low; and still farther north, bordering the Santa Ynez Valley, these rocks are considerably disturbed, dipping in various directions and at all angles between 15° and the vertical. The general inclination of the beds on the north side, however, is northward, the structure of this part of the range, broadly viewed, being anticlinal. In the San Rafael Mountains the Vaqueros strata are steeply folded along northwest-southeast lines, in conformity with the overlying Monterey. A marked example of the way in which the soft, coarse conglomerate has been left little affected occurs in Buckhorn Canyon, where thick beds of this rock, probably the basal part of the Vaqueros, lie almost horizontal.

The Tejon-Sespe-Vaqueros rocks have a thickness of at least 5,000 feet in the Santa Ynez Mountains, and further work will probably allow these figures to be considerably increased.

AGE AND FOSSILS.

At least two distinct faunas are found in the Tejon-Sespe-Vaqueros strata. The lower is characteristically Eocene, and similar to that of the Tejon formation of the type locality; the upper contains many of the species found at the type locality of the Vaqueros formation, which is the standard lower Miocene of the central California province. So far as is definitely known no species bridges the gap between these two faunas, either here or elsewhere in California, although the beds containing the two are apparently conformable not only in the Santa Ynez Range but also locally as far north as Martinez, east of San Francisco Bay.

The following tables show the fossiliferous Tejon and Vaqueros localities and the species of fossils found at each. (See map, Pl. I, in pocket; and illustrations of fossils, Pls. XII to XXVI, pp. 126–154.)

Tejon (Eocene) fossils from the Santa Maria district, California.

	4507.	4509.	4513.	4518.
Cardium brewerii Gabb (Pl. XII, fig. 1)	×			×
Codakia? sp. a	×			
Conus cf. hornii Gabb				×
Crassatellites collina Conrad (Pl. XII, figs. 2a, 2b, 3)	×	×		×
Dosinia elevata Gabb	×			
Fusus occidentalis Gabb	×		×	×
Ficus mamillatus Gabb (Pl. XII, figs. 5a, 5b)	×			×
Glycymeris cf. veatchii Gabb var. major Stanton	×	×		×
Mactra cf. uvasana Conrad			×	
Meretrix uvasana Conrad	×			
Meretrix sp			×	
Neverita? sp			×	
Nucula truncata Gabb				×
Ostrea idriaensis Gabb (Pl. XIV, figs. 1a, 1b)	×			×
Pecten (Chlamys) yneziana Arnold (Pl. XII, fig. 4; Pl. XIII, figs. 6a, 6b)	×	×		×
Phacoides cumulata Gabb (Pl. XIV, fig. 2)				×
Phacoides (Miltha?) sp	×			
Tellina? sp		×		
Turritella (martinezensis Gabb var.?) lompocensis Arnold (Pl. XIII, figs. 5a, 5b, 8)		×		
Turritella uvasana Conrad (Pl. XII, fig. 6; Pl. XIII, fig. 7)	×	×		×
Venericardia planicosta Lamarck (Pl. XIII, fig. 4)	×			×

4507. Just above San Julian ranch house, 1 mile southeast of bench mark 603.
4509. Sharp turn in road in San Miguelito Canyon, 4½ miles S. 20° W. of Lompoc bench mark 95.
4513. South side of El Jaro Creek road, one-half mile west of bench mark 927.
4518. Three miles north of Sudden, on north flank of 1,912-foot hill.

Vaqueros (lower Miocene) fossils from the Santa Maria district, California.

	4478.	4504.	4508.	4510.	4511.	4512.	4514.	4516.	4517.	4519.	4520.	4521.
Balanus cf. estrellanus Conrad									×		×	
Cardium aff. quadrigenarium Conrad		×							×			
Chione cf. mathewsonii Gabb						×						
Conus sp							×					
Crassatellites (?) sp					×							
Gasteropod, genus and species indet								×				
Meretrix (?) sp								×				
Modiolus yneziana Arnold (Pl. XV, fig. 2)		×										
Mytilus cf. mathewsonii Gabb											×	×
Ostrea eldridgei Arnold (Pl. XVI, fig. 2; Pl. XVIII, figs. 6a, 6b)	×	×		×			×					×
Ostrea, new species, near titan Conrad		×							×			×
Pecten vanvlecki Arnold (Pl. XVII, figs. 1, 2)	×											
Pecten (Lyropecten) bowersi Arnold (Pl. XVIII, fig. 5)												×
Pecten crassicardo Conrad (Pl. XVIII, fig. 1)												×
Pecten lompocensis Arnold (Pl. XVIII, figs. 2, 3, 4)												×
Pecten magnolia Conrad (Pl. XVI, fig. 1)	×	×	×		×	×			×	×	×	
Pecten sespeensis var. hydei Arnold (Pl. XVII, fig. 3)	×											
Solen sp								×				

Vaqueros (lower Miocene) fossils from the Santa Maria district, California—Continued.

	4478.	4504.	4508.	4510.	4511.	4512.	4514.	4516.	4517.	4519.	4520.	4521.
Terebratalia kennedyi Dall (Pl. XVII, fig. 4a, 4b, 4c, 4d)												×
Purpura vaquerosensis Arnold (Pl. XV, figs. 1a, 1b)		×										
Turritella sp. indet			×									
Turritella ineziana Conrad (Pl. XVI, fig. 3)							×	×	×			
Turritella variata Conrad (young?)								×				

4478. Two miles south of Santa Ynez, on knoll just east of mouth of Ballard Canyon.
4504. Three-fourths of a mile up ridge northeast of San Julian ranch house, 1¼ miles east of bench mark 603.
4508. El Jaro Creek, one-fourth mile east of Salsipuedes Creek, southeast of Lompoc.
4510. Five miles north of Concepcion, one-fourth mile west of mouth of Escondido Creek.
4511. Float on hillside along east side of Los Amoles Creek, 1 mile above El Jaro Creek.
4512. Ridge between Los Amoles and Salsipuedes creeks, 10½ miles S. 33° E. of Lompoc bench mark 95.
4514. About 10 miles west of Santa Ynez, on south bend of river 1½ miles southeast of bench mark 552.
4516. South of Santa Ynez Mission, 2½ miles up Alisal Creek, at mouth of valley on east.
4517. Three miles north of Sudden, on north flank of 1,912-foot hill, above locality 4518, which is Eocene. (See p. 29.)
4519. On ridge 2 miles east-southeast of El Jaro Creek, bench mark 603, one-half mile west of 1,111-foot hill.
4520. West side of ridge between Los Amoles and El Jaro creeks, 1 mile west of bench mark 603.
4521. Lime quarry 5 miles southwest of Lompoc.

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 probably representative of the whole of middle Miocene time. The series 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 concealed 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[a] in the early fifties to an organic shale formation typically developed near Monterey, in central California. It is very extensive in the California Coast Ranges, being the "bituminous shale" described by Whitney[b] as occurring at widely separated points north and south of the Golden Gate. Its age is generally taken as middle Miocene. It is the source of much of the petroleum found in California. The shale characteristic of this unique formation is not similar to ordinary clay shale, but is composed largely of the remains of minute marine organisms. In an

---

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

[b] Geological Survey of California, Geology, vol. 1, 1865, p. 137.

unaltered 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 series. 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 at the top of the Vaqueros is not well developed, but is replaced by a series of thin-bedded, in the main fairly hard, siliceous, calcareous, and somewhat argillaceous 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 terranes taken as wholes are distinct units, representing periods of deposition of entirely different character. As indicated by the rocks, deposition was continuous between the Vaqueros and Monterey and the change in character came suddenly, although less so in some places than in others. The general nature of the Vaqueros series 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 predominatingly of a gravelly or sandy nature or those bearing fossil mollusks are considered part of the Vaqueros; those of a fine texture and of flinty or opaline or chalcedonic nature, part of the Monterey.

Above the transitional limestone horizon between the Vaqueros and Monterey the lower half of the latter formation consists of a thick series of thin-bedded, hard, brittle, siliceous and calcareous shales, with local 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 a horizon of black, brownish, or wax-colored flint in heavy beds one to several feet thick, and similar massive beds of peculiar sand-colored limestone with characteristic lamellar weathering. The greater part of the series is made up of brittle siliceous shale, usually much fractured and rather commonly crumpled, in beds averaging about one-half to 1 inch in thickness, in places alternating with thin shaly calcareous beds or massive strata of limestone. Pls. III, *B*, and VI, *B* (p. 46), show outcrops of typical flinty shale of the lower division. Beds of flinty shale or of pure flint are included here and there. The flint is of different colors—amber, black, milky, red, brown, etc.—and of different degrees of translucency. Much of it has been fractured and recemented with chalcedonic veins.

A. CHARACTERISTIC EXPOSURE OF VOLCANIC ASH NEAR BASE OF MONTEREY FORMATION.

At point where Cuyama River enters the Santa Maria Valley. Photograph by Ralph Arnold.

B. UPTURNED AND CONTORTED SEMIFLINTY MONTEREY SHALE.

On Sisquoc River, 5 miles east of Sisquoc. Heavy oil is exuding at a point immediately to the right of the man. Photograph by Ralph Arnold.

It is in some localities banded with fine white laminæ or with bands more translucent than the rest. These bands run parallel with the bedding, and commonly show intricate contortions. The flint fractures conchoidally. From the flint there is every step in the gradation through rocks of less hardness and flinty, compact character to soft white diatomaceous shale. The soft unaltered shale in which the constituent diatom tests are plainly to be seen occurs sparingly, however, in the lower division. A striking example of its occurrence at that horizon can be found at the very base of the Monterey on the San Julian ranch, at the junction of El Jaro and Salsipuedes creeks, where it is pure, soft diatomaceous earth in thick beds, associated with flint and lime and overlying the hard fossiliferous, calcareous conglomerate of the Vaqueros. The specimen of analysis 3 (p. 45) is from this point. The varieties of shale are very numerous, but there is no departure from the general siliceous and calcareous types so peculiar to this formation. There is no common clay shale or 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 shales. Hard, coarse, yellow and grayish volcanic tuff of acidic nature is interbedded with the Monterey in the vicinity of Cuyama River (see Pl. III, *A*), and elsewhere the lowest portion of the formation is marked by beds of tuff of local extent. At the east end of the Santa Rita Hills the Vaqueros grades into the Monterey through beds of coarse basic tuff composed of small fragments of glass and crystals of various kinds and of large fragments of pumice. Round bowlders or nodules of very fine grained basalt that look like volcanic bombs are included in this tuff.

The series of hard shales of the lower division is commonly impregnated with bituminous material. The limy beds have almost universally a bituminous odor and some of them contain pockets of tarry oil. The same is true of the flint with the difference, however, that the limestone is impregnated with petroleum, owing to its porosity, whereas the oil in the compact flint seems more commonly to be contained along lines of fracture or in cavities. The great mass of the hard, brittle shales has in general a similar odor or is discolored with oil. This hard shale series, especially the lower portion of it, and in places possibly the uppermost sandstone of the formation just below it, contains the principal oil-bearing zones in the developed fields. The fact that this shale is so brittle and fractures when folded has an important bearing on the storing of oil in this portion of the Monterey. The fracturing produces cavities in which the oil can collect while the softer unfractured shales adjacent remain more or less impervious to the oil.

UPPER DIVISION.

The line of division between the lower and upper portions of the Monterey is rather arbitrary, yet if each portion 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 in various places. Where they are 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 part into the light-colored, earthy beds of the upper. Such is the occurrence, for instance, near the north edge of the hills 4 miles west-southwest of the town of Lompoc.

The greater part of the upper division is made up of white or light chocolate-colored diatomaceous shale, usually of light weight and porous, but grading in places into heavier and harder, more compact, brittle, porcelain-like shale. The soft shale is extremely fine grained, rarely being at all gritty. 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 usually 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 patches. Pl. IV illustrates two characteristic types of the soft unaltered shale. In the upper view it is massive, and bedding planes are almost indistinguishable except for lines brought into relief by weathering and erosion. In the lower view it is slightly more compact and lies in distinct platy layers. Major bedding planes from a fraction of an inch to several inches apart are distinctly apparent, and there is a further laminated structure that enables the shale to be split into plates of extreme thinness. An artificial cut through somewhat disintegrated shale of the upper part of the Monterey is shown in Pl. VIII, *A* (p. 78). The typical unaltered diatomaceous shale is pictured in Pl. V, *A*. The small round diatom tests of which it is largely composed are faintly distinguishable with the naked eye in the photograph. 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. Local chalcedonic lenses are to be found in this series roughly following the bedding planes in unaltered shale, as well as horizons of hard, porcelaneous, usually much-fractured shale; but the latter does not become predominant over the softer shale as it does in the lower division.

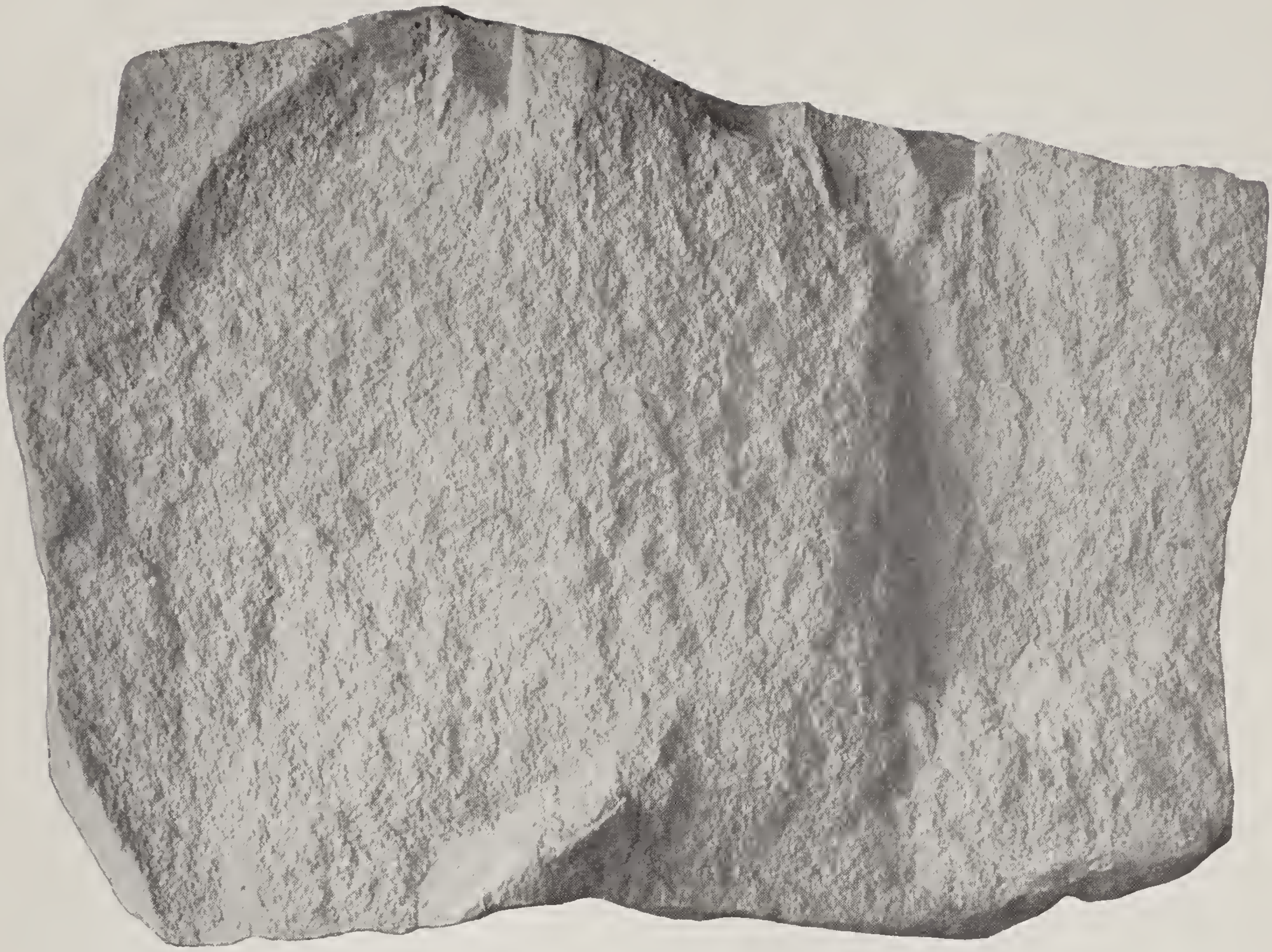
The white chalklike deposits of this formation are not fully described by the use of the word shale in its ordinary sense. Especially in the massive deposits, where bedding is not very apparent, it has neither in composition nor lamination the character of ordinary shale. But this word has come into use in connection with the Monterey for lack of any other. The major portion of the formation, however, does

A

B

SOFT WHITE DIATOMACEOUS SHALE.

A. Characteristic exposure north of Casmalia. *B*. Detail of weathering at Burton Mesa, east of Pine Canyon. Photographs by Ralph Arnold.



A

B

DIATOMACEOUS SHALE.

A. Typical soft, white, unaltered specimen. *B*. Red, brittle, and heavy specimen; metamorphosed by the burning of its hydrocarbons.

resemble shale in its thin stratification, the great difference being in the siliceous instead of argillaceous composition. Locally there are beds of clayey nature in the upper division which form a connecting link between the "chalk rock," as the diatomaceous shale is colloquially termed, and common clay shale. Characteristic oval and lenticular yellow concretions of hard lime are commonly included in the shale of the upper division. They range in diameter from a few inches to 2 feet or more. In many places they occur at irregular intervals and of irregular size along a bedding plane, locally displacing the ordinary shale and interrupting the continuity of not merely one bed but many thin beds. They are invariably elongated parallel with the bedding.

Volcanic ash is interbedded with the soft shale of the upper division in the hills immediately south of Lompoc. It is very fine grained, soft, and uncompacted, and probably corresponds in composition to rhyolite. It somewhat resembles the pulverulent diatomaceous earth, but is easily distinguishable by its grayish color and grittiness.

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 into or to show a brownish discoloration due to the presence of oil. In places the shale, otherwise white, is specked with minute black spots of bitumen. Thin sandy layers occur sparingly interbedded with the shale, and these almost without exception have absorbed considerable oil and have a dark-brown color and strong odor. But these beds of sand are very rare and make up no appreciable proportion of the series.

The soft varieties of the Monterey shale are almost invariably alkaline and have a salty taste. They contain an abundance of salts easily soluble in water that form characteristic wooly coatings of efflorescence on the surface of outcrops. This is especially true near the summit of the formation, where a soft claylike gypsum-bearing shale locally marks the contact with the Fernando above. This gypsum is crystallized in plates along seams and bedding planes much like the gypsiferous clay of the Casmalia Hills, which is supposed to be Vaqueros in age. Zones of gypsiferous shale occur also at other places in the upper division of the Monterey, but it is not known whether there are any single horizons at which it is constant. Where the gypsum occurs the shale is usually of more argillaceous character and bears a closer resemblance to ordinary clay shales. The significance of this alkalinity in the Monterey is unknown. The organic shale is considered to be of marine origin in fairly deep water, and owing to the almost complete absence of all but the finest grained detritus the alkalinity can not be considered as proof of shallow-water or brackish-water origin. The salts may have some relation to the chemical changes involved in the production of petroleum.

DIATOMACEOUS EARTH DEPOSITS.[a]

The infusorial earth, diatomaceous earth, diatomaceous shale, or tripoli, as the same material is variously called, of which the upper division of the Monterey is chiefly composed, is of fairly pure quality in this region and of considerable economic value, especially as it occurs in inexhaustible quantities close to transportation facilities. The areas of it are extended and the series of strata very thick. Deposits suitable for working occur in the hills immediately south of Lompoc; southwest and west of Lompoc; along the river east of Lompoc; in the northeastern and southeastern portions of Burton Mesa and over the Purisima Hills east of it; over wide areas in the Purisima Hills southwest, south, and southeast of Los Alamos; on the southern flanks of the Santa Rita Hills; 1½ miles north of the Santa Ynez Mission; in smaller amounts near the east edge of the area mapped, a mile north of Santa Ynez River; underlying the San Antonio terrace south of Casmalia; over a wide region southeast, east, and north of Casmalia; on Graciosa Ridge, and in the region extending from the head of Howard Canyon to a point southeast of Sisquoc. The uses to which this material can be put are numerous and the demand for it is increasing.

COMPOSITION OF THE MONTEREY SHALE.

MATERIAL OF SHALE.

The composition of the Monterey shale is of especial interest. One is able to see on examining the soft unaltered variety with a hand lens, or sometimes even with the naked eye, that it is full of small round dots ranging, to speak roughly, from 0.1 mm. to 1 mm. in diameter. These are the skeletons of minute marine organisms called diatoms. They are a low order of plants or algæ having a framework of silica. They are locally so closely packed together that they seem to form the bulk of the deposit. In some of the rock they are so well preserved that the details of their structure can be made out with the aid of higher magnification. But elsewhere they appear crushed and almost unrecognizable. It is a question how much of the shale is formed of the diatom frustules that have been thus crushed. The shale in which the remains are well preserved and abundant is extremely soft and white and may be rubbed at a touch into a powder like flour. The round diatom disks are white and soft just like the matrix surrounding them, which looks as if it, too, were made up of diatom remains that had preserved their form less perfectly. Shale in which the remains are less prominent has

---

[a] A more extended description of these diatomaceous deposits is published in "Contributions to Economic Geology, 1906" (Bull. U. S. Geol. Survey No. 315, 1907, pp. 438–447), under the title "Diatomaceous deposits of northern Santa Barbara County, Cal."

the same appearance, as if formed of the same materials, but compacting and crushing seem to have gone a little further so as to obscure the organic remains. Almost all the shale of the upper division of the Monterey contains diatom remains where it has not undergone alteration into the hard varieties. The same is true of the soft shale wherever it occurs in the lower portion of the formation, the most notable example being at the very base of the Monterey on the San Julian ranch east of the junction of Salsipuedes and El Jaro creeks, where it is associated with hard flint and limestone immediately overlying the fossiliferous limestone and conglomerate of the Vaqueros. There the shale is earthy, pure white, and full of diatoms.

When the shale has undergone alteration and hardening into the porcelaneous and flinty varieties the constituent organic remains are usually obscured, but here and there even in these the impressions may be found preserved. Usually an examination under the microscope reveals scattering circular and oval areas, of slightly different composition or character from the surrounding rock, that look as if they might represent the forms of organisms. In speaking of the exposure of Monterey rocks between the mouth of Schumann Canyon and Lions Head on the southern flank of the Casmalia Hills, H. W. Fairbanks says:[a] "The basal portion of the series is composed chiefly of clear, flinty rocks, showing abundant remains of organisms visible to the unaided eye." And in speaking of the harder varieties of Monterey shale in general of the Point Sal region he says:[b] "When examined with the hand lens much of the rock is seen to be thickly specked with little round dots, averaging, perhaps, a millimeter in diameter. Under the microscope * * * the circular areas did not appear as numerous as in the hand specimen, and were only faintly distinguished by clearer polarization."

Aside from the diatoms the rocks of the Monterey contain remains of minute Foraminifera, which have calcareous frames, and Radiolaria, which secrete silica to form their tests. The latter are present sparingly. The common siliceous shale contains very little lime and no Foraminifera have been found in it in this district, although they have been reported from the typical Monterey shale elsewhere. R. M. Bagg[c] found 66 species belonging to 17 genera in chocolate-colored, soft, fine-grained shale of the same formation near Asuncion, San Luis Obispo County. J. C. Branner in the introduction to Bagg's paper, describes the shale as follows: "The shale proper also varies; at some places it is flinty, at others it is somewhat sandy, and at still others it is soft and chocolate-colored, and contains an abundance of well-preserved Foraminifera. * * * The bulk of

---

[a] Geology of Point Sal: Bull. Dept. Geology, Univ. California, vol. 2, No. 1, 1896, p. 9.

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

[c] Miocene Foraminifera from the Monterey shale, California: Bull. U. S. Geol. Survey No. 268, 1905.

this shale is made of diatom skeletons. * * * Even when the rocks are flinty they often contain good impressions of Foraminifera." Foraminifera occur in the partially calcareous shales of the Santa Maria district, and in places the limestone is full of them. In some specimens they are perfectly preserved and various kinds may be easily seen with the unaided eye. In other places the limestone shows no trace of organisms; but it is the opinion of the writers that they have been present in such places and have lost their shape, and that foraminiferal skeletons account for a large part of all the Monterey limestone and for the calcareous portion of the limy shales. H. W. Fairbanks says in his paper quoted on page — that the limestone of the Point Sal region "appears to be formed almost exclusively of minute organisms."

Specimens representing different varieties of the Monterey shale and flint were sent to F. J. Keeley, of the Philadelphia Academy of Natural Sciences, who very kindly made examinations of them and reported regarding their diatom contents. (See Pls. XIX and XX.) He found diatoms plentiful in the unaltered earthy shale and less common in the more compact shale and in the less pure, either gritty or argillaceous shale. Sponge spicules were common in all the samples, and in those last mentioned they were more abundant than diatoms. No examination was made of the indurated varieties. Mr. Keeley was unable to make more than a hasty examination, but on request he estimated roughly that the purest material contained from 5 to 10 per cent of diatoms and that the soft shale in which fewer could be seen contained possibly 1 per cent. He found a few Radiolaria but no Foraminifera in the pure siliceous shale, diatoms and next to them sponge spicules being by far the predominant organic remains.

C. S. Boyer, of the Philadelphia Academy of Natural Sciences, kindly identified the species of diatoms in two slides prepared by Mr. Keeley from the two purest samples of diatomaceous earth that were sent to him. Mr. Keeley says: "The lists made by Mr. Boyer cover only the species he saw in the slides sent him, and an exhaustive examination of the material, which would require searching over, say, a hundred slides or more, would probably give a long list of species, many of which might not be seen more than once or twice in the course of such an examination." Nevertheless, these lists probably indicate the commonest species. In the slide made from the shale at the base of the Monterey from the locality above referred to at the junction of Salsipuedes and El Jaro creeks Mr. Boyer found the following diatoms:

Coscinodiscus marginatus Ehrenberg.
Coscinodiscus marginatus var. intermedia Rattray.
Coscinodiscus robustus Grev.
Arachnodiscus (fragment).
Diploneis? (fragment).
Melosira sulcata Ehrenberg (rare).

Mr. Boyer says: "The deposit consists almost entirely of *C. marginatus* and *C. robustus* of various sizes and often without rims. It is impossible, in certain cases, to distinguish between these two forms. The variety *intermedia* is between the two and was created by Rattray."

The second slide was made from soft shale of the uppermost portion of the Monterey, from the Pinal property on the east side of Pine Canyon, on the north flank of Graciosa Ridge. The following diatoms were found:

Coscinodiscus oculus iridis Ehrenberg (abundant) (Pl. XI, fig. XIX).
Coscinodiscus marginatus Ehrenberg.
Coscinodiscus marginatus var. intermedia Rattray.
Coscinodiscus robustus Grev. (Pl. XX, fig. 4).
Coscinodiscus radiatus Ehrenberg.
Coscinodiscus obscurus A. S. (Pl. XX, fig. 2).
Coscinodiscus nodulifer Janisch.
Coscinodiscus heteroporus Ehrenberg.
Coscinodiscus subtilis Ehrenberg (Pl. XX, fig. 3).
Actinoptychus undulatus Ehrenberg (rare) (Pl. XX, fig. 1*a*).
Arachnodiscus ehrenbergii var. californica (fragment).
Lithodesmium cornigerum Brun. (Pl. XX, fig. 1*b*).

According to Mr. Boyer this second sample consists chiefly of fragments of *Coscinodiscus oculus iridis* Ehrenberg, which is a larger and more delicate form than the one predominating in the first, and both he and Mr. Keeley comment on the peculiar absence of it there. The difference in the fauna in these different localities is of interest, inasmuch as the deposit represented by the first slide was at the base of the Monterey and that represented by the second near its summit.

Besides the small organisms that have been described as forming a portion of the shale material, and the less abundant organic remains mentioned on pages 42–43, the deposits of Monterey age contain a considerable percentage of fine siliceous and aluminous matter, probably of detrital origin, in the shape of exceedingly minute clastic grains. The chemical analyses of specimens from different localities show a large percentage of alumina, the presence of which is probably the result of fine argillaceous silt settling on the sea bottom to aid in the formation of the shale. The origin of the silica is more in doubt. There is no question of the presence of a large amount of siliceous diatom skeleton material, and the many fine-rounded and angular particles of quartz revealed by the polarizing microscope in the unaltered shale indicate that the sediments derived from shore areas carried quartz grains also, but there is no proof as to which of these sources supplied the bulk of the silica, of which the shale is mostly composed. Besides the recognizable diatom remains it is impossible to tell how much of the shale is composed of similar skeletons that have been crushed beyond any semblance of their original form. Comparatively few forms are perfectly preserved, most of those observed under the microscope being only fragments, and this makes it probable that others are still more fragmentary and in a state of complete demolition. The likelihood, therefore, is that a greater proportion of the pure shale than 5 to 10 per cent, as roughly estimated by Mr. Keeley on the basis of visible forms, is composed of silica derived from diatoms. Radiolaria, which are scattered through the shale sparingly, have contributed somewhat to the organic silica. Whatever conclusion one should come to would apply to almost all of the soft unaltered shale of the siliceous type in the Monterey of the Santa Maria district, as this type is fairly constant. Locally it is varied by an increased proportion of argillaceous material, causing a greater similarity in appearance to ordinary clay shale, or by the presence of lime; but diatoms are visible in practically all of it and the general conditions of deposition seem to have been the same throughout. The conclusion is reached elsewhere (p. 47) that the same probable origin may be assigned to all the siliceous shales of the Monterey, whether hard or soft—or, in other words, to by far the greater part of the formation.

The list of organic constituents of the shale is by no means exhausted by the small organisms of low order so far mentioned. Another important source of silica lies in the abundant sponge spicules, which are only second in number to the diatoms and which are scattered with remarkable persistency throughout the shale. In the slightly gritty beds of soft shale, which occur sparingly, these spicules even predominate over the diatoms, being possibly the cause of the grittiness. They seem also to be less easily obliterated than the fragile diatom shells and to have been preserved in places where slight alteration of the rock has destroyed the latter. One of the commonest and most characteristic features of both the unmetamorphosed siliceous and the calcareous shales is the presence of scales of fish, showing that fish remains found their way to the ooze at the ocean bottom in greater or less abundance. Locally the bones and nearly complete skeletons are also to be found. Delicate mollusk shells, usually of small size, are gathered thickly in some places in the Monterey shale, and at such points may be considered as constituting an appreciable proportion of the total volume of the deposit. As a rule they are crushed and poorly preserved, a fact that lends weight to the theory that a large part of the diatom frustules also have been destroyed. But mollusks are rare in the formation as a whole. Crab shells and claws are occasionally found, usually not whole but in small pieces, as if they had been subjected to conditions favorable to their destruction before coming to rest. Seaweed impressions are not rare. In addition to organic remains of these kinds, the shales, especially the less purely siliceous varieties, are usually full of small brown scales, spines, and fragments or impressions of nondescript shape which are of organic origin but which can not be recognized as belonging to any particular forms. Here and there, also, large bones are embedded in the deposits. They seem to be those of whales or other large marine vertebrates.

Taken as a whole, the Monterey shale may well be called an organic formation. The practically complete absence of coarse sediments derived from erosion and the abundance of fossil organisms, especially of siliceous skeletons, make it different both in appearance and composition from any other known formation of comparable thickness. The unaltered siliceous shale most nearly resembles chalk, but it contains only a small proportion of lime. Whether or not the organic remains compose more than half or as much as half of the deposit can not be stated.

MICROSCOPIC APPEARANCE.

Under the polarizing microscope little can be made out regarding the structure of the main mass of the soft shale and compact white shale. The groundmass seems to be made up of amorphous colloidal silica surrounding minute grains which are both crystalline and amorphous, but the character of which can not be recognized. Embedded in this are numerous imperfectly angular or more rarely partially rounded crystal particles, probably of quartz. Many of the latter look as if they were due to secondary development rather than originating as clastic grains.

In the more flinty varieties the rock appears to have undergone partial and local crystallization of the silica throughout its mass. In the flint, in which there are alternating, usually crumpled bands of opaque light-colored flint and clear amber-colored or black flint, the opaque bands are composed mainly of amorphous material like that of the softer shale, but in a much more compact state, and the translucent bands are mainly crystalline aggregates. The opaque bands include crystalline particles and, locally, patches of crystal grains like those of the clear flint, and they are included longitudinally by intermittent bands of the clear flint. Furthermore, they are in many specimens of a patchy appearance, parts being less amorphous than others. The bands of the clear flint are composed chiefly of small grains of crystalline quartz, and these are surrounded by a finer grained aggregate of crystalline and amorphous particles. The quartz grains have neither the rounded outlines of waterworn grains nor angular crystalline outlines, but are branching, and appear more like growths. Angular patches of the amorphous silica, many of them showing signs of incipient crystallization, are included in the clear bands, giving a brecciated appearance. The bands are parallel with the bedding planes. They are commonly followed and more rarely crossed by veins of quartz crystals.

The limestone is made up of granules of crystalline calcite, or calcite showing the beginnings of crystallization. Included in this extremely fine grained, uniform groundmass are larger but yet very small, irregular grains of crystalline calcite, and in places long spicules of the same. In some specimens the granules are more minute than in others and the included larger grains are fewer. In still others, crystallization has entirely altered portions into patches of large, intergrown crystals, leaving angular, unchanged patches sharply marked off, and thus giving an appearance like that of a breccia. The flinty calcareous shale has a minute granular texture, quartz grains both crystalline and semicrystalline being associated with those of calcite. The rock usually has light and dark bands parallel with the bedding, the light bands containing more quartz and having the calcite granules less close together than the darker bands.

CHEMICAL COMPOSITION.

The subjoined table comprises analyses of different specimens and varieties of Monterey shale from the Santa Maria district, with one (No. 5) here included for comparison, of a sample of white bituminous shale from the type locality of the formation at Monterey, farther north on the California coast.

The first three represent typical examples of the unaltered diatomaceous shale of the Monterey. Nos. 3 and 2, respectively, are analyses of the same samples that were found to be rich in diatoms when examined in slides 1 and 2 by Messrs. Keeley and Boyer, as mentioned on pages 40–41. Nos. 4 and 6 are analyses of samples from the same hand specimen, taken within 1 inch of each other, No. 4 showing the composition of unaltered white shale in which diatoms are visible, and No. 6 of the translucent, brittle, flintlike product of extremely local alteration. The next four indicate gradations in the products of the metamorphism. The last analysis (No. 11) represents limestone typical in lithologic appearance of the limestone of the Monterey.

Analyses of Monterey shale.

	Diatomaceous shale.					Flinty shale.					Limestone.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
SiO_2	65.62	72.50	83.19	80.59	86.89	92.88	86.92	92.37	97.02	98.1	....
Al_2O_3	....	11.71	....	....	2.32	....	4.27	2.46	....	Not det.	....
Fe_2O_3 (total iron)	....	2.35	....	....	1.28	....	....	....	....	Not det.	....
CaO	....	.32	....	....	1.43	....	1.60	1.70	....	....	27.86
MgO	....	.83	....	....	Trace.	....	Trace.	....	....	....	16.64
Alkalies (Na_2O,K_2O)	....	1.88	....	....	3.58	....	2.48	....	....	....	....
Ignition	11.00	9.54	....	....	4.89	....	5.13	2.74+ CO_2	....	....	....
	....	99.13	....	....	100.39	....	100.40	99.27	....	....	....

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

ALTERATION.

The differences in character and composition between the soft and hard varieties of the Monterey shale have been brought out in the foregoing discussion. The question arises, To what are these differences due? It is difficult to give a decisive answer. The main differences in the gradations from the soft to the hard shales lie in the siliceousness, compactness, hardness, and degree of crystallization. Taken as a whole the lower division is made up largely of hard shale and the upper of soft shale, but gradations from one variety to another within an extremely small space occur in both divisions. In some places a thick series of beds of similar character is marked off from a series of different character. Elsewhere a variation occurs bed by bed, or, in still other places, a single bed or lens of shale of one variety is included within another kind. The softer varieties contain at many points small lenses of hard, brittle, or semiflinty shale elongated parallel with the bedding, or strata in which lenses are strung along at irregular intervals, or single small beds composed entirely of harder material. In such occurrences there seems to be a gradation from one variety to the other, and the outlines of the hard layers are not regular or very definite. For example, the diatom-bearing shale of chemical analysis No. 4 and the glassy opaline rock of analysis No. 6 were samples taken from the same hand specimen within 1 inch of each other. The mass of the deposit from which the specimen came was soft white shale belonging high in the formation and contained a rough layer, a few inches thick, of the harder material between two beds of the soft rock.

The soft shale has been described in the preceding pages as "unaltered," and in referring to the harder varieties different degrees of "alteration" have been mentioned, for the reason that the best explanation of the origin of the harder rocks appears to be that they are products of metamorphism of the soft variety. It is believed that the soft white and chocolate-colored organic shale represents the original state of the beds of the whole formation, and that a process of silicification and crystallization has caused the changes, this process having been aided possibly by structural disturbances and pressure. The beds of soft shale are usually found in attitudes only gently disturbed, whereas the harder shale is most commonly much folded and is invariably the component rock of folds where the forces have been especially intense. This fact may throw light on the problem of the alteration of the shale, and yet it may be simply the outcome of the removal of the softer portion of the formation in the regions of greatest uplift and disturbance. The chief agent in causing the change was probably infiltrating water carrying silica in solution. In some places the process may have been simply or largely infiltration in the extremely porous original shale and deposition of silica in the interspaces, thus giving rise to hardened and compacted irregular granular aggregates of the original amorphous silica and the new crystalline silica combined, the result being an increase in the total percentage of silica. In more extreme cases the original material was probably partly taken in solution and redeposited, being replaced almost entirely along bands or in spots, and the change being carried to a less extent along other layers and in other areas, or else the replacement was almost complete throughout. As the rock was rendered more compact in this process a shrinkage may have been the result, or the same volume may have been retained and the pores filled. That solution took place along with deposition seems to be shown by the almost complete destruction of the forms of organisms.

It is possible that the differences in the shales may be original, the result of variation in the material deposited. Whole series of beds of different material might have been deposited, giving rise to harder, more siliceous rocks than the soft varieties, and the same material might have been locally deposited in thin beds or in lenses and nodules, or have been intermingled with the others to form the intermediate varieties. But it would be difficult to say what this mate-

A. CHARACTERISTIC EXPOSURE OF FERNANDO GRAVEL.

Second ridge east of Figueroa Creek, 7 miles northeast of Los Olivos. Photograph by Ralph Arnold.

B. SHARP DOUBLE FOLD IN MONTEREY SHALE.

Looking east from point northwest of Zaca Lake; Zaca Peak in distance. Photograph by Ralph Arnold.

rial might have been, and the more or less completely crystalline character of the harder shales shows that metamorphism has taken place. The most plausible theory, therefore, is that the Monterey shale as originally laid down was fairly constant in character and that it has undergone alteration extensively, as well as very locally, through the agency of siliceous waters, the older portions of the formation, and possibly the more disturbed portions, having been most generally subjected to the change. The limestone has in places been altered after a fashion somewhat similar to that of the siliceous shales, being changed to marble, probably as the result of solution and redeposition.

The Monterey rocks likewise show the result of contact metamorphism to a very local extent in the vicinity of the diabase intrusions. The process seems to have been largely one of consolidation through baking. A limestone specimen obtained near the diabase intrusion north of Zaca Peak, in the San Rafael Mountains, gives an excellent illustration of shearing. The calcite crystals have all been arranged parallel and greatly elongated, so as to give the rock a schistose structure.

STRUCTURE AND THICKNESS.

The Monterey has nowhere been left undisturbed. In places it has been but gently folded. Pls. IV (p. 36), VIII, *B* (p. 78), and IX (p. 80) show examples of moderate tilting. But at other places, as at that pictured in Pl. VI, *B* (p. 46), it has been thrown into folds so sharp and closely spaced that the succession of the beds and thickness of the series are difficult to make out. The details of its structure are discussed under the heading "Structure" (pp. 76–78). The thickness of the whole series is at least 5,200 feet. Each of the two divisions comprises a maximum known 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 in the Coast Ranges where it outcrops. Moreover, the other fossils that it contains are of little value in indicating its age. Its position in the geologic column is determined by the lower Miocene fossils found just below its base in the Vaqueros and by the upper Miocene fossils found at or near the base of the Fernando formation, which lies unconformably above it.

The following two species of mollusks occur in the Monterey diatomaceous shale on the road just above the Pinal Oil Company's office, southeast of Orcutt: *Arca* aff. *trilineata* Conrad, *Phacoides* aff. *acutilineatus* Conrad.

METAMORPHISM OF THE SHALE BY COMBUSTION.

At many different places in the Santa Maria district and elsewhere the oil-bearing shale has been burnt to a pink or deep brick-red color, or turned into a hard vesicular rock like scoriaceous lava, as shown in Pl. V, *B*, p. 36. This metamorphism is due to the combustion of the hydrocarbon content. Though the combustion is usually local in its effects, the number and wide distribution of the occurrences of burnt shale lend importance to the phenomenon. Such altered shale is of some value as indicating where the rock has been bituminous and where the conditions have favored the occurrence of seepages.

LOCALITIES WHERE THE SHALE IS AT PRESENT BURNING.

A number of localities have been observed at which combustion is at present or has been in recent years in progress within the Monterey shale. One of these is on the north side of Graciosa Ridge, south of the Santa Maria Valley, near the Rice ranch oil well No. 1. When this locality was visited by the writers early in the autumn of 1906, a fire was burning underground in the shale, causing a smoke of disagreeable odor to issue from the surface and making the ground hot over an area of many square yards. Oil was oozing up at various points near by, and the ground was heated in the neighborhood of all these seepages. The holes from which vapor issued were coated with delicate crystals of sulphur. At the point where the burning was actually going on and all about in the vicinity, for a distance of several hundred feet in some directions, the shale was altered to a bright-red color, or baked almost to the hardness of compact igneous rock, or rendered vesicular like lava.

There can be no doubt that this fire was supported by the bituminous material in the shale, and it was probably started by brush fires, though these had occurred a good many months before, as shown by the new growth of the bushes. It was said that there was a brush fire about January 1, 1906, which started the fire in the shale, and that futile attempts to put it out by dumping dirt to smother it had been made ever since that time. It seems likely, however, that this same fire has been in progress for several years. This likelihood is borne out by other accounts. It is stated that sometimes during the course of brush fires on the hills sudden darts of flames may be seen at night from a considerable distance—the result of the setting on fire of gas escaping from the rocks.

Other cases of burning in the shale have been observed in recent years at the San Marcos ranch in the Santa Ynez Valley, and at the mouth of Rincon Creek, on the coast near Santa Barbara, as described by H. C. Ford.[a] The phenomena exhibited resemble those

---

[a] Bull. Santa Barbara Soc. Nat. Hist., vol. 1, No. 2, October, 1890.

of solfataras and have given rise to the opinion that volcanic activity is present in this region. This so-called "Rincon volcano" existed before 1855, being referred to in the Pacific Railroad reports; this shows that the burning has continued a long time.

TYPICAL OCCURRENCES OF BURNT SHALE.

Outcrops of burnt shale occur in eight or ten localities in the Santa Maria district. The best examples are at various places along the ridge of the Casmalia Hills from a point south of Schumann to Waldorf; on the north and south sides of Graciosa Ridge; and on Redrock Mountain 4 miles southeast of Los Alamos. In each of these regions every stage of alteration is exhibited, from the slightly discolored shale to hard slaglike rocks of varying shades of red and black. The area of altered shale in the different localities ranges from about a hundred square feet to a half a square mile or more, as at Redrock Mountain. In each the burnt rock is surrounded by unaltered, usually soft, white, diatomaceous shales which in most places show the planes of stratification. At no point observed was a sign of stratification left in the baked shale. In every occurrence the shales in the neighborhood are bituminous and asphalt deposits are usually adjacent.

The largest area of altered shale is on the summit and surrounding ridges of Redrock Mountain. This is the highest of the hills in the basin region between the San Rafael and Santa Ynez mountains, being 1,968 feet above the sea; the height of most of the summits in the vicinity is from 1,000 to 1,500 feet. Redrock Mountain seems to owe its prominence, at least in part, to the metamorphosed shale that forms its summit. Likewise, in the 800-foot hill on the southeast side of Schumann Pass, the capping of this same character, resembling volcanic rock, seems to have caused the topographic relief. The metamorphism in these localities probably took place a long time ago. At Redrock Mountain great deposits of asphalt are in places in contact with the altered shale, and there is a large area of shale impregnated with bitumen.

DEPTH TO WHICH ALTERATION HAS EXTENDED.

The depth to which alteration has extended below the surface in these occurrences is difficult to determine. A cliff of burnt shale 50 to 100 feet high is exposed 4½ miles due south of Guadalupe, and the difference of elevation of points in the Redrock Mountain neighborhood where the altered rock outcrops amounts to several hundred feet. That such metamorphism of the shale has not been solely a surface phenomenon is shown by the fact that burnt shale has been found at considerable depths in drilling. Mr. Orcutt, of the Union Oil Company, exhibited samples of red shale, coming from depths of 950 to 1,040 feet below the surface in Hill well No. 1, in the Lompoc field, which are identical in appearance and texture with the burnt shale elsewhere. Traces of petroleum were associated with the upper stratum of burnt shale in this well. In numerous other wells in the Santa Maria field red shale, doubtless burnt, was found at depths ranging between 90 and 330 feet below the surface. The hardening consequent on the burning has in some places rendered the rock difficult to pierce with the drill.

LITHOLOGIC CHARACTER OF BURNT SHALE.

The burnt shale exhibits all stages of change from a slight induration and discoloration, due, probably, to oxidation of iron, to an extreme hardening and partial fusion. Where slightly altered, the normal white shale assumes a light-pink color. From this stage it passes through various shades of rose and brick-red and deepens in color to a reddish, bluish, or greenish black, or even a true black. In the advanced stages of change it becomes a rough, brittle, reddish, porous slag, like vesicular lava, or a very hard, compact, dark, and dull-colored rock, looking something like a compact igneous rock. An example of partly vesicular and partly compact burnt shale is shown in Pl. V, *B* (p. 36). Burnt shale is not crystalline, but the texture is so variable as to give a patchy appearance to surfaces. In one place it may be compact and black, nearly full of irregular cavities, surrounded by patches of different colors; in another, vesicular and reddish. Whereas the weight of the original shale is slight, the lighter varieties having a specific gravity less than that of water, the excessively burnt shale is very heavy. The material has evidently contracted to much less than its original volume, the angular cavities and irregular vesicles being one consequence of this contraction.

Under the microscope the rock in the more advanced stages of alteration appears to have an exceedingly fine grained, amorphous, porous groundmass, discolored with reddish-brown or gray stains. Black filaments and dots appearing like carbonaceous material are common. Exceedingly minute rounded and irregular grains scattered through the whole, but forming no appreciable proportion of it, are the only portions visible under crossed nicols. They extinguish four times in a revolution of the field and are probably clastic quartz grains. These are characteristic of the unaltered shale as well.

G. H. Eldridge[a] notes an occurrence of burnt shale near the old Blake asphalt mine, south of Graciosa Ridge. He says: "The shale now appears red, ashlike to hard and clinker-like, glazed, or silicified; bodies of bitumen contained within this have the appearance of a coke, as though derived from the solid fixed carbon of the petroleum."

---

[a] The asphalt and bituminous rock deposits of the United States: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 1, 1901, p. 428.

The likeness of varieties of the burnt shale to volcanic rocks is indicated by the fact that Thomas Antisell, in his account of the geology of the Coast Ranges in the Pacific Railroad reports,[a] describes "scoriaceous" and "amygdaloidal lava," "whitish-gray, hard trachytic rock," "volcanic," and "igneous rocks" in the region of Santa Ynez River, evidently having reference to the burnt shale. He considered these rocks to be eruptive masses, forming the oldest and axial rocks of the hill ranges, whereas they are part of the Monterey shale, which overlies the basement formation. He regarded the associated diatomaceous shales in some places, although not in others, as "magnesian" and "tremolite" rocks of igneous origin, and refers to the places where the shale is burning as examples of present volcanic activity.

CAUSE OF THE ALTERATION.

There can be little doubt that the burnt condition of the shale is in all places the result of heat produced by combustion of its hydrocarbon content. The phenomenon is confined to the Monterey shale, which is the source of a large part of the California petroleum, and to those regions in which this formation is extremely bituminous. The shale in many such places is impregnated with petroleum and the cracks partially filled with it. The areas of altered shale are almost invariably situated in the vicinity of oil seepages, which usually denote a fractured condition of the rocks such as would allow fire to spread and be supported. The observance of fires actually in progress in the shale and the changes that have taken place in the neighboring rocks—changes in every way similar to those in localities where no fire exists at present—give the best clues to the manner in which the shale has been baked in other places. It is difficult to conceive another source of heat sufficient to cause local baking of the shale in otherwise unaltered strata at a depth of 1,000 feet below the surface in such a case as has been mentioned. Probably there, as on the surface, it was due to ignition of bituminous material. It is probable that fire started in the petroliferous shale at the surface and threaded its way downward along cracks partially filled with bitumen. The failure to smother the fire in the shale on Graciosa Ridge, previously noted, indicates that such fires are able to survive with a small air supply. On the other hand, if the above theory is correct, it indicates that a considerable amount of oxygen may be present in the rocks at such a depth.

In this connection it may be mentioned that the temperature in a well near the one in which the burnt shale was found was 152° F., at a depth of 3,600 feet. The cause of ignition may be kindled fires, lightning, or the spontaneous combustion of the hydrocarbons or

---

[a] Explorations and surveys for the Pacific Railroad, vol. 7, 1857, pp. 65–72.

surface vegetation. Many of the recent cases of burning are directly traceable to the first cause, but for those which may have taken place before the advent of man either the second or third cause will have to be invoked.

RANGE IN TIME OF THE PHENOMENON.

As already mentioned, the marked influence of the hardened shale on the topography in certain places indicates that it originated in those places a long time ago. The age of some of the burnt shale is further shown by the presence of numerous fragments of it at a depth of at least 10 feet below the surface in horizontal beds of Pleistocene age. These beds consist of sand, clay, and rough gravel, and form the low hills between Guadalupe Lake and the high hills to the west. The fragments of shale are little worn and evidently of local derivation, having possibly come from the cliffs already mentioned south of Guadalupe. The fact that the Monterey shale has undergone this kind of baking in Pleistocene as well as in recent time indicates further that the accumulation of the oil and its dissemination in the surface rocks took place, or were taking place, before the latest orogenic movements in this coastal region.

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, where it is a series of unaltered sedimentary rocks lying unconformably over the Monterey, and probably representing a portion of upper Miocene time, the whole of the Pliocene, and a part of the Pleistocene. Its lower portion is the equivalent of the Santa Margarita and Pismo formations, and its upper portion is contemporaneous with the Paso Robles formation, as these three are described by Fairbanks in the San Luis folio.[b]

In the region at present under discussion the name Fernando is applied to a similar formation that represents a large part of the Pliocene and probably includes the upper Miocene and part of the lowest Pleistocene. It consists throughout of a series of sandstone, conglomerate, and shale resting unconformably upon the Monterey. Unconformities also exist locally within the Fernando. It attains a thickness of at least 3,000 feet, but no one section exposes the whole series and it is probable that the formation includes a considerably greater thickness. It is widespread in the northern part of Santa

---

[a] The Santa Clara Valley, Los Angeles, and Puente Hills oil districts, southern California: Bull. U. S. Geol. Survey No. 309, 1907, pp. 22-28.

[b] Geologic Atlas U. S., folio 101, U. S. Geol. Survey, 1904..

Barbara County, where it was deposited in the old basin between the Santa Ynez and San Rafael ranges. It covers up 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 were subjected practically 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, showing here and there pholas borings and giving evidence of marine deposition, are 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, that it followed the uplift above sea level of a portion of the Monterey, and that it was subsequent to 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 hard land areas. This change was hardly as marked as that occurring in the reverse order at the close of Vaqueros time, although it accompanied what was probably a greater time and structural break. The apparent structural conformity between the Monterey and Fernando at most places within the 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 fact that the shale of the latter was upheaved around the edges of the basin to form the mountains bordering it 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 facts that it hides the oil-bearing formation over a wide area; that it affords through its structure, however, a clue 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. In the last-mentioned way 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.

This formation is mapped as a unit, although it certainly represents a long period during which sedimentation, 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 stratum resting upon the Monterey in one place is apt to be absent in another, where an overlap of one or another stratum may occur. The lowest recognized Fernando rocks occur 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, succeeded by a 50-foot layer of diatomaceous shale that is indistinguishable from that of the Monterey. Above this shale the series grades up through about 600 feet of fine white and yellow sand and coarse sand, until a bed of conglomerate is reached. At other places, as south of Waldorf and south of Harris, the lowest stratum found at Sisquoc is either wanting or of minor importance, and beds of diatomaceous shale lie conformably over 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, in places 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 by an important unconformity from the Monterey, 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 1½ miles northeast of Divide, and also northeast of Schumann and northwest of Mount Solomon; and on the summit of the ridge in the vicinity of the head of Pine Canyon, halfway between the two latter localities, the Monterey is capped by what appears to be a part of the same series somewhat younger still. This shows that at the locality near the head of Pine Canyon either an overlap of the late Fernando occurred on an old eminence of Monterey shale that was above the sea at the time of the deposition of the part of the Fernando immediately preceding, causing the omission on its summit of hundreds of feet of sediments which were deposited around its base; or else the portion of the Fernando preceding this series was removed from above the Monterey during a period of erosion within Fernando time, this period being followed by subsidence.

Along the ridge 1 mile southeast of Redrock Mountain, in the Purisima Hills, there is a capping of diatomaceous shale resembling that of the Monterey in every respect, but containing characteristic Fernando fossils. It was not suspected that this shale belonged to a formation distinct from the Monterey until the fossils were found.

It would be difficult to work out the limits of the area that this remnant covers. In all probability it is very small, and it has not been shown on the map. This shale here forms the base of the Fernando. A pebbly layer with constituent well-worn pebbles of Monterey shale embedded in sand has aided in the accumulation of asphalt on the summit of the ridge near by, where it probably marks the basal line of the Fernando formation.

Above the soft diatomaceous or gritty shale and fine white sand that is common at or near the bottom of the Fernando 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 of well-worn pebbles, mostly of flint and hard shale, embedded in a coarse sandy matrix. Locally 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 up in the series (above the lowest horizon) just north of Canada de los Alisos, on La Laguna grant. What is probably the same bed is well exposed in cliffs west of Canada Laguna Seca, 1½ miles south of the Los Alamos Valley. This loose aggregate of sand and pebbles in alternating strata of coarse and fine material is dominantly composed of the light-colored pebbles of Monterey shale. Pebbles of other varieties occur more sparingly. Above the conglomerate lies a stratum of limestone that is constant over the whole region and seems to mark a division in the Fernando. There are two or more massive beds of hard limestone interbedded with soft, gray, very alkaline, earthy material, making a total thickness ranging from 10 to perhaps 50 feet. Its fossils indicate that it is of fresh-water origin, and possibly it marks the base of a fresh or brackish water series. The portion of the Fernando overlying this limestone probably corresponds to the fresh-water Paso Robles formation of the Salinas Valley described by Fairbanks in the San Luis folio. In some places where this higher portion of the Fernando above the limestone has not been worn away, it is found to consist of little-consolidated beds of fine sand, gravel, and clay that look as if they might have been laid down in fresh water, but no proof of their origin has been found. Such beds are well exposed in the foothills of the San Rafael Range north of Santa Ynez, where they weather characteristically into cliffs at the summit of hills. A view of such an exposure is given in Pl. VI, *A* (p. 46), which affords a good idea of the rough alternating beds of coarse material. No good lithologic or paleontologic criteria are known by which this series may be separated from the lower portion of the Fernando, and they are therefore mapped as a unit.

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 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 rarely become steeper than 30° or 35°. In places, as south and west of Sisquoc and west of Canada Laguna Seca, the beds are almost if not quite horizontal, but this is exceptional. 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 the westward extension of a great synclinal basin that runs from that locality first eastward and then 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 on both sides 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 upturned also 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 places 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, in the neighborhood of Cebada Canyon, and along the fault crossing Labrea Creek. In the first two the dip of the beds is moderate and the disturbance is not great.

DISTRIBUTION.

An idea of the distribution of the Fernando may be well obtained from the map (Pl. I, in pocket), as it is not covered by so many formations as the older series. It is much more widespread near the surface, however, than appears on the map, since it is probably present and hidden by only thin deposits over a great part of the area mapped as terrace deposits and alluvium.

The general character of the Fernando is that of a filling. Its soft, loose, spreading sands, which preserve poorly 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 and 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, at the head of Howard Canyon. On the northeastern border of the Casmalia Hills, between Schumann and Graciosa Canyon, a lime-hardened sandstone predominates and forms a prominent ridge. In the Santa Rita Hills the lines of structure that there curve around from a westerly direction to the southeast are brought out by the resistant limestone which supports the northeast flanks of the hills. The wide-stretching 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 have the appearance of belonging to a fresh or brackish water series, and they stand out with many bold faces that have been cut in the soft formation, as illustrated in Pl. VI, *A*. Elsewhere the dominant character of the Fernando and its topographic forms are due to the soft sand which forms the major portion of the series.

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 of Folsom lease in soft sandstone.

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

The beds at horizon *a* are of marine origin, are probably upper Miocene in age, and correspond in a general way to Fairbanks's Santa Margarita and Pismo formations. Those at horizons *b*, *c*, *d*, and *e* 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 Purisima and lower and upper San Diego formations. At horizon *f* are beds of fresh-water origin, probably representing Fairbanks's Paso Robles formation and Lawson's marine Merced formation.

The following is a list of the fossils obtained from the Fernando:

Fernando (upper Miocene-Pliocene-Pleistocene) fossils from the Santa Maria district, California.

	4469	4471	4472	4473	4474	4475	4476	4477	4481	4485	4486	4487	4488	4489	4490	4491	4492	4506	4523
Actæon sp																×			
Amphissa (?) sp				×															
Angulus sp				×															
Arca sp. a				×															
Arca sp. indet										×				×					
Arca trilineata Conrad (Pl. XXIV, fig. 5)		×	×	×	×	×						×						×	×
Astyris richthofeni Gabb (Pl. XXIV, fig. 3)				×	×		×		×										
Balanus cf. concavus Bronn					×		×												
Bathytoma carpenteriana Gabb var. fernandoana Arnold (Pl. XXIII, fig. 7)							×												
Bathytoma cf. tryoniana Gabb				×															
Bittium arnoldi Bartsch				×															
Bittium casmaliaensis Bartsch				×															
Cadulus fusiformis Sharp and Pilsbry (Pl. XXI, fig. 8)				×															
Calliostoma sp. indet				×	×														
Callista subdiaphana Carpenter			×	×		×							×						×
Cancellaria sp. a			×	×		×													
Cancellaria crawfordiana Dall var. fugleri Arnold (Pl. XXI, fig. 9)						×													
Cardium meekianum Gabb					×	×										×			
Cardium sp. indet		×																	
Chione sp																×			
Chlorostoma (?) sp		×																	
Chrysodomus sp							×												
Clidiophora punctata Carpenter (Pl. XXIII, figs. 2, 3)							×												
Crepidula princeps Conrad (Pl. XXIV, figs. 1, 2)		×		×		×				×			×			×		×	×
Crucibulum spinosum Sowerby					×														
Cryptomya ovalis Conrad (Pl. XXII, fig. 7)		×				×			×	×				×					
Cumingia californica Conrad (Pl. XXIII, fig. 5)						×													
Dosinia ponderosa Gray (Pl. XXII, fig. 8)		×				×				×					×				
Drillia graciosana Arnold (Pl. XXI, fig. 18)			×																
Drillia johnsoni Arnold (Pl. XXI, fig. 13)				×															
Drillia waldorfensis Arnold (Pl. XXI, fig. 12)				×															
Echinarachnius ashleyi Merriam (Pl. XXIV, figs. 6, 7)	×								×		×	×							
Echinarachnius cf. excentricus Eschscholtz var. (Pl. XXIV, fig. 8)					×											×			
Fusus sp. a		×	×																
Fusus sp. b										×									×
Galerus inornatus Gabb						×				×									
Glycymeris cf. barbarensis Conrad					×	×				×									
Kennerlia(?) sp			×	×															
Leda orcutti Arnold (Pl. XXII, fig. 9)			×	×	×								×						
Leda taphria Dall (Pl. XXII, figs. 3a, 3b)				×															
Lucapina cf. crenulata Sowerby						×													
Lunatia lewisii Gould (Pl. XXI, fig. 3)		×		×	×	×													

Fernando (upper Miocene-Pliocene-Pleistocene) fossils from the Santa Maria district, California—Continued.

	4469	4471	4472	4473	4474	4475	4476	4477	4481	4485	4486	4487	4488	4489	4490	4491	4492	4506	4523
Lymnæa alamosensis Arnold (Pl. XXI, figs. 6, 7) [a]																			
Macoma nasuta Conrad (Pl. XXII, fig. 5)		×		×	×		×			×									×
Macoma sp				×															
Macoma cf. secta Conrad					×														
Mactra sp						×	×			×									
Miopleiona oregonensis Dall				×		×													
Modiolus rectus Conrad				×	×	×				×									
Monia macroschisma Deshayes					×														
Muricidea sp					×														
Mya truncata Linné				×															
Mytilus sp. indet					×														
Nassa californiana Conrad (Pl. XXIV, fig. 4)		×			×	×	×	×	×	×						×			
Nassa waldorfensis Arnold (Pl. XXI, fig. 17)				×	×														
Natica clausa Broderip and Sowerby (Pl. XXI, fig. 16)				×	×	×													
Neverita recluziana Petit (Pl. XXI, figs. 14a, 14b, 15)					×	×	×												
Ocinebra lurida Middendorf					×														
Ocinebra micheli Ford var. waldorfensis Arnold (Pl. XXI, fig. 10)				×															
Olivella biplicata Sowerby					×		×												
Olivella cf. intorta Carpenter									×										
Opalia anomala Stearns				×	×														
Opalia varicostata Stearns				×	×														
Ostrea veatchii Gabb (Pl. XXIII, fig. 10)				×	×														
Ostrea possibly veatchii Gabb			×																
Panomya cf. ampla Dall						×													
Panopea generosa Gould		×		×	×	×													
Pecten (Plagioctenium) near cerrosensis Gabb						×													
Pecten (Patinopecten) healeyi Arnold (Pl. XXVI, figs. 1, 2)					×							×							
Pecten (Pecten) hemphilli Dall (Pl. XXV, fig. 5)					×														
Pecten (Chlamys) lawsoni Arnold (Pl. XXV, fig. 3)			×	×	×	×													
Pecten (Patinopecten) oweni Arnold (Pl. XXV, figs. 2a, 2b)										×								×	
Pecten (Pecten) stearnsii Dall (Pl. XXV, figs. 1a, 1b)						×													
Pecten (Chlamys) wattsi Arnold (Pl. XXV, fig. 4)						×													
Phacoides annulatus Reeve (Pl. XXIII, fig. 8)		×	×	×	×											×			
Phacoides intensus Dall (Pl. XXIII, figs. 9a, 9b)				×	×														
Phacoides nuttallii Conrad var. antecedens Arnold (Pl. XXII, fig. 6)		×					×		×										
Pholadidea ovoidea Conrad (Pl. XXII, figs. 1a, 1b)			×	×		×	×												
Pholadidea (?) sp. indet																		×	
Platyodon cancellatus Conrad var					×														
Pleurotoma (Borsonia) sp. a				×															
Pleurotoma sp. b						×													
Priene oregonensis Redfield var. angelensis Arnold (?)					×														
Priene oregonensis Redfield (Young) (Pl. XXI, fig. 2)				×															
Purpura crispata Chemnitz (Pl. XXII, fig. 2)					×														
Saxidomus gracilis Gould					×														
Saxidomus (?) sp. a										×									
Scala sp. a					×														
Sigaretus debilis Gould		×																	
Siliqua cf. edentula Gabb		×																	
Solen cf. sicarius Gould				×	×	×	×												
Spisula catilliformis Conrad var. alcatrazensis Arnold (Pl. XXIII, fig. 6)		×																	
Spisula sisquocensis Arnold (Pl. XXIII, fig. 1)		×																	

---

[a] Fresh-water beds in the Fernando formation, 1 mile southeast of bench mark 425, Los Alamos Valley.

Fernando (upper Miocene-Pliocene-Pleistocene) fossils from the Santa Maria district, California—Continued.

	4469	4471	4472	4473	4474	4475	4476	4477	4481	4485	4486	4487	4488	4489	4490	4491	4492	4506	4523
Tapes cf. lacineata Carpenter	...	×	...	...	×	...	×	...	...	...	...	...	...	...	...	...	...	...	...
Tapes staleyi Gabb	...	×	...	...	×	...	...	...	...	×	...	...	...	...	...	...	...	...	×
Tapes tenerrima Carpenter (Pl. XXII, fig. 10)	...	×	...	...	...	×	×	×	...	...	...	...	...	...	...	...	...	...	...
Tellina sp	...	×	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Tellina aff. bodegensis Hinds	...	...	...	...	...	...	...	...	...	...	...	...	×	...	...	...	...	...	...
Terebratalia occidentalis Dall (Pl. XXII, figs. 4a, 4b)	...	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...
Thalotia caffea Gabb (Pl. XXI, figs. 4, 5)	...	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...
Thracia cf. trapezoides Conrad	...	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...
Thyasira aff. gouldii Philippi	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Tresus nuttallii Conrad	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	×	...	...	...
Tritonium sp. indet	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Trochita radians Lamarck (Pl. XXI, fig. 1)	...	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...
Trochita sp. indet	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...
Turritella cooperi Carpenter (Pl. XXI fig. 11)	...	...	×	×	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Venericardia californica Dall (Pl. XXIII, fig. 4)	...	...	×	×	×	×	...	...	...	...	...	...	...	...	...	...	...	...	...

4469. One hundred yards northeast of California Coast oil well No. 3, 1 mile east of Divide, and 3 miles southeast of Orcutt.
4471. Alcatraz asphalt mine, 3 miles east of Sisquoc.
4472. Pennsylvania asphalt mine, 3½ miles southeast of Orcutt.
4473. Waldorf asphalt mine, 3 miles south-southeast of Guadalupe.
4474. Railroad cut 1 mile north of Schumann station.
4475. Fugler Point asphalt mine, 1 mile north-northeast of Gary, at head of Santa Maria Valley.
4476. Asphaltum layer above Monterey shale, near Folsom well No. 3, Santa Maria oil field, 3 miles southeast of Orcutt.
4477. Near Folsom well No. 4, Santa Maria oil field, 2½ miles southeast of Orcutt.
4481. Five miles N. 30° E. of Lompoc bench mark 95, in prominent sandstone beds around Purisima oil wells.
4485. One-half mile south of Sisquoc.
4486. *Echinarachnius ashleyi* horizon, immediately west of Santa Maria Oil and Gas Company's well No. 4, 2 miles southeast of Orcutt.
4487. Immediately east of head of Howard Canyon, 4 miles north-northeast of Los Alamos. *Echinarachnius ashleyi* horizon.
4488. On ridge south of road about 2¼ miles northwest of Blake.
4489. Southeast side of La Zaca Creek, where it empties from steep canyon; at base of asphalt sandstone in shale, 8 miles north of Los Olivos.
4490. Four miles east-northeast of Los Alamos, on Cuaslui Creek.
4491. Gully 2⅝ miles west-northwest of Blake.
4492. One and three-fourths miles S. 5° W. of bench mark 425 of Los Alamos Valley, one-half mile northwest of sink on top of ridge.
4506. One mile southeast of summit of Redrock Mountain, along ridge, near 1,700-foot knob.
4523. One mile due south of Sisquoc, in ravine.

QUATERNARY.

GENERAL STATEMENT.

Three distinct classes of Quaternary deposits younger than the latest Fernando can be differentiated in this region, although it is difficult to distinguish between them areally. They are terrace deposits, dune sand, and alluvium, each one of which as mapped may possibly represent more than one period of deposition. They are deposits of comparatively little thickness laid down unconformably upon the older formations subsequent to the greater part of the disturbance and deformation that has affected the region.

TERRACE DEPOSITS.

GENERAL DESCRIPTION.

Terraces are common in this region and are among the most prominent topographic features. They are fairly even surfaces, invariably inclined slightly toward the ocean or the line of drainage, and ranging in size from tens of square miles to only a few feet square. The more extended terraces fringe the coast line and the larger valleys and cover areas of low hills. The smaller ones are scattered over ridges and hilltops and along the smaller valleys. These terraces are covered with a thin coating of sand and gravel, and here and there with clayey material. The distribution of the deposits is well shown on the map, with two general exceptions. In the first place, many of the strips of land along valleys mapped as covered with terrace deposits may not represent true terraces, as it is almost impossible to draw definite distinctions between such horizontally bedded valley fillings, true terrace cappings, and recent alluvium. All post-Fernando deposits in small valleys are therefore mapped with the terrace formation, and alluvium is shown only in the extended valley bottoms, where dividing lines between it and the terrace deposits are drawn arbitrarily. In the second place, owing to the lithologic similarity of the Fernando and the terrace-deposit sand and the similar surface appearance of these two formations, the attempt has been made to represent on the map only a few areas of the terrace sand overlying the Fernando. The Fernando is doubtless capped by terrace deposits in many places, but it is usually impossible to tell whether this is true or not. The lines of contact between these formations are of necessity arbitrarily shown.

This similarity causes much difficulty in places in determining whether the deposits belong to the Fernando or to the later epoch, and whether it is necessary to go through a great thickness of Fernando beds or only a few feet to reach the Monterey below. Where fossils, distinct lines of bedding, or tilted strata are present they are indications that the sand belongs to the Fernando.

The terraces are found commonly at all altitudes up to 1,200 feet, and a few even as high as 1,400 feet. None have been definitely recognized at a higher elevation.

LITHOLOGIC CHARACTER.

The material of the terrace deposits is usually sand and conglomerate, for the most part the former. The sand is medium grained and contains scattering waterworn pebbles. It is normally soft and grayish, but in many places compact, being stained a reddish yellow and hardened by iron oxide or filled with iron-stained concretions. In this surficially compacted state it forms hard cappings on hilltops and slopes. Round, bullet-like, iron-hardened concretions are characteristic of the derived soil. Over much of the surface of Burton Mesa and in other places this deposit occurs as loose, grayish sand, hardened locally by the action of rain water and various salts or oxide of iron. The conglomerate—or gravel, as it might equally well be called—is composed of bowlders, pebbles, and fragments of Monterey flint and shale, besides pebbles of other rocks in smaller quantity. Some of the pebbles are very much waterworn, but in places the number of unworn fragments of shale almost necessitates the use of the word "breccia" in describing the deposits. Evidence of bedding is rarely prominent in the typical terrace deposits, but they invariably appear to lie horizontal, seeming to have been little disturbed by the uplift of the land that brought them to their present elevation.

No fossils have been found in these deposits, but they contain numerous pholas-bored pebbles of Monterey shale, and in places, as on Burton Mesa, the Monterey shale itself, upon which the deposits lie, has been bored by these marine mollusks.

Many of the cappings formed parallel with the surface through hardening by iron oxide have the appearance of being beds with appreciable dip, and are therefore misleading. The thickness of the coating of Burton Mesa is 25 or 30 feet and the cover of the typical terrace in other parts of the region has about the same thickness. Whether it attains a much greater development than this at any place is hard to tell. These shallow coverings hide considerable areas of the Monterey and obscure its structure, but most of the canyons that cut into the terraces reveal the presence of the oil-bearing 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. The deposits are economically of importance as reservoirs for the oil escaping from the Monterey shale, and thus they give rise to accumulations of asphalt. It is usually impossible to tell whether the sand that helps to form the asphalt is a terrace deposit or belongs to the Fernando. The terrace sand can not form as deep asphalt deposits as those due to the Fernando sand.

In some of the valley fillings above mentioned, as for instance along Salsipuedes Creek, and at the west edge of the Santa Maria Valley between Guadalupe Lake and the Casmalia Hills, there occur horizontally bedded deposits of clay, sand, and gravel differing in appearance from the terrace deposits and possibly differing in age and origin. A good example of an old valley filling which now forms the summit of a hill is shown in Pl. IV, *B* (p. 36). It consists of a sandy and earthy material through which rock fragments and pebbles are scattered. It illustrates the usual unconformity of the post-Fernando deposits with the older formations. The low hills in the region of Santa Ynez are formed largely of horizontal beds of fine gravel unlike the Pleistocene deposits found elsewhere. These exhibit in one place an appearance of being tilted, though this may be due to cross-bedding.

ORIGIN.

Most of the terrace deposits are probably of marine origin. This is proved in the case of the most typical deposits by the presence of the pholas borings already mentioned. The deposition was carried on in shallow water and much of the material was derived on the spot from the wearing away of the shore line of Monterey shale, the fragments of which were not always subjected to much polishing before being deposited and protected from agencies of erosion. These deposits give undeniable evidence of a great uplift of the coast during Pleistocene time. It seems most probable that the terraced surfaces resulted from marine planation along gradually rising shore lines and that the formation covering them represents the beach and shore deposits. The rise of the land was probably too rapid and the amount of sediment too small to allow much off-shore extension of the deposition. The material that may have been deposited in the deeper places determined by the depressions in the topography has since probably been largely removed by erosion. The terrace deposits themselves have been extensively eroded and in many places are left as mere remnants. Some of them have no doubt been subsequently added to by wind-blown sand.

It is probable that some of the terraces and horizontal Pleistocene deposits along valleys have been formed by streams. Most of the valley fillings were probably laid down in this way. At the mouths of some canyons, as along the western side of Graciosa Canyon, Pleistocene deposits have been built up in the shape of detrital fans, which have since been carved into flat-topped, steep-sided blocks by recent streams.

DUNE SAND.

The prevailing northwesterly wind from the ocean has amassed great deposits of sand in places along the coast. The process has probably been going on all through the Quaternary period and it is hard to distinguish the older of the eolian deposits from those partially or entirely of marine deposition. The line of contact of these formations as mapped is arbitrary.

The greatest mass of dune sand occurs at the northwest end of the Casmalia Hills, where the gradual slope down to the sea from an elevation of about 1,200 feet is covered by loose, yellow sand of probable eolian origin. This drifts about incessantly and is probably still in the process of collecting, being supplied from the long, low, open shore to the north and held in check by the bulwark of the Casmalia Hills on the south. This deposit has a thickness of several hundred feet. At its base along the coast is exposed a basal layer of large bowlders and horizontally stratified sand. The original slope of the hills was probably at least partly covered during the uplift of the coast by marine terrace deposits similar to those found elsewhere in the region, these being later buried by the gathering wind-blown sand. Recent marine shells are widely scattered over the surface of this sand, but are not considered by the writers as indicating its marine origin. They were probably carried there by Indians or birds.

South of the Casmalia Hills, where the coast is open to the winds, sand dunes are continually forming and covering up the terrace deposits. The sand is not retarded by an inland barrier, however, as on the north of the hills, and no such vast deposit has been formed. The sand is continually being carried into the interior valleys and spread thinly over a wide area.

ALLUVIUM.

All the valleys of this region contain a certain amount of alluvial material and stream gravels, which reach in many localities a thickness of 50 feet or more. In some places the deposit 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 of somewhat different origin. They are mapped as distinct only in the larger valleys and the contact lines are arbitrary. Practically all the hills and valleys within the territory mapped have a covering of soil.

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 all basic in composition. Layers of volcanic ash high in silica interbedded with the Monterey are discussed with the sedimentary series (p. 37). The center for igneous rocks is in the region around Point Sal of which Fairbanks made a special study, and the statements here made in regard to the igneous rocks of that region are based largely on his description.[a]

IGNEOUS ROCKS OF PRE-MONTEREY AGE.

Fairbanks describes a small intrusion of basalt having a laccolithic appearance in the Knoxville (lower Cretaceous) shales 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

---

[a] Fairbanks, H. W., The geology of Point Sal: Bull. Dept. Geology, Univ. California, vol. 3, 1896, pp. 1-92.

and believes to antedate the Knoxville. It is closely associated and intermingled with bodies of diabase and gabbro. This complex forms Point Sal Ridge and the rocky headland of Point Sal. Another complex that he believes belongs in the Knoxville forms a long dike 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 may be older than the Knoxville, and the last-mentioned occurrence of gabbro and peridotite 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, and several accessory minerals. This occurrence is of considerable 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 is common. The fact that the rock is so much altered probably indicates that it belongs to a formerly exposed older formation upon which a fairly high portion of the Monterey shale series has overlapped. It is hardly conceivable that an intrusion at such a depth in the shale could have undergone so much alteration. In either case, whether this diabase marks the base of the Monterey or whether the shales have been intruded by an igneous mass, the conditions are unfavorable for the discovery of oil in the immediate vicinity.

IGNEOUS ROCKS INTRUDING THE MONTEREY.

The youngest igneous rocks occurring in the Santa Maria quadrangle and those of chief interest in the present connection are intrusive in the Monterey (middle Miocene). Such are five small areas of diabase mapped by Fairbanks south of Point Sal 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 originated as dikes intruding the Monterey. 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 areas is of dark-green color and coarse texture and exhibits sheared serpentinous facies.

Another intrusion of probable post-Monterey age forms a single outcrop in the hills 7 miles northeast of Point Conception. It is a dike of basic porphyry related to basalt. On one side of the outcrop the bases of horizontally lying rough pentagonal columns are well exposed. It is not known whether the sedimentary rocks through which this is intruded belong to the Monterey or the upper part of the Vaqueros.

GEOLOGIC HISTORY.

EARLIEST PERIODS.

The general geologic aspect of the Santa Maria district is that of a region of comparatively recent geologic formations. Tertiary rocks, in places covered by Pleistocene deposits, are predominant, those of Cretaceous and Jurassic age less widespread, and older formations entirely absent. The Tertiary has received almost all the attention in the present study and little can be said of the history of the region previous to that period. The much-disturbed and metamorphosed Jurassic sediments (Franciscan), intruded by serpentine, form the basement of the whole region, but outcrop only very locally. In Cretaceous time a considerable thickness of marine sediments was laid down, but these deposits were probably not greatly disturbed before the beginning of deposition in the Tertiary. To the present time they have remained unmetamorphosed and no more affected by mountain-making forces than later formations. Igneous intrusions, however, took place at different times in the Cretaceous.

EOCENE PERIOD.

All the greater divisions of the Tertiary, with the possible exception of the Oligocene, are represented by marine sediments, the major part of this time having been taken up by sedimentation. The relations between the Cretaceous and Eocene rocks have not been studied. Sedimentation began at some time in the Eocene not yet determined, in the southern portion of the region mapped, and continued nearly to the end of the Eocene, when it ceased for a period of unknown length. It was probably in the period just preceding that of the deposition of the Eocene sediments that the forces began to work which caused the structural features south of the region where the San Rafael Mountains now stand to assume an east-west trend. In this way may have been formed the depression extending east and west across the region now occupied by the Coast Ranges, which afforded a basin of deposition for the Eocene and possibly a connection between the ocean and the basins in which strata of the same age were deposited in the interior. A large part of the Santa Ynez Mountains is composed of Eocene strata which have been lifted up along east-west lines of structure. The main uplift did not occur at the close of Eocene time, but it is probable that orogenic movements did bring to a close the period during which the Eocene sediments were laid down by raising the strata slightly above the sea and preventing for a time further deposition. How long this time was is not known, but it corresponds approximately with the Oligocene.

LOWER MIOCENE PERIOD.

The movements immediately following the deposition of the Eocene caused no appreciable disturbance in the Eocene strata, and when sedimentation recommenced over the same area in lower Miocene time neither the old nor the new strata preserved any positive evidence in their relative position that a time break had occurred. The great masses of coarse conglomerate forming the base of the lower Miocene portion of the group record a change to conditions of very shallow water, and the abrupt change of faunas indicates that a long time interval separated their deposition from that of the subjacent Eocene. It is most probable, however, that the post-Eocene movements, which were gentle, were also somewhat local, and that in portions of the Santa Ynez Mountains to the east of the region under discussion sedimentation was more nearly continuous. At about the close of the Oligocene period the Eocene basin was again depressed; deposition of sediments, almost entirely of detrital origin and very similar to those previously laid down, ensued in a widening area covered by the sea; and subsidence of the land gradually continued. The Vaqueros formation, which resulted from this period of depression, represents the greater part of lower Miocene time.

MIDDLE MIOCENE PERIOD.

The middle Miocene (Monterey) shale formation is one of striking individuality, and conditions of unusual character prevailed during its period of deposition. At the beginning of middle Miocene time the land sank over a large part of the region of California now occupied by the Coast Ranges and fairly deep water conditions became prevalent. The wearing away of extended land areas ceased as they became submerged, and the material for the formation of coarse detrital deposits was no longer plentiful. Two varieties of deposits, which were largely of organic origin, were the chief ones to be formed during the long period that followed. These were the laminated limestones and the much more abundant siliceous shales. Silt of extremely fine grain, both of siliceous and argillaceous nature, was swept into the sea waters, probably from considerable distances, and settled down to form a considerable proportion of the deposits; but sand and other coarse detritus found their way only at rare intervals to the main portions of the quiet sea bottom which was formerly the surface of the land and which had been given a comparatively low relief by the long period of erosion that preceded the submergence.

During the period of transition between the Vaqueros and the Monterey, limestone was formed chiefly, but somewhat inclosed basins where deposits of alkaline mud were laid down apparently existed in places. Such a basin is indicated by the alkaline gypsiferous clays on the south side of the Casmalia Hills, probably representing upper Vaqueros. In some places, as, for instance, in the San Rafael Mountains, sandstone beds were formed early in Monterey time, probably in the neighborhood of locally unsubmerged areas. But later very little sand was deposited anywhere. Further submergence no doubt took place during the period, removing the sources of this sand and allowing to be deposited under fairly constant conditions a thickness of beds greater than a mile. It is not probable, however, that the depth of the sea was at any time as much as this, being more likely closer to half a mile.

During the early part of Monterey time conditions were variable, calcareous and siliceous deposits alternating, probably as a result of alternating temporary predominance in the sea of organisms with calcareous or siliceous shells. As the period progressed the siliceous organisms became more predominant and remained so, making up a large fraction of the total bulk of the Monterey formation. It was an age of diatoms. These small marine plants lived in extreme abundance in the sea and fell in showers with their siliceous tests to add to the accumulating ooze of the ocean bottom, just as they are forming ooze at the present day in some oceanic waters. It is well known that diatoms multiply with extreme rapidity. It has been calculated that starting with a single individual the offspring may number 1,000,000 within a month. One can conceive that under very favorable life conditions, such as must have existed, the diatom frustules may have accumulated rapidly at the sea bottom and aided the fine siliceous and argillaceous sediments in the quick building up of the thick deposits of middle Miocene time. A principal obstacle to the rapid accumulation of the diatoms might be the limited supply of silica from which these algæ derive the material of their tests. Other organisms with their shells and skeletons were also present to aid in building up the shale beds. They were Radiolaria and Foraminifera; sponges with their spicules, which were abundant; Crustacea; fishes, the remains of which are numerous in the shales; and mollusks with delicate shells, which are common, though poorly preserved.

Volcanic eruptions, possibly submarine, broke out at different times during the latter part of the lower Miocene (Vaqueros) and the early part of the middle Miocene (Monterey.) They may have accompanied movements that took place during the transition period. Acidic volcanic ash of a rhyolitic type was ejected, and it settled in the ocean to form regular beds of considerable thickness and extent interstratified with the other sediments. The occurrence of ash interbedded with diatomaceous earth that probably belongs fairly high in the Monterey formation indicates that these eruptions did not cease in the early part of middle Miocene time. Neither the centers of eruptions nor any lava equivalents of the ash have been found in the field. Similar eruptions were characteristic of the lower and middle Miocene for long distances north and south of this region.

LATE TERTIARY AND EARLY QUATERNARY PERIOD.

The Monterey period of deposition was brought to a close by orogenic movements which folded the shales and lifted them above the sea in many places. In some regions the folding was intense, the greatest disturbances accompanying the uplift of the mountain ranges to an altitude of thousands of feet. The San Rafael Mountains, which were upheaved at this time, probably extended along the lines of former mountains, and some smaller mountainous or hilly areas likewise, such as the Casmalia Hills and perhaps portions of the Santa Ynez Range, followed former zones of uplift. But for the most part the Santa Ynez Range was probably new. It is doubtful whether it was ever completely covered by Monterey sediments, and its structure may have been determined by minor folding previous to the beginning of the Monterey, but it is probable that this range did not have any approach to its present proportions until after middle Miocene time. In other regions low, broad folds were formed during the post-Monterey disturbance and the strata were not upheaved to a great altitude; such was the case in parts of the basin region between the San Rafael and Santa Ynez mountains.

After the formation of the middle Miocene shales they were intruded at several different points by basic igneous masses, mostly of the nature of diabase. The disturbance which put an end to the period was profound and this igneous activity was probably an accompaniment of it. The rocks were locally hardened by contact action in consequence of the intrusions.

After an erosion interval, probably of comparatively short duration, the land again sank, though not so extensively nor to such depth as in the previous subsidence, and a large part of the Santa Maria district, especially the lower regions, became submerged. The deposition of the Fernando followed, beginning before the close of the Miocene. Owing to differences in altitude and possibly also to local difference in the amount of subsidence, the deposition began in some places before it did in others. Over the areas in which the Monterey has been only slightly folded, the Fernando beds assumed conformable positions with it. In regions where the Monterey beds had been more highly tilted the later sediments were laid down unconformably. In places the first Fernando beds were of similar lithologic character to the Monterey shale, being deposited probably under similar conditions or else derived from the redeposition of the shale material. This similarity, added to the bedding conformity, caused the formations to appear as completely conformable and continuous. But the presence in places of layers of brecciated Monterey shale at the base of the Fernando, and in places of true angular unconformities, proves that a period of erosion preceded the Fernando deposition.

After the period of deposition of the finer sediments usually found at the base of the Fernando, shallow-water conditions prevailed. The deposits were almost entirely detrital, the product of erosion on land, much of the material coming from areas of Monterey shale. Fresh-water or possibly brackish-water conditions may have prevailed in the latter part of Fernando time. They certainly did for a time and locally, at least, when the brackish-water limestone beds were formed.

MAIN QUATERNARY PERIOD.

Downward and upward movements of the coastal region were probably in progress during the Fernando period, but were intensified early in Pleistocene time, and disturbance of the strata along the lines influenced by the post-Monterey upheaval took place. In this way the mountain ranges were upraised in their present position and the Fernando became warped along the lines of further folding in the Monterey.

After this uplift erosion set in and eventually removed the Fernando from some parts of the region over which it had formed a thick covering. The mountain regions were worn into rugged shapes, Santa Maria and Santa Ynez rivers developed graded valleys, and the sea planed off the coast extensively by cutting. During the same period, however, land building over this region was in progress as the result of differential movements of the coast. The great resultant changes of level in post-Fernando time, as indicated by the records, were a pretty general depression to a depth of 1,100 to 1,200 feet, and locally to at least 1,400 feet; and a later uplift to the present level. These movements were probably gradual and continuous, but not sufficiently slow to allow the formation of deposits of great thickness. During these movements the sea cut into the land as the water encroached and receded, forming terraces inclined toward the ocean, and beach and shallow-water sediments were laid down as thin coatings over the newly planed surfaces. These deposits were probably formed as the land rose. During the periods of depression the streams built up deposits of gravel, sand, and clay at different levels, giving rise to extensive terraces and to filled valleys. Great deposits of wind-blown sand were formed also, and their formation is continuing at present. During the late Quaternary the deposits and topographic forms resulting from all these processes have been carved by erosion; wide areas have been denuded of the thin Pleistocene capping; and in many places bits of terrace deposits are left merely as scattering remnants.

STRUCTURE AND CONDITIONS AFFECTING THE PRESENCE OF OIL.

THE ANTICLINAL THEORY.

The anticlinal theory of oil accumulation assumes that the oil, being of lesser gravity, rises above the water present in porous rocks and collects at the highest possible points in upward folds, being there confined by impervious strata arching over the folds. The presence of water, according to this theory, is considered as fundamentally necessary for the carrying out of the process of accumulation in anticlines.

The presence of oil in anticlinal folds was repeatedly observed in the eastern part of North America during the latter half of the nineteenth century. E. B. Andrews noted its occurrence along low anticlines in West Virginia and Ohio as early as 1861, and described this occurrence that same year,[a] and again, with more assurance of its wide application, in 1866.[b]

In 1863 the Canadian geologists,[c] in describing the oil springs immediately north of Lake Erie, noted their close relation to the anticlinal structure, and formulated the theory that the rise of the oil is due to the presence of water in the rocks. Their brief statement is as follows:

> Some of these springs appear to be on the line of the great anticlinal which runs through the western peninsula, and subordinate undulations of a similar character will be found connected with others. The oil, being lighter than water and permeating with it the strata, naturally runs to the highest part, which is the crown of the anticlinal, whence it escapes to the surface by some of those breaks which are usually found in such positions.

Also in 1863 Sterry Hunt, to whom the above-cited conclusions in the Canadian report are probably due, described the oil of western Ontario as derived from low anticlines.[d]

The following quotation is from an account written in 1885 by I. C. White[e] of his search for some method of determining the location of gas accumulations:

> In the prosecution of this work I was aided by a suggestion from Mr. William A. Earsenian, of Allegheny, Pa., an oil operator of many years' experience, who had

---

[a] Am. Jour. Sci., 2d ser., vol. 32, July, 1861, pp. 85-93.
[b] Am. Jour. Sci., 2d ser., vol. 42, July 1866, pp. 33-37.
[c] Geology of Canada, Canadian Geol. Survey, 1863, p. 379.
[d] Am. Jour. Sci., 2d ser., vol. 35, March, 1863, pp. 169-170.
[e] Science, vol. 5, No. 125, June 26, 1885.

noticed that the principal gas wells then known in western Pennsylvania were situated close to where anticlinal axes were drawn on the geological maps. From this he inferred there must be some connection between the gas wells and the anticlines. After visiting all the great gas wells that had been struck in western Pennsylvania and West Virginia, and carefully examining the geological surroundings of each, I found that every one of them was situated either directly on or near the crown of an anticlinal axis, while wells that had been bored in the syncline on either side furnished little or no gas, but in many cases large quantities of salt water. Further observation showed that the gas wells were confined to a narrow belt, only one-fourth to 1 mile wide, along the crests of the anticlinal folds. These facts seemed to connect gas territory unmistakably with the disturbance in the rocks caused by their upheaval into arches, but the crucial test was yet to be made in the actual location of good gas territory on this theory. During the last two years I have submitted it to all manner of tests, both in locating and condemning gas territory, and the general result has been to confirm the anticlinal theory beyond a reasonable doubt.

The anticlinal theory was found applicable, according to Redwood,[a] by various investigators in the Eastern Hemisphere, in the Caucasian and Carpathian fields, in India, Persia, and Algiers, and as stated by Lyman,[b] in some at least of the wells in Japan. Further credence has been lent to it by investigators in various parts of the world in subsequent reports on oil districts. It has, however, not been proved to be of universal application.

ACCUMULATION OF OIL IN THE SANTA MARIA DISTRICT.

In the Santa Maria and Lompoc fields the evidence indicates that anticlinal structure is favorable although probably not absolutely essential to the accumulation of oil. But whether or not this fact is explainable on the basis of the anticlinal theory as previously advanced, and as seemingly applicable to eastern fields, remains a question, for the reason that definite evidence is lacking regarding the presence or absence of water in the strata containing the oil. The fields of the Santa Maria district are not yet old enough to make it ascertainable whether water occupies lower levels in the same porous strata in which the oil is contained, or strata below those containing the oil, and whether water will take the place of the oil on its exhaustion in the wells; or, on the other hand, whether the oil occurs unassociated with water in large amounts. What evidence there is throws doubt on the assumption that water is present in sufficient amounts materially to affect the position of the oil in the strata. Although over a hundred wells have been sunk to depths ranging between 1,500 and considerably more than 4,000 feet in various positions relative to the axes of folds, water has been reported in only four wells at a depth of more than 1,000 feet below the surface, or below sea level, and in only a few wells below 300 or 400 feet. In other words, whatever water is present occurs in all but four wells

---

[a] Redwood, Boverton, assisted by Holloway, G. T.: Petroleum and its products, London, 1st ed., 1896, vol. 1, pp. 44-46; also 2d ed., 1906, vol. 1, p. 112.

[b] Geological survey of the oil lands of Japan, Tokio, 1877 and 1878.

near the surface, or at least considerably above the oil-producing zones.

It may be questioned whether the presence of water is essential for the accumulation of petroleum in the upward folds of the strata under the conditions presented by the Santa Maria and Lompoc fields. Here the oil tends to rise to the surface and form seepages wherever channels of escape are offered. This is probably not due to hydrostatic pressure, as there is no evidence that the water tended to rise in the same way; and it is just the opposite of the tendency ascribed to oil by upholders of the anticlinal theory, which would result in the oil descending and gathering in the synclinal troughs on subsidence or removal of the water. In the fields under discussion the oil is always intimately associated with gas. There do not seem to be, as a rule, separated stores of gas and oil, but the two are intermingled, or at least closely brought together, so that one is not usually found without the other, although gas is sometimes found alone. The oil exhibits a tendency to migrate, as shown by its original concentration from widely separated points of origin, by its surface seepage, and by the energetic way in which it rises in the drill holes when a source of it is tapped. This migratory faculty may be ascribed entirely to the presence of the associated gas, which would cause the oil to fill every crevice offering a point of escape or a point of lodgment. If this is granted, it is evident that the points of accumulation of oil will be determined chiefly by the presence of cavities, large or small, offering a place for it to gather. Anticlines, being points of fracturing and in some places opening out of the strata, would afford likely places for the oil to lodge in those beds subject to fracture and for it to be imprisoned by overarching impervious beds.

Aside from ideas as to accumulation of oil after such a fashion, the writers have come to the conclusion that in this region many of the "oil sands," so called, are not true sands, but zones of fractured shale or flint offering interspaces in which the oil can gather. Beds of sand in the Monterey are scarce and thin. Some of the oil-producing zones are very thick, amounting to tens or even hundreds of feet. The oil occurs chiefly in the lower portion of the formation, where brittle, flinty shale is abundant; and as it is a noticeable fact that wherever these hard, flinty layers appear at the surface they are usually much more contorted and fractured than the associated softer shales, which are, in general, only folded and not broken, it seems likely that the same fracturing and resultant formation of an ideal reservoir for the oil takes place in the depths as at the surface. Where it is so fractured, the shale occupies a greater volume than before, showing spaces some of which are open and others partially or wholly filled with chalcedonic or bituminous material. The unfractured beds are more or less impervious to the rapid migration of the petroleum, and so act as barriers to keep the oil in the porous zones.

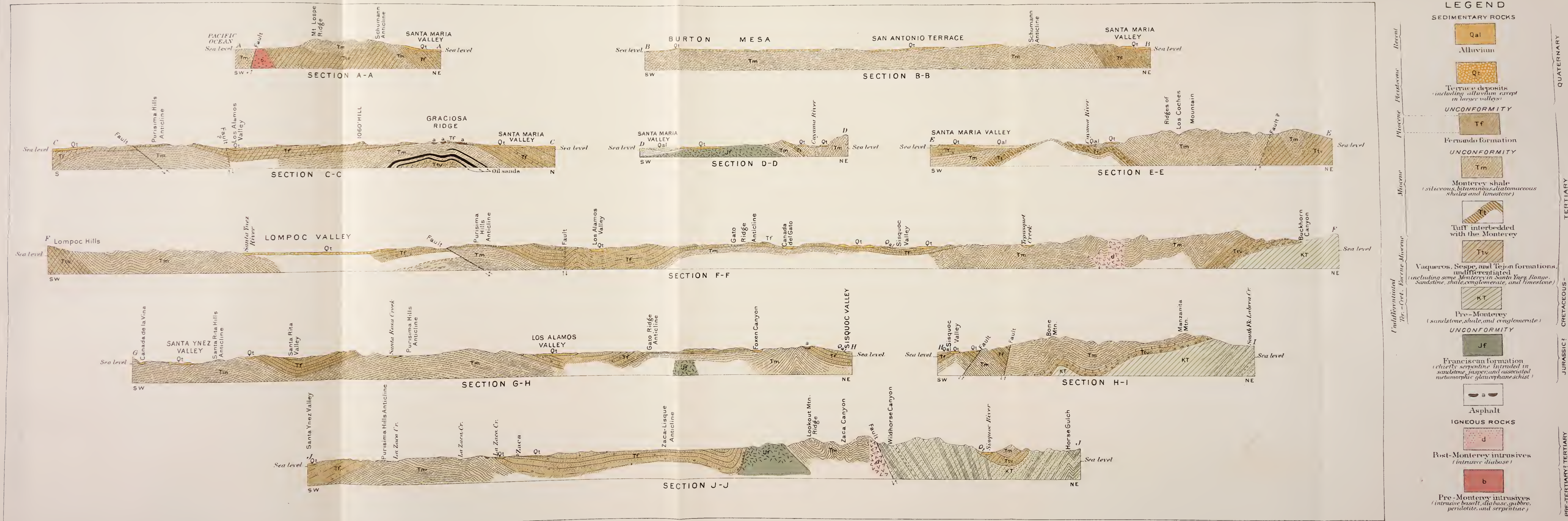
It is therefore possible that in the Santa Maria district the gas pressure is the chief agent in giving the oil mobility, and that the condition of the rocks is the chief factor that controls the matter of where the oil is stored most abundantly. Hydrostatic pressure may not play an important part. The especially large accumulations in anticlines may be accounted for primarily by the cavities offered by the strata along upward folds, and secondarily by the presence of less pervious beds arching over such folds and affording favorable conditions for the confinement of oil and gas tending to escape. Lesser stores of oil may occur at other points within the formation.

INDICATIONS OF OIL.

The chief criteria for judging as to the presence or absence of oil in appreciable quantities in this region have been the attitude of the beds, their position in the series, and the surface indications. Other minor evidences of a local nature have also been taken into account. In drawing conclusions from structural indications anticlines have been considered as the chief factors favoring accumulation, inasmuch as the oil appears to have gathered in them in a majority of the proved occurrences in this district, other conditions being favorable. The conclusion has been reached that anticlines afford a fairly trustworthy clew to the location of the most important oil deposits. Close folding appears to play a part in this district in depriving the rocks of their oil, and excessive disturbance and fracturing is unfavorable to its retention. But, on the other hand, moderate folding would appear to be favorable, if not requisite, for the accumulation of stores of oil, and probably the most favorable conditions are afforded by anticlinal folds of such sharpness as to render the brittle rocks porous by fracturing, but to leave less pervious arches of more elastic rock.

The second criterion is the statigraphic position in the formation of the beds exposed over the area in which oil is sought. As has been before stated, the oil-bearing strata occur chiefly in the lower portion of the Monterey. Where the outcropping beds belong to the higher portion of the formation there is a greater likelihood that the underlying oil-bearing strata have been able to retain their contents than where the lower strata have been denuded of the greater part of the overlying beds or where they are themselves exposed or partially removed.

As regards the third criterion, the chief surface indications are afforded by the presence of seepages of oil or tarry material from the shales, by asphalt deposits, bituminous shales, 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 excessively saturated shale. The burnt shale is



SECTIONS ALONG LINES A-A TO J-J ON GEOLOGIC MAP, PL. I

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 miles

1907

the rose-colored or slaglike rock observed at many places in this and other oil-bearing regions within the Monterey formation. It is fully discussed on pages 48–52. It is the result of the burning of the hydrocarbons that have impregnated the shale, and its presence therefore indicates where seepages have existed.

GENERAL STRUCTURAL 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 those which trend east and west. (See Pl. VII.) The system causing the northeast-southwest structure was probably the older and dominating one, as it brought forth the highest ranges and most extreme folding and conformed with the great system which has determined not only the Coast Ranges of California but 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 those of the other system 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; in the extreme southern portion lines trending east and west prevail. The region between these two areas is occupied by folds and faults, some of whose component parts exhibit allegiance to one system and some to the other, but whose resultant trend is intermediate between the two. In a general way the lines of disturbance as well as the topographic relief within this central province radiate fanlike from the point of divergence of the Santa Ynez and San Rafael ranges east of the town of Santa Ynez.

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

DETAILED DISCUSSION OF STRUCTURE.

In the field study of the structures of the formations and in the present discussion special attention has been paid to the structure of the Monterey shales, because that formation has apparently given origin to the petroleum and in it the bulk of the oil is stored.

For convenience 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 southeast of its head; the region of the Santa Ynez Range; and the province of low hills and shallow valleys intervening between the two mountain masses. The reading of the following paragraphs describing the structure of various areas should be accompanied by reference to the map. (Pl. I, in pocket.) For the sake of compactness the conclusions as to the possibilities of productiveness of the Monterey shale have been stated, together with the description of its main structural features.

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. Some of the lines, therefore, 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?) in this district, 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 of this series.

AREAS OF MONTEREY AND LATER FORMATIONS.

FOLDS.

Considered as a whole the Monterey 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. Great variation exists in the relative steepness of dip along these folds, but 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 and thence southeastward into the region of Zaca Peak. Here the folds become so compressed and in places overturned that it is difficult to trace them. Pl. III, *B* (p. 34) and VI, *B* (p. 46) give an idea of the closeness of the folding. In contrast with this constricted portion 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 crossing Tunnel Canyon and Horse Gulch just north of Sisquoc River. 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 Goodchild's 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 Lompoc 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 former. Such a plunge would be apt to give rise to the northeast-southwest table between Bone Mountain and Manzanita Mountain that interrupts the structure to the northwest and southeast, and this table may, therefore, represent a buckling across an otherwise continuous structure.

Southwest of Los Coches Mountain one or more folds are overturned, but the northwestern extensions of these folds have not been examined.

The region southeast of Round Corral and Asphaltum creeks 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 southern flank of Zaca Peak. West of Round Corral Creek the structure lines bow 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 series 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 Lompoc 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 Pliocene and Monterey may extend from a point near the mouth of Round Corral Canyon to Labrea Creek.

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

EVIDENCES 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 shales, here thrown into a pronounced anticline which has been flexed in such a manner as to open out 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 and brea deposits occurring in the San Rafael Mountains:

1. Branch of upper Tepusquet Creek. Slight seepage in bed of creek three-fourths of a mile above junction with main stream. At anticlinal axis. Has been located.
2. On Colson Fork of Tepusquet Creek. Black bituminous streaks, veinlets, and pockets, associated with calcareous shales which are considerably folded on a minor scale. This also has been located.
3. Labrea Creek, at and near junction with Rattlesnake Canyon.
4. Sisquoc dairy. Seepage and asphaltic sands 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. (Shown in Pl. III, *B*, p. 34.)
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 shales 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. The mine is shown in Pl. VIII, *A*.
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 but significant area similar in occurrence to the two preceding. This area overlies the axis of an anticline in the Monterey shale.

A. ALCATRAZ ASPHALT MINE, 3 MILES EAST OF SISQUOC.

Showing the horizontal Fernando brea deposits overlying the steeply tilted Monterey shale.

B. UNCONFORMITY BETWEEN TILTED MONTEREY SHALE AND HORIZONTAL PLEISTOCENE SAND AND GRAVEL.

In railroad cut northeast of Casmalia. Photograph by Ralph Arnold.

CONCLUSIONS REGARDING FUTURE DEVELOPMENT.

On account of the greater intensity of the folding 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 in the region of the San Rafael Mountains 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, in pocket). There are one or two local anticlines not shown, which might also be prospected with good results. The hard shales exposed in this region are probably lower Monterey and, if such, do not offer as much promise of 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 was 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 sharply folded as to give indications of probable loss of their petroleum content by excessive fracturing. 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 northwest 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 beds, 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 deposit; 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, however, there is evidence of the presence 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. 88–89).

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 the flank of what may be thus broadly considered as a monocline. These folds have been compressed 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 shales dip 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 flank of the monocline, which thus becomes unbroken.

The greater part of the strata in the hills south of Lompoc belong low in the Monterey formation, 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 which is paralleled on the south side by an important anticline. The dips on either side of the broad summit of this fold range from a few degrees 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.

---

[a] Called locally Cat Canyon.

A, *B*. MONOCLINE IN MONTEREY SHALE IN CASMALIA HILLS.

About 1¼ miles northwest of Casmalia, looking northwest. Photograph by Ralph Arnold.

C, *D*. GRACIOSA AND WESTERN UNION OIL COMPANIES' WELLS.

South side of Santa Maria field; Mount Solomon in distance. Photograph by Ralph Arnold.

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 formation and the folding is gentle. No surface indications of petroleum were found, except a patch of burnt 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 half a 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 composed chiefly of Tejon and Vaqueros rocks and its structure is therefore much less important in connection with the oil deposits than that of the areas underlain by the Monterey shale. 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 trends. The folds that expose the Tejon-Vaqueros and the underlying Franciscan beneath the Monterey toward the west end of the range are in places abrupt and complex. The anticline of the Santa Rita Hills has the appearance of crossing the Santa Ynez Valley and continuing in a large fold to the southeast.

REGION BETWEEN THE SAN RAFAEL AND SANTA YNEZ MOUNTAINS.

CASMALIA HILLS AND SAN ANTONIO TERRACE.

Two dominant structural lines control the region of the Casmalia Hills and the San Antonio terrace. One is a typical fault starting on the coast south of Lions Head and 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, represented on the map as the Schumann anticline. Northeast of the area of igneous rocks that meets the sea at Lions Head Miocene 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 (shown in Pl. IX, *A*, *B*) that extend 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 over and drops off abruptly. The axis along which this steepening of the dip occurs is in a way equivalent to an anticlinal axis and is the line mapped. In places it is a true anticline, completed by beds of gentle dip that form a broad syncline of the platform on its southwest 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 Tejon-Vaqueros rocks 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 along and near its contact with the Fernando on the northeastern side of that part of the hills which lies 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 will be penetrated and will yield lighter 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 formation 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. Southeast of the point where the road south of Waldorf crosses the ridge the territory appears promising, especially along the anticline and on its east side. The oil which is supposed to rise on the steep eastern flank of the fold probably does not reach far under the broad western flank. 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 anticline of the San Antonio terrace.

The main anticline on the coast north of Point Sal, already mentioned, is in the Vaqueros and is 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 structure seems to cause the formations 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 is a region of numerous low folds in the Monterey. Along the coast the flinty shales are 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 mesa appears to be structurally a continuation of the region near Lompoc as much as it is of the Purisima Hills, although topographically it is a continuation of the latter. In the neighborhood of Pine and Santa Lucia canyons there is a thick series of shales striking far to the north of west and directing the structural lines across the Lompoc Valley as if to join those in that region that show a tendency to curve northward. 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 ranges from 10° to 30°. A characteristic appearance of the shale and dip on the northeastern flank is shown in Pl. IV, *B* (p. 36). 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 start across the mesa between Tangair and San Antonio Creek. The summit of all these anticlines so far mentioned on 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 south of Antonio before mentioned and another on the east edge of the mesa that is discussed in connection with the Purisima 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 found in places in the flint on the surface. On the northern 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.

The Purisima Hills anticline can not be traced farther westward than is shown on the map, but at the west 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 these hills. There is a likelihood that oil may be found along this fold as well as along the main anticline.

FAULTS AND ASPHALT DEPOSITS.

A thrust fault is well exposed in two forks of Cebada Canyon, where the Monterey has been thrust to the southwest up over the Fernando. The dip of the fault plane 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 & Denigan oil well No. 8 by large asphalt deposits occupying fractures in the Fernando that dip at an angle corresponding to that of the fault plane. The asphalt back of the Wise & Denigan 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 these 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 is present 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 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 sands interbedded with soft shale occur in the upper portion of the Monterey 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 patch 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 well No. 1, and the shale is bituminous in the neighborhood of the Todos Santos well.

CONCLUSIONS REGARDING FUTURE DEVELOPMENT.

The Purisima Hills anticlinal fold seems to offer a favorable location for oil wells along most of its south flank. Owing to the plunging of the fold toward its middle, 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 Canada 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 accumulations of oil will be found there.

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 structural continuation of that of the Purisima Hills, and it probably extends under the gravels 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 the map 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 in a way 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. X, p. 92). Whether or not the anticline extending through the Santa Maria Oil and Gas and the Escolle properties should be considered the true extension of the Mount Solomon anticline, or whether the Hartnell anticline should be so considered, 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 evidence offered by the data used in compiling the map favored the relations shown on Pl. X. 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 southern flank of the Gato Ridge anticline, losing its individuality toward the southeast end of the 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 are 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 are 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.

Asphaltum 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 the asphaltum in the joint cracks of the shale gives a clew 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. X, p. 92) 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 synclinal position 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 Graciosa Ridge, which is, broadly, a quaquaversal fold 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, and the first productive stratum is thought to be at a lower horizon in the shale on the former flank than on the latter, so that it is probable that the oil zone will be struck at a greater depth from the surface 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 mouth 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 northwest, 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 Howard Canyon road northwestward, is a gentle arch with dips on the flanks rarely more than 5°, except northwest of Los Alamos, where the dips of some of the youngest beds exposed change abruptly from 3° or 4° to 15°. The northwestern extremity of the anticline fades off into the low slopes toward the Santa Maria Valley. From Howard Canyon eastward the southerly 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. Although the southerly dip increases in steepness toward the east along the anticline, the dip of the northern slope becomes less, ranging 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. In the region of Cuaslui Creek the flexure is therefore not a typical anticline in the regularly accepted sense, the horizontal being used as datum, but in every other way it conforms to the characters of such a structural feature.

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 southeastern end of which merges into the almost horizontal northern flank of the Gato Ridge anticline. At no place along its course is this structural feature well developed, although it appears to be fairly persistent for a considerable distance.

Evidences 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 rocks 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 in 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. North and northwest of this region, however, especially near the axes of the Gato Ridge anticline and the anticline north of it, 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 locality westward to the upper portion 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 dip of the beds from 3° to 12° SW. to 35° or 40° or possibly more, in the same direction. Wells would have to be sunk to a considerable 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, as shown in Pl. VI, *A* (p. 46), and 30° SW. at the junction of Figueroa and Lisque creeks.

Conclusions regarding future development.—No indications of petroleum were noticed in proximity to 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 in general 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 continually, however, that absolute determination, by work on the surface, of the possibilities of 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 a summation of surface indications and structural conditions.

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

North and northeast 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, more especially the south side.
Anticline at head of Santa Lucia Canyon.
Region about Mount Solomon and related anticlines.
Along Gato Ridge anticline and south of it between Canada de los Alisos and Canada 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 knobs and the Gato Ridge anticline.
Region northwest of the head of Howard Canyon, especially along the axis of the anticline south of Gary.
Arroyo Grande field. (See pp. 107–108.)

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. A note on the Huasna field, east of Arroyo Grande, is also appended.

SANTA MARIA FIELD.

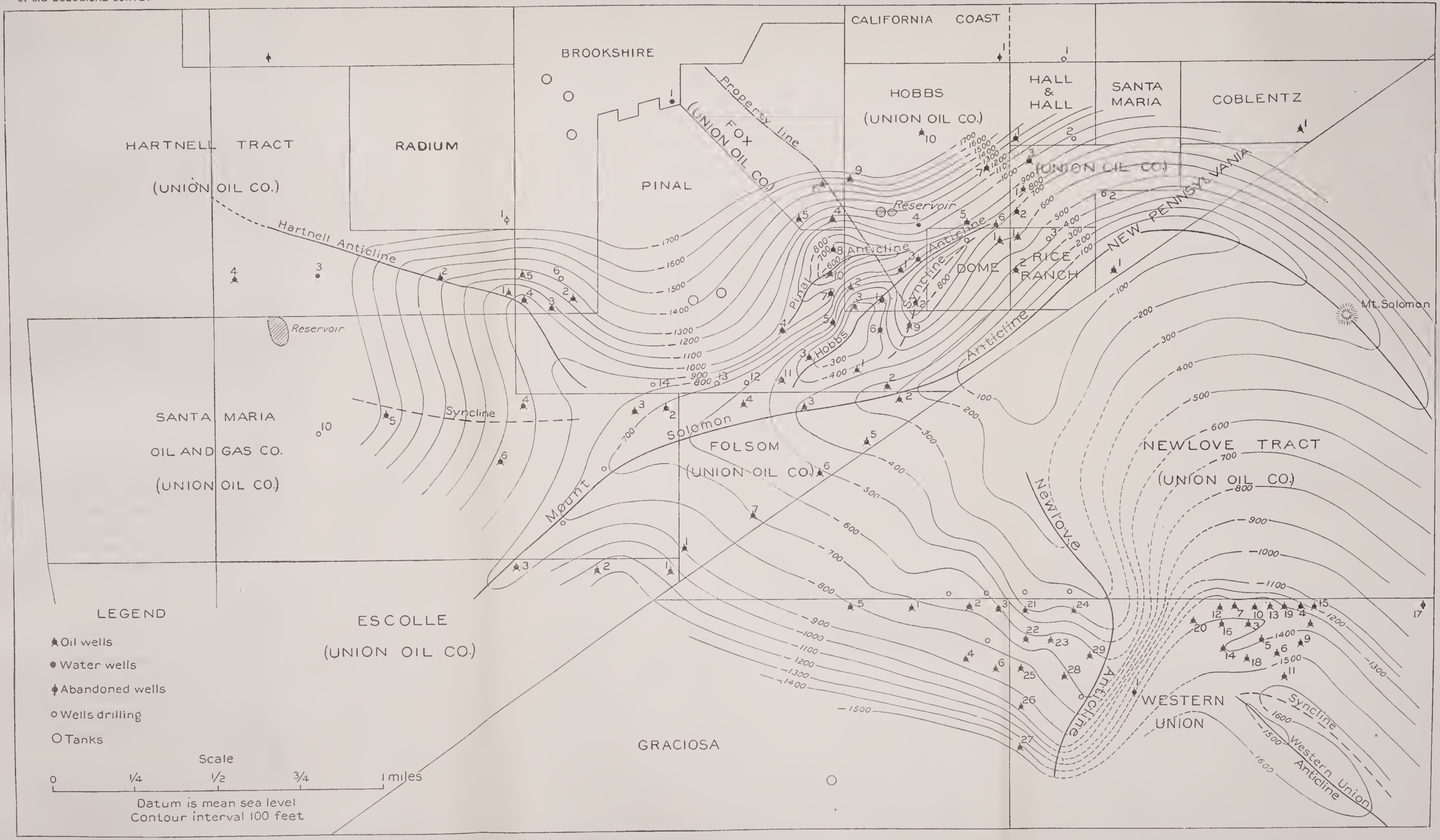
CONTOUR MAP.

WHAT IT SHOWS.

The contour map of the Santa Maria field (Pl. X) 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 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



Compiled by Ralph Arnold

SKETCH CONTOUR MAP OF SANTA MARIA OIL FIELD.

the latter was followed. In the Fernando formation, which unconformably overlies the Monterey shale, it was natural to expect variance with the structure in 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 successful study and mapping of the underlying oil-bearing formations as any other 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 available, and to supplement these details by showing for the untested areas what seem to be the most likely conditions of underground structure. It is very easy to make an ambiguous statement which will apply equally well to any conditions exposed by future development, no matter what they may be; but it is impossible to make an ambiguous map. However, it is deemed advisable 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 the 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.

Although in many instances detailed correlation from one well to another is impossible, four fairly well defined oil 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.

With the exception of the lowest zone in the wells in the eastern part of the field and of a few others mentioned in the detailed discussion of the local areas, the oil zones appear to represent fractured portions of the shales, the interstices in the breccia or possibly joint cracks in the beds being the reservoirs for the storage of the oil. The exceptions to the brecciated productive zones are apparently typical sands and gravels.

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 territory, in which it swings from a northeastward to a southeastward trend. In addition to the main anticline there appear to be one or more local flexures involved in the structure of the field, 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. X).

GEOLOGY OF THE WELLS.

Nearly all the wells in this area, with the exception of the Hall, Meridian, and Coblentz start down in the Monterey shale. Those farthest away 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 was experienced in going through it in this well, the formation being mostly sand. From the top of the Monterey shale 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 is 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 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 to 2,100 feet, varying according to the position of the well geographically and relatively 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 in the wells 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" and more or less porous sandy layers. In at least one of the wells the oil accumulates only under the hard "shell" layers. Zone A is the only one penetrated by some of the wells farthest away from the anticlinical 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, yield the oil in this zone.

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 distance 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 ranges 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 their location explains 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 (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 in many wells 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 ranging 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 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 to 2,650 feet, or between 400 and 600 feet above zone B. (See Pl. X, p. 92.) 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 ranges from 8 or 10 to nearly 150 feet, but several more or less important oil-bearing zones lie between this and the next lower (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 appear to consist largely of hard shales, with some fine sands, although some excellent examples of a true siliceous sand are obtained in many of the wells. A hard limestone "shell" overlies zone B in one well.

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

Water underlies oil-zone B in one of the wells and zone C in another. This occurrence of water below the oil, so common in most fields, is very rare in this one. Whether or not in the course of time water will follow up the oil in the productive zones is something that 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 ranges 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 the wells.

The production of the individual wells ranges 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 AREAS.

LOCATION AND STRUCTURE.

The area discussed in this section comprises the Folsom lease, the southern part of the Pinal property, the central and southern portion 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, which plunges northwestward through its center, being the only fold of consequence immediately affecting the area. The mapping of the anticline near Escolle well No. 3 is based entirely on the evidence offered by the well logs, which is at variance with the northwesterly dips in the Fernando in the vicinity of Escolle wells Nos. 2 and 3.

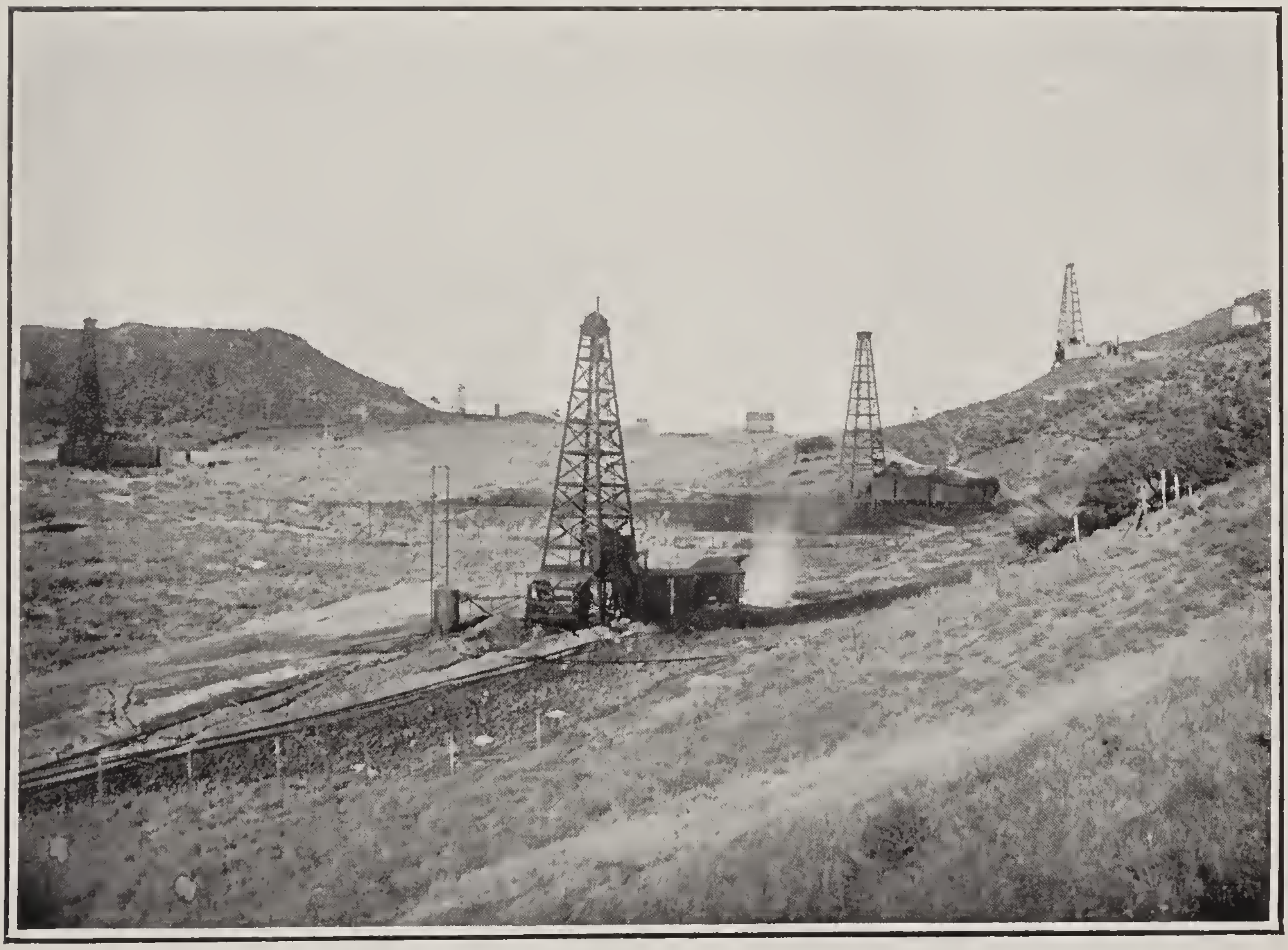
GEOLOGY OF THE WELLS.

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 water-worn material is not known. Asphaltum is reported 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. (See Pl. XI, *A*.) 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 occur accumulations of gas and locally of oil.

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 "shells" layers are encountered are reported from some of the wells; one of these is about 500 feet above the second oil zone (B), and the other immediately underlies it.

A. DARK-COLORED FOSSILIFEROUS BREA DEPOSIT OVERLYING MONTEREY SHALE.

Graciosa Ridge at Folsom well No. 3; Pinal camp on left and Santa Maria Valley in distance. Looking north. Photograph by Ralph Arnold.



B. SADDLE IN MONTEREY, FERNANDO, AND PLEISTOCENE BEDS.

Graciosa Ridge at Hartnell well No. 1, near Orcutt; Pleistocene on left, Fernando (Pliocene) in upper right, Monterey (Miocene) in saddle. Looking east. Photograph by Ralph Arnold.

The first oil zone (A), which lies from 250 to 500 feet above zone B, is struck at depths ranging from 1,400 to 2,450 feet. Its thickness ranges 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, which afford a reservoir for the oil, probably on account of their fractured condition. Beds of fine sand in this zone may also contain some of the petroleum.

The second oil zone (B), occurs at depths of 1,950 to 3,150 feet and is penetrated by all of the wells in this area. It ranges in thickness from nearly 50 to about 250 feet, in the wells; 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 layers of hard shale and fine sandstone.

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 downward, to a point where a 3-foot layer of water sand limits the productive zone. 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 ranges 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 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 the ridge running northwestward from a point near the west end of Graciosa Ridge, and in the broad valley to the south. The major structural feature developed in the beds underlying the area 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 on examining the map (Pl. X, p. 92) 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. (See Pl. XI, *B*.) It has been suggested that such a condition is most easily explained by the presence of 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. Some of the wells starting in the post-Monterey formations penetrate 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 half a 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 shale, and very rarely fine sandy layers. "Shell" strata, many of them underlain by gas and some by oil and gas, are encountered here and there throughout the shale.

The first oil zone (A) occurs about 400 feet above zone B, is struck at depths ranging from 2,150 to more than 3,000 feet, and is said to be from 2 to 5 feet thick. On examination of the material coming from this and the underlying productive zones, it is quite apparent that the oil must come from the joint cracks or interstices between the fragments of more or less fractured shale, as no true sands of sufficient coarseness to allow the rapid transmission of the oil have 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 zone B, are one or more productive zones 2 to 15 feet thick. 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 thick. Below the main or upper part of this zone are other productive layers, some at least 200 feet below zone B. The oil-bearing measures in these zones, as in zone 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, especially, being under heavy pressure.

The production of the individual wells in this group ranges from an initial output of 12,000 barrels per day 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 31 miner's inches, or 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 northwestern 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 of the beds underlying the developed area is apparently simple, as they are on 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 farther northwest. 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 sands of the Fernando, penetrating this formation for 70 to 300 feet. No water is reported from this sand, but asphaltum is said to have been found at its base in one of the wells. From the base of the Fernando to the top of the main productive zone the formation consists of blue and brown shales with many hard "shell" layers, some beds of sticky shale, and rarely a little sandy material. Streaks of asphaltum are reported as occurring in the shale in some of the wells, and in others gas is present under some of the "shells."

The first oil zone (B of the northern part of the field) is reported from only one well, where 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 ranging from 2,670 to something more than 3,800 feet, 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 ranges in thickness from 18 to about 240 feet and consists of alternating light and dark 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. Certain of the wells, however, are said to show a comparatively low gas pressure.

The production of the individual wells ranges from 300 to 3,000 barrels per day, the flow of many 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, inasmuch as 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 north line. Slightly more than half a mile to the 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 the wells, as indicated by the logs (see Pl. X, p. 92), is more or less complicated, the general strike of the beds apparently changing abruptly 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 to be seen in the Fernando beds. The dip of the beds on the southwestern flank of this fold ranges at the surface 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° occurs 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, as would be expected after an examination of the surface geology, 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 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 to 1,800 feet, and ranges 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 as a rule rather fine grained and is accompanied both above and below by shale and rarely by shell. In some of the wells the oil zone appears to be 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 2,100 feet below the first, the formation between the second and third zones being practically all shale. Comparatively little oil was obtained from this zone in this part of the field, 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 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 ranges from 5 to 154 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, in pocket); from the evidence offered by the logs of the Hill and Logan wells the axis of the anticline, 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. This is clearly a reverse 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 in the strata (if the anticline affecting the oil sands passes south of well No. 2) might account for the difference in depth of the oil sand 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 occurrence 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 Lompoc field start in the Fernando formation and penetrate its clays, sandstones, and conglomerates for distances 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). Hard siliceous "shell" layers are encountered here and there 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 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 within it at certain points about 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 to 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 throughout 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 Lompoc field is struck at depths below the surface ranging from about 2,200 to more than 4,100 feet. In nearly all the wells the productive strata are overlain by a more or less prominent series of 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 varying quantities of shale and limestone "shells." The thickness of the oil zone varies from about 160 to 700 feet, and a productive series of sands, shales, and "shells" is said to be penetrated for a distance of 1,100 feet in one well. 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 the No. 3 Wise & Denigan well of the Union Oil Company. The relations of occurrence of the two grades are not known. One of the wells yields an emulsion of water and 20° oil, which is reddish brown in color as it comes from the well. This oil turns to the usual black color on separation of the water by settling.

PRODUCTION.

The production of the individual wells ranges 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 at first, suddenly began flowing 1,000 barrels per 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, in the San Luis quadrangle, San Luis Obispo County, a short distance north of the area shown on Pl. I, are underlain by productive oil formations. The successful wells belong to the Tiber Oil Company, and are located on the west 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

---

[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.

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 small area of Monterey volcanic ash, shale, and diatomaceous earth north of Pismo, is 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 formation 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 upon the upturned and more or less contorted shale of the Monterey. Its occurrence in beds occupying a synclinal position 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 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 sands 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 sands retain 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 evidenced by the fact that although the gravity of the oil from the Monterey formation in the Santa Maria field averages about 25°, that from the Pismo in the Arroyo Grande field is only 14°.

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 Fairbanks's interpretation of the structure of the area, the depth at which the oil will be struck ought to decrease from the middle of the area toward both the northeast and southwest. The only well fully tested in the region yields 500 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 the petroleum, so that a thorough knowledge of this is essential to economical test drilling.

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 Monterey area is probably the continuation of that exposed in the northeastern part of the Lompoc quadrangle, and may connect the latter with the Monterey area east of Arroyo Grande and also with that covering the summit of the Santa Lucia Range a few miles east of San Luis Obispo. It is to be regretted that no maps adequate for showing the structure of the formations in the region east of the San Luis quadrangle 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 has already been done for the two quadrangles mentioned.

OIL OF THE SANTA MARIA DISTRICT.

ORIGIN.

There is no doubt that the petroleum in the Santa Maria district is indigenous to the Monterey shale. Bitumen is a characteristic part of that formation throughout its wide extent over an area covering hundreds of square miles, and there is no other formation but the Eocene shales in which it is characteristic, or in which it occurs in appreciable quantity except locally, although there are numerous formations which would be capable of storing oil if any had originated in them. Moreover, the bituminous Monterey shale of the Coast Ranges does not occur consistently above or below any one formation from which the oil could have been derived. It lies unconformably upon ancient metamorphic rocks; granite and other igneous rocks; Jurassic, Cretaceous, or early Tertiary sediments; or conformably over lower Miocene beds, according to local conditions; and it is either not covered by later deposits or is buried by sediments of various ages, in different places.

The decision is therefore unavoidable that some ingredients of the Monterey shale gave rise to the oil, and the question arises what these were. The organic composition of the strata making up this formation is discussed on pages 38–43, where a number of animal and plant forms that may have contributed to the oil are enumerated. The writers are strongly of the belief that the petroleum was derived largely from the minute organisms, especially the plant organisms (diatoms), which are present in such abundance in these shales. The chemists Peckham and Clarke believe that the nitrogen present in the California oil proves its origin from animal substance. But it is not necessary to consider that this petroleum originated entirely from either animal or vegetable matter; it is more probably the product of remains of both kinds combined, much of the nitrogenous material being furnished by animal tissue.

Other small organisms of a low order present in the Monterey shale besides the diatoms are Foraminifera and Radiolaria, both orders of marine animals. They became embedded in the mass of the organic and adventitious silt material of the deposit at the sea bottom, and their bodies were thus preserved with the hard parts and may have become a source of hydrocarbons and nitrogen for the petroleum. The fact that the limestone and calcareous shale of the Monterey are usually very bituminous suggests the conclusion that the Foraminifera were great oil formers, inasmuch as these rocks are thought to be made up largely of foraminiferal remains, although of course the calcareous strata may owe their petroliferous character to their porosity. In many places the body of the limestone is full of minute specks of oil contained in cavities about the size of the interior of foraminiferal skeletons, and these specks give the impression that the oil is not far from its point of origin. Albert Mann, of the United States Department of Agriculture, makes the suggestion that possibly Foraminifera originally made up a greater part of the shales than now appears and that their easily destroyed calcareous tests were leached out, the soft parts adding their quota to the total amount of petroleum formed and owing to their animal character helping to cause the relatively high percentage of nitrogen found in the California oils.

Fish skeletons are sometimes found in the shale, and flat impressions, large and small, that appear to be the scales of fish are abundant and very characteristic of certain portions of this formation, seeming to show that fish remains were in sufficient abundance to add at least something to the oil and to supply a portion of the nitrogen. On the other hand, these fossilized parts may have been originally separated from the tissue before they dropped to the ocean bottom or before being buried in the deposit, as by far the greater number of fish are believed to die violent deaths and to serve as food for larger fish or other animals.

Other animal organisms which were present and which may have contributed hydrocarbons and nitrogen were sponges, mollusks, and crustaceans—such as crabs and possibly ostracods. The impressions of seaweed occur in the shale but sparingly, probably because plants of this kind are restricted in habitat to shallower water than that in which it is believed the greater part of the Monterey was laid down, so that it is not probable that these plants have been large contributors to the material of the oil.

It is certain that there was a sufficiency of organic material included with the Monterey deposits to give rise to a vast quantity of petroleum, as is proved by a rough estimate based on low calculations of the amount of such material present. If the area covered by the Monterey formation in the Santa Maria district, including territory surely covered by it whether the formation now outcrops there or not, be taken as 800 square miles and the thickness of the formation as half a mile, the total volume of the deposit would be 400 cubic miles. These figures are low, especially in view of the fact that the average thickness and the areal extent of the formation were much greater when the oil began to be accumulated than at present. If we regard for the moment the diatoms alone to be the source of the oil, and only 1 per cent of the formation to be made up of these organisms, there would be 4 cubic miles of diatoms; and if we suppose further, simply as a rough guess, that these forms gave rise to an amount of petroleum equaling 1 per cent of their volume, we would have 1,000,000,000 barrels of oil as the amount distilled within the Monterey in this district, or more than thirty-three times the total production of oil in California for 1904, or eight times the production in the United States for the same year. According to Albert Mann, who has recently made an extensive study of diatoms, these plants when living secrete algal wax or oil in amounts varying from 0.75 per cent to as much as 4 per cent of their total volume. The amount of petroleum that might be derived from the diatoms is entirely unknown; but if the figure assumed hypothetically as being 1 per cent is too liberal, it would seem that the low estimates of the amount of diatomaceous material present and the complete ignoring of the other important organic sources for oil in the shale, would still cause the estimate to be conservative.

In considering the question, What kind of organic material has a character most favorable for producing oil? the relative rate of putrefaction is important. Plants have the advantage in respect to their slower rate of decomposition. David White inclines to the view that plants are more favorable to the production of oil, largely for this reason. He says that putrefaction, which is largely a bacterial process, goes on more rapidly in animal tissue, while vegetable material has a tendency to turn into hydrocarbons. The slow decomposition of the protoplasm contents of the diatom frustule is especially significant. F. J. Keeley, of the Philadelphia Academy of Natural Sciences, says as follows in a letter:

> The only point I can think of that might have any bearing on the question of the relation of diatoms to petroleum is the fact that the organic matter of diatoms does not appear to decompose and become dissipated quickly after death, as is the case with most low organisms. It is well known that diatoms kept in water will show the shrunken contents for years, and Ehrenberg noted the presence of such organic contents in old fossil diatoms from Hanover, while J. Brun reports a similar observation in a fossil deposit from Holland.

It is worthy of note that many of the round white diatom tests of the soft Monterey shale contain minute specks of black that appear like bituminous material derived in situ from the diatom. These specks, however, are present in but a small proportion of the tests and there is no proof that the black substance has not come from infiltration and deposition in the slight hollow of the shell. Thin sections of the shale reveal small black filaments that appear to be carbonaceous material.

It is probable that the ooze at the sea bottom in Monterey time was being deposited very rapidly. The idea of rapid accumulation of the deposits of diatoms, aided by the accession of organic and detrital material of other kinds, is quite in keeping with the well-known faculty of these organisms for quick and abundant reproduction; and it is not only in keeping with but an essential corollary of the fact that deposits of such vast thickness were formed during middle Miocene time. This rapid accumulation created further favorable conditions for the production of oil, inasmuch as the organic substance that reached the sea floor became quickly buried without sufficient time intervening for decomposition to go very far. Thus the contents of the diatom frustules and all the other plant and animal remains became included in the body of the deposit.

The alkalinity of the shale may have been another favoring factor. As the deposits grew, salts of the sea water were probably included in the porous mass and they may have acted as preservatives of the organisms to some extent.

As regards the age of the oil, it is stated by F. W. Clarke[a] that the process of formation of the oil from organic sources may not be slow, but, on the other hand, comparatively rapid. It is usually thought, however, that the process of distillation is slow and is continued during a long time. The petroleum in the Monterey may have been formed immediately after the deposit was laid down, or the production of it may be still in progress. There is evidence, however, in the presence of burnt shale in a Pleistocene deposit (see p. 52), in the old and eroded deposits of asphalt, and in the presence in certain asphalt deposits of the bones of extinct Pleistocene mammals[b] which were caught in tar springs in Pleistocene time, that much of the oil at least was formed in the Monterey and disseminated to the surface a long time ago. The accumulation and dissemination of the oil has probably gone on continuously ever since its first formation, the two processes taking place simultaneously. There may be portions of the formation from which the hydrocarbon content has not yet been extracted in the form of oil, whereas other portions may no longer contain any of the oil in its original disseminated condition. The metamorphism that gave rise to the harder shales may have had the effect of driving out the oil more completely than it has been separated from the softer shale, and thus aided its accumulation, although this is conjectural.

The general conclusion is that in the Santa Maria district the organic material in the Monterey shale that may have acted as the source of the oil was without a doubt adequate in amount for the production of the vast quantity of petroleum now present, and that the forms included in greatest abundance, the diatoms, were the chief source, although animals and perhaps other plants also contributed largely.

PHYSICAL PROPERTIES.

GENERAL STATEMENT.

The Santa Maria district yields four distinct grades of petroleum, in addition to the heavy oil which flows from springs or collects as asphalt deposits. These petroleums vary widely in their physical and chemical properties and as a consequence are utilized in many different ways, the lighter oils usually for refining, the heavier for fuel, road dressing, etc.

The oil as it comes from the wells contains varying quantities of gas, often amounting to a considerable percentage. The two prod-

---

[a] The data of geochemistry (in preparation for publication by the United States Geological Survey).

[b] Bull. U. S. Geol. Survey No. 309, 1907, pp. 154-155.

ucts are usually separated at the wells, the gas being utilized for heat or directly for power and the oil being run into tanks. This tank oil still contains gas, most of which, however, gradually passes off on exposure to the air, with a consequent lowering of the gravity of the oil. Before transportation by steamer it is necessary to pass the oil through a partial refining process for the removal of the lighter, volatile, more dangerous constituents; this is done at present in the refineries at Port Harford and Gaviota.

COLOR AND ODOR.

Nearly all of the oil in the Santa Maria district is dark brown in color. The exceptions are the black oil from the Arroyo Grande field, the reddish emulsion from one of the wells in the Hartnell-Brookshire area, and the brown to greenish oil found in certain of the wells in the Lompoc field. The heavier oil is the darker; the lighter grades show the greenish hues. The darkest oil in the Santa Maria field proper is the 19° petroleum from the wells in the eastern Western Union group. Some very dark oil is also said to come from the Lompoc field.

The heavy oil gives off an aroma not unlike some grades of lubricating oil, and, doubtless owing to the absence of hydrogen sulphide in solution, has little of the disagreeable odor common to that from some of the other California districts. In this district the lighter the oil, as a rule, the sharper and less agreeable is its odor.

GRAVITY.

The gravity of the oil ranges from 14° to about 35° Baumé. The heaviest oil (14°) comes from the Arroyo Grande field; 18° to 24° oil from the Lompoc field; 19° oil from the eastern group of Western Union wells; 24° to 29° oil from the Santa Maria field; and 35° oil from the Los Alamos Oil and Development Company's well and one of the Wise & Denigan wells. The average gravity of the oil from the Santa Maria field proper is between 26° and 27°, thus putting it well into the class of valuable refinable petroleums.

VISCOSITY.

The relative viscosity of several of the oils from the Santa Maria district, together with similar data for other California oils, is shown in the table on page 116.

CHEMICAL PROPERTIES.

Few data concerning the chemical properties of the oil from the Santa Maria district are at present available for publication except those found in Bulletins Nos. 31 and 32 of the California State Mining Bureau. The analyses of Santa Maria oil contained in these bulletins were made by H. N. Cooper, and, together with those of oils from some of the other California districts, are copied in the table below.

The only definite information concerning the ultimate composition of the oil is contained in a table by P. W. Prutzman[a] showing the incidental constituents of California crude oil. This author states that a Santa Maria oil of 17° (probably from the eastern group of Western Union wells) contained 0.43 per cent of nitrogen, no sulphur, and 8.37 per cent of asphaltene. The freedom of the Santa Maria oil from sulphur is one of its chief and valuable characteristics.

The following table[b] contains analyses of four oils from the Santa Maria district, accompanied by analyses of twelve other California oils for purposes of comparison. The oil of analysis No. 3 in the table is the most characteristic of the average product of the Santa Maria field.

Following the table are distillation tests.

Chemical analyses of California petroleum.

[By H. N. Cooper, chemist. Samples collected by Marion Aubury, field assistant.]

No. of analysis.	Name of company.	County.	District.	Gravity.	Specific gravity of crude at 15° C. (about 60° F.).
				° *B.*	
1	Western Union Oil Co	Santa Barbara	Western Union	20	0.9337
2	do	do	Carreaga	34.6	.8508
3	Pinal Oil Co	do		27.6	.8882
4	Union Oil Co. of California	do	Lompoc	16.2	.9574
5	Sea Cliff Oil Co	do	Summerland	14.9	.9665
6	King Refining Co	Kern	Kern River field	13	.9792
7	I. W. Shirley	Los Angeles	Middle field	16.5	.9559
8	Southern Pacific Oil Co	Kern	McKittrick	18.5	.9425
9	Home Oil Co	Los Angeles	Whittier	20.7	.9291
10	Brea Canyon Oil Co	Orange	Fullerton	23	.9147
11	Los Angeles Pacific Rwy. Co	Ventura	Santa Paula	27.3	.8900
12	Union Oil Co. of California	do	Adams Canyon	28.9	.8814
13	California Oilfields (Limited)	Fresno	Coalinga	31.3	.8680
14	Home Oil Co	do	do	34.1	.8530
15	Los Angeles Pacific Rwy. Co	Ventura	Timber Canyon	35.1	.8481
16	Pacific Coast Oil Co	Los Angeles	Pico Canyon	37.3	.8367

---

[a] Bull. California State Mining Bureau No. 32, 1904, p. 224.

[b] For a detailed description of the methods used in obtaining the data recorded in this table the reader is referred to Bull. California State Mining Bureau No. 31, p. 1; idem, No. 32, 1904, table opp. p. 230; or to Bull. U. S. Geol. Survey No 309, 1907, pp. 205-208.

Chemical analyses of California petroleum—Continued.

No. of analysis.	Flash.	Viscosity.				Sulphur.	Calorific value of dry samples.[a]	Calorific values per cubic centimeter.
		At 15° C. (about 60° F.).		At 85° C. (185° F.).				
		Seconds.	Seconds divided by 27½ or water=1.	Seconds.	Seconds divided by 27½ or water=1.			
	°					*Per cent.*		
1	Below 15	1,060	38.40	77½	2.81	2.08	10,369	9,907
2	15	47⅖	1.72	29⅖	1.07	.60	10,825	9,203
3	Below 15	90	3.27	37⅗	1.36	1.56	10,543	9,364
4	21	Over 1,800	Over 65.00	227	8.23	4.43	10,258	9,822
5	Above 70	Over 1,800	Over 65.00	108	3.91	.44	10,348	10,001
6	Above 70	Over 1,800	Over 65.00	410	14.86	....	....	....
7	Above 70	Over 1,800	Over 65.00	78	2.83	.85	10,437	9,976
8	32	1,100	39.85	54	1.96	.77	10,402	9,804
9	26	393	14.24	43	1.56	....	....	....
10	Below 15	264	9.56	41½	1.50	.94	10,581	9,678
11	Below 15	61⅗	2.23	34½	1.24	....	....	....
12	Below 15	162½	5.91	37	1.34	.48	10,647	9,384
13	Below 15	56	2.03	32½	1.18	.38	10,739	9,321
14	Below 15	28½	1.03	25½	.99	.06	10,598	9,040
15	Below 15	45⅘	1.66	31⅕	1.13	....	....	....
16	Below 15	38½	1.40	29½	1.07	.28	11,141	9,322

No. of analysis.	Distillation.									
	Percentage.									
	Water.	Up to 100° C.	100°-150° C.	150°-200° C.	200°-250° C.	250°-300° C.	300° C. to asphalt.		Asphalt.	Loss or gain.
							A.	B.		
1	None.	0.9	6	10.5	9.3	11	39.5	....	22	−0.8
2	None.	8.6	16	12	13.4	10.8	23	7.4	8	− .8
3	None.	8.2	17.7	12.1	9.4	9.1	29.7	....	12	−1.8
4	7	1.3	3.9	5.5	7.7	18.3	34.3	....	20.6	−1.4
5	.7	0	0	1	10	17.4	45.5	....	23.5	−1.9
6	None.	0	0	0	0	22.5	37.5	6.9	31.1	−2
7	.8	0	0	0	7.6	13.9	40	14.5	21.8	−1.4
8	None.	0	4.2	8.9	8.7	20.2	27.5	7.5	22.5	− .5
9	None.	0	4.2	9.6	14	14.7	23	16.8	15.7	−2
10	None.	4.2	13.9	8.9	9.7	18.3	24.2	5	13.3	−2.5
11	None.	9.3	16.5	11.8	7.7	9.1	31.8	....	13	− .8
12	None.	4	14.1	9.1	9.3	10.1	43	....	9.8	− .6
13	None.	10.4	13.8	10.5	10.3	17.5	20.8	7.3	9.1	− .3
14	None.	5.5	30.6	21.5	25.4	8.1	5	....	4.1	+ .2
15	None.	15.3	15	9.5	9.9	9.9	28	....	10.6	−1.8
16	None.	10.5	20.4	13.8	13	11.1	16.9	6.8	6.8	− .7

No. of analysis.	Distillation.						
	Gravity of preceding fractions at 15° C. (about 60° F.).						
	Up to 100° C.	100°-150° C.	150°-200° C.	200°-250° C.	250°-300° C.	300° C. to asphalt.	
						A.	B.
1	....	0.7596	0.8087	0.8538	0.8875	0.9167	....
2	0.7185	.7683	.8028	.8354	.8574	.8788	0.8822
3	.7123	.7617	.8132	.8583	.8899	.9085	....
4	....	.7737	.7906	.8316	.8613	.8992	....
5	....	....	....	.8516	.8840	.9347	....
6	....	....	....	....	.8901	.8997	.8938
7	....	....	....	.8625	.8849	.9021	.9053
8	....	.7760	.8235	.8427	.8976	.8982	.8985
9	....	.7756	.8313	.8672	.8991	.9210	.9166
10	.7252	.7701	.8172	.8597	.8937	.8955	.9062
11	.7228	.7724	.8202	.8613	.8901	.9154	....
12	.7250	.7736	.8111	.8388	.8547	.8778	....
13	.6906	.7630	.8041	.8382	.8774	.8866	.9062
14	.7395	.8074	.8396	.8919	.9227	.9374	....
15	.7002	.7639	.8015	.8321	.8624	.8875	....
16	.7472	.7659	.8040	.8359	.8606	.8870	.8720

---

[a] To convert calories into British thermal units, multiply by 1.8.

Proximate analysis of a Santa Maria oil.[a]

[Gravity, 16.9° Baumé.]

	Per cent.	Gravity (°B.).
DISTILLATION.		
Below 150° C.	1.0	....
150° to 270° C.	24.0	39.5
Above 270° C.	31.1	....
Asphalt, grade D	41.9	....
Loss	2.0	....
CALCULATED ANALYSIS.		
Total gasoline	2.7	55
Kerosene	16.8	41
Middlings and lubricants	36.6	....
Asphalt, by volume[b]	41.9	....
Loss	2.0	....

[a] Prutzman, P. W., Bull. California State Mining Bureau, No. 32, 1904, Table 25.

[b] By weight (154 pounds per barrel), 46.2 per cent.

The following analyses of oils from the Santa Maria district have been kindly furnished by Prof. Edmond O'Neill, of the University of California, who writes concerning them as follows:

> I do not know the exact locations of the wells from which these oils were derived, but they are from the first wells opened in the Santa Maria property [probably the Hartnell or the Santa Maria Oil and Gas Company lease]. There is very little difference in the character of oils from all this district, except in the proportion of light constituents and the corresponding percentage of sulphur. Most of these oils contain water, which seems to be either in a state of fine emulsion, or possibly in some feeble form of hydration—that is, frequently the water will not settle out on standing, even by centrifugalizing—nor will it all be driven off at a temperature of 100° Centigrade; but at a somewhat higher temperature it seems to be given off almost with explosive violence.

Analyses and tests of six samples of oil from wells near Santa Maria.

[Made by Edmond O'Neill.]

ANALYSES.

	No. 3.	No. 4.	No. 5.
Gravity at 15.5° C. (=60° F.)	0.891	0.894	0.893
Gravity in degrees Baumé	27.800	27.600	27.500
Flash point, open tester	(a)	(a)	(a)
Flash point, closed tester	(a)	(a)	(a)
Burning point, open tester	23° C.=73.4° F.	22° C.=71.6° F.	21° C.=70° F.
Gasoline precipitate (asphaltine, etc.) ..... per cent.	0.6	0.3	0.8
Sulphur ..... do.	1.57	1.59	1.56
Calorific value ..... calories.	10,260	10,363	10,229
Calorific value ..... B. T. U.	18,468	18,653	18,415

	No. 6.	No. 7.	No. 13.
Gravity at 15.5° C. (= 60° F.)	0.897	0.908	0.926
Gravity in degrees Baumé	26.800	24.800	21.670
Flash point, open tester	(a)	(a)	(a)
Flash point, closed tester	(a)	[a)	(a)
Burning point, open tester	21° C.=68° F.	20° C.=68° F.	24° C.=75° F.
Gasoline precipitate (asphaltine, etc.) ..... per cent.	0.7	1.6	3.0
Sulphur ..... do.	1.61	2.09	1.8
Calorific value ..... calories.	10,284	18,375	8,078
Calorific value ..... B. T. U.	18,512	18,676	14,541

[a] Under 15° C.=60° F.

Analyses and tests of six samples of oil from wells near Santa Maria—Continued.

RESULTS OF DISTILLATION.

	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 13.
Water, per cent by volume	1.2	0.2	Trace.	Trace.	Trace.	10.8
Benzines, boiling point under 150° C. (302° F.):						
Per cent	24.5	22.1	20.2	23.5	18.5	16.8
Gravity Specific	.745	.740	.740	.752	.752	.742
Gravity Baumé	60°	61. °2	61. °2	52°	52°	60. °8
Kerosene, boiling point 150° C.–250° C. (302° F.–482° F.):						
Per cent	21.5	20.5	21.5	18.7	18.5	22.1
Gravity Specific	.8345	.821	.818	.823	.822	.843
Gravity Baumé	39	41.8	42.5	41.4	41.4	37
Lubricants, boiling point 250° C.–350° C. (482° F.–662° F.):						
Per cent	19.0	22.8	19.2	20.0	25.5	17.2
Gravity Specific	.905	.889	.898	.897	.895	.899
Gravity Baumé	25.3	28.2	26.6	26.6	27	26.4
Lubricants, boiling point above 350° C. (666° F.):						
Per cent	23.0	22.7	20.3	25.5	22.5	16.2
Gravity Specific	.917	.905	.924	.917	.903	.906
Gravity Baumé	23.2	25.3	22	23.2	25.6	25
Asphaltum:						
Per cent	10.8	11.7	8.8	12.3	15.0	16.9

ASSOCIATED HYDROCARBONS.

NATURAL GAS.

Throughout the Santa Maria district wherever any oil has been found it is invariably accompanied by considerable quantities of natural gas; indeed, this form of hydrocarbon is somewhat more widely distributed than the oil, occurring in many places in the shale above the oil zones and in some wells which have yielded no petroleum. The pressure of the gas varies from zone to zone and from well to well. The greatest pressure so far recorded was in Hartnell well No. 1, where, according to Mr. Orcutt, it was over 400 pounds per square inch during the initial flow of oil and gas. Most of the gas is utilized for the generation of heat or of power direct in gas engines. Some of it is utilized for domestic purposes in the field and the immediate vicinity.

ASPHALT.

Great deposits of asphalt are associated with the petroleum-bearing and later formations over certain portions of the Santa Maria district. The asphalt (in the broader sense of the word) within the district occurs in several different ways—as veins penetrating the Monterey shale and later formations; as impregnations of the shale, sands, or gravels in or overlying the Monterey; and as more or less impure effusions at the surface. The more important deposits are in the hills northwest of Arroyo Grande; in the region of Asphaltum and La Zaca creeks, east of Sisquoc; in Graciosa Ridge; and in the vicinity of Redrock Mountain. These deposits have been described in detail by George H. Eldridge,[a] and are mentioned at various places throughout this bulletin; further discussion of them is therefore unnecessary.

TECHNOLOGY OF PRODUCTION AND UTILIZATION.

OIL COMPANIES OF THE SANTA MARIA DISTRICT.

The following is a statement of the oil operations in the Santa Maria district, compiled from all data available up to January 1, 1907:

Oil companies and wells in Santa Maria district.

Company.	Field.	Oil wells.			
		Productive.	Abandoned.	Drilling.	Total.
Anglo-Californian Oil Syndicate	Lompoc			1	1
Associated Oil Co	Arroyo Grande			1	1
Barca Oil Co	Lompoc		1		1
Brookshire Oil Co	Santa Maria	4	[b]1	1	6
California Coast Oil Co	do		1		1
California Coast Oil Co. (Union Oil Co.)	do	3			3
California-Newlove Oil Co	Arroyo Grande			1	1
Casmalia Ranch Oil and Development Co	Santa Maria		1		1
Claremont Oil Co	do		[b]1	1	2
Coast Line Oil Co	Lompoc		1		1
Coblentz Oil Co	Santa Maria			1	1
Crown Oil Co	Arroyo Grande			1	1
Crystal Oil Co	do			1	1
Diamond Oil Co	Santa Maria				
Dome Oil Co	do	1		1	2
Graciosa Oil Co	do	6		2	8
Hall & Hall Oil Co	do	1		1	2
La Grande Oil Co	Arroyo Grande			1	1
Laguna Land Co	do			1	1
Lompoc Oil Developing Co	Lompoc				
Los Alamos Oil and Development Co	do	1	2		3
Las Flores Land and Oil Co	Santa Maria				
McNee Oil Co	Arroyo Grande			1	1
Meridian Oil Co	Santa Maria			1	1
National Oil and Transportation Co. (Associated Oil Co.).	do			1	1
New Huasna Oil Co	Arroyo Grande			1	1
Oak Park Oil Co	do			1	1
Pennsylvania Oil Co	Santa Maria		1	1	2
Perpetual Oil Co	Arroyo Grande			1	1
Pacific Oil and Transportation Co. (Associated Oil Co.).	Santa 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 and Newhall)	do		2	2	4
Rice Ranch Oil Co	do	2		1	3
Santa Barbara Oil Co	Santa Ynez			1	1
Santa Lucia Oil Co	Arroyo Grande			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				
Syndicate Oil Co. (Union Oil Co.)	do			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

---

[a] The asphalt and bituminous rock deposits of the United States: Twenty-second Ann. Rept. U. S. Geol. Survey, part 5, 1901, pp. 209-452, pls. 25-58, figs. 1-52.

[b] Water well.

Oil companies and wells in Santa Maria district—Continued.

Company.	Field.	Oil wells.			
		Productive.	Abandoned.	Drilling.	Total.
Union Oil Co.—Continued.					
Fox lease	Santa Maria	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	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
		94	25	55	174

WELL DRILLING.

The wells in the Santa Maria district are among the deepest oil producers in the world, one of them reaching a depth of over 4,400 feet. Except at three or four wells, where rotary drills have been used to penetrate the soft sands and shales near the surface, all of the drilling has been done with the standard rig. The casing used ranges in diameter from 12 to 16 inches at the top down to 4½ inches, and in some wells, it is believed, even smaller, at the bottom. The cost of the deeper wells runs in general from $12,000 to $20,000, but several of the deepest are said to have cost even more than the latter figure.

Owing to the close texture of the shale, it is usually possible to carry the hole down for a considerable distance below the casing without danger of caving. Wherever the wells penetrate the soft Fernando beds for any considerable distance much trouble is experienced, but otherwise the drilling in the field is said to be as a rule comparatively easy.

PRODUCTION.

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

Nearly all of the oil so far produced in the district has come from the Santa Maria field. 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 of 42 gallons each.]

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 the district 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 earthern reservoirs. The reservoirs are located 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 district is distributed by means of pipe lines, tank cars, and some of it eventually by tank steamers. The principal pipe lines of the district are four connecting the field with Port Harford and one running from the Western Union wells to 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:

Pipe lines in Santa Maria oil district.

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

---

[a] Compiled from data furnished by the different operating companies.

REFINERIES.

The principal refineries utilizing the oil from the Santa Maria district are as follows:

California Petroleum Refineries, Limited.—The refinery of this newly organized company is now in course of erection at Oil Port, south of Port Harford. It is said that the initial capacity of this refinery will be about 7,000 barrels per day, and that all the usual products will be refined.

Pacific Oil Transportation Company.—The refinery of this company is located at Gaviota, and consists of nine stills with a capacity of 1,050 barrels of crude oil per day. The principal products are illuminants and fuel residue.

Standard Oil Company.—The plant of this company is located at Point Richmond, Contra Costa County, and is said to consist of 19 stills with a capacity of 5,000 barrels of crude oil and 4,000 barrels re-run per day. The products are illuminants, lubricants, and coke.

Union Oil Company of California.—The main refinery of this company is located at Oleum, Contra Costa County, and consists of a number of stills capable of producing illuminants, distillate, and asphalt.

UTILIZATION OF THE OIL.

Most of the oil from the Santa Maria district is refined, the lighter products being used for illuminants and for the direct generation of power in gas engines, and the heavier products and unrefined heavy oil for fuel, lubricants, road dressing, etc. With the exception of a very small amount used locally, all the oil is sent out of the district, the greater part of the product at present, it is believed, going to the refineries near San Francisco. Contracts recently made in South America, Japan, and the Hawaiian Islands indicate that within a short time much of the product of the district will be exported.

RÉSUMÉ.

The Santa Maria oil district, comprising the Santa Maria, Lompoc, Arroyo Grande, and Huasna fields, occupies the central and northern portions of the Lompoc and Guadalupe quadrangles, northern Santa Barbara County; the southern part of the San Luis quadrangle, southern San Luis Obispo County, and a small part of the unmapped area between the Lompoc and San Luis quadrangles.

The larger part of the district is a basin region inclosed between two divisions of the Coast Ranges—the San Rafael and Santa Ynez mountains—and the Pacific Ocean. The formations in this basin have undergone less disturbance than in the mountains and the conditions in it are good for the accumulation of oil.

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; Tejon (Eocene) sandstone, shale, and conglomerate; Vaqueros (lower Miocene) conglomerate, sandstone, and shale; Monterey (middle Miocene) diatomaceous and flinty shale, limestone, calcerous shale, and volcanic ash; Fernando (Miocene-Pliocene-Pleistocene) conglomerate, sandstone, and shale; and Quaternary gravel, sand, clay, and alluvium. The sedimentary formations of Tertiary and early Quaternary age have a combined maximum thickness of at least 13,200 feet.

A variety of igneous rocks of Cretaceous and Tertiary age, mostly intrusive, outcrop over small areas.

The Monterey shale (middle Miocene) is the original and chief oil-bearing formation, the petroleum having originated and remained in it in large quantities. Some has escaped by seepage and collected in the overlying Fernando formation or the Quaternary terrace deposits, or has been dissipated. The oil is supposed to accumulate in fractured zones and porous sands in the lower portion of the Monterey, where brittle shale predominates, anticlines furnishing the most favorable conditions for accumulation. The Monterey shale is in large part of organic origin, being especially rich in diatoms, and the oil is supposed to be a product of the plant and animal remains inclosed in it. The quantity of these remains originally deposited with this formation is sufficient to account for a vast amount of derived oil.

Two structural systems prevail in the district, the features in the northeastern portion striking northwest and southeast, those in the southern portion striking east and west, and those in the intervening region 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.

The wells range in depth from 1,500 to more than 4,000 feet. In the Santa Maria and Lompoc fields they obtain oil from zones of fractured shale, and possibly in certain places from sandy layers in the lower portion of the Monterey formation. The production of the individual wells ranges from 5 to 3,000 barrels per day, the average being between 300 and 400 barrels. The oil ranges in gravity from 19° to 35° Baumé, the greater part of it being about 25° to 27°. In the Arroyo Grande field the oil comes from sandstone at the base of the Fernando and is of 14° gravity. There is in all these fields much undeveloped territory which offers great promise of being highly productive. The conditions affecting the presence of oil have been discussed for individual areas and those places enumerated in which the conditions seem favorable for its accumulation.

There are 52 oil companies interested in the district; 11 of these own all the producing wells. Of the 174 wells in the district 94 are productive, 55 are drilling, and 25 are abandoned. The total production of the field up to January 1, 1907, was 9,117,076 barrels; the production for 1906 alone was 4,906,513 barrels.

PLATES XII TO XXVI.

PLATE XII.

TEJON (EOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

FIG. 1. *Cardium brewerii* Gabb. Type. Right valve; altitude 61 mm. View of exterior. Pal. California, vol. 1, 1869, pl. 24, fig. 155. A common species in the Eocene of the Santa Ynez Mountains.

FIG. 2*a*. *Crassatellites collina* Conrad. U.S.N.M. 165312. Left valve; longitude 87 mm. View of exterior. San Julian ranch (4507). Characteristic of this horizon.

FIG. 2*b*. View of anterior end of same specimen.

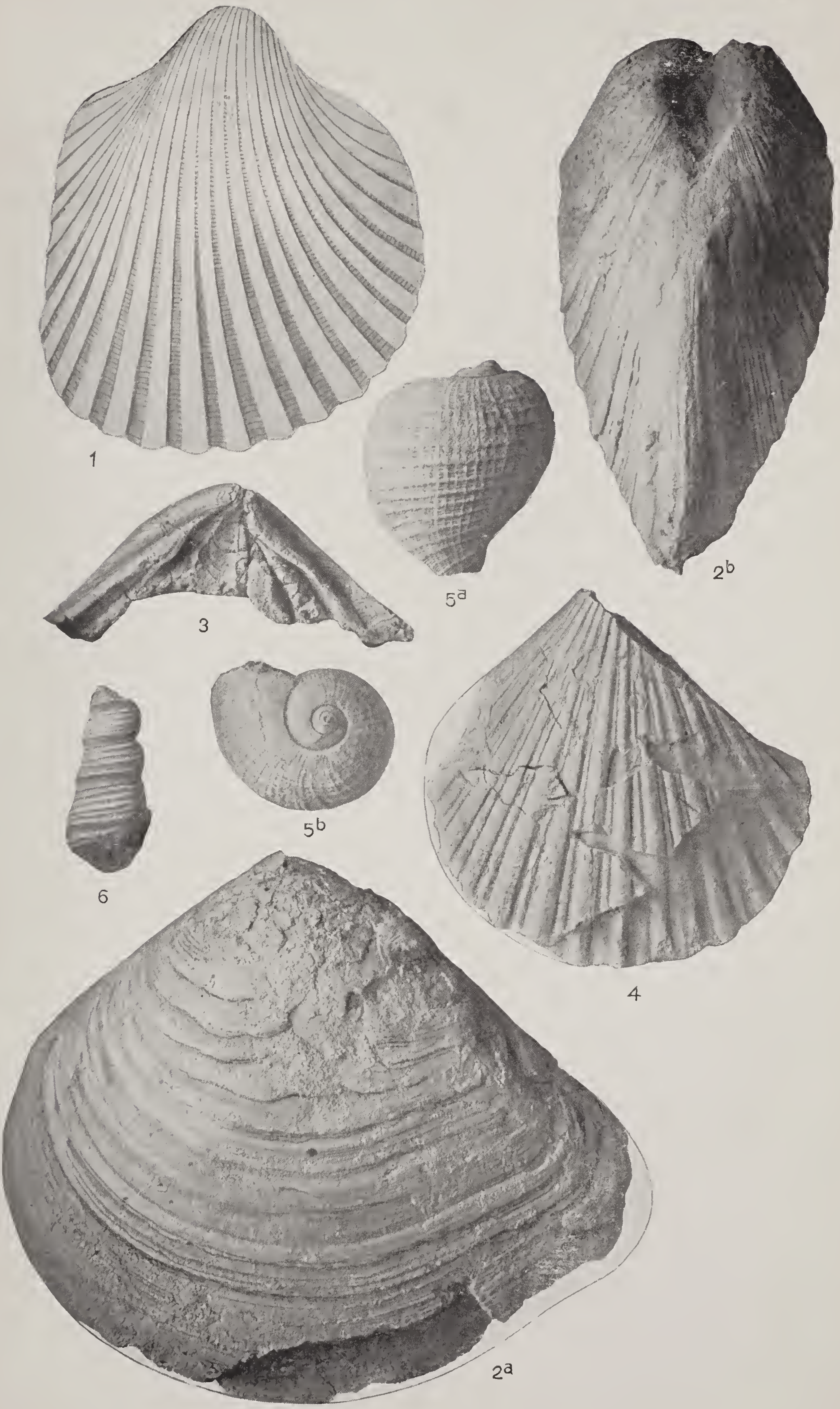
FIG. 3. *Crassstellites collina* Conrad. U.S.N.M. 165312. Hinge. Same locality as fig. 2.

FIG. 4. *Pecten* (*Chlamys*) *yneziana* Arnold. U.S.N.M. 165313. Paratype. Altitude 52 mm. View of exterior. San Julian ranch (4507). Characteristic of this horizon.

FIG. 5*a*. *Ficus mamillatus* Gabb. U.S.N.M. 165319. Altitude 31 mm. View of back. North of Sudden (4518). Characteristic of this horizon.

FIG. 5*b*. View of top of same specimen.

FIG. 6. *Turritella uvasana* Conrad. U.S.N.M. 165327. Altitude of imperfect specimen 25 mm. Aperture view. North of Sudden (4578). Characteristic of this horizon.



TEJON (EOCENE) FOSSILS.

PLATE XIII.

KNOXVILLE (CRETACEOUS) AND TEJON (EOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

FIG. 1. *Aucella piochii* Gabb. U.S.N.M. 30831. Right valve; altitude 25 mm. View of exterior. Knoxville (lower Cretaceous) formation, East Fork Tepusquet Creek (4173). Characteristic of the lower Cretaceous throughout the Coast Ranges.

FIG. 2. *Aucella piochii* Gabb. U.S.N.M. 30831. Left valve; altitude 15 mm. View of exterior, × 2. Same locality and horizon as fig. 1.

FIG. 3*a*. *Aucella piochii* Gabb. Left valve; altitude 27 mm. View of exterior. Bull. U. S. Geol. Survey No. 133, 1895, pl. 4, fig. 6.

FIG. 3*b*. Exterior of right valve of same specimen. Op. cit., pl. 4, fig. 7.

FIG. 4. *Venericardia planicosta* Lamarck, U.S.N.M. 164973. Left valve; longitude 84 mm. Eocene, Little Falls, Wash. This is the most widespread and characteristic Eocene species in the world.

FIG. 5*a*. *Turritella* (*martinezensis* Gabb) var. *? lompocensis* Arnold. Paratype. Altitude of fragment, 30 mm. Back view. Same locality as fig. 8.

FIG. 5*b*. Basal view of same specimen.

FIG. 6*a*. *Pecten* (*Chlamys*) *yneziana* Arnold. U.S.N.M. 165313. Type. Right valve; altitude 64 mm. View of exterior. San Julian ranch (4507). Characteristic of this horizon.

FIG. 6*b*. Same species. Length of hinge of right valve 25 mm.

FIG. 7. *Turritella uvasana* Conrad. U.S.N.M. 165326. Altitude of imperfect specimen 68 mm. Aperture view. San Julian ranch (4507). Characteristic of the Eocene throughout the Coast Ranges.

FIG. 8. *Turritella* (*martinezensis* Gabb) var. *? lompocensis* Arnold. U.S.N.M. 165316. Type. Longitude 68 mm. View of back. Southwest of Lompoc (4509).

2

1

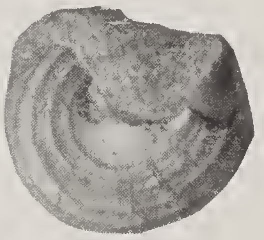
3a

6b

3b

8

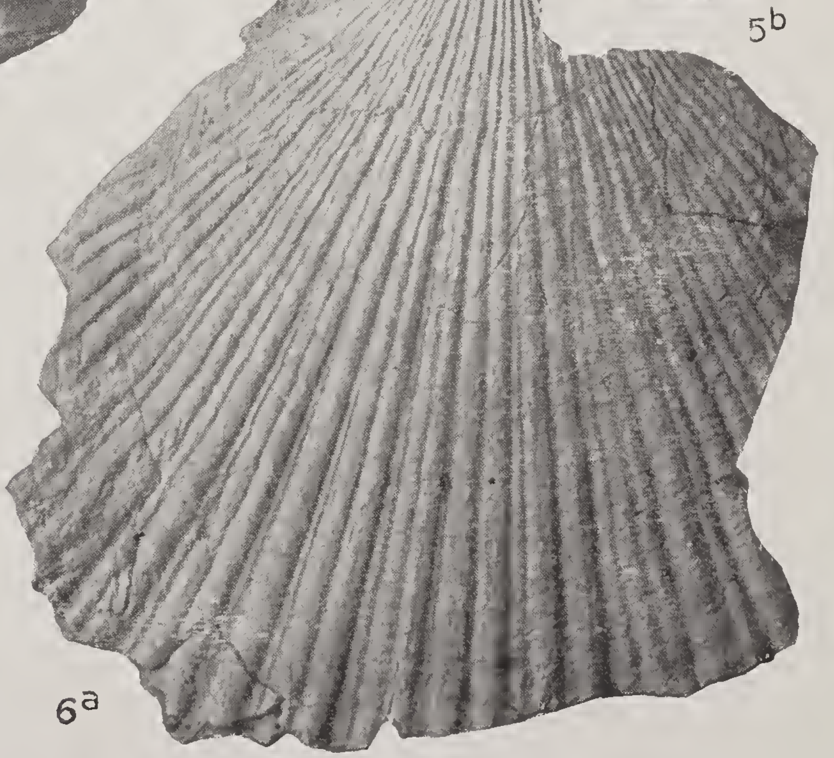
4



5b

5a

7



6a

KNOXVILLE (CRETACEOUS) AND TEJON (EOCENE) FOSSILS.

PLATE XIV.

Tejon (Eocene) Pelecypoda.

(Unless otherwise indicated all figures are natural size.)

Fig. 1*a*. *Ostrea idriaensis* Gabb. U.S.N.M. 165318. Left valve; altitude 114 mm. View of exterior. North of Sudden (4518). Characteristic of this horizon.

Fig. 1*b*. View of exterior of right valve of same specimen.

Fig. 2. *Phacoides cumulata* Gabb. U.S.N.M. 165328. Right valve; altitude 10 mm. View of exterior, × 4. Three miles north of Sudden (4518); also known from type locality of Tejon formation.

1a

2

1b

TEJON (EOCENE) PELECYPODA.

PLATE XV.

VAQUEROS (LOWER MIOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

FIG. 1*a*. *Purpura vaquerosensis* Arnold. Collection of Delos Arnold. Type. Altitude 100 mm Aperture view. Lynchs Mountain, Monterey County, Cal.

FIG. 1*b*. Back view of same specimen.

FIG. 2. *Modiolus ynezianа* Arnold. U.S.N.M. 165324. Type. Right valve; altitude 31 mm. View of exterior, × 2. San Julian ranch (4504). Characteristic of this horizon.

2

1a

1b

VAQUEROS (LOWER MIOCENE) FOSSILS.

PLATE XVI.

VAQUEROS (LOWER MIOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

FIG. 1. *Pecten* (*Lyropecten*) *magnolia* Conrad. U.S.N.M. 165317. Right valve; altitude 155 mm. View of exterior, × ½. San Julian ranch. A characteristic Vaqueros species.

FIG. 2. *Ostrea eldridgei* Arnold. U.S.N.M. 165307. Left valve; altitude 100 mm. View of exterior. Mouth of Ballard Canyon, 2 miles south of Santa Ynez (4478). Characteristic of this horizon.

FIG. 3. *Turritella ineziana* Conrad. U.S.N.M. 165321. Altitude 120 mm. View of side. Ten miles west of Santa Ynez (4514). Characteristic of this horizon throughout the Coast Ranges.

1

3

2

VAQUEROS (LOWER MIOCENE) FOSSILS.

PLATE XVII.

VAQUEROS (LOWER MIOCENE) PELECYPODA AND BRACHIOPODA.

(Unless otherwise indicated all figures are natural size.)

FIG. 1. *Pecten* (*Pecten*) *vanvlecki* Arnold. U.S.N.M. 165305. Type. Right valve; altitude 64 mm. View of exterior. Mouth of Ballard Canyon, 2 miles south of Santa Ynez (4478). Characteristic of this horizon.

FIG. 2. *Pecten* (*Pecten*) *vanvlecki* Arnold. U.S.N.M. 165306. Paratype. Left valve; altitude 72 mm. View of exterior. Mouth of Ballard Canyon, 2 miles south of Santa Ynez (4478). Characteristic of this horizon.

FIG. 3. *Pecten* (*Chlamys*) *sespeensis* var. *hydei* Arnold. U.S.N.M. 165308. Left valve; altitude 60 mm. View of exterior. Mouth of Ballard Canyon, 2 miles south of Santa Ynez (4478). Characteristic of this horizon.

FIG. 4*a*. *Terebratalia kennedyi* Dall. U.S.N.M. 165325. Type. Ventral valve; altitude 26 mm. View of exterior. Lime quarry 5 miles southwest of Lompoc (4521). Characteristic of this horizon.

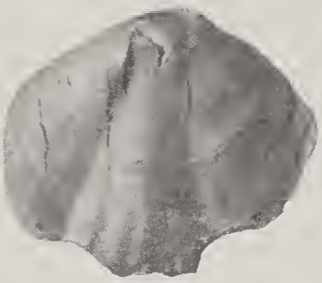
FIG. 4*b*. Dorsal valve of same species; altitude of fragment 18 mm. View of exterior.

FIG. 4*c*. Dorsal valve of same species: altitude 19 mm. View of exterior.

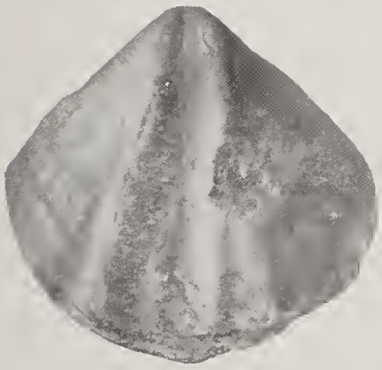
FIG. 4*d*. Ventral valve of same species; altitude 28 mm. View of exterior.

2

4a



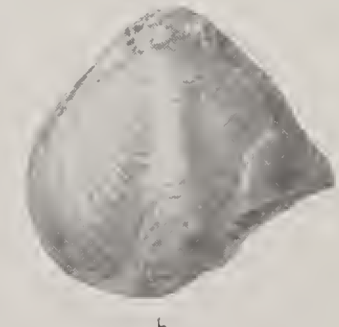
4c



4d

3

1



4b

VAQUEROS (LOWER MIOCENE) PELECYPODA AND BRACHIOPODA.

PLATE XVIII.

VAQUEROS (LOWER MIOCENE) PELECYPODA.

(Unless otherwise indicated all figures are one-half natural size.)

FIG. 1. *Pecten* (*Lyropecten*) *crassicardo* Conrad. U.S.N.M. 164967. Exterior of valve, showing characteristic sculpture; altitude 90 mm. Ojai Valley, Ventura County, Cal. This species ranges throughout the Miocene, being commoner in the lower part in southern California, in the upper part in central California.

FIG. 2. *Pecten* (*Amusium*) *lompocensis* Arnold. Collection of California Academy of Sciences. Holotype. Mold of interior of left valve; altitude 105 mm. Four miles south of Lompoc.

FIG. 3. *Pecten* (*Amusium*) *lompocensis* Arnold. U.S.N.M. 164852. Paratype. Interior of a portion of left valve; altitude 90 mm. Ojai Valley, Ventura County, Cal.

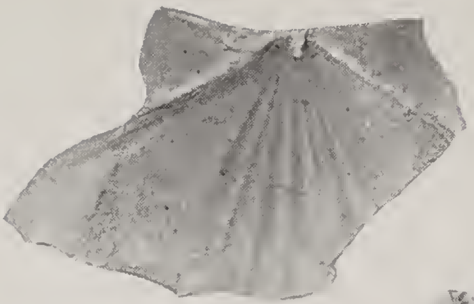
FIG. 4. *Pecten* (*Amusium*) *lompocensis* Arnold. Collection of California Academy of Sciences. Paratype. Imperfect mold of interior of right valve; hinge line 42 mm. Same locality as fig. 2.

FIG. 5. *Pecten* (*Lyropecten*) *bowersi* Arnold. Collection of University of California. Type. Exterior of slightly imperfect right valve; altitude 150 mm. Santa Ynez Canyon.

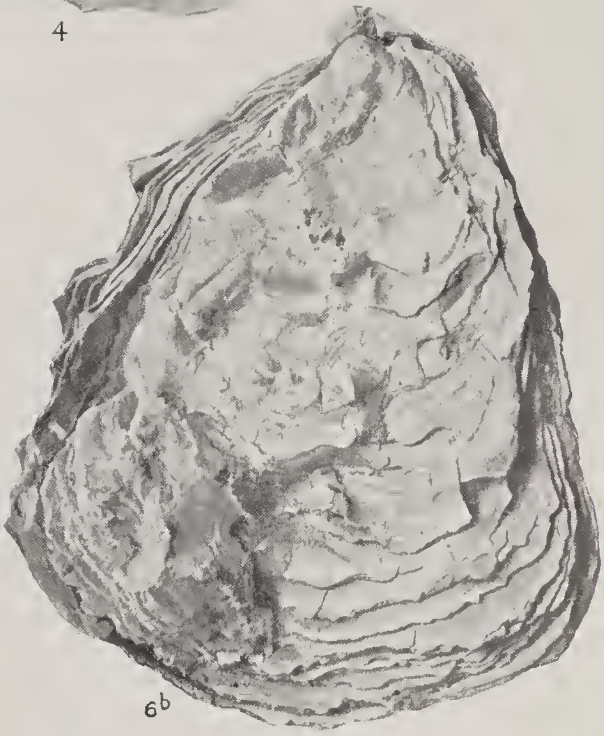
FIG. 6*a*. *Ostrea eldridgei* Arnold. U.S.N.M. 165320. Left valve; altitude 114 mm. View of exterior. El Jaro Creek (4519). Characteristic of this horizon.

FIG. 6*b*. View of exterior of right valve of same specimen.

1

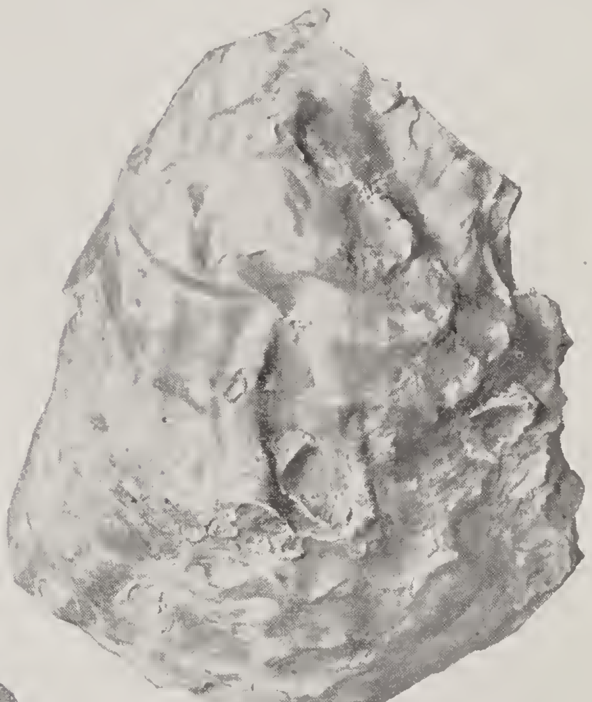


4

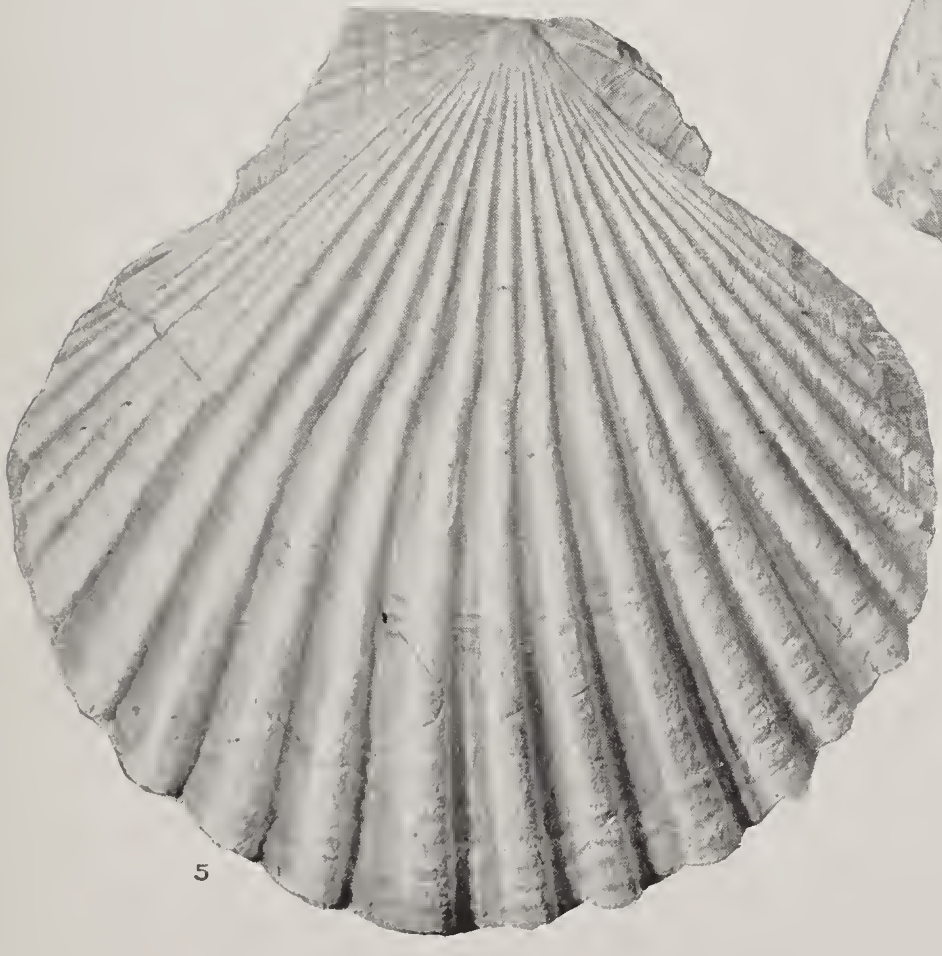


6^b

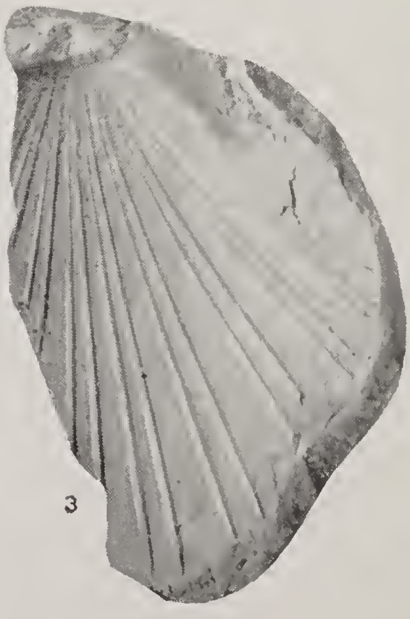
2



6^a



5



3

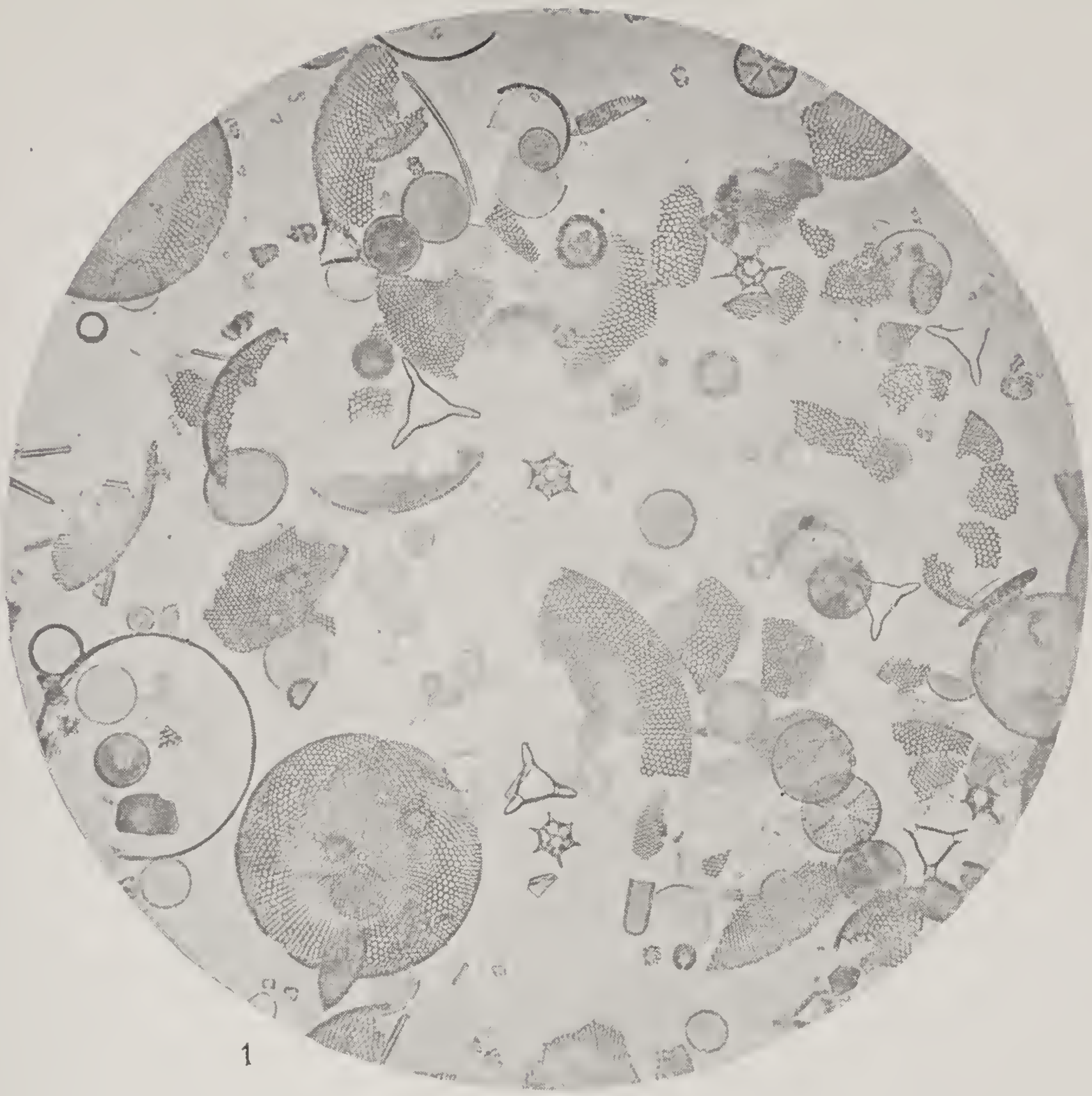
VAQUEROS (LOWER MIOCENE) PELECYPODA.

PLATE XIX.

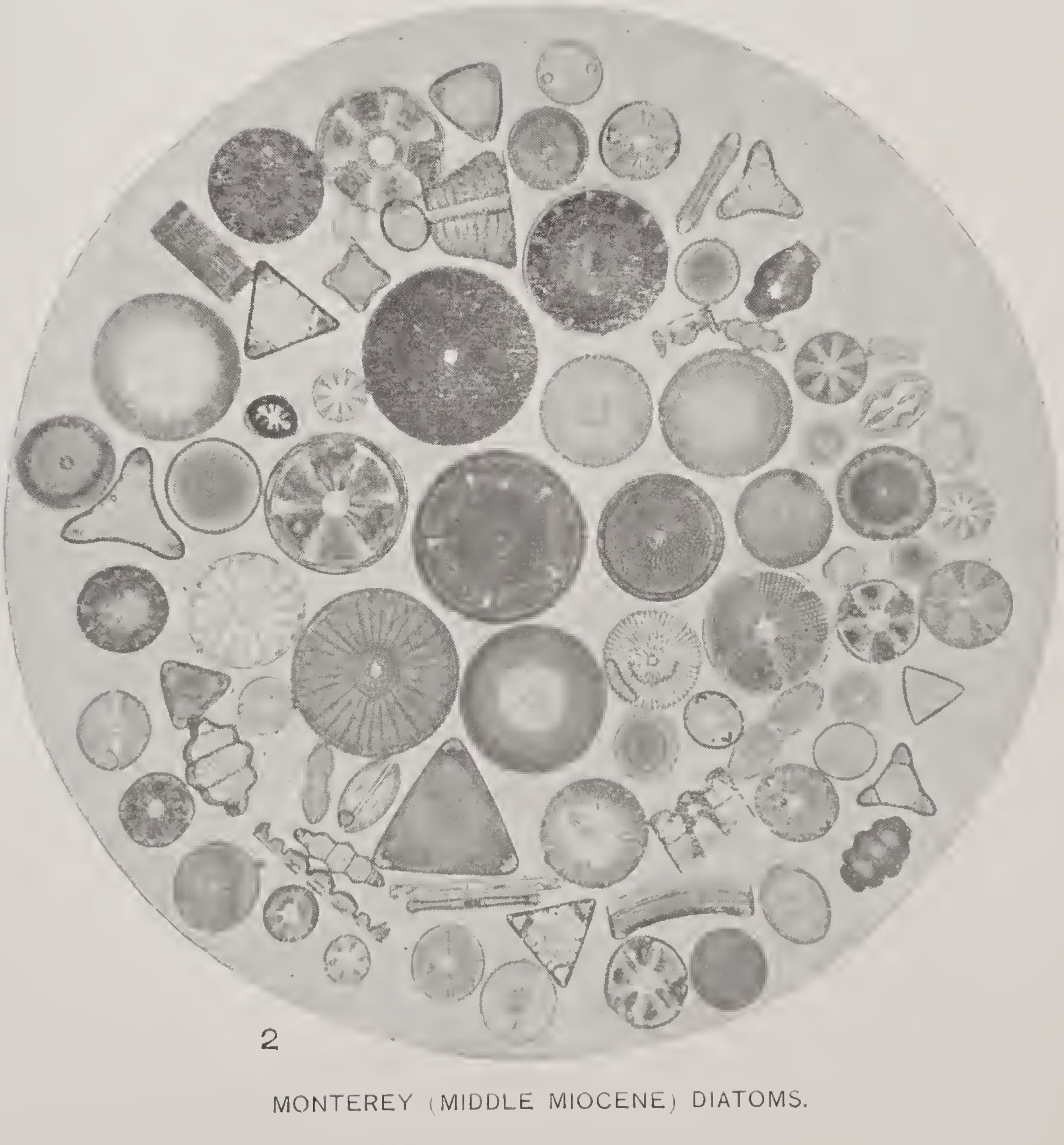
MONTEREY (MIDDLE MIOCENE) DIATOMS.

FIG. 1. Photomicrograph of slide of partially cleaned diatomaceous shale material from the Lompoc quadrangle, × 100. All the larger individuals and fragments are *Coscinodiscus oculus iridis* Ehrenberg.

FIG. 2. Photomicrograph of slide of diatoms from the Monterey shale at Santa Monica, Los Angeles County, Cal , × 60. Nearly all the species shown on this slide occur in the diatomaceous deposits in the Santa Maria district.



1



2

MONTEREY (MIDDLE MIOCENE) DIATOMS.

PLATE XX.

MONTEREY (MIDDLE MIOCENE) DIATOMS.

FIG. 1*a*. *Actinoptychus undulatus* Ehrenberg.

FIG. 1*b*. *Lithodesmium cornigerum* Brun.

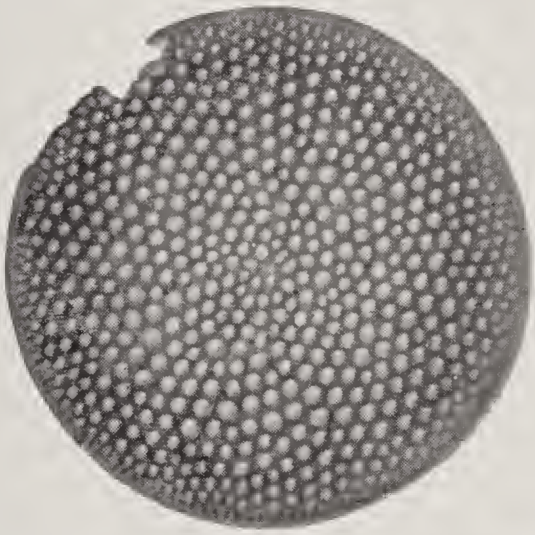
FIG. 1*c*. *Dictyocha gracilis* (not a diatom; nature unknown). Enlargement to 1,000 diameters of a portion of the slide shown in Pl. XIX, fig. 1.

FIG. 2. *Coscinodiscus obscurus* A. S., × 1,000. From the Monterey shale of the Santa Maria district.

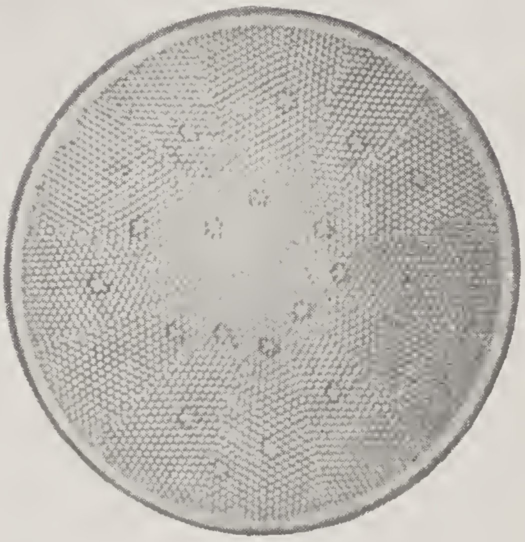
FIG. 3. *Coscinodiscus subtilis* Ehrenberg, × 1,000. From the Monterey shale of the Santa Maria district.

FIG. 4. *Coscinodiscus robustus* Grev., × 1,000. From the Monterey shale of the Santa Maria district.

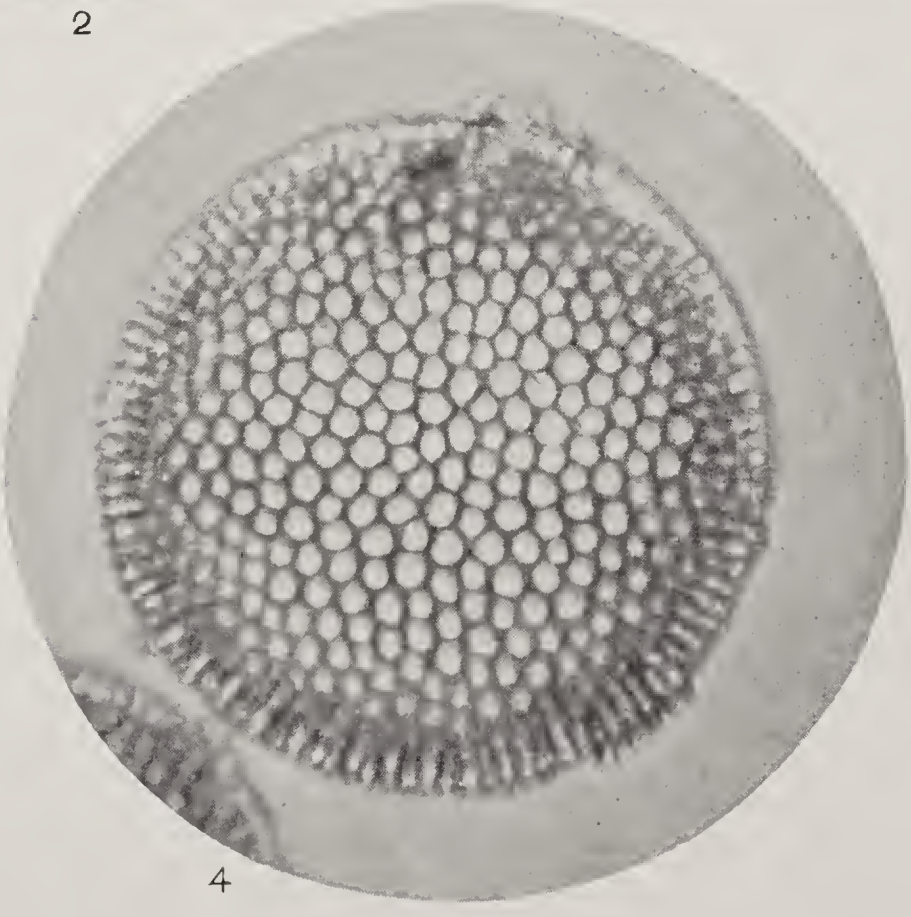
1



2



3



4

MONTEREY (MIDDLE MIOCENE) DIATOMS.

PLATE XXI.

FERNANDO (PLIOCENE) GASTEROPODA.

(Unless otherwise indicated figures are natural size.)

FIG. 1. *Trochita radians* Lamarck. U.S.N.M. 165310. Maximum diameter of fragment 20 mm. View of top, × 2. Fugler Point asphalt mine, near Gary (4475). Characteristic of the upper Miocene and lower Pliocene of this region.

FIG. 2. *Priene oregonensis* Redfield (young). U.S.N.M. 165262. Altitude 46 mm. Aperture view. Waldorf asphalt mine (4473). Also known recent.

FIG. 3. *Lunatia lewisii* Gould. U.S.N.M. 165264. Young specimen; altitude 23 mm. Aperture view, × 2. Waldorf asphalt mine (4473). Also known recent.

FIG. 4. *Thalotia caffea* Gabb. U.S.N.M. 165298. Latitude 29 mm. Back view. Fugler Point asphalt mine, near Gary (4475). Also known recent.

FIG. 5. *Thalotia caffea* Gabb. U.S.N.M. 165297. Latitude of fragment 21 mm. View of side of fragment, slightly tilted up. Same locality as fig. 4.

FIG. 6. *Lymnæa alamosensis* Arnold. U.S.N.M. 165426. Type. Altitude 6 mm. Aperture view, × 6. Fresh-water beds, 1 mile southeast of bench mark 425, Los Alamos Valley.

FIG. 7. *Lymnæa alamosensis* Arnold. U.S.N.M. 165426. Young specimen; altitude 3.5 mm. Same locality as fig. 6.

FIG. 8. *Cadulus fusiformis* Sharp and Pilsbry. U.S.N.M. 165267. Longitude 10 mm. Side view, × 3. Waldorf asphalt mine (4473). Known also recent.

FIG. 9. *Cancellaria crawfordiana* Dall var. *fugleri* Arnold. U.S.N.M. 165322. Type. Altitude 22.5 mm. Aperture view, × 2. Fugler Point asphalt mine, near Gary (4475). Characteristic of this horizon.

FIG. 10. *Ocinebra micheli* Ford var. *waldorfensis* Arnold. U.S.N.M. 165261. Type. Altitude 11 mm. Aperture view, × 3. Waldorf asphalt mine (4473).

FIG. 11. *Turritella cooperi* Carpenter. U.S.N.M. 165273. Altitude 34 mm. Aperture view, × 2. Waldorf asphalt mine (4473). Common in the Pliocene and Pleistocene.

FIG. 12. *Drillia waldorfensis* Arnold. U.S.N.M. 165270. Type. Altitude 18.5 mm. Aperture view of imperfect specimen, × 2. Waldorf asphalt mine (4473). Characteristic of this horizon.

FIG. 13. *Drillia johnsoni* Arnold. U. S. N.M. 165263. Altitude 34 mm. Back view, × 2. Waldorf asphalt mine (4473). Also found fossil at San Pedro.

FIG. 14*a*. *Neverita recluziana* Petit. U.S.N.M. 165323. Altitude 35 mm. Aperture view. Fugler Point asphalt mine near Gary (4475). Also known recent.

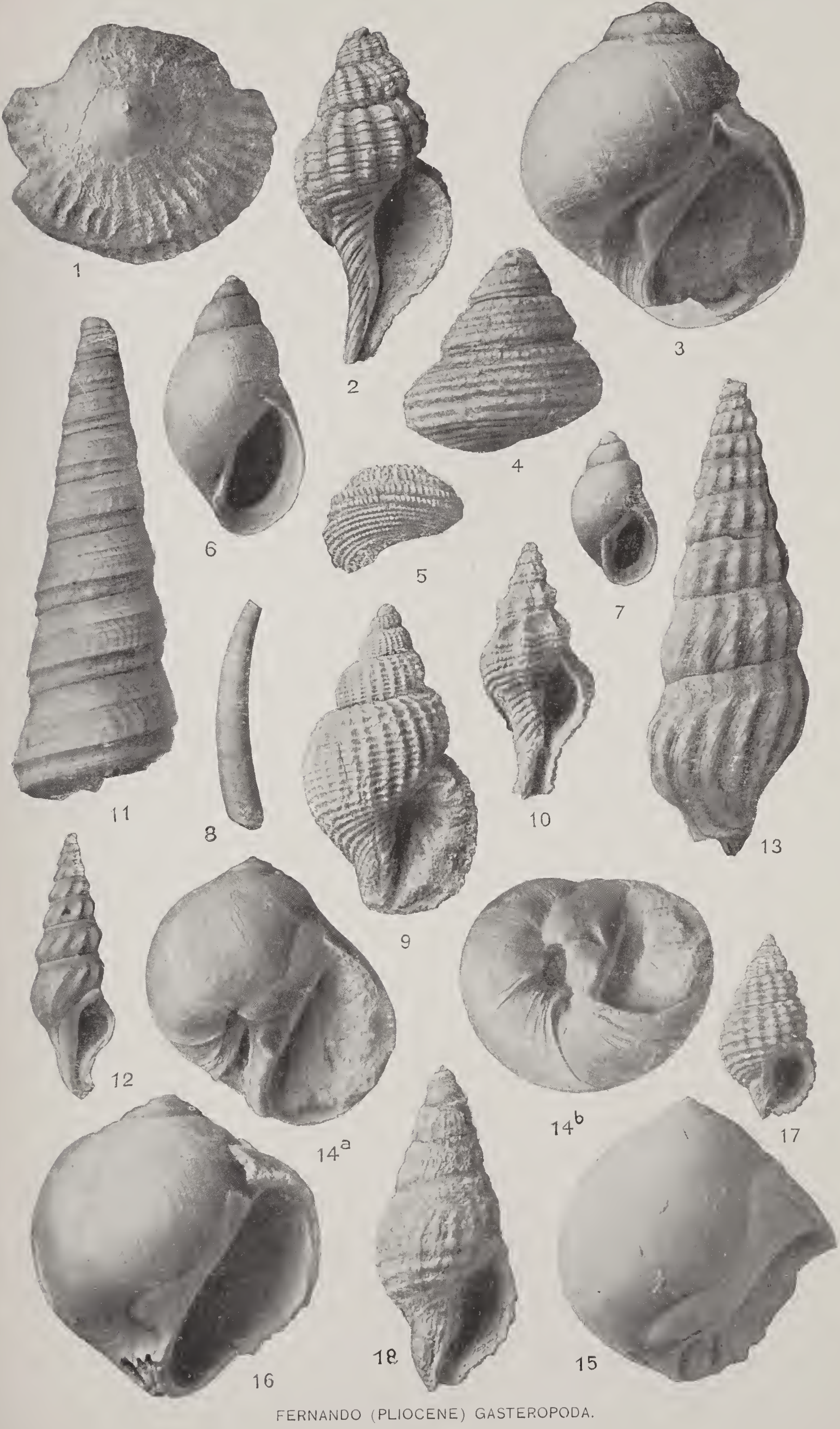
FIG. 14*b*. View of base of same specimen.

FIG. 15. *Neverita recluziana* Petit. U.S.N.M. 165299. Altitude 20 mm. Aperture view, × 2. Fugler Point asphalt mine, near Gary (4475). Also known recent.

FIG. 16. *Natica clausa* Broderip and Sowerby. U.S.N.M. 165269. Altitude 21 mm. Aperture view, × 2. Waldorf asphalt mine (4473). Also known recent.

FIG. 17. *Nassa waldorfensis* Arnold. U.S.N.M. 165272. Type. Altitude 13 mm. Aperture view, × 2. Waldorf asphalt mine (4473). Characteristic of this horizon.

FIG. 18. *Drillia graciosana* Arnold. U.S.N.M. 165309. Type. Altitude 14 mm. Aperture view, × 3. Graciosa Ridge, near Orcutt (4476). Characteristic of this horizon.



FERNANDO (PLIOCENE) GASTEROPODA.

PLATE XXII.

FERNANDO (PLIOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

FIG. 1*a*. *Pholadidea ovoidea* Gould. U.S.N.M. 165277. Longitude 58 mm. View of valve. Waldorf asphalt mine (4473). Also known recent.

FIG. 1*b*. View of hinge region of both valves.

FIG. 2. *Purpura crispata* Chemintz. U.S.N.M. 165278. Altitude 20 mm. Aperture view. One mile north of Schumann (4474). Also known recent.

FIG. 3*a*. *Leda taphria* Dall. U.S.N.M. 165296. Longitude 10.5 mm. View of exterior, × 3. Fugler Point asphalt mine, near Gary (4475). Also known recent.

FIG. 3*b*. View of hinge region of both valves.

FIG. 4*a*. *Terebratalia occidentalis* Dall. U.S.N.M. 165300. Ventral valve; latitude 30 mm. View of exterior. Fugler Point asphalt mine, near Gary (4475). A variable species. Also known recent.

FIG. 4*b*. View of dorsal valve of same specimen.

FIG. 5. *Macoma nasuta* Conrad. U.S.N.M. 165276. Longitude 47 mm. View of right valve. Waldorf asphalt mine (4473). Also known recent and in Miocene.

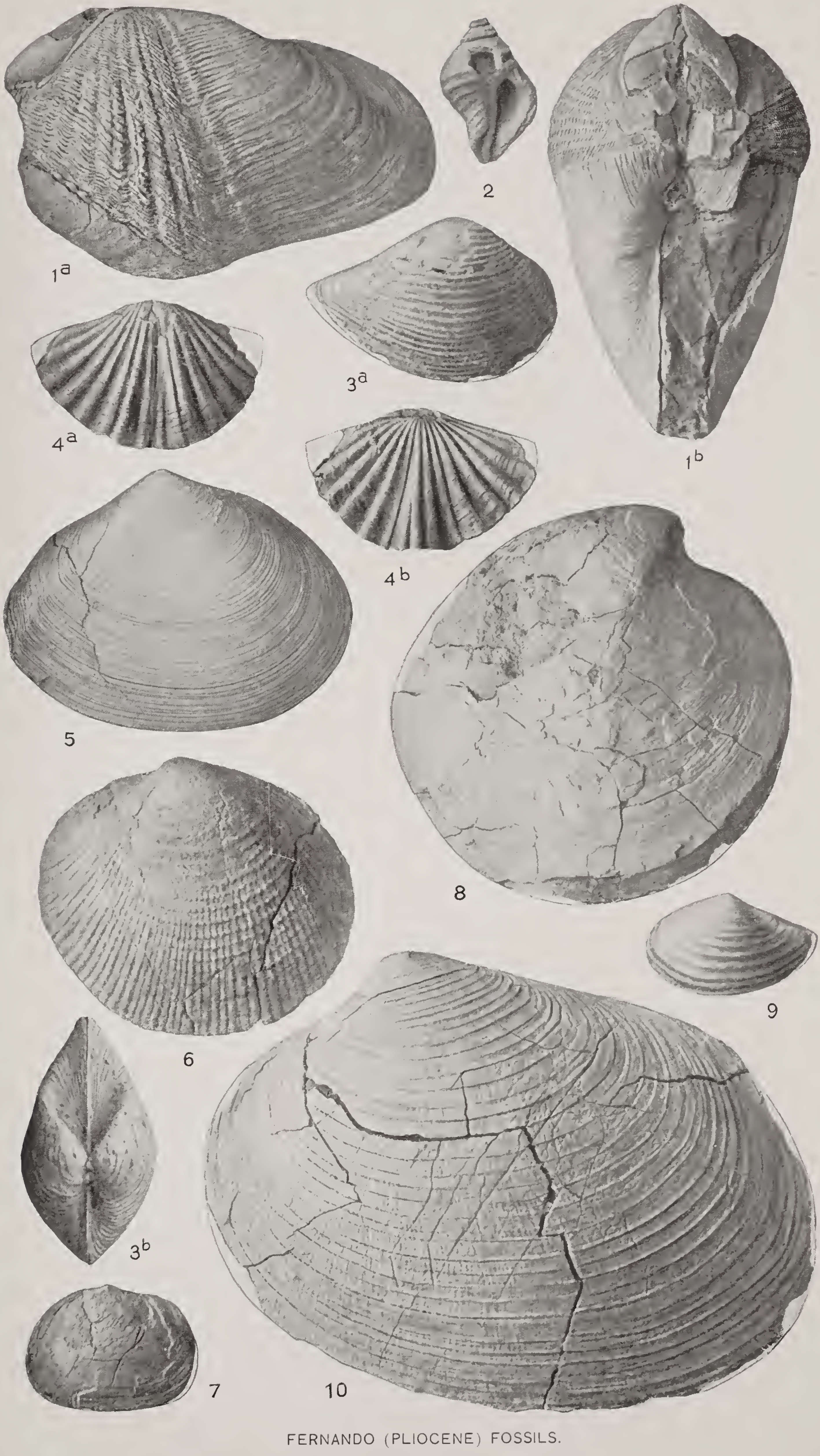
FIG. 6. *Phacoides nuttalli* Conrad var. *antecedens* Arnold. U.S.N.M. 165290. Type. Left valve; longitude 23 mm. View of exterior, × 2. Alcatraz asphalt mine, near Sisquoc (4471). Characteristic of this horizon.

FIG. 7. *Cryptomya ovalis* Conrad. U.S.N.M. 165289. Left valve; longitude 23 mm. Alcatraz asphalt mine, near Sisquoc (4471). Characteristic of this horizon.

FIG. 8. *Dosinia ponderosa* Gray. U.S.N.M. 165295. Right valve; altitude 105 mm. View of exterior, × ½. Alcatraz asphalt mine, near Sisquoc (4471). Also known recent.

FIG. 9. *Leda orcutti* Arnold. U.S.N.M. 165271. Type. Longitude 7 mm. View of exterior, × 3. Waldorf asphalt mine (4473). Characteristic of this horizon.

FIG. 10. *Tapes tenerrima* Carpenter. U.S.N.M. 165293. Left valve; longitude 83 mm. View of exterior. Alcatraz asphalt mine, near Sisquoc (4471). Common in the Pliocene Also known recent.



FERNANDO (PLIOCENE) FOSSILS.

PLATE XXIII.

Fernando (Pliocene) Fossils.

(Unless otherwise indicated all figures are natural size.)

Fig. 1. *Spisula sisquocensis* Arnold. U.S.N.M. 165292. Type. Left valve; longitude 120 mm. View of exterior, × ½. Alcatraz asphalt mine, near Sisquoc (4471). Characteristic of this horizon.

Fig. 2. *Clidiophora punctata* Carpenter. U.S.N.M. 165302. Right valve; longitude 36 mm. View of exterior. Graciosa Ridge, near Orcutt (4476). Also known recent.

Fig. 3. *Clidiophora punctata* Carpenter. U.S.N.M. 165283. Left valve; longitude 35 mm. View of interior. Graciosa Ridge, near Orcutt (4476). Also known recent.

Fig. 4. *Venericardia californica* Dall. U.S.N.M. 165274. Altitude 29 mm. Aperture view. Waldorf asphalt mine (4473). Characteristic of this horizon.

Fig. 5. *Cumingia californica* Conrad. U.S.N.M. 165311. Left valve; longitude 17 mm. View of exterior, × 2. Fugler Point asphalt mine, near Gary (4475). Also known recent.

Fig. 6. *Spisula catilliformis* Conrad var. *alcatrazensis* Arnold. U.S.N.M. 165291. Type. Right valve; longitude 128 mm. View of exterior, × ½. Alcatraz asphalt mine, near Sisquoc (4471). Characteristic of this horizon.

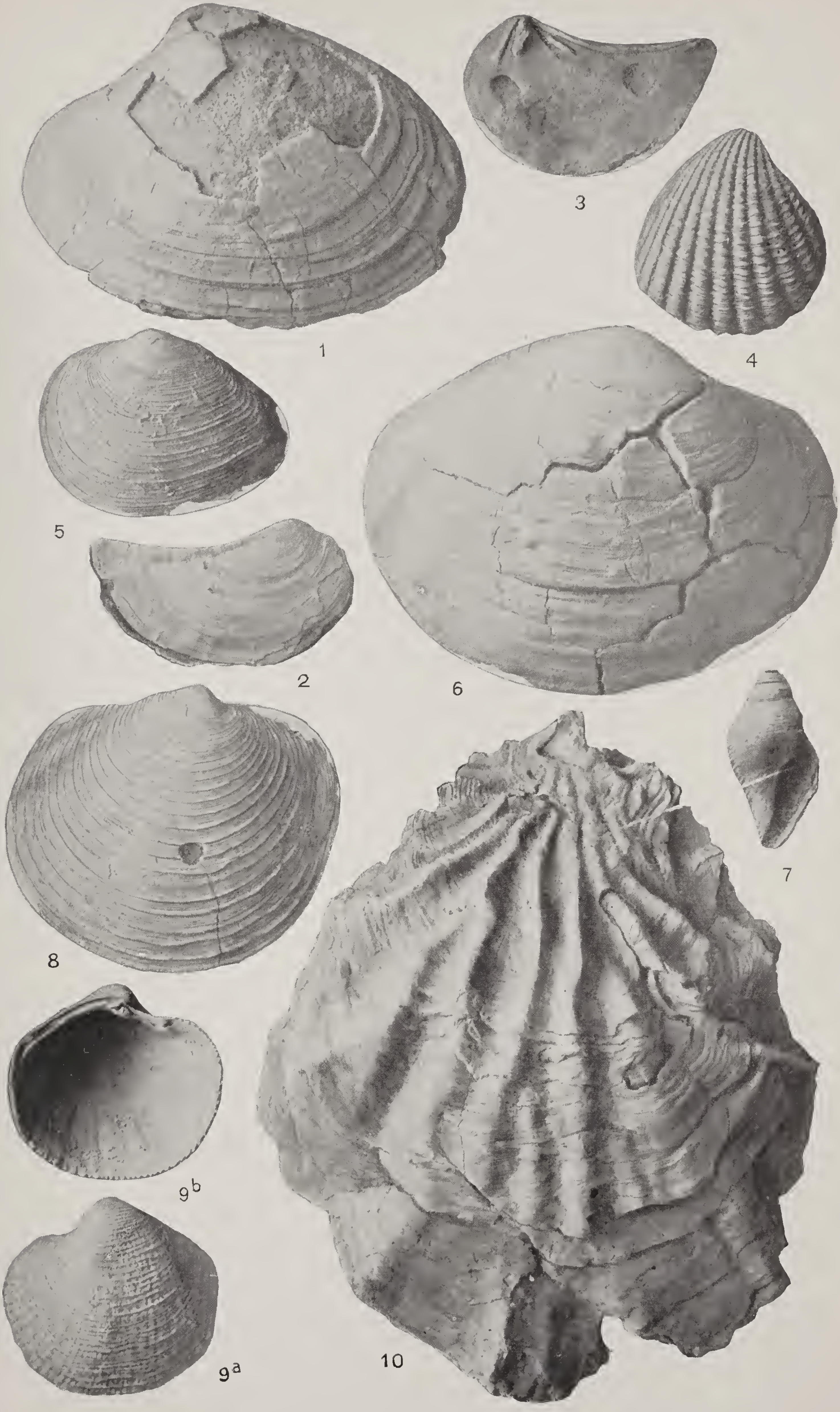
Fig. 7. *Bathytoma carpenteriana* Gabb var. *fernandoana* Arnold. U.S.N.M. 165303. Type. Altitude 24 mm. Aperture view. Graciosa Ridge, near Orcutt (4476). Characteristic of this horizon.

Fig. 8. *Phacoides annulatus* Reeve. U.S.N.M. 165286. Right valve; longitude 45 mm. View of exterior. One mile north of Schumann (4474). Common in the Fernando and also found recent.

Fig. 9*a*. *Phacoides intensus* Dall. U.S.N.M. 165260. Left valve; altitude 6.5 mm. View of exterior, × 4. Waldorf asphalt mine (4473). Found also in same horizon at San Diego.

Fig. 9*b*. View of interior of same specimen, × 4.

Fig. 10. *Ostrea veatchii* Gabb. U.S.N.M. 165282. Left valve; altitude 96 mm. View of exterior. One mile north of Schumann (4474). Characteristic of this horizon.



FERNANDO (PLIOCENE) FOSSILS.

PLATE XXIV.

FERNANDO (PLIOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

FIG. 1. *Crepidula princeps* Conrad. U.S.N.M. 165268. Longitude 76 mm. Side view. Waldorf asphalt mine (4473). Known only in the fossil state, and found in Santa Barbara County only in the Fernando formation, although it is known from the lower Miocene farther north.

FIG. 2. *Crepidula princeps* Conrad. U.S.N.M. 165315. Longitude 106 mm. View of interior, showing deck. Packards Hill, Santa Barbara.

FIG. 3. *Astyris richthofeni* Gabb. U.S.N.M. 165266. Altitude 14 mm. Aperture view, × 2. Waldorf asphalt mine (4473). So far known only as fossil.

FIG. 4. *Nassa californiana* Conrad. U.S.N.M. 165304. Altitude 30 mm. Aperture view. Graciosa Ridge, near Orcutt (4477). Characteristic of this horizon in the Santa Maria district.

FIG. 5. *Arca trilineata* Conrad. U.S.N.M. 165301. Left valve; longitude 46 mm. View of exterior. Fugler Point asphalt mine, near Gary (4475). Common in the Fernando and equivalent formations and also found in the Monterey.

FIG. 6. *Echinarachnius ashleyi* Merriam. U.S.N.M. 165259. Maximum diameter 69 mm. View from above. Graciosa Ridge, near Orcutt (4469).

FIG. 7. *Echinarachnius ashleyi* Merriam. U.S.N.M. 165259. Maximum diameter 47 mm. View from below. Same locality as fig. 6.

FIG. 8. *Echinarachnius excentricus* Eschscholtz var. U.S.N.M 165285. Maximum diameter 41 mm. View of top. One mile north of Schumann (4474). This variety is probably characteristic of this horizon.

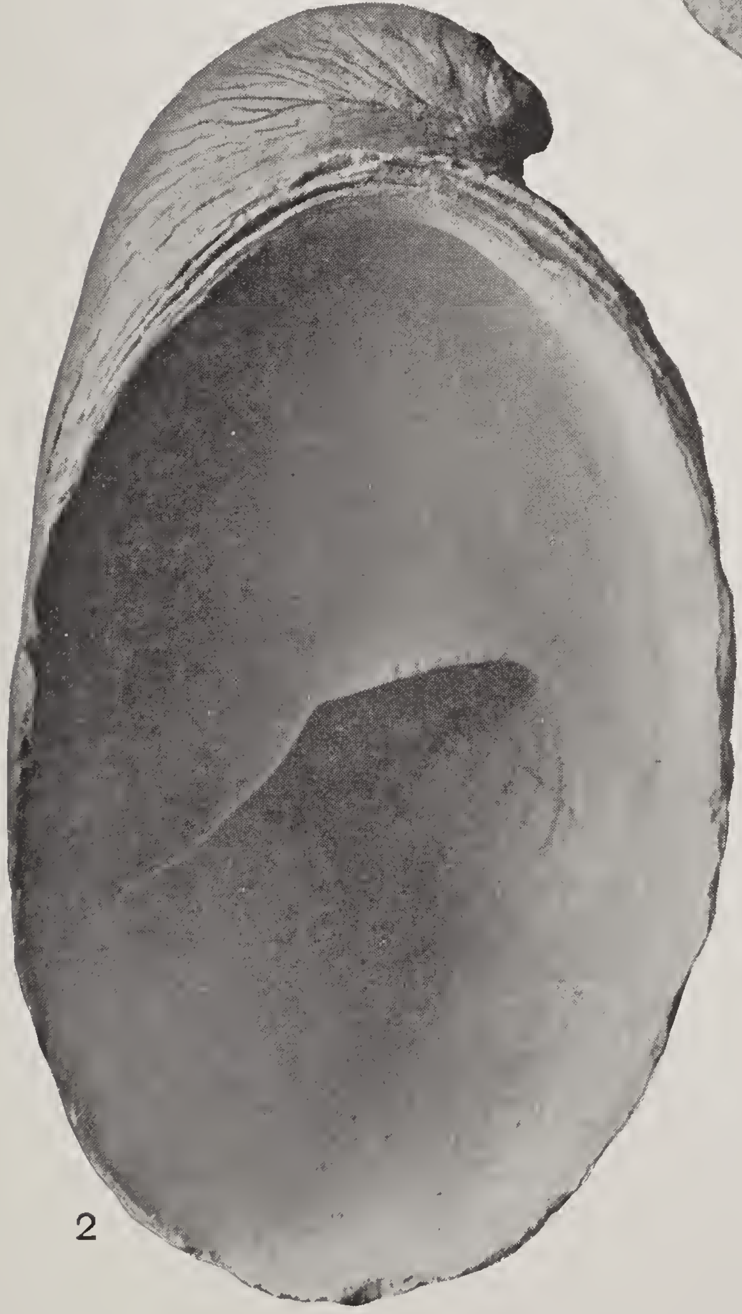

1

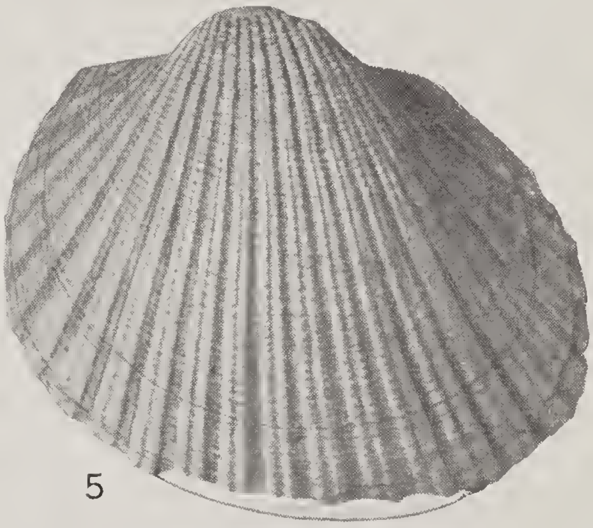

3


4


8


6


2


5


7

FERNANDO (PLIOCENE) FOSSILS.

PLATE XXV.

FERNANDO (PLIOCENE) PECTENS.

(Unless otherwise indicated all figures are two-thirds natural size.)

FIG. 1*a*. *Pecten* (*Pecten*) *stearnsii* Dall. U.S.N.M. 148008. Right valve; altitude 87 mm. View of exterior. San Diego formation (Pliocene), Pacific Beach, San Diego County, Cal. Common in the Fernando formation of southern California.

FIG. 1*b*. Same specimen as fig. 1*a*. Exterior of left valve.

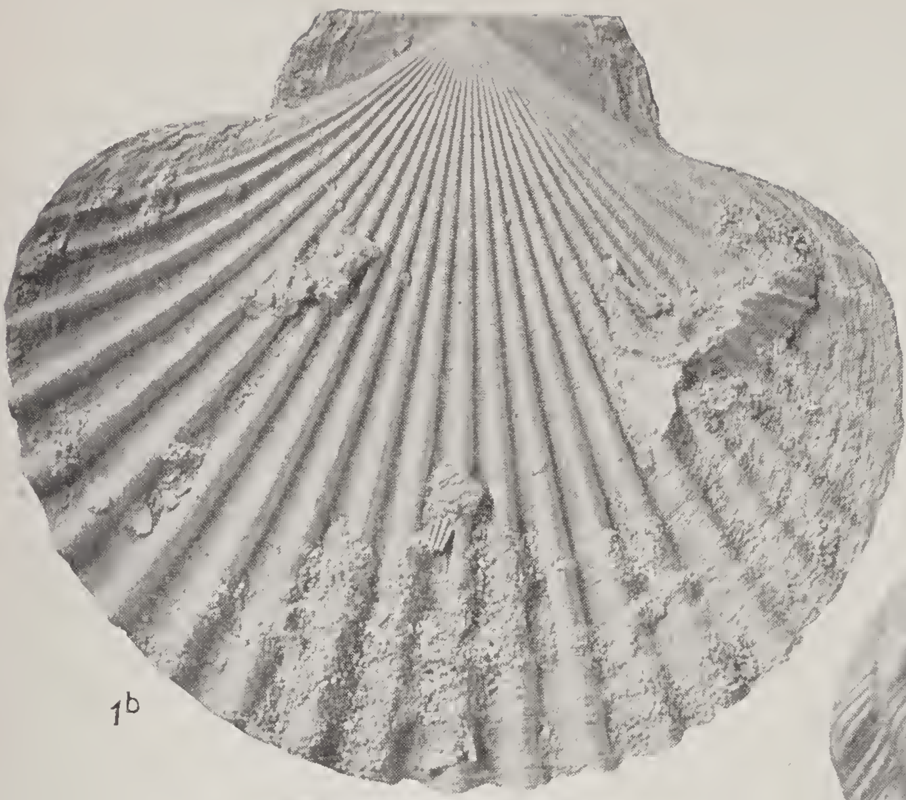
FIG. 2*a*. *Pecten* (*Patinopecten*) *oweni* Arnold. Collection of University of California. Type. Right valve, anterior ear slightly broken; altitude 85 mm. View of exterior. Foxen's ranch. Characteristic of this horizon.

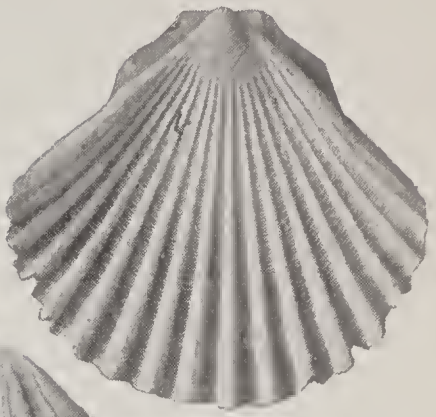
FIG. 2*b*. Same specimen as fig. 2*a*. Exterior of left valve.

FIG. 3. *Pecten* (*Chlamys*) *lawsoni* Arnold. Collection of California Academy of Science. Type. Right valve (umbo and ears missing); longitude 65 mm. View of exterior. One mile north of Schumann. Characteristic of this horizon.

FIG. 4. *Pecten* (*Chlamys*) *wattsi* Arnold. Collection of California Academy of Science. Type. Slightly imperfect left valve; altitude 66 mm. View of exterior. Lower Pliocene, Kreyenhagen's ranch, Fresno County. Common in the Fernando of southern California.

FIG. 5. *Pecten hemphilli* Dall. U.S.N.M. 165280. Left valve; altitude 22.50 mm. View of exterior, × $1\frac{2}{3}$. One mile north of Schumann (4474). Characteristic of this horizon.

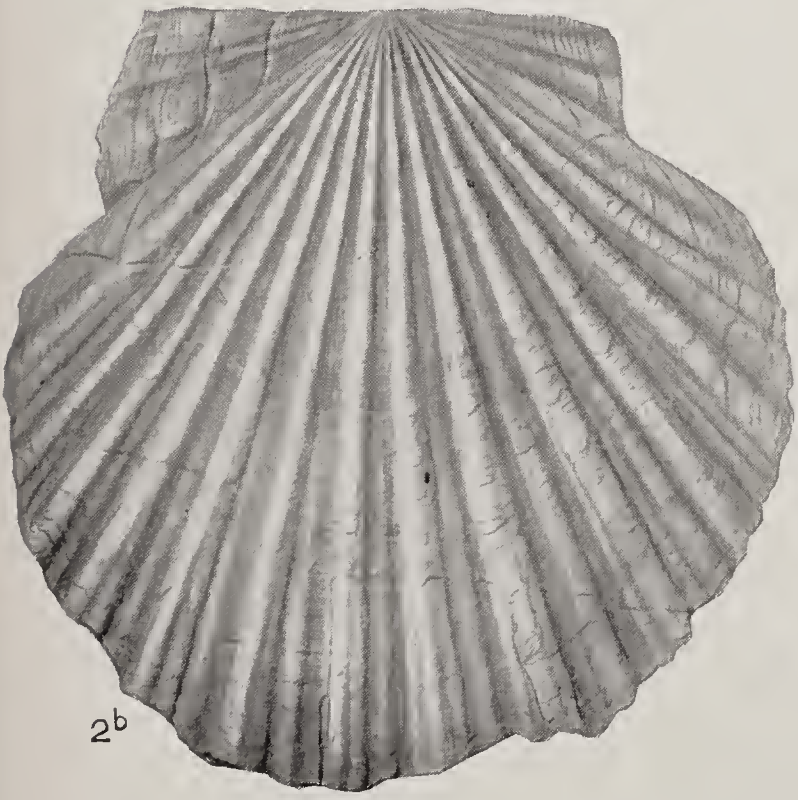

1^b

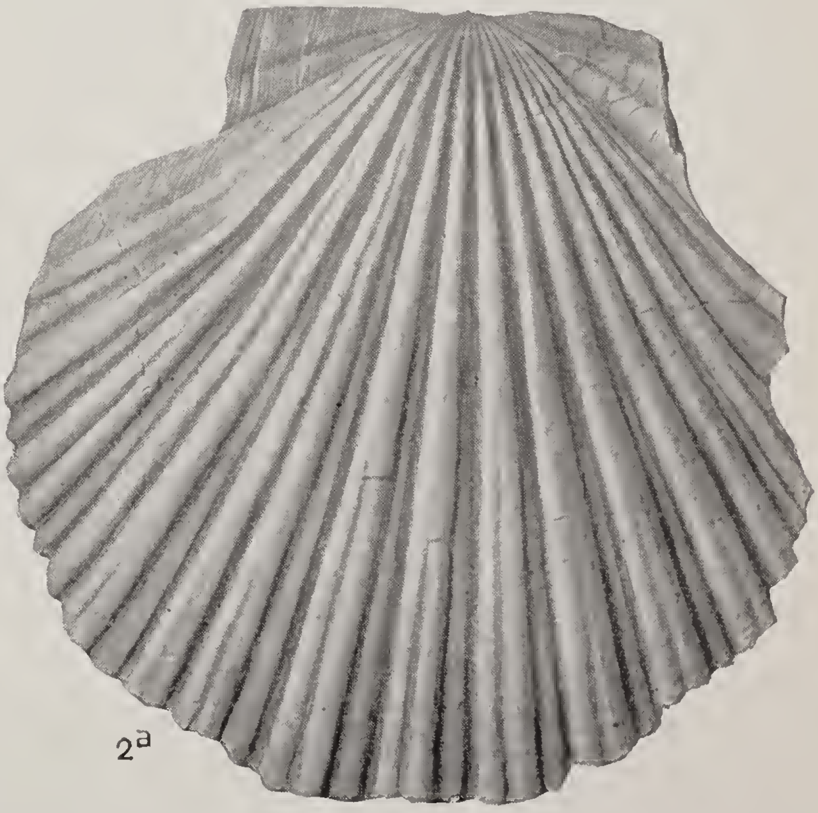

5


4


1^a


3


2^b


2^a

FERNANDO (PLIOCENE) PECTENS

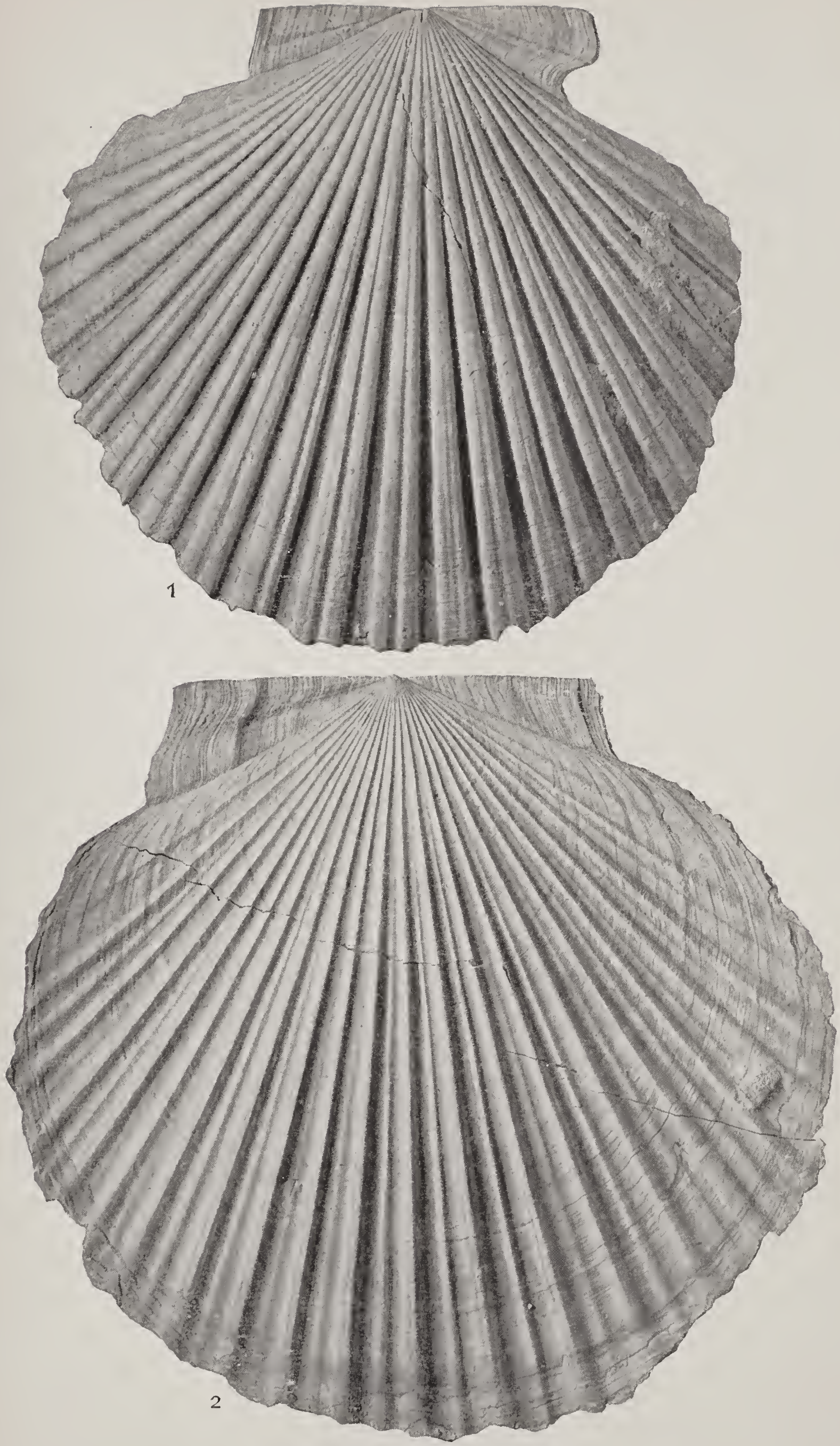
PLATE XXVI.

FERNANDO (PLIOCENE) PECTEN.

(Unless otherwise indicated all figures are two-thirds natural size.)

FIG. 1. *Pecten* (*Patinopecten*) *healeyi* Arnold. U.S.N.M. 148012. Holotype. Right valve; altitude 121 mm. View of exterior. San Diego formation (Pliocene), San Diego County, Cal. Characteristic of the Fernando formation throughout the Coast Range.

FIG. 2. *Pecten* (*Patinopecten*) *healeyi* Arnold. U.S.N.M. 154162. Paratype. Left valve; altitude 141 mm. View of exterior. San Diego formation (Pliocene), Pacific Beach, San Diego County, Cal.



FERNANDO (PLIOCENE) PECTENS.

INDEX.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 322.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports; Q, Fuels; R, Structural materials. This paper is the one hundred and third in series A and the one hundred and twenty-seventh in series B, the complete lists of which follow (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES A, ECONOMIC GEOLOGY.

B 21. Lignites of Great Sioux Reservation: Report on region between Grand and Moreau rivers, Dakota, by Bailey Willis. 1885. 16 pp., 5 pls. (Out of stock.)

B 46. Nature and origin of deposits of phosphate of lime, by R. A. F. Penrose, jr., with introduction by N. S. Shaler. 1888. 143 pp. (Out of stock.)

B 65. Stratigraphy of the bituminous coal field of Pennsylvania, Ohio, and West Virginia, by I. C. White. 1891. 212 pp., 11 pls. (Out of stock.)

B 111. Geology of Big Stone Gap coal field of Virginia and Kentucky, by M. R. Campbell. 1893. 106 pp., 6 pls. (Out of stock.)

B 132. The disseminated lead ores of southeastern Missouri, by Arthur Winslow. 1896. 31 pp. (Out of stock.)

B 138. Artesian-well prospects in Atlantic Coastal Plain region, by N. H. Darton. 1896. 228 pp., 19 pls.

B 139. Geology of Castle Mountain mining district, Montana, by W. H. Weed and L. V. Pirsson. 1896. 164 pp., 17 pls.

B 143. Bibliography of clays and the ceramic arts, by J. C. Branner. 1896. 114 pp.

B 164. Reconnaissance on the Rio Grande coal fields of Texas, by T. W. Vaughan, including a report on igneous rocks from the San Carlos coal field, by E. C. E. Lord. 1900. 100 pp., 11 pls. (Out of stock.)

B 178. El Paso tin deposits, by W. H. Weed. 1901. 15 pp., 1 pl.

B 180. Occurrence and distribution of corundum in United States, by J. H. Pratt. 1901. 98 pp., 14 pls. (Out of stock; see No. 269.)

B 182. A report on the economic geology of the Silverton quadrangle, Colorado, by F. L. Ransome. 1901. 266 pp., 16 pls. (Out of stock.)

B 184. Oil and gas fields of the western interior and northern Texas Coal Measures and of the Upper Cretaceous and Tertiary of the western Gulf coast, by G. I. Adams. 1901. 64 pp., 10 pls. (Out of stock.)

B 193. The geological relations and distribution of platinum and associated metals, by J. F. Kemp. 1902. 95 pp., 6 pls.

B 198. The Berea grit oil sand in the Cadiz quadrangle, Ohio, by W. T. Griswold. 1902. 43 pp., 1 pl. (Out of stock.)

PP 1. Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska, by A. H. Brooks. 1902. 120 pp., 2 pls.

B 200. Reconnaissance of the borax deposits of Death Valley and Mohave Desert, by M. R. Campbell. 1902. 23 pp., 1 pl. (Out of stock.)

B 202. Tests for gold and silver in shales from western Kansas, by Waldemar Lindgren. 1902. 21 pp. (Out of stock.)

PP 2. Reconnaissance of the northwestern portion of Seward Peninsula, Alaska, by A. J. Collier. 1902. 70 pp., 11 pls.

PP 10. Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen, and Kowak rivers, by W. C. Mendenhall. 1902. 68 pp., 10 pls.

PP 11. Clays of the United States east of the Mississippi River, by Heinrich Ries. 1903. 298 pp., 9 pls. (Out of stock.)

PP 12. Geology of the Globe copper district, Arizona, by F. L. Ransome. 1903. 168 pp., 27 pls.

B 212. Oil fields of the Texas-Louisiana Gulf Coastal Plain, by C. W. Hayes and William Kennedy. 1903. 174 pp., 11 pls. (Out of stock.)

B 213. Contributions to economic geology, 1902; S. F. Emmons and C. W. Hayes, geologists in charge. 1903. 449 pp. (Out of stock.)

PP 15. The mineral resources of the Mount Wrangell district, Alaska, by W. C. Mendenhall and F. C. Schrader. 1903. 71 pp., 10 pls.

B 218. Coal resources of the Yukon, Alaska, by A. J. Collier. 1903. 71 pp., 6 pls.

B 219. The ore deposits of Tonopah, Nevada (preliminary report), by J. E. Spurr. 1903. 31 pp., 1 pl. (Out of stock.)

PP 20. A reconnaissance in northern Alaska in 1901, by F. C. Schrader. 1904. 139 pp., 16 pls.

PP 21. Geology and ore deposits of the Bisbee quadrangle, Arizona, by F. L. Ransome. 1904. 168 pp., 29 pls.

B 223. Gypsum deposits in the United States, by G. I. Adams and others. 1904. 129 pp., 21 pls. (Out of stock.)

PP 24. Zinc and lead deposits of northern Arkansas, by G. I. Adams. 1904. 118 pp., 27 pls.

PP 25. Copper deposits of the Encampment district, Wyoming, by A. C. Spencer. 1904. 107 pp., 2 pls. (Out of stock.)

B 225. Contributions to economic geology, 1903, by S. F. Emmons and C. W. Hayes, geologists in charge. 1904. 527 pp., 1 pl. (Out of stock.)

PP 26. Economic resources of the northern Black Hills, by J. D. Irving, with contributions by S. F. Emmons and T. A. Jaggar, jr. 1904. 222 pp., 20 pls.

PP 27. A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho, by Waldemar Lindgren. 1904. 123 pp., 15 pls.

B 229. Tin deposits of the York region, Alaska, by A. J. Collier. 1904. 61 pp., 7 pls.

B 236. The Porcupine placer district, Alaska, by C. W. Wright. 1904. 35 pp., 10 pls.

B 238. Economic geology of the Iola quadrangle, Kansas, by G. I. Adams, Erasmus Haworth, and W. R. Crane. 1904. 83 pp., 11 pls.

B 243. Cement materials and industry of the United States, by E. C. Eckel. 1905. 395 pp., 15 pls.

B 246. Zinc and lead deposits of northwestern Illinois, by H. Foster Bain. 1904. 56 pp., 5 pls.

B 247. The Fairhaven gold placers of Seward Peninsula, Alaska, by F. H. Moffit. 1905. 85 pp., 14 pls.

B 249. Limestones of southeastern Pennsylvania, by F. G. Clapp. 1905. 52 pp., 7 pls.

B 250. The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits, by G. C. Martin. 1905. 65 pp., 7 pls

B 251. The gold placers of the Fortymile, Birch Creek, and Fairbanks regions, Alaska, by L. M. Prindle. 1905. 89 pp., 16 pls.

WS 117. The lignite of North Dakota and its relation to irrigation, by F. A. Wilder. 1905. 59 pp., 8 pls.

PP 36. The lead, zinc, and fluorspar deposits of western Kentucky, by E. O. Ulrich and W. S. T. Smith. 1905. 218 pp., 15 pls.

PP 38. Economic geology of the Bingham mining district, Utah, by J. M. Boutwell, with a chapter on areal geology, by Arthur Keith, and an introduction on general geology, by S. F. Emmons. 1905. 413 pp., 49 pls.

PP 41. Geology of the central Copper River region, Alaska, by W. C. Mendenhall. 1905. 133 pp., 20 pls.

B 254. Report of progress in the geological resurvey of the Cripple Creek district, Colorado, by Waldemar Lindgren and F. L. Ransome. 1904. 36 pp.

B 255. The fluorspar deposits of southern Illinois, by H. Foster Bain. 1905. 75 pp., 6 pls. (Out of stock.)

B 256. Mineral resources of the Elders Ridge quadrangle, Pennsylvania, by R. W. Stone. 1905. 86 pp., 12 pls.

B 259. Report on progress of investigations of mineral resources of Alaska in 1904, by A. H. Brooks and others. 1905. 196 pp., 3 pls.

B 260. Contributions to economic geology, 1904; S. F. Emmons and C. W. Hayes, geologists in charge. 1905. 620 pp., 4 pls.

B 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, and M. R. Campbell, committee in charge. 1905. 172 pp. (Out of stock.)

B 263. Methods and cost of gravel and placer mining in Alaska, by C. W. Purington. 1905. 273 pp., 42 pls. (Out of stock.)

PP 42. Geology of the Tonopah mining district, Nevada, by J. E. Spurr. 1905. 295 pp., 24 pls.

PP 43. The copper deposits of the Clifton-Morenci district, Arizona, by Waldemar Lindgren. 1905. 375 pp., 25 pls.

B 264. Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch. 1905. 106 pp.

B 265. Geology of the Boulder district, Colorado, by N. M. Fenneman. 1905. 101 pp., 5 pls.

B 267. The copper deposits of Missouri, by H. Foster Bain and E. O. Ulrich. 1905. 52 pp., 1 pl.

B 269. Corundum and its occurrence and distribution in the United States (a revised and enlarged edition of Bulletin No. 180), by J. H. Pratt. 1906. 175 pp., 18 pls.

PP 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. (In three parts.) 1,492 pp., 13 pls.

B 275. Slate deposits and slate industry of the United States, by T. N. Dale, with sections by E. C. Eckel, W. F. Hillebrand, and A. T. Coons. 1906. 154 pp., 25 pls.

PP 49. Geology and mineral resources of part of the Cumberland Gap coal field, Kentucky, by G. H. Ashley and L. C. Glenn, in cooperation with the State Geological Department of Kentucky, C. J. Norwood, curator. 1906. 239 pp., 40 pls.

B 277. Mineral resources of Kenai Peninsula, Alaska: Gold fields of the Turnagain Arm region, by F. H. Moffit; Coal fields of the Kachemak Bay region, by R. W. Stone. 1906. 80 pp., 18 pls.

B 278. Geology and coal resources of the Cape Lisburne region, Alaska, by A. J. Collier. 1906. 54 pp., 9 pls. (Out of stock.)

B 279. Mineral resources of the Kittanning and Rural Valley quadrangles, Pennsylvania, by Charles Butts. 1906. 198 pp., 11 pls.

B 280. The Rampart gold placer region, Alaska, by L. M. Prindle and F. L. Hess. 1906. 54 pp., 7 pls. (Out of stock.)

B 282. Oil fields of the Texas-Louisiana Gulf Coastal Plain, by N. M. Fenneman. 1906. 146 pp., 11 pls.

PP 51. Geology of the Bighorn Mountains, by N. H. Darton. 1906. 129 pp., 47 pls.

B 283. Geology and mineral resources of Mississippi, by A. F. Crider. 1906. 99 pp., 4 pls.

B 284. Report on progress of investigations of the mineral resources of Alaska in 1905, by A. H. Brooks and others. 1906. 169 pp., 14 pls.

B 285. Contributions to economic geology, 1905; S. F. Emmons and E. C. Eckel, geologists in charge. 1906. 506 pp., 13 pls. (Out of stock.)

B 286. Economic geology of the Beaver quadrangle, Pennsylvania, by L. H. Woolsey. 1906. 132 pp., 8 pls.

B 287. Juneau gold belt, Alaska, by A. C. Spencer, and A reconnaissance of Admiralty Island, Alaska, by C. W. Wright. 1906. 161 pp., 27 pls.

PP 54. The geology and gold deposits of the Cripple Creek district, Colorado, by W. Lindgren and F. L. Ransome. 1906. 516 pp., 29 pls.

PP 55. Ore deposits of the Silver Peak quadrangle, Nevada, by J. E. Spurr. 1906. 174 pp., 24 pls.

B 289. A reconnaissance of the Matanuska coal field, Alaska, in 1905, by G. C. Martin. 1906. 34 pp., 5 pls.

B 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp.

B 293. Reconnaissance of some gold and tin deposits of the southern Appalachians, by L. C. Graton, with notes on the Dahlonega mines, by W. Lindgren. 1906. 134 pp., 9 pls.

B 294. Zinc and lead deposits of the upper Mississippi Valley, by H. Foster Bain. 1906. 155 pp., 16 pls.

B 295. The Yukon-Tanana region, Alaska, description of Circle quadrangle, by L. M. Prindle. 1906. 27 pp., 1 pl.

B 296. Economic geology of the Independence quadrangle, Kansas, by Frank C. Schrader and Erasmus Haworth. 1906. 74 pp., 6 pls.

B 297. The Yampa coal field, Routt County, Colo., by N. M. Fenneman, Hoyt S. Gale, and M. R. Campbell. 1906. 96 pp., 9 pls.

B 298. Record of deep-well drilling for 1905, by Myron L. Fuller and Samuel Sanford. 1906. 299 pp.

B 300. Economic geology of the Amity quadrangle in eastern Washington County, Pa., by Frederick G. Clapp. 1907. 145 pp., 8 pls.

B 303. Preliminary account of Goldfield, Bullfrog, and other mining districts in southern Nevada, by F. L. Ransome, with notes on the Manhattan district, by G. H. Garrey and W. H. Emmons. 1906. 98 pp., 5 pls.
B 304. Oil and gas fields of Greene County, Pa., by Ralph W. Stone and Frederick G. Clapp. 1906. 110 pp., 3 pls.
PP 56. Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil, by A. C. Veatch. 1907. 178 pp., 26 pls.
B 308. A geologic reconnaissance in southwestern Nevada and eastern California, by S. H. Ball. 1907. 218 pp., 3 pls.
B 309. The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California, by G. H. Eldridge and Ralph Arnold. 1907. 266 pp., 41 pls.
B 312. The interaction between minerals and water solutions, with special reference to geologic phenomena, by E. C. Sullivan. 1907. 69 pp.
B 313. The granites of Maine, by T. Nelson Dale, with an introduction by G. O. Smith. 1907. 202 pp., 14 pls.
B 314. Report of progress of investigations of mineral resources of Alaska in 1906, by A. H. Brooks and others. 1907. 235 pp., 4 pls.
B 315. Contributions to economic geology, 1906, Part I: Metals and nonmetals, except fuels; S. F. Emmons and E. C. Eckel, geologists in charge. 1907. 504 pp., 4 pls.
WS 215. Geology and water resources of a portion of the Missouri River Valley in northeastern Nebraska, by G. E. Condra. 1908. — pp., 11 pls.
WS 216. Geology and water resources of the Republican River Valley in Nebraska and adjacent areas, by G. E. Condra. 1907. 71 pp., 13 pls.
B 316 Contributions to economic geology, 1906, Part II: Coal, lignite, and peat. M. R. Campbell, geologist in charge. 1907. — pp., 23 pls.
B 317. Preliminary report on the Santa Maria oil district, Santa Barbara County, Cal., by Ralph Arnold and Robert Anderson. 1907. 69 pp., 2 pls.
B 318. Geology of oil and gas fields in Steubenville, Burgettstown, and Claysville quadrangles, Ohio, West Virginia, and Pennsylvania, by W. T. Griswold and M. J. Munn. 1907. 196 pp., 13 pls.
B 320. The Downtown district of Leadville, Colo., by S. F. Emmons and J. D. Irving. 1907. 75 pp., 7 pls.
B 321. Geology and oil resources of the Summerland district, Santa Barbara County, Cal., by Ralph Arnold. 1907. 91 pp., 20 pls.
B 322. Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Cal., by Ralph Arnold and Robert Anderson. 1907. 161 pp., 26 pls.

SERIES B, DESCRIPTIVE GEOLOGY.

B 23. Observations on the junction between the Eastern sandstone and the Keweenaw series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 124 pp., 17 pls. (Out of stock.)
B 33. Notes on geology of northern California, by J. S. Diller. 1886. 23 pp. (Out of stock.)
B 39. The upper beaches and deltas of Glacial Lake Agassiz, by Warren Upham. 1887. 84 pp., 1 pl. (Out of stock.)
B 40. Changes in river courses in Washington Territory due to glaciation, by Bailey Willis. 1887. 10 pp., 4 pls. (Out of stock.)
B 45. The present condition of knowledge of the geology of Texas, by R. T. Hill. 1887. 94 pp. (Out of stock.)
B 53. The geology of Nantucket, by N. S. Shaler. 1889. 55 pp., 10 pls. (Out of stock.)
B 57. A geological reconnaissance in southwestern Kansas, by Robert Hay. 1890. 49 pp., 2 pls.
B 58. The glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois, by G. F. Wright, with introduction by T. C. Chamberlin. 1890. 112 pp., 8 pls. (Out of stock.)
B 67. The relations of the traps of the Newark system in the New Jersey region, by N. H. Darton. 1890. 82 pp. (Out of stock.)
B 104. Glaciation of the Yellowstone Valley north of the Park, by W. H. Weed. 1893. 41 pp., 4 pls.
B 108. A geological reconnaissance in central Washington, by I. C. Russell. 1893. 108 pp., 12 pls. (Out of stock.)
B 119. A geological reconnaissance in northwest Wyoming, by G. H. Eldridge. 1894. 72 pp., 4 pls.
B 137. The geology of the Fort Riley Military Reservation and vicinity, Kansas, by Robert Hay. 1896. 35 pp., 8 pls.
B 144. The moraines of the Missouri Coteau and their attendant deposits, by J. E. Todd. 1896. 71 pp., 21 pls.
B 158. The moraines of southeastern South Dakota and their attendant deposits, by J. E. Todd. 1899. 171 pp., 27 pls.
B 159. The geology of eastern Berkshire County, Massachusetts, by B. K. Emerson. 1899. 139 pp., 9 pls.
B 165. Contributions to the geology of Maine, by H. S. Williams and H. E. Gregory. 1900. 212 pp., 14 pls.
WS 70. Geology and water resources of the Patrick and Goshen Hole quadrangles in eastern Wyoming and western Nebraska, by G. I. Adams. 1902. 50 pp., 11 pls.

B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.

PP 1. Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska, by A. H. Brooks. 1902. 120 pp., 2 pls.

PP 2. Reconnaissance of the northwestern portion of Seward Peninsula, Alaska, by A. J. Collier. 1902. 70 pp., 11 pls.

PP 3. Geology and petrography of Crater Lake National Park, by J. S. Diller and H. B. Patton. 1902. 167 pp., 19 pls.

PP 10. Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen, and Kowak rivers, by W. C. Mendenhall. 1902. 68 pp., 10 pls.

PP 11. Clays of the United States east of the Mississippi River, by Heinrich Ries. 1903. 298 pp., 9 pls. (Out of stock.)

PP 12. Geology of the Globe copper district, Arizona, by F. L. Ransome. 1903. 168 pp., 27 pls.

PP 13. Drainage modifications in southeastern Ohio and adjacent parts of West Virginia and Kentucky, by W. G. Tight. 1903. 111 pp., 17 pls. (Out of stock.)

B 208. Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California, by J. E. Spurr. 1903. 229 pp. 8 pls. (Out of stock.)

B 209. Geology of Ascutney Mountain, Vermont, by R. A. Daly. 1903. 122 pp., 7 pls.

WS 78. Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 51 pp., 2 pls.

PP 15. Mineral resources of the Mount Wrangell district, Alaska, by W. C. Mendenhall and F. C. Schrader. 1903. 71 pp., 10 pls.

PP 17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.

B 217. Notes on the geology of southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 83 pp., 18 pls.

B 219. The ore deposits of Tonopah, Nevada (preliminary report), by J. E. Spurr. 1903. 31 pp., 1 pl.

PP 20. A reconnaissance in northern Alaska in 1901, by F. C. Schrader. 1904. 139 pp., 16 pls.

PP 21. The geology and ore deposits of the Bisbee quadrangle, Arizona, by F. L. Ransome. 1904. 168 pp., 29 pls.

WS 90. Geology and water resources of part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.

PP 25. The copper deposits of the Encampment district, Wyoming, by A. C. Spencer. 1904. 107 pp., 2 pls. (Out of stock.)

PP 26. Economic resources of the northern Black Hills, by J. D. Irving, with contributions by S. F. Emmons and T. A. Jaggar, jr. 1904. 222 pp., 20 pls.

PP 27. A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho, by Waldemar Lindgren. 1904. 122 pp., 15 pls.

PP 31. Preliminary report on the geology of the Arbuckle and Wichita mountains in Indian Territory and Oklahoma, by J. A. Taff, with an appendix on reported ore deposits in the Wichita Mountains, by H. F. Bain. 1904. 97 pp., 8 pls.

B 235. A geological reconnaissance across the Cascade Range near the forty-ninth parallel, by G. O. Smith and F. C. Calkins. 1904. 103 pp., 4 pls.

B 236. The Porcupine placer district, Alaska, by C. W. Wright. 1904. 35 pp., 10 pls.

B 237. Igneous rocks of the Highwood Mountains, Montana, by L. V. Pirsson. 1904. 208 pp., 7 pls.

B 238. Economic geology of the Iola quadrangle, Kansas, by G. I. Adams, Erasmus Haworth, and W. R. Crane. 1904. 83 pp., 1 pl.

PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1905. 433 pp., 72 pls.

WS 110. Contributions to hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge, 1905. 211 pp., 5 pls.

B 242. Geology of the Hudson Valley between the Hoosic and the Kinderhook, by T. Nelson Dale, 1904. 63 pp., 3 pls.

PP 34. The Delavan lobe of the Lake Michigan glacier of the Wisconsin stage of glaciation and associated phenomena, by W. C. Alden. 1904. 106 pp., 15 pls.

PP 35. Geology of the Perry Basin in southeastern Maine, by G. O. Smith and David White. 1905. 107 pp., 6 pls.

B 243. Cement materials and industry of the United States, by E. C. Eckel. 1905. 395 pp., 15 pls.

B 246. Zinc and lead deposits of northeastern Illinois, by H. F. Bain. 1904. 56 pp., 5 pls.

B 247. The Fairhaven gold placers of Seward Peninsula, Alaska, by F. H. Moffit. 1905. 85 pp., 14 pls.

B 249. Limestones of southwestern Pennsylvania, by F. G. Clapp. 1905. 52 pp., 7 pls.

B 250. The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposit, by G. C. Martin. 1905. 65 pp., 7 pls.

B 251. The gold placers of the Fortymile, Birch Creek, and Fairbanks regions, Alaska, by L. M. Prindle. 1905. 16 pp., 16 pls.

WS 118. Geology and water resources of a portion of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.

B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.

PP 36. The lead, zinc, and fluorspar deposits of western Kentucky, by E. O. Ulrich and W. S. Tangier Smith. 1905. 218 pp., 15 pls.

PP 38. Economic geology of the Bingham mining district of Utah, by J. M. Boutwell, with a chapter on areal geology, by Arthur Keith, and an introduction on general geology, by S. F. Emmons. 1905. 413 pp., 49 pls.

PP 41. The geology of the central Copper River region, Alaska, by W. C. Mendenhall. 1905. 133 pp., 20 pls.

B 254. Report of progress in the geological resurvey of the Cripple Creek district, Colorado, by Waldemar Lindgren and F. L. Ransome. 1904. 36 pp.

B 255. The fluorspar deposits of southern Illinois, by H. Foster Bain. 1905. 75 pp., 6 pls. (Out of stock.)

B 256. Mineral resources of the Elders Ridge quadrangle, Pennsylvania, by R. W. Stone. 1905. 85 pp., 12 pls.

B 257. Geology and paleontology of the Judith River beds, by T. W. Stanton and J. B. Hatcher, with a chapter on the fossil plants, by F. H. Knowlton. 1905. 174 pp., 19 pls.

PP 42. Geology of the Tonopah mining district, Nevada, by J. E. Spurr. 1905. 295 pp., 24 pls.

WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls. (Out of stock.)

WS 136. Underground waters of Salt River Valley, Arizona, by W. T. Lee. 1905. 194 pp., 24 pls.

PP 43. The copper deposits of Clifton-Morenci, Arizona, by Waldemar Lindgren. 1905. 375 pp., 25 pls.

B 265. Geology of the Boulder district, Colorado, by N. M. Fenneman. 1905. 101 pp., 5 pls.

B 267. The copper deposits of Missouri, by H. F. Bain and E. O. Ulrich. 1905. 52 pp., 1 pl.

PP 44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1905. 394 pp., 34 pls.

WS 148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls.

B 270. The configuration of the rock floor of Greater New York, by W. H. Hobbs. 1905. 96 pp., 5 pls.

B 272. Taconic physiography, by T. M. Dale. 1905. 52 pp., 14 pls.

PP 45. The geography and geology of Alaska, a summary of existing knowledge, by A. H. Brooks, with a section on climate, by Cleveland Abbe, jr., and a topographic map and description thereof, by R. M. Goode. 1905. 327 pp., 34 pls.

B 273. The drumlins of southeastern Wisconsin (preliminary paper), by W. C. Alden. 1905. 46 pp., 9 pls.

PP 46. Geology and underground water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906. 422 pp., 51 pls.

PP 49. Geology and mineral resources of part of the Cumberland Gap coal field, Kentucky, by G. H. Ashley and L. C. Glenn, in cooperation with the State Geological Department of Kentucky. C. J. Norwood, curator. 1906. 239 pp., 40 pls.

PP 50. The Montana lobe of the Keewatin ice sheet, by F. H. H. Calhoun. 1906. 62 pp., 7 pls.

B 277. Mineral resources of Kenai peninsula, Alaska: Gold fields of the Turnagain Arm region, by F. H. Moffit; and the coal fields of the Kachemak Bay region, by R. W. Stone. 1906. 80 pp., 18 pls. (Out of stock.)

WS 154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls.

B 278. Geology and coal resources of the Cape Lisburne region, Alaska, by A. J. Collier. 1906. 54 pp., 9 pls. (Out of stock.)

B 279. Mineral resources of the Kittanning and Rural Valley quadrangles, Pennsylvania, by Charles Butts. 1906. 198 pp., 11 pls.

B 280. The Rampart gold placer region, Alaska, by L. M. Prindle and F. L. Hess. 1906. 54 pp., 7 pls. (Out of stock.)

B 282. Oil fields of the Texas-Louisiana Gulf Coastal Plain, by N. M. Fenneman. 1906. 146 pp., 11 pls.

WS 157. Underground water in the valleys of Utah Lake and Jordan River, Utah, by G. B. Richardson. 1906. 81 pp., 9 pls.

PP 51. Geology of the Bighorn Mountains, by N. H. Darton. 1906. 129 pp., 47 pls.

WS 158. Preliminary report on the geology and underground waters of the Roswell artesian area, New Mexico, by C. A. Fisher. 1906. 29 pp., 9 pls.

PP 52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 pp., 28 pls.

WS 159. Summary of underground-water resources of Mississippi, by A. F. Crider and L. C. Johnson. 1906. 86 pp., 6 pls.

PP 53. Geology and water resources of the Bighorn basin, Wyoming, by C. A. Fisher. 1906. 72 pp. 16 pls.

B 283. Geology and mineral resources of Mississippi, by A. F. Crider. 1906. 99 pp., 4 pls.

B 286. Economic geology of the Beaver quadrangle, Pennsylvania (southern Beaver and northwestern Allegheny counties), by L. H. Woolsey. 1906. 132 pp., 8 pls.

B 287. The Juneau gold belt, Alaska, by A. C. Spencer, and a reconnaissance of Admiralty Island, Alaska, by C. W. Wright. 1906. 161 pp., 37 pls.

PP 54. The geology and gold deposits of the Cripple Creek district, Colorado, by W. Lindgren and F. L. Ransome. 1906. 516 pp., 29 pls.

PP 55. Ore deposits of the Silver Peak quadrangle, Nevada, by J. E. Spurr. 1906. 174 pp., 24 pls.

B 289. A reconnaissance of the Matanuska coal field, Alaska, in 1905, by G. C. Martin. 1906. 36 pp., 5 pls.

WS 164. Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois, by L. C. Glenn. 1906. 173 pp., 7 pls.

B 293. Reconnaissance of some gold and tin deposits of the southern Appalachians, by L. C. Groton, with notes on the Dahlonega mines, by W. Lindgren. 1906. 134 pp., 9 pls.

B 294. Zinc and lead deposits of the upper Mississippi Valley, by H. Foster Bain. 1906. 155 pp., 16 pls.

B 295. The Yukon-Tanana region, Alaska, description of Circle quadrangle, by L. M. Prindle. 1906. 27 pp., 1 pl.

B 296. Economic geology of the Independence quadrangle, Kansas, by Frank C. Schrader and Erasmus Haworth. 1906. 74 pp., 6 pls.

WS 181. Geology and water resources of Owens Valley, California, by Willis T. Lee. 1906. 28 pp., 6 pls.

B 297. The Yampa coal field, Routt County, Colo., by N. M. Fenneman, Hoyt S. Gale, and M. R. Campbell. 1906. 96 pp., 9 pls.

B 300. Economic geology of the Amity quadrangle in eastern Washington County, Pa., by F. G. Clapp. 1906. 145 pp., 8 pls.

B 303. Preliminary account of Goldfield, Bullfrog, and other mining districts in southern Nevada, by F. L. Ransome; with notes on Manhattan district, by G. H. Garrey and W. H. Emmons. 1907. 98 pp., 5 pls.

B 304. Oil and gas fields of Greene County, Pa., by R. W. Stone and F. G. Clapp. 1907. 110 pp., 3 pls.

WS 188. Water resources of the Rio Grande Valley in New Mexico and their development, by W. T. Lee. 1906. 59 pp., 10 pls.

B 306. Rate of recession of Niagara Falls, accompanied by a report on the survey of the crest, by W. Carvel Hall. 1906. 31 pp., 11 pls.

PP 56. Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil, by A. C. Veatch. 1907. 178 pp., 26 pls.

B 308. A geologic reconnaissance in southwestern Nevada and eastern California, by S. H. Ball. 1907. 218 pp., 3 pls.

B 309. The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California, by G. H. Eldridge and Ralph Arnold. 1907. 266 pp., 41 pls.

PP 57. Geology of the Marysville mining district, Montana, a study of igneous intrusion and contact metamorphism, by Joseph Barrell. 1907. 178 pp., 16 pls.

WS 191. The geology and water resources of the western portion of the Panhandle of Texas, by C. N. Gould. 1907. 70 pp., 7 pls.

B 311. The green schists and associated granites and porphyries of Rhode Island, by B. K. Emerson and J. H. Perry. 1907. 74 pp., 2 pls.

WS 195. Underground waters of Missouri, their geology and utilization, by Edward Shepard. 1907. 224 pp., 6 pls.

WS 199. Underground water in Sanpete and central Sevier valleys, Utah, by G. B. Richardson. 1907. 63 pp., 6 pls.

WS 215. Geology and water resources of a portion of the Missouri River Valley in northeastern Nebraska, by G. E. Condra. 1908. — pp., 11 pls.

WS 216. Geology and water resources of the Republican River Valley in Nebraska and adjacent areas, by G. E. Condra. 1907. 71 pp., 13 pls.

B 317. Preliminary report on the Santa Maria Oil district, Santa Barbara County, Cal., by Ralph Arnold and Robert Anderson. 1907. 69 pp., 2 pls.

B 318. Geology of Oil and gas fields in Steubenville, Burgettstown, and Claysville quadrangles, Ohio, West Virginia, and Pennsylvania, by W. T. Griswold and M. J. Munn. 1907. 196 pp., 13 pls.

B 319. Summary of controlling factors of artesian flows, by M. L. Fuller. 1908. — pp., 7 pls.

B 320. The Downtown district of Leadville, Colo., by S. F. Emmons and J. D. Irving. 1907. 75 pp., 7 pls.

B 321. Geology and oil resources of the Summerland district, Santa Barbara County, Cal., by Ralph Arnold. 1907. 91 pp., 20 pls.

B 322. Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Cal., by Ralph Arnold and Robert Anderson. 1907. 161 pp., 26 pls.

Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

OCTOBER, 1907.

O

E.M. Douglas, Geographer.
R. B. Marshall, Topographer in charge.
Topography by S. N. Stoner.
Triangulation by U.S. Coast and Geodetic Survey and C.F. Urquhart
Surveyed in 1903 and 1904.

PRELIMINARY GEOLOGIC AND STRUCTURAL MAP OF THE LOMPOC AND GUADALUPE QUADRANGLES, CALIFORNIA
INCLUDING A LARGE PART OF THE SANTA MARIA OIL DISTRICT

Geology by Ralph Arnold,
Robert Anderson, H. R. Johnson
and H. W. Fairbanks.
Surveyed in 1906.

Scale $\frac{1}{125000}$
1 ½ 0 1 2 3 4 5 miles
1 ½ 0 1 2 3 4 5 kilometers
Contour interval 100 feet
Datum is mean sea level
1907