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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

PROFESSIONAL PAPER 116

THE SUNSET-MIDWAY OIL FIELD CALIFORNIA

PART I. GEOLOGY AND OIL RESOURCES

BY

R. W. PACK

WASHINGTON
GOVERNMENT PRINTING OFFICE
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Location.—The Sunset-Midway oil field, in Kern County, Calif., lies at the south end of San Joaquin Valley and embraces the eastern foothills of the Coast Ranges and the northern foothills of the San Emigdio Mountains, which connect the Coast Ranges with the Sierra Nevada. The region is semiarid, and, as most of it is valueless for agriculture, it is inhabited almost wholly by those who have been brought in by the petroleum industry.

Geology.—Granitoid rocks, part of the batholith of the Sierra Nevada, together with various schists, crystalline limestones, and other metamorphic rocks—the remnants of the rocks into which the granite was intruded—form the foundation upon which rest the Tertiary sedimentary formations. The granitoid rocks are probably of late Jurassic age, but the age of the metamorphic rocks is unknown. These old rocks crop out in only a small area, for in most of the district they are buried under a thick cover of Tertiary and later sedimentary beds. Cretaceous rocks are not exposed, but they probably underlie a small part of the north end of the district, beneath the Tertiary rocks.

The Tertiary formations are at least 18,000 feet thick. They range in age from Eocene to late Pliocene and are in the main composed of poorly consolidated sands, gravels, and clays, but in the central part of the section there is a formation (of Miocene age) about 4,800 feet thick composed largely of the remnants of diatoms (siliceous marine plants of minute size). This formation is the one in which the petroleum originated and in or about which the commercial accumulations of oil are now found.

Sedimentation was not continuous throughout Tertiary time, for there are numerous unconformities in the Tertiary section; but most of the periods of erosion to which these unconformities correspond were short, and during many of them only a relatively small part of the region was undergoing erosion. Most of the Tertiary beds were laid down in marine waters, but a considerable part of even the older Tertiary material was laid down on the surface of the land or in fresh-water lakes. The youngest marine sedimentary beds are of late Miocene or Pliocene age, the more recent formations being composed wholly of terrestrial or lacustrine beds that were deposited under conditions similar to those now existing in the region.

Volcanism was rare during the Tertiary period, and only in the San Emigdio Mountains are there outcrops of Tertiary igneous rocks. These rocks, which are basaltic and andesitic flows and tuffs, are only a few hundred feet thick.

The structure of the district is complex. The foothills of the Temblor Range, in the western part, are closely folded after a fashion similar to that of other parts of the Coast Ranges; the San Emigdio Mountains are broken by innumerable faults.

In the central part of the Temblor Range the beds are closely folded and even crumpled, but in the outer hills the folds are fewer and more open, and in the outermost foothills along the border of San Joaquin Valley the folds are broad and open and extend from the main range into the valley. It is about these obliquely trending folds that the petroleum has accumulated. There are very few faults in this western part of the region.

The chief line of fracture in the San Emigdio Mountains is the San Andreas fault, or "earthquake line," as it is commonly known, which passes through the central part of the mountains. Movements along this line have been profound. The other faults in the San Emigdio Mountains fall into two classes—those trending between N. 40° W. and N. 75° W. and those trending between N. 45° E. and due east. Along some of these faults the movement has been great, though not so great as along the San Andreas fault.

Production of oil.—The deposits of asphalt and seeps of oil in this region were known to the earliest settlers, but not until the late eighties was any attempt made to mine either oil or asphalt, and the real development of the oil field did not commence until 1900. Up to January 1, 1918, the field had produced more than 2,827,900,000 barrels of oil.

The largest well in the field was well No. 1 of the Lakeview Oil Co., which flowed for 18 months and is said to have produced more than 8,000,000 barrels of oil and to have had a maximum daily production of about 65,000 barrels.

A large number of wells produced oil, when first drilled in, at a rate of several thousand barrels daily. These wells are chiefly those in the parts of the field where the oil sands lie deep, although in places big wells have been obtained at a distance no greater than half a mile from the outcrop, the oil coming from a depth of less than 1,200 feet. In July, 1917, the daily yield of the average well was 54 barrels.

The oil ranges in gravity from less than 11° Baumé (specific gravity, 0.9929) near the outcrop to 31° or 32° Baumé (specific gravity, about 0.8641) in the part of the field where the oil comes from great depths. The average gravity of the oil obtained from the sands near the outcrop is between 14° and 18° Baumé (specific gravity, 0.9722 to 0.9459); that of the oil obtained in the Buena Vista Hills and other parts of the field where the sands lie deep is 21° to 28° Baumé (specific gravity, 0.9271 to 0.8860). The oil normally carries but little gasoline, the proportion distilling at a temperature of less than 150° C. being usually less than 4 per cent.

In the Buena Vista Hills the beds lying above the oil-bearing sands contain "dry" gas under heavy pressure, commonly as much as 1,000 pounds to the square inch and in one well reported to be more than 2,000 pounds to the square inch.

Five 8-inch pipe lines serve the field, and the maximum capacity for all is about 145,000 barrels daily. Two lines take gas from the field, one to Bakersfield and the other to Los Angeles.

Gasoline is "squeezed" from the gas at a number of plants in the field, and the average amount recovered in 1916 was between 1 and 3 gallons from 1,000 cubic feet of gas.

Most of the recent deep drilling (1916) has been done by a combination of the rotary and standard methods, the water string being set in a hole drilled with rotary tools and the well being finished with standard tools. Most wells drilled near the outcrop are drilled with standard tools, as are also some of the deep wells. A few companies drill the entire hole with rotary tools, but fortunately this custom is becoming less popular than formerly.

The productive wells range in depth from about 500 feet in the western part of the field, near the outcrop, to more than 3,500 feet in the eastern part.

The cost of drilling varies greatly, but in 1914 a price commonly paid to contract rotary drillers for drilling to the point where water was shut off was $4.50 a foot of hole.

Up to the end of June, 1917, more than 2,200 wells had been drilled in the Sunset-Midway field, and on that date 1,840 were producing.

Geologic occurrence of petroleum.—The petroleum has originated in the diatomaceous shale formations, chiefly from the alteration of organic matter contained in diatoms and foraminifers, but probably in part also from the alteration of terrestrial vegetal débris.

Some of the oil now contained in the productive pools has originated in the part of the region in which these pools occur, but much of it has been formed in the shale that lies beneath San Joaquin Valley. The oil has migrated from the beds beneath the valley to the foothills and collected in the small anticlines that extend from the hills out into the valley.

The reservoirs from which the wells derive their oil are chiefly the late Tertiary (Miocene or Pliocene) sandy beds that rest unconformably upon the diatomaceous shale. Sandy lenses within the shale yield a small proportion of the oil.

The oil-bearing beds in the late Tertiary sequence are feebly consolidated coarse and fine sands that range in thickness from a few feet to a few hundred feet. These beds crop out in the foothills of the Temblor Range, and their line of outcrop marks the western limit of the main productive field. Toward the east the productive oil sands are buried progressively deeper beneath the surface. In the eastern part of the field the productive sands, which are usually 10 to 50 feet thick, are interspersed with barren beds of equal thickness through a section 600 to 800 feet thick. Near the outcrop the total thickness of the zone containing oil sands is rarely more than 200 or

300 feet, but the portion of it composed of oil sand is greater there than in the parts of the field where the sands lie deeper.

The sands impregnated with oil bear a fairly constant relation to the diatomaceous shale, the richest sands lying close to the contact with that shale. These oil-bearing beds are, however, not of the same age throughout the field, for the formation of which they are a part rests unconformably on the shale, and younger beds abut against the shale in the western part of the field than in the eastern part.

The oil has evidently moved chiefly through the lowest part of the formation that rests upon the diatomaceous shale, as these beds are fairly porous and offer less resistance to the movement of the oil than the shale. The movement is therefore chiefly parallel to the plane of unconformity—that is, to the top of the shale. Near the outcrop, either by fractionation or by reaction with alkaline water, the oil becomes very viscous or tarry and seals more or less completely the beds through which the oil is moving. When this avenue of escape to the surface is closed the oil moves out from the plane of unconformity through the more porous of the beds in the formation that rests upon the shale. The movement of the oil in this manner is rendered easy by the fact that the younger formation was laid down in a transgressing sea and the different beds in it abut against the shale just as horizontal layers of sand held in a huge bowl would rest against the sides of the bowl. The distance that the sands which extend out from the unconformity are filled with oil is variable, but each sand beyond the point at which it contains oil is filled with water.

When viewed in cross section the arrangement of the oil sands near the outcrop may be compared to a branch from one side of which a number of parallel twigs extend, the oil sands along the unconformity being the branch and the oil sands in the formation that rests upon the diatomaceous shale the twigs.

Along the anticlines that are separated by synclines from the outcrop of the oil sands the oil has collected in sands that lie some distance above the plane of unconformity. This oil has evidently moved vertically through the lenticular sands. In any sand that contains oil and gas in these outer anticlines there is a notable tendency for the gas to occupy the higher parts of the fold and the oil the lower parts or saddles of the same fold. In the outer anticlines dry gas has collected 200 or 300 feet above the oil.

In parts of the field where the oil is buried more than 2,000 feet a zone of tar-filled sand lies less than 1,000 feet below the surface. This zone is believed to mark the place where the upward-moving hydrocarbons have met and been oxidized by surface waters. The evidence indicates that these hydrocarbons have moved more or less vertically through the intervening 2,000 feet of beds. They were probably in a gaseous state.

The gravity of the oil varies with the grain of the sand, the oil being lighter in the fine-grained beds; with the distance from the outcrop; with the relation of the oil to mineralized water, the oil in contact with water of certain types being tarry; and with the position on the fold, the oil being lighter on the higher parts of the anticline.

The pressure under which oil and gas are now contained in the sand probably affords no measure of the pressure that caused them to accumulate. The hydrocarbons have probably changed since they first entered the sand they now occupy, both viscous material that sealed reservoirs and lighter portions that increased the pressure of the hydrocarbons contained in the pool being formed.

The tarrification of the oil is caused chiefly by the addition of sulphur derived from the sulphate-bearing surface waters. In places this same reaction has caused the formation of deposits of sulphur.

Oil sands and water sands are interdigited, and neither the water nor the oil can be considered as indigenous to the bed in which it is now found. Furthermore, analyses of the fluids now contained in the various sands do not indicate directly the character of the fluids those sands originally contained, for both oil and water have been altered by chemical reaction that involved them both or involved one of them and certain solid minerals contained in the sediments.

THE SUNSET-MIDWAY OIL FIELD, CALIFORNIA.

PART I. GEOLOGY AND OIL RESOURCES.[1]

By ROBERT W. PACK.

INTRODUCTION.

PURPOSE OF THE REPORT.

During the last year or two, and especially since the entrance of the United States into the war, a large amount of earnest consideration has been given to the problem of the available supply of petroleum, for so many of the industries of the country and so many of the devices used in carrying on the war are dependent upon petroleum and its products that it became of the greatest importance to know to just what extent we might rely upon the resources of our own country to supply these demands. Many estimates of the quantity of oil remaining available have been made, and, as is natural, a variety of conclusions as to the exact amount have been reached; but without exception these estimates show that the known supply is relatively small compared with the present demand, and especially small compared with the even greater demand that it appears certain is to be made upon this supply in the near future. The petroleum deposits of the United States are wonderfully rich, a vast quantity of oil has been taken from them, and an even greater amount still remains to be taken; yet, if the next generation is not to feel the pinch of the dwindling supply, the present generation must use all due care so to handle these deposits as to permit the least possible waste.

For a long time the general public refused to believe that the supply of oil was other than inexhaustible, and even many of the men who were actively engaged in the production of petroleum paid little attention to the question of the total supply but were content if their production satisfied the daily demands made upon them. The pronounced rise in the price of gasoline in 1915 was, however, too apparent and affected directly too many people to pass unnoted. A number of possible causes for this abrupt rise have been suggested, but whatever may have been the immediate causes, one effect has been that the attention of the people has been called in no unmistakable manner to the fact that the supply of petroleum is really limited, and that sooner or later the price of gasoline and of all other products of petroleum is sure to rise.

So long as the limited nature of the supply of petroleum was not appreciated it was not possible to do anything toward conserving this supply, but now that the fact is becoming more and more widely accepted that sooner or later the world must get along somehow with a greatly reduced supply of petroleum many things that were before considered impracticable are being done, and the producers of petroleum are giving earnest thought to the conservation of the oil—not by locking it up for the use of the next generation, but the true conservation that consists of utilizing to the utmost, without waste, that which the country possesses.

Within the last decade great changes have been made in the methods of handling oil. The mechanical devices and methods of drilling, of transporting, and of refining have been so greatly improved that oil may now be produced and taken to the ultimate consumer in a much more efficient manner than formerly. Yet in many and perhaps in most fields the

[1] This report on the Sunset-Midway field is published in two parts. Part I (Professional Paper 116), by R. W. Pack, describes the general geology of the Sunset-Midway region and the development and underground conditions in the productive field and discusses also the origin and migration of the oil. Part II (Professional Paper 117), by G. S. Rogers, contains analyses of the oil, gas, and oil-field waters and a discussion of their composition in relation to their geologic occurrence; some figures on the geothermal gradient; and a brief discussion of the invasion of oil sands by water.

methods of production leave much to be desired, for no systematic effort is made to use the mass of data furnished by the wells or to weave together these data into a picture showing the underground conditions, which may be used in the guidance of future drilling. No matter how efficient the mechanical work of drilling or of producing oil may be, it is impossible to recover the maximum amount of oil, or even to produce oil efficiently, unless the underground conditions are clearly understood. Lack of knowledge of the underground conditions is in the long run vastly more productive of waste than faulty methods of drilling or of production.

Of course much of the ignorance of underground conditions is unavoidable, for in the very nature of things the drillers of the first well in a new pool must go ahead more or less blindly; but with the information derived from this first well and from each succeeding well, drilling in that pool should become less and less a matter of faith and more and more an exact science. The determination of the position of the top of the producing zone, important as such a determination may be, is the least part of the work, for to be of real value the study of the well data should show the position of each oil sand within the productive zone, and, what is in many places of even greater significance, the position of each water sand. It should show the character of the productive oil sands, the position and character of the strata in which water may be shut off, the position and character of the gas sands, and a multitude of other like facts. Then as the natural conditions—that is, the conditions existing before drilling commenced—become better and better known it becomes possible to understand the nature of the conditions produced when the movement of the fluids is interfered with by the wells that are drilled, and to predict in a measure the probable life of a well or its rate of decline, the direction and rate of movement of water, the probable production of new wells, and other like features.

In order that this result may be attained and that each new well in a field may not be a special and isolated venture, it is necessary that a systematic record be kept of the data furnished by the wells, and that the geologic significance of these data be interpreted by someone competent to make such interpretations. Moreover, it is particularly important that this study should be extended over the whole pool, not confined to a part of it, for a general study of the field brings out features that are not at all apparent in a study restricted to a small area, and features which appear at first sight to be quite unusual and which lead to the supposition of unique and special conditions are found when the full story is known to accord fully with the accepted theories.

Viewed in a broad way the petroleum industry may be divided into three major parts—one concerned with the search for productive pools, another with the draining of these pools, and the third with the handling of the oil after it has reached the surface.

It is commonly supposed that the geologist is concerned with only the first of these problems, and that once the position of the new field is pointed out his duties are ended. But in reality the efficient handling of any pool depends upon the geologist as much as upon the engineer or the well driller, especially such pools as those which occur in the feebly consolidated sedimentary beds of the Tertiary. The proper interpretation of the well records and the correlation of these data with the areal geology depend upon the geologist more than upon anyone else, and his work should afford the comprehensive picture of the underground conditions that is so essential to the petroleum operator.

The search for new pools, which is to-day occupying the full attention of most of the petroleum geologists of the country, will become increasingly keen as the production of oil decreases and the demand continues to increase, but the geologist will in the future render his chief service to the petroleum industry through intensive studies of the productive fields, made for the purpose of aiding in the efficient extraction of the oil.

During the last 18 years the United States Geological Survey has been carrying on an investigation of the petroleum resources of California, having examined not only practically all the major productive field but also several large areas that offered some promise of yielding oil, the attempt being made to precede drilling and to outline those areas which were of greatest prospective value. The results of much of this work have been set forth in a number of published reports. The reports that are concerned with the productive fields present as full a discussion of the underground conditions as was justified by the data obtained from the drilling done up to the time the fields were examined.

The present report is twofold. In the first place the geology of the general area of which the productive fields constitute a small part is described; then into this setting are fitted the intimate details of the geology of the productive areas as interpreted chiefly from a study of the records of the wells. The interpretation of the geologic conditions in the productive fields is based on the data made available by drilling that had been done prior to July, 1916. It is not presented as a completed picture accurate in all its details; in the very nature of things it can not be that. It is presented, however, as an interpretation that may serve as a framework into which to fit other data that may become available from time to time, and it should thus serve in the guidance of future work. The writer has taken the opportunity of giving also certain data and conclusions which will be of interest to the student of the geology of the Coast Ranges if not to the oil man, as well as data regarding the productivity and rate of exhaustion of oil sands and the interference of wells, which will be of interest to the engineer if not to the geologist.

LOCATION OF THE FIELD.

The Sunset-Midway oil field lies in the western part of Kern County, Calif., about 40 miles southwest of the city of Bakersfield. It extends over part of the northeastern flank of the Temblor Range, over the outlying foothills ranges known as the Buena Vista and Elk hills, and over a portion of the western border of the almost level floor of the San Joaquin Valley. The location of this field and of the other principal oil fields in California is shown on the index map (fig. 1). The region shown on the geologic map (Pl. II) covers not only the productive oil field, but also a considerable part of the northern slope of the San Emigdio Mountains, which lie southeast of the oil field and in which rocks that lie stratigraphically below the oil-bearing measures are exposed. The productive field is shown in detail on Plates I, III, and XLIII.

Most of the hilly part of the area shown on the geologic map (Pl. II) and also a large part of the floor of San Joaquin Valley immediately adjacent to the hills is unsuited for agriculture, and except for a few settlers who are dry farming in the western part of the San Emigdio Mountains and for the workers on the San Emigdio ranch this part of the region is inhabited only by those who have been brought there by the petroleum industry. The chief settlements in the Sunset-Midway field are Maricopa, Taft, and Fellows. At the north end of the area shown on Plate II is McKittrick, which is the railroad shipping point for the McKittrick oil field.

The Sunset-Midway field is served by the Sunset Railroad, which is operated jointly by the Southern Pacific and the Atchison, Topeka & Santa Fe and joins the main lines of those roads at Bakersfield, from which the distance is 315 miles by rail to San Francisco and 170 miles to Los Angeles. A branch line of the Southern Pacific connects Bakersfield and McKittrick. Numerous auto stages are run between Taft and Maricopa and Bakersfield, and between Taft and the coast at Los Angeles and Pismo.

Excellent roads connect Taft and Maricopa with Bakersfield and with the State highway that runs up San Joaquin Valley and over the Tehachapi Mountains to Los Angeles. A network of excellent, poor, and indifferent roads extends through the oil field and along the western edge of the valley to and beyond McKittrick.

RELIEF.

San Joaquin Valley, at whose south end lies the Sunset-Midway oil field, forms the southern half of the structural depression that occupies the central part of California and extends from the Klamath Mountains, near the north line of the State, to the San Emigdio and Tehachapi mountains. On the east the valley is bordered by the Sierra Nevada, which rises gently, almost imperceptibly at first, through a broad belt of foothills to lofty snow-capped summits. On the west are the Coast Ranges, which, though far lower than the Sierra Nevada, for the most part rise more abruptly from the plain and mark the valley's edge more sharply. On the south San Joaquin Valley is limited by the San Emigdio and Tehachapi mountains, which in places rise more than 7,000 feet above the valley within a distance of only 10 miles from its edge. These mountains join the Coast Ranges with the Sierra Nevada and form a rugged mountain barrier between San Joaquin Valley on the north and the Mohave Desert on the south.

South of San Francisco the Coast Ranges occupy the region lying between San Joaquin Valley and the ocean. They comprise a number of approximately parallel ranges separated by structural valleys of variable width. The individual ranges trend somewhat more easterly than the mountainous area as a whole and, cutting across it, run out into San Joaquin Valley. On account of this oblique arrangement of the individual ranges the western border of San Joaquin Valley is formed not by a single range but by two, the Diablo and

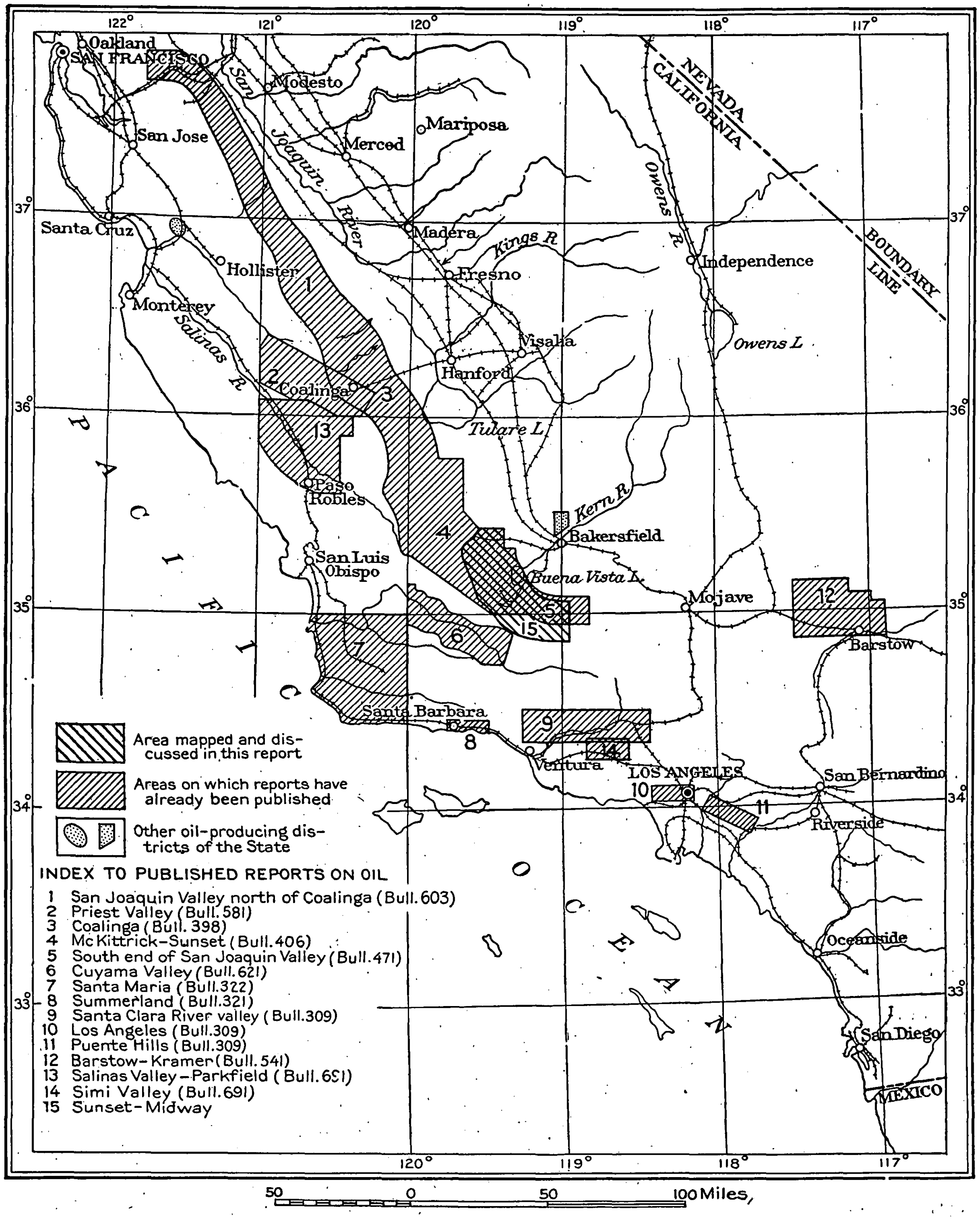
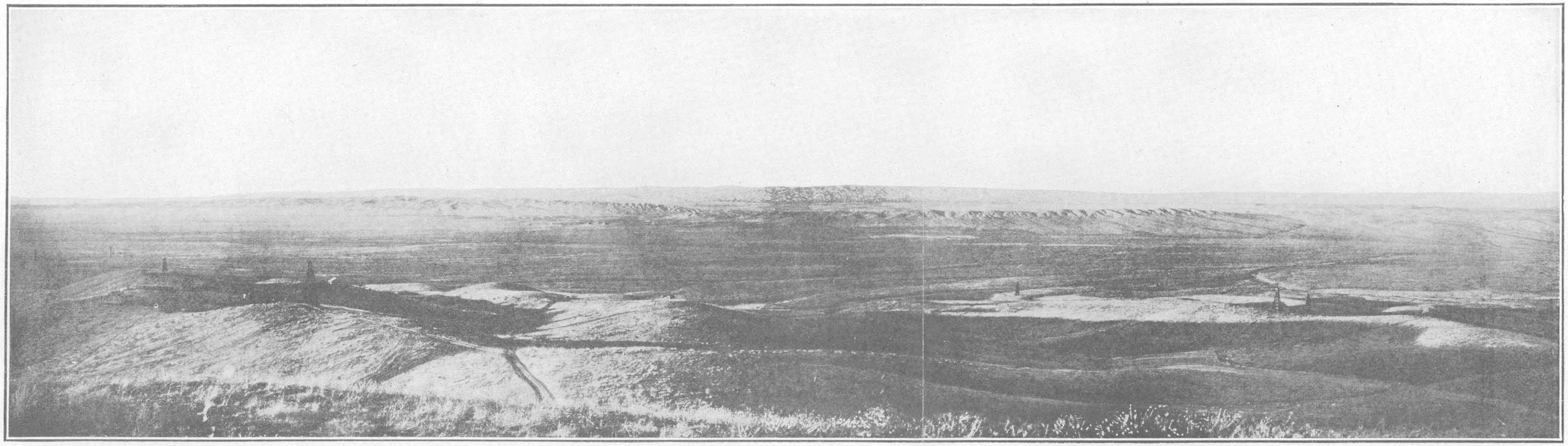


FIGURE 1.—Index map of a part of California showing oil fields described in published reports.



A. MIDWAY OIL FIELD IN 1907.

Looking northeastward from Twenty-five Hill across present site of Taft. Buena Vista Hills in middle distance and Elk Hills beyond. Photograph by Ralph Arnold.

B. SUNSET OIL FIELD IN 1901.

Looking eastward from southwest corner of NW. $\frac{1}{4}$ sec. 2, T. 11 N., R. 24 W. Photograph by G. H. Eldridge.

Temblor ranges. On the eastern flank of the Temblor Range, the more southerly of the two, lies the Sunset-Midway field.

This range extends, as an elongated mass, from the vicinity of the north line of Kern County southeastward some 70 miles to Sunset, where it joins the eastward-trending San Emigdio Mountains. For the most part the south end of the Temblor Range presents no very striking topographic features, and as seen from the central part of the valley it appears to be no more than a group of low, fairly evenly rounded, barren hills. The average altitude of the crest of this part of the range is a little over 3,000 feet above sea level, or between 2,000 and 2,500 feet above the valley floor at the edge of the hills. The maximum altitude, 3,651 feet, is reached in Midway Peak. Throughout its length the Temblor Range proper is narrow, being in few places more than 10 miles across. Near the south end, however, two groups of low hills project eastward into San Joaquin Valley and, together with the main range, form a belt of hilly land almost 20 miles in width, lying between San Joaquin Valley and the Carrizo Plain, the structural depression that limits the Temblor Range on the southwest. These two foothill ranges, the Buena Vista and Elk hills, are separated from the main range and from each other by broad, gently sloping valleys covered with gravelly wash from the hills.

Although the larger features of the topography are broadly rounded, the smaller features are sharply sculptured, the drainage courses being deeply cut and the canyon sides in places standing at slopes of 40° or steeper. The hills are so bare of vegetation that even the minute features of the sculpture are readily visible and stand out strongly in the oblique light of early morning or late evening.

One of the most notable features in the topography of this area is the remarkable control exercised by the geologic structure. All the principal hill groups are formed by structural uplifts, and the broad valleys between by structural depressions. Thus the main Temblor Range is broadly anticlinal, being an assemblage of close folds whose general effect has been a doming of the strata; the Buena Vista Hills and the Elk Hills are also the topographic expression of anticlinal structure; and the gently sloping Midway and Buena Vista valleys, which lie between the different hill groups, outline the position of the downward-arching folds. Not only do the larger topographic units reflect the major structural features, but even the position of the smaller units is determined by the lesser features, as is well shown in the northern part of the Buena Vista Hills, where, instead of a single ridge, a collection of low, approximately parallel ridges faithfully outline the position of the numerous small anticlinal folds that together form the general anticline.

The topographic reflection of the broader structural features is quite as strongly shown in the San Emigdio Mountains as in the Temblor Range, for the San Emigdio and the Tehachapi mountains constitute essentially a fault block that has been uplifted with respect to the valley on the north. Within the San Emigdio Mountains, however, the structure is so complex that, except for the San Andreas fault, no one feature dominates sufficiently to be as strongly reflected in the topography as the lesser features in the Temblor Range. In consequence the difference in the lithology of the rocks plays a much greater part in determining the form of the surface here, and the most prominent topographic feature is the change from the abrupt and rugged slopes of the higher hills, formed of the resistant crystalline rocks, to the broadly rounded slopes of the foothills, formed of the softer Tertiary sedimentary rocks. Parts of the low foothills, particularly those formed of the coarse gravelly beds of the upper Miocene, have been carved into typical badlands, and of such a nature are most of Wheeler Ridge and the low hills near the mouths of Salt and Tacuya creeks. A good example of badland erosion of this type is shown in Plate V.

CLIMATE AND VEGETATION.

The climate of the south end of San Joaquin Valley is semiarid, the rainfall rarely exceeding 10 inches a year and the average being about 6 inches. The Temblor Range is much lower than the ranges west of it, and in consequence the moisture that travels eastward from the ocean and passes over the mountains lying close to the coast is not halted by the Temblor Range but is carried across San Joaquin Valley and precipitated as snow or rain in the upper slopes of the Sierra Nevada. Thus the precipitation on the eastern slope of the Temblor Range is far too small to support perennial streams. Most of the stream valleys carry water during only a few days in the winter, and many for only a few hours following heavy rains, for the vegetation is so scant on the hills that but a small proportion of the rainfall is held in the ground.

The San Emigdio Mountains rise to altitudes of over 7,000 feet, and in many years the higher portions are snow covered from November until May. Both Santiago and San Emigdio creeks, which drain the higher parts of the west end of these mountains, carry running water throughout the year. Practically all the normal flow of San Emigdio Creek is now used for irrigation, but doubtless some day the flood water will be stored and a much larger acreage in the valley watered. The deeply intrenched canyon in the lower 3 miles of the course of San Emigdio Creek offers an excellent reservoir site for the impounding of these waters. The water of Santiago Creek contains too large an amount of mineral salts to be serviceable for irrigation, and, moreover, the flow during the summer months is very small. Buena Vista Lake is an artificial lake whose water is used for irrigating the San Joaquin Valley lands north of the Elk Hills. The water is not potable.

The eastern flank of the Temblor Range and the outlying foothill ranges support no trees other than those that have been planted about the different camps and carefully watered, the natural vegetation being limited to small shrubs and a sparse growth of grass which serves as winter feed for sheep. The higher portions of the San Emigdio Mountains are covered by small pine, oak, and juniper, and on the lower slopes grass grows sufficiently thick to make a good range for cattle.

Heavy localized storms or cloudbursts are not at all uncommon in the San Emigdio Mountains. These storms have at several places torn trees and soil alike from the steeper slopes, leaving great brown scars of barren rock that may be seen for miles and carrying huge masses of rock and trees for great distances, in places far out into the valley (See Pl. VI.)

FIELD WORK AND ACKNOWLEDGMENTS.

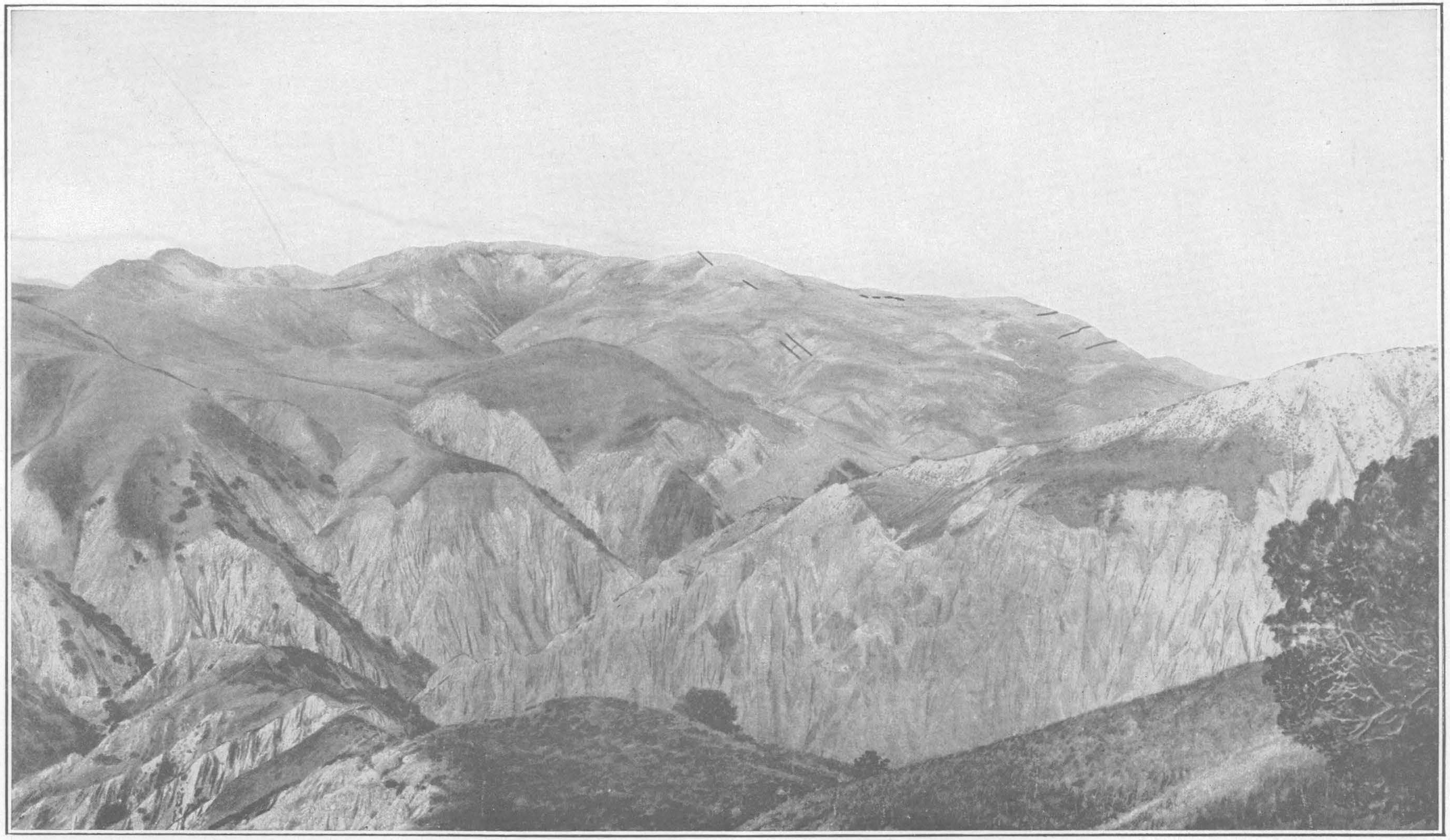
The field work upon which this report is based extended over a number of years, for different parts of the area were examined independently, some for one immediate purpose and some for another. All the work, however, formed a part of the general scheme that the Survey has been following in an examination of the petroleum resources of California.

The areal geology of the north flank of the San Emigdio Mountains was mapped in 1911 and 1912 by the writer, with the assistance during the first season of A. T. Schwennesen and during the second season of R. G. Davies. Similar work had been done in the Temblor Range in 1908 by Ralph Arnold and H. R. Johnson, and the results were published in 1910.[1] This work in the Temblor Range was chiefly in the nature of a reconnaissance, and in consequence many parts of the area, particularly the outlying foothills, were not examined in the detail of which later developments have shown them worthy. A more detailed examination of the foothills of the main Temblor Range and of the Buena Vista and Elk hills was therefore made by the writer in the summer of 1914. During the same year a small area near Pattiway, in the west end of the San Emigdio Mountains, was mapped by the writer with the assistance of W. A. English and Wallace Gordon.

The writer has found no occasion to alter the chief geologic conclusions expressed by Arnold and Johnson in the preliminary report of the geology of the Temblor Range, but he has been able to correct some minor ones and to add a very considerable amount of detail that is of prime importance in the intensive study of the underground conditions in the productive fields.

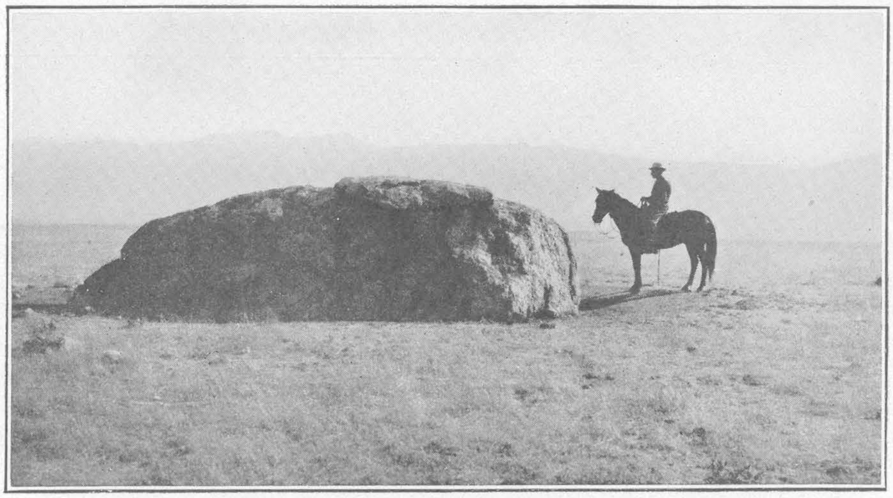
During the summer of 1914 and a couple of weeks in the fall of 1916 the writer collected a great mass of detailed information regarding underground conditions. Through the hearty cooperation of the operators, logs of practically every well drilled up to July, 1916, in the Sunset and Midway fields were obtained, as were also detailed maps, records of production of individual wells and of groups of wells, gravity cuts, and samples of oil sand, of oil, and of water. Indeed the mass of data has been so great and its character so varied that its proper assimilation has been no small task. During 1914 G. S. Rogers was in the field with the writer investigating the geologic relations

[1] Preliminary report on the McKittrick-Sunset oil region, Calif.: U. S. Geol. Survey Bull. 406, 1910.



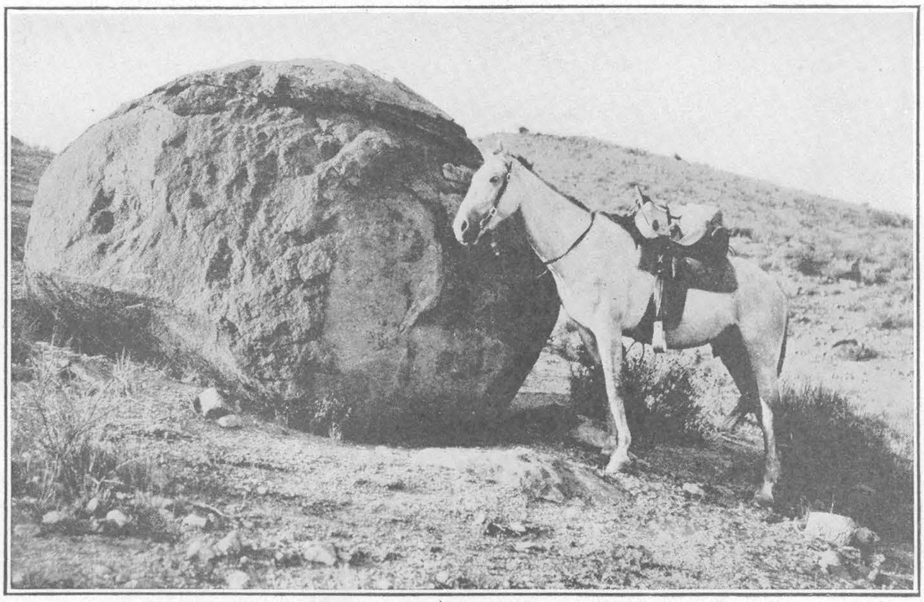
FOOTHILLS FORMED OF TERTIARY ROCKS ON WEST SIDE OF SALT CREEK.

Looking westward from divide between Tacuya and Salt creeks about 1 mile from edge of San Joaquin Valley. Sharp ridge at extreme left formed by Tertiary volcanic rocks lying in the Vaqueros formation. Syncline in center occupied by diatomaceous Maricopa shale. Badlands carved in gravels in the Vaqueros formation.



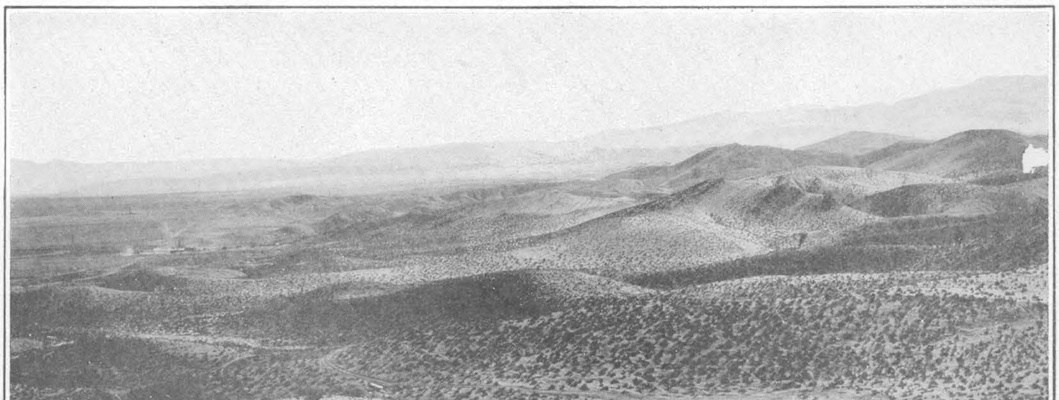
A. BOULDER OF GRANITIC ROCK IN SAN JOAQUIN VALLEY.

This boulder lies 2 miles from the mouth of Tacuya Canyon and must have traveled that distance over a surface which is inclined only about 200 feet in a mile.



B. GRANITE BOULDER IN UPPER PART OF MARICOPA SHALE WEST OF FELLOWS.

This boulder has weathered out of a lens of granitic material bedded with fine diatomaceous shale. Photograph by Ralph Arnold.



C. WEST END OF SAN EMIGDIO MOUNTAINS.

Looking eastward from foothills 1 mile west of Pioneer. Refinery at extreme left. Higher parts of San Emigdio Mountains at right. Photograph by G. H. Eldridge.

of oil and water. Much of the information pertaining to the development work in certain parts of the field was collected by him.

To his colleagues on the Survey, particularly to those who are engaged in the study of oil fields in other parts of the United States, and to Mr. M. R. Campbell, under whose direction the work was started, the writer is indebted for many helpful criticisms and suggestions.

It is with a feeling of genuine pleasure that the writer finds an opportunity of expressing his appreciation of the hearty cooperation extended to him in his work by the operators, and of their evident effort to make his stay in the field both profitable and pleasant. To name all who have so assisted would mean the construction of a list of almost all those engaged in the development of the field, and of that space here will hardly admit. But to the following the writer is especially indebted: Messrs. M. E. Lombardi, G. C. Gester, E. G. Gaylord, F. B. Tough, Dr. E. A. Starke, R. A. Stoner, Capt. William Matson, P. M. Paine, Thomas Kingston, T. A. O'Donnell, F. W. Fuqua, John Gourlay, E. O. Faulkner, F. C. Ripley, Capt. John Barneson, A. L. Weil, B. E. Parsons, and R. E. Sperry.

Through the courtesy of the officers of the Kern Trading & Oil Co. the writer is able to present the topographic map of the Sunset-Midway oil field that accompanies this report (Pl. I). That map has been compiled from a topographic atlas made by the company for its own use in the field.

BIBLIOGRAPHY.

The following is a list of the more important papers describing the geology or the occurrence of petroleum in the Sunset-Midway oil field:

1868. Cronise, T. F., The mineral wealth of California, 696 pp. Brief mention is made (pp. 117, 118) of the oil seeps about Sunset. The description of the work done southeast of "Buena Vista Lake" and the shipment of several thousand gallons of oil to San Francisco evidently has reference to the operations about what is now the McKittrick field.

1894. Watts, W. L., The gas and petroleum yielding formations of the central valley of California: California State Min. Bur. Bull. 3, 100 pp., maps, plates, and figures. Contains a careful description of the development work that had been done in the Sunset field up to 1894, gives the logs of most of the wells at Old Sunset, and the analyses of water from several of these wells.

1900. Watts, W. L., Oil and gas yielding formations of California: California State Min. Bur. Bull. 19, 236 pp., maps, plates, and figures. Contains a discussion of the geology of the productive fields in California, detailed descriptions of the development, and a general discussion of the geologic range of the oil-bearing formations in California and of the relation of structure to the occurrence of petroleum.

1903. Eldridge, G. H., The petroleum fields of California: U. S. Geol. Survey Bull. 213, pp. 306–321. Contains a brief outline of the geology of the Midway and Sunset fields. Eldridge correlated with the San Pablo formation the poorly consolidated sandstones and clays that overlie the siliceous shale of the Monterey group.

1903. O'Neill, Edmond, Petroleum in California: Am. Chem. Soc. Jour., vol. 25, pp. 699–711. Gives analyses of various California oils, two from the Sunset field among them.

1904. Cooper, H. N., Chemical analyses of California petroleum: California State Min. Bur. Bull. 31 (also inserted as appendix to Bull. 32). Analyses of oils from two wells in the Sunset field are included in the list.

1904. Prutzman, P. W., Production and uses of petroleum in California: California State Min. Bur. Bull. 32, 230 pp., maps, plates, and figures. Contains maps of the Sunset and Midway fields showing ownership and location of the wells. The principal part of the report consists of notes concerning the chemical and physical properties of California oils, their uses, and methods of refining.

1905. Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., Geology, vol. 2, pp. 156–248, pls. 13–35, 1 map.

1908. Anderson, F. M., A further stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 1–40.

In both of these papers the salient features of the geology of the mountains on the west side of San Joaquin Valley are discussed, and in the first paper many fossils found in the Tertiary formations are described and figured. The region described most in detail lies somewhat north of the Midway field.

1910. Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Calif.: U. S. Geol. Survey Bull. 406, 225 pp., 5 pls., 2 figs. The geology of the eastern flank of the Temblor Range is mapped and described, and the productive oil fields at McKittrick, Midway, and Sunset are discussed in detail. The southern part of the region discussed by Arnold and Johnson is described in the present report, and their work has been used freely in its preparation.

1911. Allen, I. C., and Jacobs, W. A., Physical and chemical properties of the petroleum of the San Joaquin Valley, Calif., with a chapter on analyses of natural gases from the southern California oil fields by G. A. Burrell: U. S. Bur. Mines Bull. 19. Contains analyses of oil and gas from the Sunset and Midway fields.

1911. Anderson, F. M., The Neocene deposits of Kern River, Calif., and the Temblor Basin: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 73–148, pls. 2–13. Deals mainly with the Tertiary formations about Kern River on the east side of San Joaquin Valley and with the Kern River oil field. The formations are, however, in part the same as those exposed in the Sunset-Midway field, and brief mention is made of the geology of the Temblor Range.

1911. Forstner, William, The occurrence of oil and gas in the South Midway field, Kern County, Calif.: Econ. Geology, vol. 6, pp. 138–155, 4 figs. Discusses the conditions under which oil and gas exist in the Midway field, and gives some data on the flowing wells in the northern end of the field.

1912. Requa, M. L., Bradley, F. W., and Stadler, Walter, Fuel resources of California: Commonwealth Club of San Francisco Trans., June, 1912. Contains a brief statement regarding the history of the Sunset and Midway oil fields, and statistics of production; also a general discussion of the possibly productive territory, the cost of production, and methods of controlling development.

1912. Anderson, Robert, Preliminary report on the geology and possible oil resources of the south end of the San Joaquin Valley, Calif.: U. S. Geol. Survey Bull. 471, pp. 106–136, 1 pl. (map). This paper, based upon a short reconnaissance, describes the foothills at the south end of San Joaquin Valley, just east of the Sunset field, pointing out the areas that may possibly yield oil.

1914. Arnold, Ralph, and Garfias, V. R., Geology and technology of the California oil fields: Am. Inst. Min. Eng. Bull. 87, pp. 383–469. The report contains in concise form the salient features regarding the geology; methods of production and transportation of oil; and statistics on production of the principal California fields.

1914. Allen, I. C., Jacobs, W. A., Crossfield, A. S., and Matthews, R. R., Physical and chemical properties of the petroleums of California: U. S. Bur. Mines Tech. Paper 74. Contains analyses of oils from Sunset and Midway fields.

1915. McLaughlin, R. P., and Waring, C. A., Petroleum industry of California: California State Min. Bur. Bull. 69, 519 pp. and atlas. Chapter on westside fields in Kern County contains brief review of geology but is concerned chiefly with the mechanical features of producing petroleum.

1917. Rogers, G. S., Chemical relations of the oil-field waters in San Joaquin Valley, Calif.: U. S. Geol. Survey Bull. 653.

STRATIGRAPHY.

GENERAL CHARACTER AND DISTRIBUTION OF FORMATIONS.

The rocks exposed in the Sunset-Midway field and in the foothills along the north flank of the San Emigdio Mountains are chiefly sedimentary and were laid down no earlier than the beginning of the Tertiary. The foundation upon which these formations rest is composed of igneous and metamorphic rocks which reach the surface in the central part of the San Emigdio Mountains, but these rocks are of no importance so far as the presence of oil is concerned. The general character and thickness of the several formations is shown in the accompanying columnar section (fig. 2).

The oldest rocks that crop out in the vicinity of the Sunset-Midway oil field are those that form the crystalline mass exposed in the central part of the San Emigdio Mountains. This central mass consists largely of pre-Cretaceous granitoid rocks that are intrusive into rocks of unknown age, now altered to schists and gneisses. The granitic and metamorphic rocks are the equivalent of those commonly known as the basement complex in the Sierra Nevada, into which they may be traced in unbroken outcrop through the San Emigdio and Tehachapi mountains. They are not exposed in the Sunset-Midway oil field, but they evidently underlie it, buried deeply beneath the Tertiary sedimentary rocks.

The granitic and metamorphic rocks are overlain by Tertiary sedimentary rocks that are mainly though not wholly of marine origin. The oldest of these rocks exposed within the area shown on the geologic map are comprised in the Tejon formation, of Eocene age. This formation is composed of massive arkosic sandstone and dark clay shale that were laid down in marine waters upon a very uneven surface of granitic and metamorphic rocks in the area now occupied by the San Emigdio Mountains and upon rocks of Cretaceous age in the area now occupied by the north end of the Temblor Range. The formation crops out in the San Emigdio Mountains and in the north end of the Temblor Range, but not in the oil field proper, although it almost certainly underlies a part if not all of the field beneath the cover of later Tertiary formations. The maximum exposed thickness of the Tejon is 4,300 feet.

Resting upon the Tejon is a formation several thousand feet thick that embraces beds of varied character—coarse, ill-sorted conglomerate that was evidently laid down by running water on the surface of the land, massive marine sandstones, and fine carbonaceous clay shale—intermingled in a manner that makes the untanglement of the record of deposition peculiarly difficult. In the eastern part of the San Emigdio Mountains the lower deposits resting on the Tejon are chiefly marine beds that contain an excellent fauna of Oligocene age, but the overlying deposits in the same region are largely terrestrial beds of Miocene age, corresponding to those which in previous reports have been mapped and described as the Vaqueros formation. No satisfactory line of separation could be drawn between these Oligocene and Miocene deposits, for the two grade into each other, and in this region, where the structure is so complicated, the data upon which a separation is based must be definite or the separation can not be made. These Oligocene beds are therefore for convenience included in the Vaqueros formation on the map and in the text descriptions. This course is considered preferable to the introduction of a new name. The maximum thickness of the Vaqueros exposed is at least 3,700 feet.

The Vaqueros formation is overlain by several thousand feet of shale containing abundant remains of diatoms and other minute forms of sea life that is commonly known as diatomaceous shale. This formation is mapped and discussed in this report as the Maricopa shale.[1] The lower part of this shale is the equivalent of the shale in the Monterey group, commonly known as "Monterey" shale, but the upper part, which is composed of coarse granitic gravel and diatomaceous shale, is equivalent to the Santa Margarita formation. At the type locality the thickness of the Maricopa shale exposed is 4,800 feet.

In a small area in the north slope of the San Emigdio Mountains occurs a coarse arkosic sandstone containing a Santa Margarita fauna. This sandstone rests unconformably on the Vaqueros formation and on the Tejon, but it nowhere rests on the diatomaceous shale forming the lower part of the Maricopa shale. Because of its fossils and stratigraphic position this sandstone is correlated with the Santa Margarita formation and is here designated Santa Margarita.

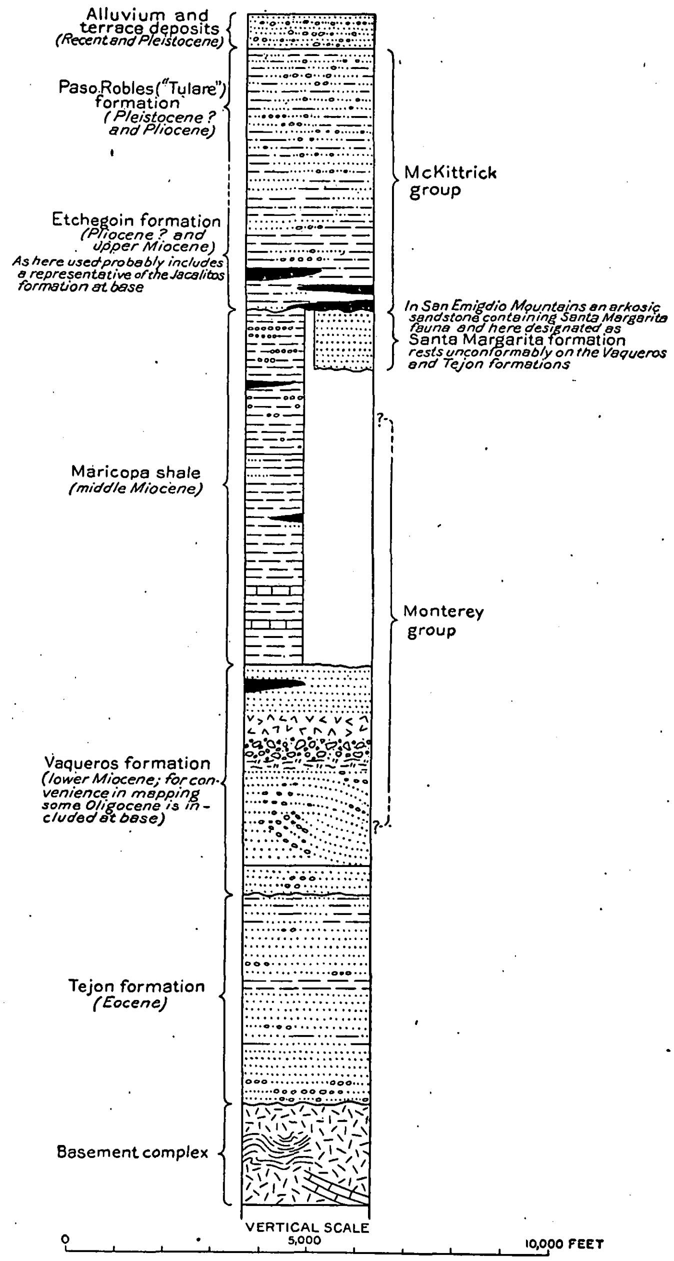


FIGURE 2.—Generalized columnar section of the rocks in the Sunset-Midway oil field and in the north flank of the San Emigdio Mountains. Position of oil-bearing beds indicated by solid black.

The Maricopa shale and the Santa Margarita formation in the San Emigdio Mountains are overlain unconformably by the McKittrick group, which is composed of poorly consolidated sand, gravel, and clay. The lower part of the McKittrick group is made up of beds that were deposited in marine or estuarine waters and is the equivalent of the Etchegoin and Jacalitos formations of the Coalinga district, of upper Miocene and Pliocene (?) age. The upper formation comprises beds that were deposited in brackish or fresh water lakes, or subaerially, and is the equivalent of the Paso Robles ("Tulare") formation, of Pliocene and Pleistocene (?) age. The McKittrick group is at

[1] A redefinition of the name as used in U. S. Geol. Survey Bull. 621, as explained on pages 27–28 of this report.

least 5,400 feet thick in the Sunset-Midway oil field.

The McKittrick group is overlain by poorly consolidated sand, gravel, and clay that form the Recent alluvium filling the valleys and the terrace deposits. This material is not essentially different from that embraced in the upper part of the McKittrick, and an exact separation of the two terranes can not be made.

PRE-TERTIARY ROCKS.

CRYSTALLINE ROCKS.

GENERAL CHARACTER.

The granitoid rocks that crop out in the central part of the San Emigdio Mountains form part of the granitic batholith that was intruded in late Mesozoic time into the region now occupied by the Sierra Nevada. In the area now occupied by the San Emigdio and Tehachapi Mountains but little trace remains of the rocks into which this granitic mass was intruded, and, except for a few small masses of dark slate and of amphibolitic schist, the rocks that crop out within a mile or so of the contact with the Tertiary rocks are all granitoid.

As a whole the granitoid rocks are rather basic and may well be described as granodiorite. Their character is, however, by no means constant and ranges from that of a rock containing abundant quartz to that of one containing 75 or 80 per cent of amphibole or pyroxene. A rock made up largely of coarse crystals of hornblende forms a considerable part of the north flank of the Tehachapi Mountains east of Tejon Pass, whereas quartz-bearing porphyritic granite forms the north slope of the ridge extending northwestward from San Emigdio Mountain.

West of the area shown on the map (Pl. II) the granitic rocks are covered by the Tertiary sedimentary formations, and except for two fault blocks, one about 5 miles south of the south edge of the area mapped and the other just west of the crest of the Temblor Range, west of the Midway field, granitic rocks do not appear at the surface between the San Emigdio Mountains and the San Jose Range, a distance of almost 50 miles. Thus those who postulate a single period of granitic intrusion in California and assign a like age to the granite of the Sierra Nevada and that of the Coast Ranges must rest their case upon evidence other than continuity of outcrop.

ECONOMIC IMPORTANCE.

The crystalline rocks have no bearing upon the occurrence of oil, serving neither as an original source of petroleum nor as a reservoir in which it might collect, but they contain deposits of several metallic minerals, notably stibnite. The chief deposit of stibnite occurs on the east slope of Antimony Peak, where veins containing this mineral cut the granite and may be traced for a distance of over 4,000 feet. A smaller deposit was noted in sec. 7, T. 9 N., R. 20 W., where quartz veins containing stibnite cut an amphibolite schist. At the locality on Antimony Peak considerable work was done about 25 years ago and a reduction plant was erected on San Emigdio Creek, but this has long since been abandoned and the mine was completely caved when visited in 1912. It is reported that in 1915, when the price of antimony rose greatly, the mine was reopened and considerable work was done.

LATE MESOZOIC ROCKS.

In the south end of San Joaquin Valley the late Mesozoic record is scant, and much of the history of this time can only be inferred from fragmentary evidence, for the Franciscan (Jurassic ?), Knoxville (Lower Cretaceous), and Chico (Upper Cretaceous) rocks that form so large a part of the Coast Ranges to the north are nowhere exposed. Rocks of the Franciscan and Knoxville formations probably do not occur in the region mapped. During the later part and possibly during most of the time during which these formations were being deposited in the region to the north the region shown on the map (Pl. II) was elevated above the sea and subjected to erosion. It seems probable, however, that Upper Cretaceous (Chico) sediments were deposited both in the Sunset-Midway region and in the San Emigdio Mountains, for rocks of that age are now exposed in the Temblor Range, only a few miles north of the area shown on the geologic map. In the San Emigdio Mountains also the basal Eocene beds which rest upon the granite contain pebbles of unmetamorphosed sandstone that were evidently derived from beds at one time exposed in the central part of the mountains, for it is from that area that the sediments composing the Eocene beds were derived. Therefore Cretaceous rocks, similar to those now exposed in the northern part of the

Temblor Range, probably underlie a considerable part of the Sunset-Midway region beneath the cover of Tertiary formations.

TERTIARY SYSTEM.

TEJON FORMATION (EOCENE).

GENERAL CHARACTER AND STRATIGRAPHIC RELATIONS.

The oldest unmetamorphosed sedimentary beds now exposed in the region are those embraced in the Tejon formation (Eocene). This formation is composed mainly of fine-grained arkosic sandstone and sandy shale with a small amount of conglomerate, and was deposited in marine waters upon a very uneven surface of granitic rock. It is overlain unconformably by the rocks here mapped as Vaqueros. Its relation to the overlying rocks is, however, not very well shown, for nowhere within the area examined do the two formations show measurable discordance in angle of dip, nor is there any marked lithologic change in passing from one to the other. It seems evident, however, that an unconformity exists at the top of the Tejon in this region just as it does in the northern part of the Temblor Range, north of the limits of the area shown on the geologic map (Pl. II), for the change in the fauna is too abrupt and complete to be explained readily in any other way. Moreover, the presence of an unconformity at the top of the Tejon is suggested by the variation in the thickness of that formation, although in this region, where both the thickness and lithology of the Tertiary formations varies so greatly, such variation can not be accepted as positive proof of a break in sedimentation. The Tejon increases gradually in thickness westward from Salt Creek and reaches its maximum thickness near San Emigdio Creek, where shales unlike anything in the Salt Creek section constitute the topmost part of the formation exposed. It may be that these shales are but a lithologic variation of the beds at the top of the formation on Salt Creek, but as nearly as may be judged from the somewhat unsatisfactory field evidence the alternate hypothesis—that they are the equivalent of beds which are not exposed in the Salt Creek area and therefore that an unconformity marks the top of the Tejon—seems more probable. This shale is described on pages 24-25.

DISTRIBUTION AND LITHOLOGY.

The Tejon formation crops out in the north flanks of the Tehachapi and San Emigdio mountains from a point 8 miles east of Tejon Pass—or Cañada de las Uvas, as it was known to the early inhabitants of this region—to Santiago Creek, a distance of about 30 miles. East of San Emigdio Creek the Tejon is steeply tilted and crops out in a belt that is usually not more than a mile across; but west of that creek, where the formation is exposed in the trough of the Devils Kitchen syncline, the belt broadens and in places is as much as 3 miles wide. Besides this main belt of outcrop patches of the Tejon isolated by erosion from the main body of the formation rest upon the granitic rock in the central part of the range and are especially numerous about 3 miles east of Tejon Pass. Only two such remnants of the basal Tejon were found within the area shown on the map, on the north slope of Antimony Peak; but doubtless a careful search would reveal others stranded upon the granitic rocks in the higher parts of the mountains.

It is thus evident that the basin in which the Tejon was laid down extended considerably southward from the belt of outcrop shown on the map, and the formation may have been deposited over the whole of the San Emigdio Mountains and the region to the south as far as the drainage basins of Sespe and Piru creeks, where Eocene beds, practically if not exactly the equivalent of the Tejon but locally known as the Topatopa formation, are exposed. It seems more probable, however, that parts of the San Emigdio Mountains were above the sea throughout Eocene time, because a large part of the material of which the Tejon is composed was derived from the granitic rocks forming these mountains, and although the Topatopa and the Tejon were deposited synchronously, it is not yet established that they were laid down in the same basin.

The lower part of the Tejon is usually coarse grained, being especially so east of San Emigdio Creek and also west of that creek on the north side of the granite that is exposed north of the axis of the Devils Kitchen syncline. East of San Emigdio Creek the lower 75 to 200 feet of the Tejon is composed of massive sandstone formed largely of granitic débris and containing many fragments 1 or 2 inches in diameter. These beds are well exposed on the east side of Pleito Creek where they weather to prominent rugged outcrops. At Los Lobos Creek, on the north side of the granite exposed north of the axis of the Devils Kitchen syncline, the lower 200 feet of the Tejon is composed of fossiliferous shaly sandstone interstratified with massive sandstone filled with boulders of basic igneous rock derived from the crystalline mass upon which they rest. These boulders are only moderately well rounded and vary considerably in size, the largest being about 2 feet in diameter. Exposures of these basal beds on Los Lobos Creek are shown in Plate VII.

The middle part of the Tejon is composed mainly of shaly sandstone and shale that weather easily, forming a fairly deep yellowish-brown soil. The shaly beds weather so much more easily than the sandy beds that the section there, if judged by weathered outcrops, appears much more sandy than it really is. In places the fine-grained beds contain lenses of conglomerate 5 or 10 feet thick, and weathering brings into slight relief indurated calcareous beds, usually somewhat coarser than the bed in this part of the formation and containing fossils; but on the whole the middle part of the Tejon east of San Emigdio Creek presents no striking lithologic divisions, and the tabulated section of the formation as exposed near Pleito Creek given below presents a very fair description of the formation throughout this part of the region. West of San Emigdio Creek and south of the isolated body of granitic rocks exposed there the Tejon is formed almost wholly of fine-grained micaceous thin-bedded or flaggy sandstone and dark clay shale. These beds were evidently deposited in shallow water, for they show ripple marks and contain a little carbonaceous matter and impressions of terrestrial vegetation.

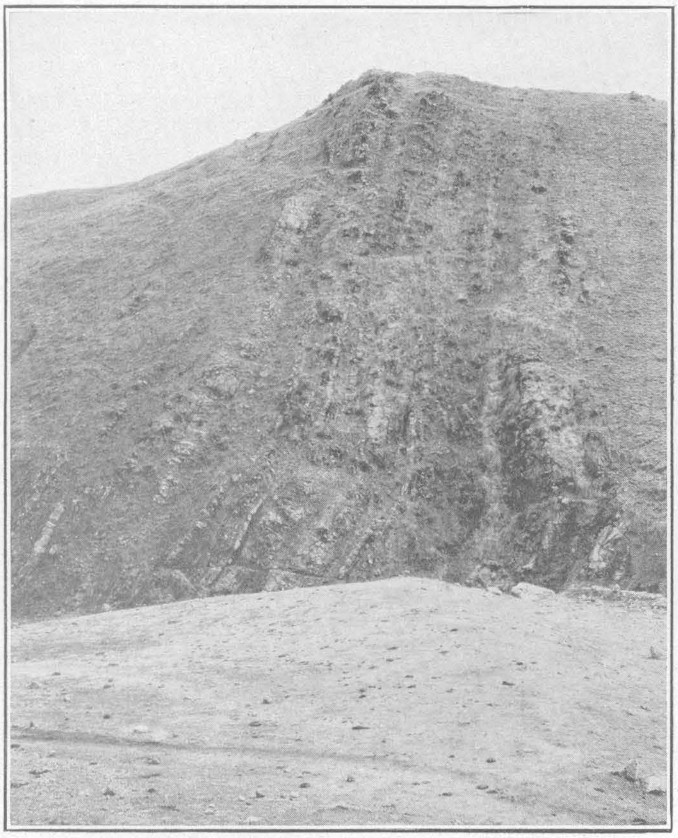
The thickness of the Tejon exposed varies greatly, probably owing both to the uneven surface upon which the formation was deposited and to the unconformable overlapping of the Vaqueros formation. The exposed thickness is greatest near Pleito Creek, about 4 miles east of San Emigdio Canyon, where the formation comprises sandstone, shale, and conglomerate aggregating a thickness of about 4,300 feet. The following section was measured near the point where the exposed thickness is greatest. The recorded thicknesses are accurate to about 10 per cent.

Section of Tejon formation on ridge between Salt and Pleito creeks in sec. 31. T. 10 N., R. 20 W., and sec. 5, T. 9 N., R. 20 W.

	Feet.
1. Sandstone; hard, calcareous, gray when fresh, weathering to dark brown; fine, even grained, average diameter of grains about 0.2 millimeters; weathers to prominent outcrops. Filled with fossil marine shells. Mapped as base of Miocene.	
2. Sandstone; fine grained, shaly, probably gray when fresh but weathers easily to brownish sandy soil. Contains a few calcareous layers carrying marine fossils	1,200
3. Conglomerate; well-rounded fragments, mainly quartzite and granitic rocks, filled with marine fossils	10
4. Sandstone; much like bed 2 above but includes numerous dark-brown concretions hardened by lime and iron and containing fossil shells. A few pebbles of granitic rocks on surface	1,890
5. Sandstone; somewhat more indurated and slightly coarser grained than that in overlying beds; weathers to prominent outcrops	100
6. Sandstone; very fine, even grained but less shaly than bed 8 below	350
7. Sandstone; slightly coarser than underlying bed 8 and contains a few well-rounded quartzitic cobbles having a maximum diameter of 5 inches	100
8. Sandstone; very fine, even grained and shaly; weathers to minute light-brown angular fragments; contains many impressions of terrestrial vegetation; exposures poor, soil deep	300
9. Sandstone; coarse grained, containing many fragments as large as No. 6 shot and a few granitic cobbles a few inches in diameter. Material evidently derived from granitic rocks of central part of San Emigdio Mountains. Weathers to prominent outcrops traceable for several miles. Rests upon crystalline rocks	250
	4,200

Between Pleito and San Emigdio creeks the uppermost part of the Tejon is composed of shale that varies in color from greenish black to chocolate-brown. This shale is thickest on San Emigdio Creek. It wedges out rather abruptly toward the east and was not recognized in the canyon of Pleito Creek. This wedging out may be due to the replacement of the shale by sand, but, as is explained on page 23, the writer is inclined to believe that the shale is younger than the uppermost Tejon exposed on Salt Creek and Cañada de las Uvas, and that the disappearance of the shale is caused by the unconformable overlapping of the Vaqueros formation.

In the first canyon west of Pleito Creek—that is, the one draining northward through the western part of sec. 34, T. 10 N., R. 21 W.—the shale is about 75 feet thick. In this vicinity it weathers to a deep, loose soil that supports little vegetation, or to hill slopes covered with angular shale fragments one-fourth to one-half inch wide. The shale is distinctly a clay shale

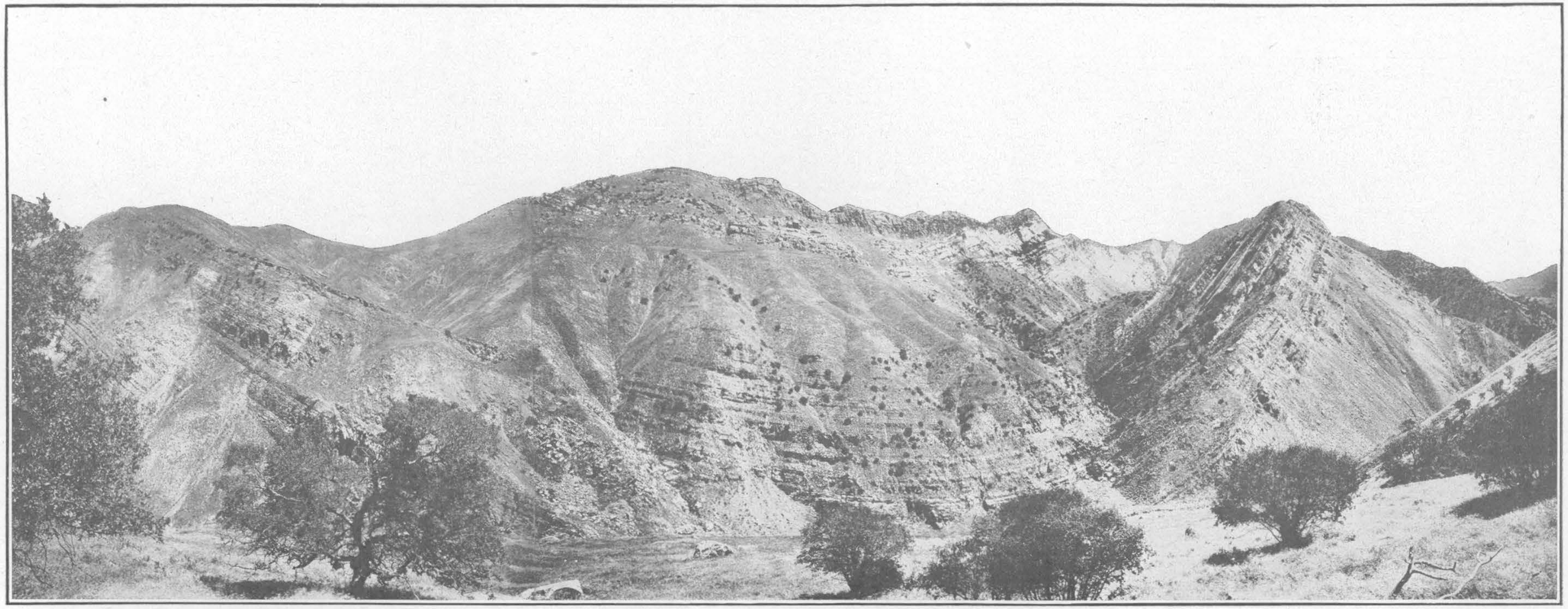


A. GENERAL VIEW.

B. DETAIL.

BASAL PART OF TEJON FORMATION ON LOS LOBOS CREEK IN FOOTHILLS OF SAN EMIGDIO MOUNTAINS.

Interstratified arkosic sandstone and coarse boulder beds. Note small fault at base of exposure.



DEVILS KITCHEN, SAN EMIGDIO CANYON.

Looking east across canyon. The sharp peak at the right is Eagle Rest. The massive beds forming Eagle Rest are marine Oligocene; shale of the Tejon formation covers the broad slope to the right of this peak. Photograph by W. C. Mendenhall.

as distinguished from the lighter-colored sandy shale in the lower part of the Tejon. Beneath this shale are fine-grained grayish sandstones and shales that closely resemble those of the overlying Vaqueros formation, and about the only noticeable difference in the lithology of the two formations is the character of the concretions. The concretions in the Tejon are usually regularly formed and smoothly rounded, looking like large balls or dumbbells, and when broken or even when considerably weathered they show a shelly or concentric structure. On the other hand, most of those of the Vaqueros formation are irregular lenticular masses whose greatest length lies parallel to the bedding. In the field these concretions were termed "concretionary layers" to distinguish them from the more symmetric concretions common in the older formations.

In the canyon of San Emigdio Creek the shale composing the uppermost part of the Tejon is best exposed opposite the mouth of Williams Creek. Most of the Tejon that crops out east of the creek, in the north flank of the Devils Kitchen syncline, is composed of sandy shale that weathers to chocolate-brown. This shale supports little vegetation other than a few scattered groups of juniper trees. In general aspect it resembles the more clayey phases of the later Tertiary diatomaceous shale in this region or the Kreyenhagen and Moreno shales in the Coalinga region.[1]

The general lithologic similarity and the like stratigraphic relations suggest that this shale may be the equivalent of the Kreyenhagen shale. No fossils were found in the shale, and for the present at least it is considered as part of the Tejon.

On Grapevine Canyon (Cañada de las Uvas) the Tejon is somewhat broken by faults and the lower part is covered by landslides of granite débris that have come from the higher parts of the range on the south. It is therefore difficult to make out the true character of the formation or to determine its thickness with accuracy. It is unfortunate that this, according to Whitney's description, is the type section of the Tejon, for the formation is apparently thicker, is better exposed, and contains more fossils west of this locality, in the vicinity of Pleito Creek.

[1] Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Calif.: U.S. Geol. Survey Bull. 603, pp. 50, 75, 1915.

AGE AND CORRELATION.

The Tejon formation is of Eocene age, as is shown by the marine invertebrate fossils that occur scattered throughout it. The type section of the formation is at Grapevine Canyon, or Tejon Pass (Cañada de las Uvas of the early explorers). The geology of this section was first studied by Blake, geologist for the Pacific Railroad Survey, and the fossils collected by him were determined as Eocene by Conrad. Later Gabb, paleontologist of the Geological Survey of California, after a careful study of the fossils from this region, referred these beds to the Upper Cretaceous. The name Tejon was applied by Whitney from their occurrence near old Fort Tejon, in Grapevine Canyon, although in the same sentence he says that the beds are also typically exposed in the Mount Diablo region. More recent studies of the fauna of the Tejon have shown that it is properly referable to the Eocene and not to the Upper Cretaceous.

Dickerson[2] has studied the fauna of the Tejon in considerable detail and has published lists of the species collected by him at the south end of San Joaquin Valley from the exposures of the Tejon in and east of the canyon of Salt Creek, chiefly from Liveoak, about 3 miles east of Tejon Pass. There the uppermost beds of the Tejon contain an abundance of fossils, and it was probably from these very exposures or in float from them that Blake collected the fossils he obtained.

IMPORTANCE WITH RELATION TO PETROLEUM.

No evidence of petroleum has been discovered in the Tejon formation anywhere in the southern part of San Joaquin Valley. The shale that forms the uppermost part of the formation in the vicinity of San Emigdio resembles somewhat the more clayey phases of the organically formed shales—the diatomaceous shales—which are found in the productive oil regions and in which the oil originated. It is not improbable, therefore, that oil may occur in this part of the formation and that it might concentrate in certain places and form pools of commerical value if the structure were favorable for such concentration. The structure does not appear to favor concentration, how-

[2] Dickerson, R. E., Stratigraphy and fauna of the Tejon Eocene of California: California Univ. Dept. Geology Bull., vol. 9, pp. 420–421, 1916.

ever, except in the short anticline that lies between San Emigdio and Pleito creeks and on the north side of the Devils Kitchen syncline. The possible occurrence of petroleum here is discussed on page 170.

OLIGOCENE AND MIOCENE ROCKS.

NOMENCLATURE.

Relation of the formations.—In the present report the strata of Oligocene and early Miocene ages are grouped into formations that do not correspond precisely with the formations that have been described for other parts of the Coast Ranges of California. The writer believes that the structure and geologic history of this particular region are brought out more clearly by this grouping, and was not able to devote sufficient time in the field to the study of these strata to permit their segregation into formations corresponding precisely to those that may be termed the standard formations of the Coast Ranges. The relation of the formations described in the present paper to the formations commonly described in other parts of the Coast Ranges is shown in the accompanying table and is described in the following paragraphs.

Relation between formations described in the present report and in previous reports on this and near-by areas.

<table>
<tr><th colspan="2">Present report.</th><th colspan="2">Previous reports.</th></tr>
<tr><td rowspan="2">McKittrick group.</td><td>Paso Robles ("Tulare") formation.</td><td rowspan="2">McKittrick formation.</td><td>Tulare formation.</td></tr>
<tr><td>Etchegoin formation, probably including a representative of Jacalitos formation.</td><td>Etchegoin and Jacalitos formations.</td></tr>
<tr><td rowspan="2">Maricopa shale.</td><td>Santa Margarita formation.</td><td colspan="2">Santa Margarita formation.</td></tr>
<tr><td>Absent.</td><td rowspan="2">Monterey group.</td><td>Monterey shale, diatomaceous shale, Salinas shale.</td></tr>
<tr><td colspan="2" rowspan="2">Vaqueros formation, including, for convenience, some Oligocene at base.</td><td>Vaqueros formation.</td></tr>
<tr><td colspan="2">Kreyenhagen shale.</td></tr>
<tr><td colspan="2">Tejon formation.</td><td colspan="2">Tejon formation.</td></tr>
</table>

Vaqueros formation.—As explained on page 21 the term Vaqueros formation is used in this report to designate a thick succession of sandstone, conglomerate, and shale that was deposited during Oligocene and early Miocene time. The lower or Oligocene beds (here for convenience included in the Vaqueros) consist of marine sandstones containing abundant invertebrate fossils which correspond well with the fauna of a part of the "Astoria group"[1] and with that of the Sobrante sandstone or Agasoma zone in Contra Costa County, Calif.[2] These formations are now believed to be Oligocene, and this lower part of the Vaqueros formation as here mapped is therefore to be considered as of Oligocene age. The upper part of the formation, to judge both from the meager fauna it contains and from its close stratigraphic relation to the overlying diatomaceous shale, is evidently of lower Miocene age and to be considered as the equivalent of the Vaqueros formation. The writer did not have sufficient time to separate the deposits into these two parts, for the structure in this region is so complicated that it would take detailed stratigraphic and paleontologic work to make the separation in a satisfactory manner. For the present, therefore, the strata are grouped into a single formation, which for convenience is termed the Vaqueros formation, although the Oligocene beds do not properly constitute a part of that formation. It will doubtless be possible, when more detailed work is done, to separate the Oligocene beds from the lower Miocene beds or Vaqueros proper. However, in spite of the fact that the conditions governing deposition varied in different parts of the south end of San Joaquin Valley during the time these sediments were being laid down, the general relations of the beds indicate that deposition was fairly constant and that such interruptions as occurred were local. It seems appropriate, therefore, that the whole succession of beds should be considered as one formation. It is probable that in other parts of California an equally close relation exists between lower Miocene and Oligocene beds, and that in certain areas beds which have been de-

[1] Arnold, Ralph, and Hannibal, Harold, The marine Tertiary stratigraphy of the north Pacific coast of America: Am. Philos. Soc. Proc., vol. 52, No. 212, November-December, 1913.

[2] Clark, B. L., The occurrence of Oligocene in the Contra Costa Hills of middle California: California Univ. Dept. Geology Bull., vol. 9, pp. 9-21, 1915.

scribed as part of the Vaqueros formation are in reality of Oligocene age.

Monterey group.—The Monterey group is not mapped as such on the geologic map accompanying the present report, although its approximate boundaries are shown on the map, and the term Monterey is used in places in the text. As the previous usage of the term Monterey has not always been uniform it becomes necessary to define the use to which the term is put in this report.

The term Monterey has been used in descriptions of California geology in two distinct ways. One group of writers has applied the terms "Monterey series," "Monterey group," "Monterey formation" to a terrane of varied lithology including both coarse material, such as sandstone, gravel, and boulder beds, and fine material, chiefly diatomaceous shale, that was deposited during a period of continuous sedimentation in early Miocene time. Another group of writers has sought to restrict the term Monterey to the fine-grained or shaly beds that were deposited chiefly during the later part of this time, and hence the terms "Monterey shale" and "Monterey formation" have been used to describe the deposits of diatomaceous shale that are so abundant in the southern Coast Ranges of California. The coarse-grained beds associated with the diatomaceous shale have been described by these writers as another formation, usually called the Vaqueros formation.

It is convenient in describing the geology of the southern Coast Ranges of California to have definite names by which to designate separately the shaly and the sandy beds that were deposited during this time, for in most places it is possible to make some sort of a separation in the field between the coarse beds below and the fine ones above.

To the writer it seems evident that in this south end of San Joaquin Valley there was no considerable interval of erosion separating the Monterey into two divisions, but rather it appears that there were many local and unrelated periods of erosion during one general period of sedimentation. It is thus equally convenient and necessary to have some name to apply to the beds laid down during the whole of this period of sedimentation as to have two names to designate the principal parts separately.

It is therefore desirable to have three distinct names for use in describing the deposits—a name for the group as a whole, a name for the lower and dominantly coarse-grained part, and a name for the upper and dominantly shaly part. The trouble lies in the fact that the name Monterey has been used for the group as a whole and also for the shale alone.

A full discussion of the propriety of these different usages of the term Monterey would require more space than can be spared in this report, but it may be said that the term as first used was probably meant to designate the larger unit of deposition rather than only the subordinate lithologic phase. Certainly it was in this broader sense that the term Monterey first had wide application in geologic literature, although both usages are now common among those working in the geology of the California Coast Ranges. A description of the ways in which the term Monterey had been used up to 1912 has been given by Louderback,[1] and to his paper the reader is referred for a more detailed discussion of the subject. Monterey has been adopted in the larger or group sense by the United States Geological Survey.

In the present report the term wherever employed in the text is therefore used to designate the larger unit, and as here defined the Monterey group includes all the Miocene beds older than the Santa Margarita. These beds are the equivalent of those that were described by Arnold and Johnson[2] as the Vaqueros formation and Monterey shale. As thus described the Monterey group corresponds to the Vaqueros formation (exclusive of the Oligocene beds which for convenience are here included in the Vaqueros) and the lower part of the Maricopa shale as shown on the geologic map (Pl. II).

Maricopa shale.—In the present report the term Maricopa shale is used to describe the thick mass of diatomaceous shale that forms the central part of the south end of the Temblor Range and crops out in places along the north flank of the San Emigdio Mountains. The

[1] Louderback, G. D., The Monterey series in California: California Univ. Dept. Geology Bull., vol. 7, pp. 177-241, 1913.

[2] Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Kern and San Luis Obispo counties, Calif.: U. S. Geol. Survey Bull. 406, pp. 42-62, 1910.

lower part of this diatomaceous shale is the equivalent of the upper part of the Monterey group as defined on page 27, but the upper part of the shale is equivalent to the Santa Margarita formation as developed in the Salinas Valley. In the preliminary report these beds were described as the Monterey shale and the Santa Margarita (?) formation. Although it is possible along the east flank of the Temblor Range and in a part of the Pleito syncline to separate the shale on a lithologic basis into two parts, the upper of which contains more coarse sandy beds and lenses made up of granite boulders than the lower part, the writer can not see that there is good evidence for assuming that the line thus drawn is the same as the line between the Monterey group and the Santa Margarita formation. Inasmuch as the diatomaceous shales are of so great importance in the consideration of the occurrence of oil—they are believed to be the original source of the oil—it seems best to consider all the shale as belonging to a single formation, especially as the field evidence indicates that deposition was probably continuous throughout the time during which these beds were laid down.

The name Maricopa was selected for these diatomaceous shales from a typical section near Maricopa, in Sunset Valley, and the name was first published in a report by W. A. English,[1] to designate certain strata in Cuyama Valley, west of the area described in the present report, the strata exposed there being correlated with the diatomaceous shale exposed near Maricopa. Further field work, however, done in the east flank of the Temblor Range and in Cholame Valley during 1915 and 1916, in carrying on the investigations of the petroleum resources of California, has brought out the fact that the upper part of the typical Maricopa shale in the Sunset region is composed of younger beds than any of those that were termed Maricopa shale in the Cuyama Valley, being in fact equivalent to the Santa Margarita formation, and the correlation of these beds in the Cuyama Valley with the typical Maricopa shale is therefore not correct. In a later paper [2] English describes diatomaceous shales that form the upper part of the Monterey group as the Salinas shale, and the shale termed Maricopa shale in the report on Cuyama Valley should properly be called Salinas shale.

Santa Margarita formation.—In the foothills forming the north flank of the San Emigdio Mountains are exposed coarse sandstones that contain typical marine invertebrate fossils of Santa Margarita age. These beds are the equivalent in age of the beds forming the upper part of the Maricopa shale in the foothills on the east flank of the Temblor Range. They rest unconformably on the Vaqueros and Tejon formations and are unconformably overlain by the Etchegoin formation. Because of their fauna and their stratigraphic position they are here designated the Santa Margarita formation.

VAQUEROS FORMATION (LOWER MIOCENE).[3]

GENERAL CHARACTER AND STRATIGRAPHIC RELATIONS.

The Vaqueros formation as mapped in this area is made up in part of beds that were deposited in shallow, near-shore marine water; in part of beds that were deposited in quiet and probably deeper marine water; and in part of coarse beds that were laid down by running water. A very considerable part of the coarse débris contained in the formation was derived from a rugged land mass, composed largely of granitic rocks, that lay in the region now occupied by the Tehachapi Mountains and the eastern part of the San Emigdio Mountains. On the flanks of the rugged mountains that occupied this area were deposited the coarse arkosic sandstones and the ill-sorted boulder beds that now crop out in the foothills east of San Emigdio Creek. Farther from the mountains and beneath marine waters were laid down the finer sediments that now form the sandstones and shales which crop out in the western part of the San Emigdio Mountains west of Santiago Creek.

The area in which the Vaqueros formation now occurs as shown on the geologic map (Pl. II) is but a small part of the basin in which this formation was deposited, for beds of equivalent age crop out in much of the southern Coast Ranges and also in the western flank of the Sierra Nevada, near the Kern River oil field. The area mapped, however, lies at the outer edge of the basin of deposition, for throughout the period during which these sediments were

[1] Geology and oil prospects of Cuyama Valley, Calif.: U. S. Geol. Survey Bull. 621, pp. 191-215, 1916.

[2] Geology and oil prospects of the Salinas Valley-Parkfield area, Calif.: U. S. Geol. Survey Bull. 691, pp. 228-229, 1918.

[3] In this report some beds of Oligocene age are for convenience included in the Vaqueros formation, as explained on p. 21.

being deposited a high mountain barrier must have occupied the region where the Tehachapi Mountains now stand. The eastern part of the San Emigdio Mountains was likewise above the sea during most of the period, as is shown by the fact that the volcanic rocks that occur in the upper part of the Vaqueros formation in the eastern part of the area rest upon the granitic rocks near the headwaters of Santiago Creek. It is interesting to note that the fossiliferous marine beds in the lower part of the deposits, here for convenience included in the Vaqueros formation, now crop out at an altitude of 6,200 feet above sea level, on the north slope of the San Emigdio Mountains, giving a rough measure of the amount of vertical movement that the region has undergone since early Oligocene time.

With the underlying Tejon formation the Vaqueros is evidently unconformable, although the two formations are so alike lithologically that they can be differentiated only with great difficulty. The evidence of unconformity is discussed in the section describing the stratigraphic relations of the Tejon.

With the overlying Maricopa shale the Vaqueros appears to be perfectly conformable, and the two formations, grading one into the the other, are evidently the products of practically uninterrupted sedimentation.

LITHOLOGY AND DISTRIBUTION.

The Vaqueros formation crops out in an irregular belt several miles wide in the north flanks of the Tehachapi and San Emigdio Mountains from the vicinity of the Tejon ranch, 12 miles east of Tejon Pass, westward to and beyond the west end of the San Emigdio Mountains. The older rocks upon which the formation rests crop out east of Santiago Creek, but west of that creek the Vaqueros forms the crest of the San Emigdio Mountains and extends in unbroken outcrop down their south flank. On the southwestern flank of the Temblor Range, west of the area shown on the geologic map (Pl. II), the upper part of the Vaqueros is exposed. The intervening area, in which lies the productive Sunset-Midway oil field, is underlain beneath the younger Tertiary formations by the lower Miocene or Vaqueros beds proper and perhaps also by the Oligocene beds which for convenience are here included in the Vaqueros.

AREA EAST OF SANTIAGO CREEK.

In the eastern part of the area mapped the deposits here included in the Vaqueros formation may be divided into four lithologic divisions. The lowest of these divisions is characterized by massive arkosic sandstone filled with marine Oligocene fossils; the second division is composed of ill-sorted beds of coarse granitic conglomerate and sand that were probably in large part deposited subaerially; the third division is composed of basaltic and andesitic flows and tuffs; and the uppermost division is composed of fine sand and sandy shale in part if not wholly of marine origin.

Near Pleito Creek the lowest division is about 750 feet thick and is composed chiefly of massive arkosic pebbly sandstone containing numerous highly fossiliferous calcareous beds that weather dark reddish brown and a few lenses of conglomerate formed largely of fairly well rounded pebbles. The massive sandstone that forms the characteristic feature of this division weathers to long dip slopes barren of vegetation that are a striking feature of the landscape on both the east and west sides of Pleito Creek. Outcrops of these massive sandstones are shown in Plate VIII. On the whole these sandstones closely resemble the underlying sandstones of the Tejon, and no structural break is apparent between them, nor is a distinct lithologic change apparent in many places. The basal bed as mapped is the lowest calcareous sandstone that contains Oligocene fossils. About 100 feet stratigraphically below this fossiliferous calcareous sandstone Eocene fossils were collected. The beds lying above the fossiliferous Eocene sandstone and below the lowest bed in which Oligocene fossils were collected might belong equally well with either the Oligocene or the Tejon. For the present they are mapped with the Tejon.

The division next above the massive sandstone is composed mainly of coarse ill-sorted conglomerate made up of poorly rounded fragments of granitic and other crystalline rocks derived from the complex that forms the higher parts of the mountains to the south and east. These coarse beds contain fragments that differ greatly in size, the largest ones seen having a diameter of 5 or 6 feet. With the coarse beds are irregular beds of fine arkosic sand which weather so easily that they form a very inconspicuous part of the section, and the conglomerate appears much thicker than it really is. The bedding in this part of the section is exceedingly irregular, huge lenses of conglomerate more than 100 feet thick wedging out within a few hundred feet along the strike.

A notable feature of this part of the formation is the bright color that it shows locally as far west as Pleito Creek. The color is best shown on Tacuya Creek, where the basal sandstone is not prominent and the whole of the formation below the basalt and agglomerate is composed of ill-sorted gravel, grit, and sand with a few lenses of clay. These beds weather to rugged badlands, and the vertical cliffs, brightly colored in irregular streaks of various shades of red, brown, green, gray, and yellow, give a highly fantastic touch to the landscape. The particular color a bed may show does not appear to bear any definite relation to the lithology of the bed, except that the reddish color is usually of a deeper tone in the fine-grained or clayey beds than in the coarse beds.

Most of this part of the formation is barren of fossils, but on account of its general lithologic character, its prevailing reddish color, and its lack of the marine fossils that are so abundant in the underlying beds, this member is believed to have been deposited subaerially. However, all of it can not be considered to have been so deposited, nor can the size of the boulders alone be considered as proof of subaerial deposition, for the uppermost beds of this division east of Pleito Creek contain fossiliferous marine sandstones bedded with conglomerate formed of coarse boulders some of which have a diameter of 4 feet. Characteristic outcrops of this division near Salt Creek are shown in Plate V.

West of Pleito Creek the conglomeratic member of the Vaqueros formation can not be differentiated from the underlying massive Oligocene sandstone, and at the Devils Kitchen, on the east side of San Emigdio Creek, the lower 2,000 feet consists of alternating beds of massive sandstone and conglomerate composed of fairly well rounded fragments. The following roughly estimated section shows the character of the formation at the Devils Kitchen. The beds described, which are shown in Plate VIII, are on the north limb of the syncline.

Section of Vaqueros formation in the Devils Kitchen.

	Feet.
Sandstone, massive, gray, of variable grain, containing numerous conglomerate lenses formed of well-rounded fragments that range from sand grains to pebbles with a diameter of 3 or 4 inches. Sandstone weathers to bare dip slopes 600 or 700 feet long near axis of eastward-plunging syncline	700
Sandstone and conglomerate, much like the overlying beds but weather more easily, and on north flank of syncline underlie grassy slope	400
Sandstone, massive and shaly, interstratified in beds 2 or 3 feet thick. Massive beds weather out and give corded appearance to the hill slope. This and overlying zone become coarser grained and more resistant to weathering on north slope of Eagle Rest	300
Sandstone, massive, with relatively little conglomerate. Thin beds of brownish calcareous sandstone filled with Oligocene fossils occur throughout but are especially prominent toward base. For convenience included in Miocene Vaqueros formation. This zone, like the overlying zones, is coarser grained on the south limb of the syncline than on the north limb. Rests on dark shale mapped as Tejon	600
	2,000

The following section shows the character of the Vaqueros formation in the hills just south of the point where Williams Creek enters San Emigdio Creek, on the south limb of the Devils Kitchen syncline. The uppermost part of the Vaqueros exposed in the Devils Kitchen syncline on the east side of San Emigdio Creek has been eroded from this area, and the beds described in the section given below are the equivalent of the three lower divisions described in the tabulated section given above.

Section of Vaqueros formation on south limb of Devils Kitchen syncline, between two branches of San Emigdio Creek.

	Feet.
Sandstone and conglomerate; sandstone coarse and uneven grain, weathers to yellowish-white outcrops	500
Sandstone, massive, fine grained, with a small amount of conglomerate	250
Sandstone, fine grained; weathers brownish; contains numerous calcareous beds that weather deep red-brown and contain many fossil shells of Oligocene age	200
Shale, dark when fresh; weathers to yellow-brown	150
Sandstone, fine grained, thin bedded, grayish-brown outcrops	50
Sandstone, fine grained; weathers greenish brown; concretionary	200
Sandstone, much like overlying but contains calcareous beds filled with Oligocene fossils. Rests on dark clay shale mapped as Tejon	50
	1,400

The third division of the Vaqueros formation east of Santiago Creek is composed almost wholly of tuff and scoriaceous lava. These beds yield but little to the agencies of erosion, and their outcrops usually stand out in bold relief from the softer sands and sandy shales. Even the massive conglomerates of the underlying division are much less resistant and nowhere weather out so prominently. This division shows a perfect gradation into the underlying division, for between the coarse boulder beds composed of granitic débris and the overlying craggy-weathering andesitic agglomerates are beds formed largely of fine angular tuff but containing also many rounded pebbles of granitic rock. The change from a bed composed wholly of detrital material to one composed wholly of pyroclastic material is so gradual that it is not possible to say just where the predominance of one type of material ends and that of the other begins. These transition beds are well developed between Salt and Pleito creeks, where they attain a thickness of about 200 feet. Besides this transition from the detrital rocks to the scoriaceous lava, the close relationship between the two parts of the formation is shown by the presence of thin beds of sandstone intercalated with the basaltic flows. The character of the igneous rock that constitutes the upper part of this division is described on pages 52–54.

Overlying the volcanic rocks in the region east of San Emigdio Creek are fine-grained grayish arkosic sandstone and clayey sands that are little indurated and weather to smoothly rounded hills which support a fair growth of grass. These beds contain marine fossils, but the forms so far obtained are not very diagnostic. It is believed that these beds are the equivalent of the shale that forms the upper part of the Vaqueros and crops out between the headwaters of Santiago and Bitter creeks and also in the vicinity of the point where those streams enter San Joaquin Valley, along the southern limb of the Cienaga syncline and the east end of the Pioneer anticline. The main reasons for this correlation lie in the facts that the chocolate-colored shale at the headwaters of Santiago Creek overlies andesitic and basaltic rocks which are the equivalent of those exposed east of San Emigdio Creek and that the shale mapped as the upper part of the Vaqueros on the south limb of the Cienaga syncline lies stratigraphically above the horizon marked by a small bed of andesitic agglomerate that crops out in sec. 11, T. 10 N., R. 23 W.

Westward from the vicinity of San Emigdio Creek to Santiago Creek the Vaqueros formation is mainly fine-grained sandstone and sandy shale with relatively little agglomerate, but it contains many higly fossiliferous beds that are indurated by a calcareous cement and weather to rather prominent red-brown outcrops. These beds are especially prominent between San Emigdio and Pleitito creeks some 2 to 4 miles from the edge of the valley, where they weather to smoothly rounded hills markedly in contrast to the massive slabs of sandstone and conglomerate that form the Devils Kitchen and to the badlands carved out of the younger Tertiary beds that lie closer to the plain. Plate IX, *A*, shows very well the difference in weathering between these beds and the younger Tertiary.

The highly fossiliferous massive calcareous sandstones of Oligocene age that are for convenience here mapped as the basal part of the Vaqueros formation east of San Emigdio Creek continue westward in the Devils Kitchen syncline as far as the NE. ¼ sec. 4, T. 9 N., R. 22 W., where they rest upon the Tejon in the vicinity of the westernmost point where that formation is exposed on the south limb of the syncline. Westward from this point younger and younger beds of the Vaqueros rest upon the granitic rock until, near the headwaters of Santiago Creek, at the west end of the exposure of granitic rocks, volcanic rocks equivalent to those that make up the third member of the Vaqueros east of San Emigdio Creek are the lowest beds exposed. Most of the Vaqueros rocks between San Emigdio and Santiago creeks are fine grained, and even the beds in contact with the granite contain but little conglomerate of the type that is so characteristic of the formation farther east. The contact between the Tejon and Vaqueros formations has not been mapped in detail on the north flank of the Devils Kitchen syncline, and, although the beds resting on the granite west of Los Lobos Creek are mapped as Vaqueros, a narrow belt of Tejon may also crop out there.

The section given on page 32 is shown graphically in figure 3.

Section of Vaqueros formation below the andesitic tuff, on ridge between Salt and Pleito creeks.

	Feet.
16. Tuff; coarse craggy-weathering andesitic tuff that forms crest of hill.	
15. Tuff and thin-bedded tuffaceous sandstone, as below, containing fragments of granitic rocks, some with a diameter of as much as half an inch	140
14. Tuffaceous sand and clay, in alternating beds that range in thickness from 6 to 24 inches. Color gray, in places light grayish green. Very arkosic; black mica exceptionally abundant and fresh. Apparently water-laid deposit of pyroclastic material	50
13. Sandstone; grains vary in diameter, the largest about size of B shot; with coarse pebbles. A few fragments of fossil marine shells, probably of Miocene age	16
12. Conglomerate; fragments of acidic granite as much as 4 feet in diameter, in sandy matrix, locally colored red	12
11. Sandstone, as above but lacks reddish color; contains fossils, probably of Miocene age	15
10. Sandstone, arkosic, average grain about size of No. 8 shot, locally colored red, filled with fragments of fossil shells, probably of Miocene age	9
9. Conglomerate, coarse and ill sorted; contains rocks of varied type—acidic and basic granitic rocks, limestone, quartzite, and volcanic rocks. Upper 50 feet alternating beds of fine sandstone and gravel containing boulders of acidic granite, the largest 5 feet in diameter. Whole zone colored reddish, but intensity of color not constant	1,130
8. Gravel, sand, and clay; grade into overlying coarse gravel	290
7. Sandstone; intermingled massive pebbly sandstone as below and soft reddish sandstone and gravel as above	80
6. Conglomerate and massive sandstone; sandstone as below, conglomerate of well-rounded pebbles as much as 8 inches in diameter	315
5. Sandstone, very massive, weathering to dip slope and forming steep north side of ridge. Well-rounded pebbles scattered throughout; a few seal-brown calcareous sandstones filled with fossils of Oligocene age	260
4. Sandstone, massive, arkosic, containing poorly consolidated conglomerate lenses and scattered pebbles. Near center are two gritty calcareous sandstones 8 to 12 inches thick containing Oligocene fossils	125
3. Sandstone, conglomerate, and clay shale intermingled; colored irregularly red and gray, the color varying along strike; clay beds usually more reddish than coarser ones. Pebbles in lower part well rounded and usually less than 4 inches in diameter. Upper part contains irregular fragments a foot or so in maximum diameter	225
2. Sandstone, yellowish gray when weathered, grain about like underlying bed. A few thin calcareous beds in lower half containing Oligocene fossils. Upper half poorly exposed	125
1. Sandstone, hard, calcareous; gray when fresh; weathers to dark brown; fine, even grained; average diameter of grain about 0.2 millimeter. Weathers to prominent outcrops. Filled with fossil marine shells of Oligocene age. Rests on fine-grained sandstone mapped as Tejon	15
	2,807

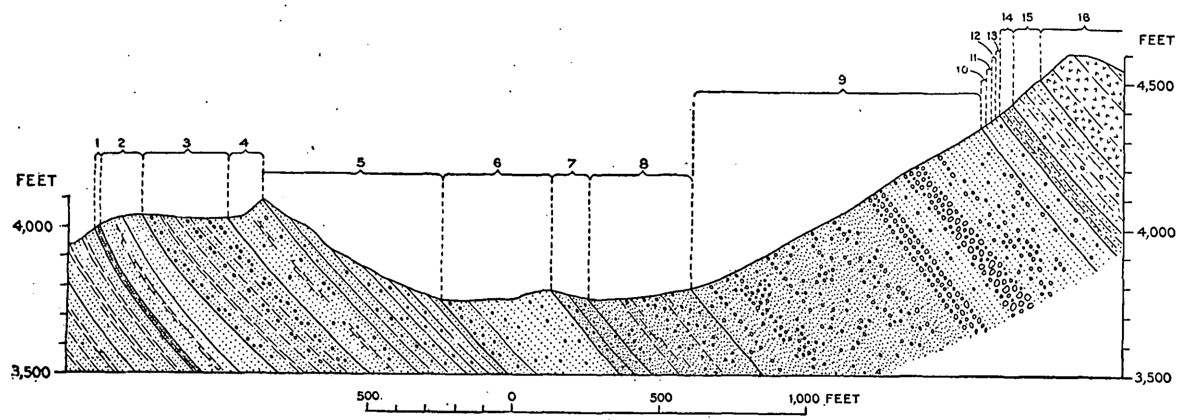
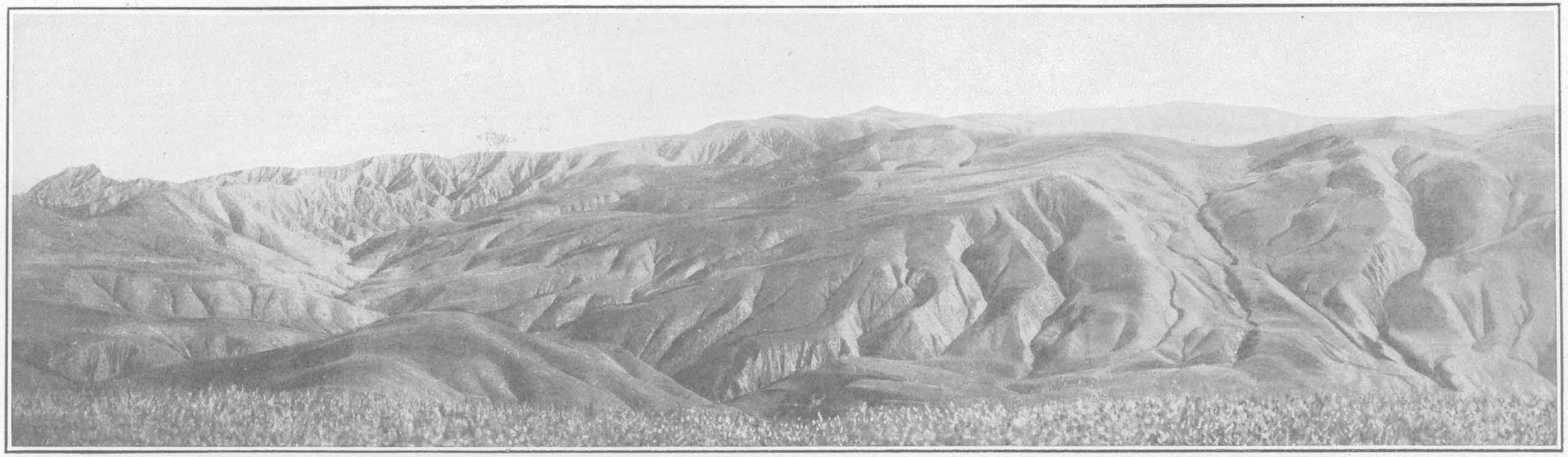


FIGURE 3.—Section of Vaqueros formation below the Tertiary volcanic rocks as exposed on divide between Salt and Pleito creeks. Numbers correspond to those in section given in the text.

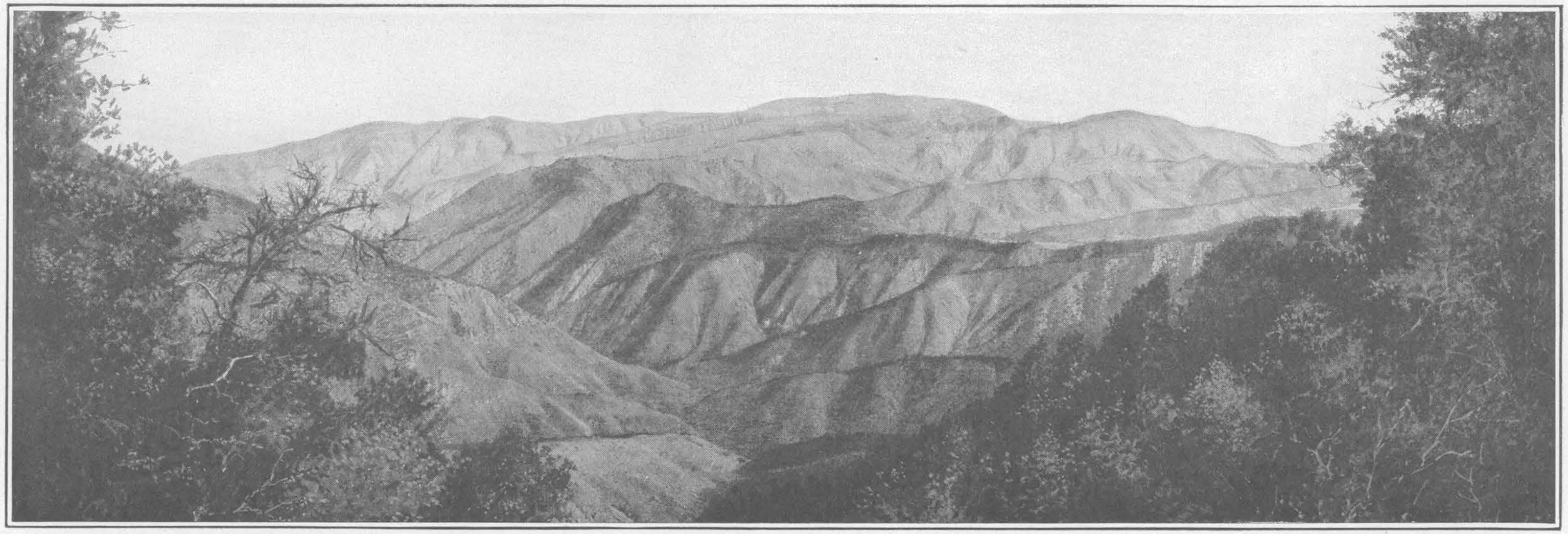
AREA WEST OF SANTIAGO CREEK.

West of Santiago Creek the base of the beds here included in the Vaqueros formation is not exposed, but from the lowest bed which crops out along the axis of the anticline that extends through secs. 9 and 10, T. 10 N., R. 23 W., to the base of the Maricopa shale there is at least 3,700 feet of sandstone and shale. The Vaqueros formation here is divisible into two main parts. The lower part is at least 2,700 feet thick and



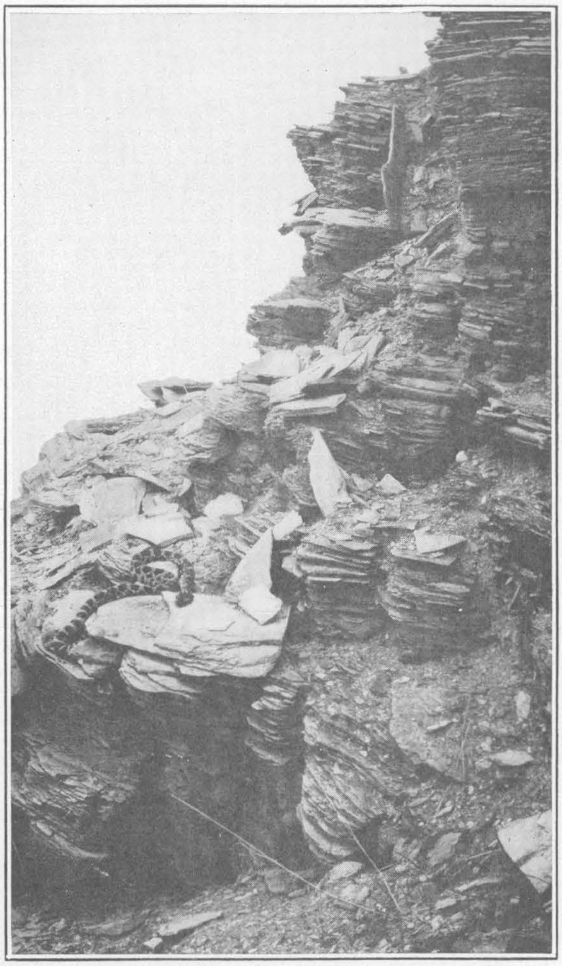
A. OUTER FOOTHILLS EAST OF SAN EMIGDIO CREEK.

The smoothly rounded hills to the right are carved in the upper part of the Vaqueros formation; badlands at the left in later Tertiary gravels.



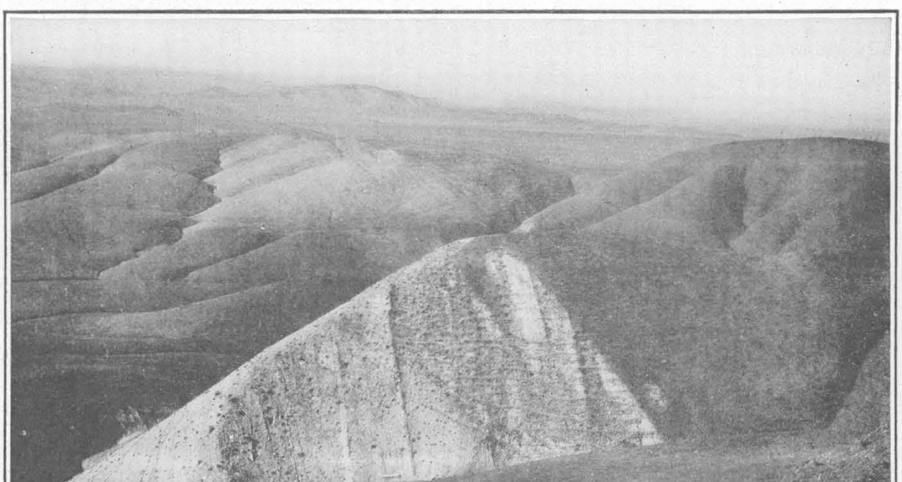
B. FOOTHILLS ON NORTH SLOPE OF SAN EMIGDIO MOUNTAINS.

Looking northeast across Pleito Creek from divide between Pleito and San Emigdio creeks about 2 miles north of Antimony Peak. The hills in the foreground are carved in the Tejon formation. The sharp ridge on the right in the distance is formed of Tertiary volcanic rocks lying in the Vaqueros formation.



A. OUTCROP OF DIATOMACEOUS MARICOPA SHALE IN PLEITO HILLS.

This shale is of the more thinly laminated type. Photograph by G. C. Gester.



B. UNCONFORMITY BETWEEN DIATOMACEOUS MARICOPA SHALE AND CLAY SHALE OF ETCHEGOIN FORMATION IN SAN EMIGDIO REGION.

Looking west across Muddy Creek. The bedding of the diatomaceous shale is indicated by the hard calcareous layers. The bedding of the clay shale is practically parallel with the contact, which is shown by the sharp change in color.

is composed of massive arkosic, somewhat concretionary gray sandstone that weathers to dark-brown outcrops. The upper part is about 1,000 feet thick and is formed largely of dark carbonaceous and in part diatomaceous shale that contains many thin beds of iron-gray sandstone and dark calcareous layers which weather light yellow. The shale is almost black when fresh but usually weathers to a dark chocolate color or even grayish white, approaching in appearance the weathered outcrops of the overlying Maricopa shale.

The lower sandy portion of the Vaqueros crops out in the central part of T. 10 N., R. 23 W., and forms a belt of fairly rugged hills which trend westward through secs. 10, 9, 8, 15, 16, and 17 of that township. It is exceptionally well exposed on Bitter Creek near the east line of sec. 8. Massive iron-gray fine-grained arkosic sandstone that weathers to irregular brownish outcrops forms the most prominent part of the formation here, but bedded with this sandstone are shaly sandstone and clay shale. The shale is precisely like that which forms the upper part of the formation in this part of the region. It is black when fresh but weathers to a dark chocolate color, is sandy, and occurs in very irregular lenses. This mixed succession of massive sandstone and carbonaceous shale is excellently exposed in the canyon of Bitter Creek in secs. 17 and 20, T. 10 N., R. 23 W., where the lenticular character of the beds is well shown. In one place in the wall of the canyon a bed of sandstone 2½ feet thick wedges out within a distance of 10 feet along the strike. The lenticularity of the larger bodies of sand is of necessity not so clearly shown in the outcrops as that of these small lenses, yet in relation to their thickness the large bodies of sand are no more continuous than the small ones. On the whole this lower part of the Vaqueros formation becomes gradually more shaly toward the top, grading into the overlying shaly division of the formation. Fossils occur sparingly throughout the lower division and were found most abundantly near the top of it, where they occur in irregular light-gray sandy limestones a few inches thick. The species found are not, however, very characteristic of the lower Miocene but have a fairly long range.

The upper shaly division of the formation is best exposed between the headwaters of Bitter and Santiago creeks and near the mouths of these creeks, on the south flank of the Cienaga syncline. Most of this division is composed of thin-bedded clay shale that is almost black when fresh but weathers quickly to a chocolate color or even to a grayish white. The shale is usually somewhat sandy and in a measure resembles the dark shale that occurs near the top of the Tejon on San Emigdio Creek. Interstratified with the shale are irregular or lenticular beds of fine sandstone a few inches thick and also thin beds of calcareous sandstone that weathers reddish brown. Most of these calcareous layers are filled with irregular bits of gray shale which give a mottled or blotchy appearance to the rock or which weather out and form a minutely cavernous surface on the outcrop. In places sandstone forms 50 per cent of this division, but usually not over 20 per cent.

Part of the shale that forms the upper division of the Vaqueros formation here evidently contains a large amount of diatom remains, like the overlying Maricopa shale, and it is possible that a large part of the dark carbonaceous shale at one time contained the remains of these minute marine plants, although under the microscope no trace of them can now be seen. Their absence now can not be taken to mean that these organisms may not originally have been contained in the shale, for the siliceous skeletons, which are the only traces of these plants that are now found in the truly diatomaceous shales, are so delicate that they would have been dissolved readily in the organic acids that must have been formed in the decay of the coarser vegetable matter that furnished the carbonaceous matter with which the shale is now filled. The shales contain large quantities of alkaline salts, and although small springs are numerous in the deep canyons near the San Andreas fault, all furnish water so charged with mineral salts as to be valueless.

The upper division of the Vaqueros is poorly exposed along the south flank of the Cienaga syncline, but the beds here appear to be slightly more sandy than they are on upper Santiago Creek. They seemingly grade upward into the overlying Maricopa shale, the line of separation having been drawn in secs. 3 and 4, T. 10 N., R. 23 W., at the top of a sandy zone containing fragments of pectens and stained slightly reddish. Above this zone the beds are more markedly shaly.

AREA ALONG PIONEER ANTICLINE.

The Vaqueros formation as exposed along the Pioneer anticline east of Cienaga Canyon is composed of rather shaly sandstone and dark clay shale that are the equivalent of the upper or shaly division of the formation as exposed south of the Cienaga syncline. The massive sandstones characteristic of the lower part of the formation do not crop out here, and the beds weather easily to form a belt of low relief, which west of Cienaga Canyon is bounded by ridges formed of the more resistant Maricopa shale. The Vaqueros formation is much more sandy than the overlying Maricopa shale, yet a very large proportion of the formation is composed of carbonaceous and probably in part diatomaceous shale. It is believed probable that the formation becomes much finer grained toward the north, and that coarse sandstones are even less abundant in it where it lies buried beneath the younger deposits that fill San Joaquin Valley than they are where it crops out along the Pioneer anticline. The probability that the rocks of the formation are fine grained where it is covered by the more recent deposits is suggested by the fact that they become progressively finer grained westward along the north flank of the San Emigdio Mountains, and in the Temblor Range west of the area mapped the formation contains a large amount of clay and diatomaceous shale. The less indurated sandy beds are impregnated with gypsum that has been concentrated near the surface by the upward movement and evaporation of meteoric water. The deposits of gypsite, as this gypsiferous sandstone is called, are most abundant east of Cienaga Canyon, and that area is dotted with trenches that have been dug as assessment work to hold the land, which has been located under the provisions of the placer-mining law. Like the shale near the headwaters of Bitter Creek, the Vaqueros formation here contains considerable sulphur, and locally in secs. 27 and 28, T. 11 N., R. 23 W., both it and the overlying gravelly beds, which are probably part of the Paso Robles ("Tulare") formation, are heavily impregnated with sulphur.

AREA ABOUT SUNSET CANYON.

In the vicinity of Sunset Canyon dark-colored sandstones which aggregate about 5,000 feet in thickness are mapped as the Vaqueros formation. The base of the formation is not exposed here, for the beds are faulted up against the overlying Maricopa shale. The lower 1,000 feet of the formation consists mainly of fine-grained sandstone and shaly sandstone that weather easily to a belt of low relief. Above this lower division is about 2,300 feet of soft greenish-gray sandstone, that weathers greenish brown, with many beds of indurated sandstone 4 to 6 feet thick. Near the middle of this division are two zones of somewhat cavernous-weathering indurated sandstone, each about 100 feet thick. Above this division is 700 feet of interstratified poorly consolidated fine-grained sandstone and resistant calcareous sandstone in beds 3 to 10 feet thick that weather to prominent reef-like outcrops. These calcareous beds contain abundant finely ground shell fragments, mainly oysters, barnacles, and pectens. The rocks of this division become finer grained and less calcareous toward the top, grading into those of the overlying division. The upper 1,000 feet or so of the formation is composed of interstratified sandstone and diatomaceous clay shale. In the lower half of this division shale predominates and the interbedded sandstone is fairly well indurated; in the upper half sandstone predominates. In the upper part of this division the sandstone is softer and lighter colored than that in the lower part, and the shale weathers almost pure white, in contrast to the pinkish outcrops of the shale in the lower half.

IMPORTANCE WITH RELATION TO PETROLEUM.

The shaly beds that constitute the upper part of the Vaqueros formation west of Cienaga Canyon are in part diatomaceous and contain a very considerable amount of carbonaceous material. Shales of this type, especially those that are formed largely of diatomaceous material, are regarded as the source of petroleum in the oil fields in this part of California, and in places in the area shown on the geologic map (Pl. II), notably along the axis of the Pioneer anticline, the Vaqueros formation contains beds saturated with oil. This part of the formation should be critically examined, and the character, thickness, and structural relations of the beds composing it should be determined. These features of the Vaqueros appear most favorable for the concentration of oil along the Pioneer anticline.

The Vaqueros formation differs from the overlying Maricopa shale, which is probably the source of most of the oil in the Sunset-Midway field, in that it contains a very considerable amount of sandstone interstratified with the shale. These sandy beds would probably serve as reservoirs in which much of the oil that originated in the shale would collect in places where the structure favored its concentration and retention. The Maricopa shale contains relatively little sandstone, and the porous beds that serve as the reservoirs in which oil has collected are chiefly those that rest unconformably upon the shale. This difference in the abundance and position of the sandy beds acting as reservoirs for oil is of considerable importance, for within the formation in which the oil originated the conditions favor the formation of a number of relatively small, discontinuous pools, whereas in the beds unconformably overlying that formation the conditions favor the formation of a much more widespread and probably much richer pool.

Within the main part of the Sunset-Midway field, in which oil is obtained from the beds overlying the Maricopa shale, the Vaqueros formation is far too deeply buried to be reached by the drill, and it may be disregarded as a prospective source of petroleum.

MARICOPA SHALE (MIDDLE MIOCENE).

GENERAL CHARACTER AND STRATIGRAPHIC RELATIONS.

The Maricopa shale is composed mainly of thin-bedded siliceous, diatomaceous shale containing numerous thin calcareous layers and in the lower part a relatively small amount of arkosic sandstone, but in the upper part numerous lenses of arkosic sandstone and boulder beds. It is typically developed in the gulch that drains northward through secs. 13 and 24, T. 11 N., R. 24 W., where the exposed thickness is about 4,800 feet. The shale rests conformably upon the Vaqueros formation and is overlain unconformably by the Etchegoin formation.[1] Good evidence of the relation of the Maricopa shale to the Etchegoin is difficult to obtain from the outcrops, for in most of the foothill belt west of the Midway field the shale-pebble beds of the Paso Robles ("Tulare") formation overlap the Etchegoin and rest directly upon the Maricopa shale. A study of the underground conditions as revealed by the well records shows that the Etchegoin was deposited in a sea that was transgressing westward over the Temblor Range, and in consequence the lower beds of the Etchegoin wedge out in that direction. This relation is shown in the geologic sections of Maricopa Flat (Pls. XXVIII-XXXI).

Southeast of the town of McKittrick, at the north end of the area shown on the geologic map (Pl. II), the Maricopa shale is overlain unconformably by a fine-grained grayish or brownish arkosic sandstone with beds and lenses of coarse sand and pebbly layers, mapped as the Etchegoin formation. At the west end of the prominent 1,210-foot hill in the NE. ¼ sec. 29, T. 30 S., R. 22 E., just east of the main wagon road between McKittrick and Midway, these beds contain abundant specimens of *Pecten eldredgei*. The relation of the Etchegoin here to the underlying Maricopa shale has been described by Arnold and Johnson.[2]

> Less than one-fourth mile due south of the Dabney (now the Providence) headquarters, and just east of the Midway road, is an isolated hill of grayish sandstone which appears to be a closely appressed syncline of McKittrick formation [Etchegoin formation of McKittrick group folded into the underlying Santa Margarita (?) [Maricopa shale]. Immediately south of this hill and parallel to it is a small lens of fine-grained brownish sandstone about 18 feet thick, which is apparently interbedded in the vertical shale but shows at one place that it has been either pushed or sifted into fractures which cut across the bedding of the inclosing shale. The lens contains small shale inclusions. It has the peculiar oblique and more or less angular jointing common to sandstone dikes and shows on the weathered surface a semiconcretionary structure. If this small area is a sand-filled fracture, the source of the material is obscure. The sandstone is well impregnated with oil. One-half mile east of here and north of the axis are similar masses of sandstone, but their relation to the shale is much clearer. At this point the anticline is overturned toward the northeast so that the sandstone, which is roughly parallel to the bedding of the shales, dips very steeply southwest. Its contact with the shales, especially on the south, is very irregular and indicates that the surface of the shales must have been pitted and honeycombed before the sands accumulated. Irregular masses and lenses of shale within the sand itself are harder to explain but may be fragments fallen from an overhanging bluff of shale during deposition of the sand upon a weather-beaten and precipitous rocky shore. The presence of an irregular scattering conglomerate of dark porphyry, schist, quartz, and granite pebbles at the base of the sandstone further emphasizes the likelihood of such an origin. Above the sandstones

[1] As treated in this report the Etchegoin formation probably includes a representative of the Jacalitos formation at the base.

[2] Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Calif.: U. S. Geol. Survey Bull. 406, p. 68, 1910.

(to the northeast) are conformable beds of rather soft greenish to cream-colored argillaceous shales of McKittrick [Paso Robles] age, and hence it is practically assured that the sandstones are the basal beds of the post-Santa Margarita (?) [Maricopa shale] formation. They continue to the southeast along the flank of the fold for nearly 2 miles and form an important oil-bearing bed.

The unconformity between the Etchegoin and the lower part of the Maricopa shale is excellently well shown in the foothills of the San Emigdio Mountains near Muddy Creek. Plate X, *B*, shows a view of the unconformity in that locality.

The unconformable relation existing in the San Emigdio Mountains between the Santa Margarita formation and the overlying Etchegoin formation is discussed in the section dealing with the Santa Margarita formation (p. 42).

CONDITIONS GOVERNING DEPOSITION.

The conditions under which the Maricopa shale was deposited are not thoroughly understood. Fine shales composed so largely of the remains of diatoms are not at all common in other parts of the world, and it would appear at first sight as if the shale here was deposited under special and local conditions. But the Maricopa shale, or lithologically similar shale that is its stratigraphic equivalent, is widespread in the Coast Ranges of California, and, moreover, shales of like character, which also have a wide distribution, occur in this same province at still other horizons between the top of the Cretaceous and the top of the Miocene. It seems unlikely, therefore, that the conditions which governed the deposition of the Maricopa shale were very much out of the ordinary.

From the fine-grained character of the shale it was evidently deposited in quiet water, not necessarily in deep water, nor even at any considerable distance from shore, but at least in a basin into which few large or torrential streams emptied.

Because of the fact that the diatomaceous deposits which are forming in the present oceans are found at great depths, it has been supposed by many that these deposits of diatomaceous shale were also laid down in very deep water and that they are in fact lithified diatom oozes. It should be noted, however, that the Maricopa shale and indeed all the thick formations of diatomaceous shale in California contain a large amount of detrital matter, and, although certain beds may be made up principally of the remains of diatoms, when viewed as a whole the formations appear rather as diatomaceous clay shales than as clayey diatomaceous deposits. The facts that they contain so much detrital material and that coarse beds which clearly were deposited in the littoral zone appear at so many horizons show that these deposits of diatomaceous material can not be considered deep-sea deposits.

Recently Branner [1] has suggested an ingenious hypothesis to account for the occurrence of these deposits. After pointing out that diatoms flourish in the colder waters of the ocean, he says:

> As these organisms perish their siliceous skeletal remains sink slowly to the bottom, especially in those places where the currents are not strong enough to sweep them along. In this connection attention is directed to the geography of the coast of California during the geologic period when our greatest deposits of diatomaceous shales were being laid down. The geology of California suggests that the region of the present Coast Ranges was an archipelago, separating the sea that filled the great valley on the east from the open ocean on the west. The marine currents that flowed southward from Alaska brought down great quantities of marine algae, the diatoms floating as usual near the surface. Once within the zone of islands these floating materials were probably driven into the cul-de-sac at the lower or southern end of the present San Joaquin Valley, where the granite mountains of the Sierras bend westward and northwestward. Here the prevailing winds of the region are from the north during the greater part of the year, and materials carried at or near the surface of the water could not escape if, as is assumed, the embayment was fairly well closed at the extreme southern end. It is exactly here, at and around at the extreme southwestern corner of the San Joaquin Valley, that the deposits of diatom skeletons are thickest. The total thickness of these shales is here more than 5,000 feet. In general these diatomaceous shales thin out toward the north and are inconspicuous in the geology north of San Francisco.
>
> It is not to be expected that the theory here put forward to explain accumulation under the circumstances mentioned is competent to account for all diatomaceous deposits and much less for all deposits of petroleum. Even in this instance it is evident that all of the diatoms were not caught in the angle of the coast; some of them were never carried to the landward of the coast archipelago, while others escaped to sink farther down the coast.
>
> It is believed, however, that the prevailing winds, in this instance at least, have been an important factor in the accumulation of the oil-bearing deposits.

This hypothesis, although at first sight somewhat surprising, has much to recommend it, for it suggests an explanation of the intercalation of fine diatomaceous shale with coarse sandstones and boulder beds such as is characteristic of the upper part of the Maricopa shale. As has been shown in the

[1] Branner, J. C., Geol. Soc. America Bull., vol. 24, pp. 94-95, 1913.

description of the Vaqueros formation, the eastern portion of the region shown on the geologic map (Pl. II) stood at a considerable elevation above the sea during Oligocene and early Miocene time, while the western portion of the San Emigdio Mountains and much if not all of the Temblor Range was submerged. Owing to a gradual subsidence of the whole region, the sea gradually encroached upon the land mass in the eastern part of the San Emigdio Mountains until, at the end of the time during which the Vaqueros formation was deposited, the sea must have submerged most of those mountains and covered the south end of the Temblor Range to a depth of several hundred feet. This submergence continued through much of the Miocene epoch, and, although oscillatory movements varied the depth of water, it seems probable that for no considerable part of this time did this area lie close to the margin of the sea. Also it is probable that the land masses in this general region had been reduced to relatively low relief by the erosion that they had suffered during early Miocene time. Thus relatively little detrital matter was brought into the basin of deposition and that which was laid down was fine grained.

Toward the end of the period during which the Maricopa shale was deposited there appears to have been a rejuvenation of the streams that emptied into the sea in which the shale was being laid down. These streams carried into the sea great quantities of sand, gravel, and boulders of granitic material, but the streams were few, and the time during which any one stream carried in coarse material does not seem to have been very long. In consequence the beds of coarse material are very lenticular.

DISTRIBUTION.

The Maricopa shale within the area mapped crops out in a broad belt that occupies the higher part of the Temblor Range and extends southeastward to the vicinity of Santiago Creek. This area is the southeast end of the belt of outcrop that occupies much of the south end of the Temblor Range. The formation continues to the east, underlying much if not all of the south end of San Joaquin Valley, and the sandy beds that crop out in the foothills near Kern River on the east side of the valley are in part its equivalent. The Maricopa shale is the equivalent of the diatomaceous beds mapped as the Monterey shale[1] in the Santa Maria region, some 40 miles to the west.

LITHOLOGY.

GENERAL CHARACTER.

The Maricopa shale in the central part of San Joaquin Valley is regarded as the great feeding ground from which was obtained a large part of the oil that is now concentrated in the foothills at the border of the valley. As the oil is believed to have been derived from the remains of organisms contained in the shale, the character of the shale beneath this valley filling is an important factor in any consideration of the petroleum in the foothills. There is, of course, no direct evidence regarding the character of the buried shale, but from the facts that the shale is very diatomaceous at its easternmost exposure in the San Emigdio Mountains and that the beds of the Monterey group near Kern River, although evidently laid down close to the eastern margin of the basin of deposition, are largely fine grained, it seems probable that the Maricopa shale maintains in most if not all of the south end of the valley beneath the cover of younger formations the character typical of it in the Temblor Range.

In the Temblor Range and in the east end of the San Emigdio Mountains the Maricopa shale is divided into two parts, the lower part composed chiefly of hard siliceous shale containing few coarse sandy lenses, and the upper part made up largely of soft, "punky" shale with many lenses of coarse gravel or boulder beds. It must be remembered, however, that the separation is based on lithology and the line shown on the map does not mark a definite stratigraphic horizon.

LOWER DIVISION.

AREA IN THE SAN EMIGDIO MOUNTAINS WEST OF SAN EMIGDIO CREEK.

The lithologic character of the Maricopa shale is relatively constant throughout the eastern flank of the Temblor Range and the west end of the San Emigdio Mountains. As a rule deposits of diatomaceous shale are remarkably constant when compared with the other Tertiary formations in this region, and although the middle part of the Maricopa shale

[1] U. S. Geol. Survey Bull. 322, pp. 33-52, 1907.

is more siliceous, finer grained, and thinner bedded than either the upper or lower parts, the beds do not vary greatly along the strike in the manner so characteristic of the other Tertiary formations in the region.

The lower part of the Maricopa shale where exposed along the Cienaga syncline is composed of sandy shale and fine angular-grained gray sandstone in alternating beds that range in thickness from a few inches to a few feet. Many of the sandstone beds are indurated by a calcareous cement and weather out slightly from the sandy shale, as likewise do numerous beds of impure limestone, or limy clay shale, black when fresh but weathering light yellow. Near the base of the formation as mapped on the south limb of the Cienaga syncline some of the sandy beds are stained reddish and a few fragments give an oily odor when broken.

The Maricopa shale is well developed on the north limb of the Pioneer anticline south of Pioneer, and the type section of the formation is exposed in the canyon that drains northward through secs. 13 and 24, T. 11 N., R. 24 W., past the old Sunset refinery. The following section was measured in this canyon:

Section of the Maricopa shale south of Pioneer.

	Page.
Sandstone and shale, soft "earthy" diatomaceous shale interbedded with rather poorly consolidated white sandstone, usually of medium grain but in places finely conglomeratic. Locally indurated and containing a few fossils, mainly large oysters and pectens. Calcareous lenses are rare	500
Shale, diatomaceous; weathers to pinkish outcrops. Contains relatively few calcareous layers like those common in underlying division	600
Shale, diatomaceous, like that in overlying division but containing numerous lenses of impure limestone or fine sandy calcareous clay that weathers to yellowish outcrops. This zone weathers less easily than the overlying and underlying divisions and determines a prominent line of hills	800
Shale, siliceous, thin bedded, brittle, diatomaceous, dark when fresh but weathers to light chocolate-colored or almost white outcrops. Calcareous beds or lenses like those in the overlying beds are scattered throughout. Shale somewhat clayey and sandy near the base	2,750
Clay shale, somewhat sandy, containing less diatom remains than the overlying division and weathering to darker outcrops. Grades into sandy shale of underlying Vaqueros formation	150
	4,800

AREA IN THE TEMBLOR RANGE.

In the higher part of the Temblor Range west of the Sunset and Midway fields the Maricopa shale has been flexed into a great number of folds. The position of the larger folds is shown on the map, but there are a great many small wrinkles or crumpled areas much too small to be mapped, and the structural details are far more complex than would appear from a strict interpretation of the lines that are shown. The lower part of the Maricopa shale is exposed in the southwest corner of T. 32 S., R. 23 E., where it consists of interbedded massive sandstone and sandy shale that weather to chocolate-colored outcrops. These beds are similar to those that occur near the base of the formation south of Maricopa, and, as in that region, they constitute a gradation into the underlying Vaqueros formation.

The main part of the lower division is composed of thin-bedded brittle shale, highly siliceous, in places really flint or chert. Calcareous layers, usually a little more sandy than the inclosing shale, are abundant, and as they weather a little less easily than the shale they form prominent yellowish outcrops that can be traced with the eye for long distances across the barren spur ridges on the eastern slope of the Temblor Range. At many places the shale is stained purplish, probably by the oxidized product of some hydrocarbon, either oil or gas. Such coloring is most pronounced where the shale is overlain, unconformably by the late Tertiary or younger beds, as in the E. ½ sec. 32, T. 12 N., R. 24 W., but it is noticeable also in the steeply tilted shale at various horizons within the formation.

Toward the top of the lower division many beds of arkosic sandstone are interstratified with the thin-bedded diatomaceous shale. These beds range from fine pulverulent gray sand that forms inconspicuous outcrops to pebbly sandstone that is indurated by the addition of a calcareous cement and weathers out prominently. The soft pulverulent sands are fairly well exposed north of the 1,773-foot hill 2 miles west of Maricopa. From this locality they may be traced northwestward into secs. 34 and 35, where they are indurated and weather to prominent outcrops just south of the old Californian Amalgamated water wells. Farther northwest, in the northeastern part of T. 32 S., R. 23 E., sandy beds occur at several horizons in the upper half of this lower division of the Maricopa shale.

These arkosic sandstones are identical in lithologic character with the finer-grained sandstones that are interstratified with soft diatomaceous shale and coarse boulder beds in the overlying upper division of the formation, and in places, notably in the center of sec. 13, T. 32 S., R. 22 E., they resemble the beds in the upper division in containing fragments of large oysters and pectens. Thus, it is apparent that no sharp line can be drawn here between the two divisions, and it seems more reasonable to believe that the whole succession of diatomaceous shales mapped as the Maricopa shale were deposited in the Temblor Range during one general period of sedimentation. Yet even though no sharp line of separation can be drawn between the two divisions, when viewed broadly they are lithologically somewhat different, the diatomaceous shale of the upper division being much more earthy and far less silicified than that of the lower, and the coarse boulder beds far more abundant.

AREA EAST OF SAN EMIGDIO CREEK.

Diatomaceous shale crops out in an area several square miles in extent between San Emigdio and Tacuya creeks. This shale ranges in character from the hard flinty type, containing many calcareous beds that weather out to prominent yellowish outcrops, characteristic of the lower division of the Maricopa shale in the Temblor Range, to the soft, punky white variety, containing numerous lenses of granitic sand and conglomerate which in places carry fossils, chiefly large oysters, like the coarse lenses in the upper division of the Maricopa shale. Characteristic outcrops of the platy and fairly pure diatomaceous shale in the Pleito Hills are shown in Plate X, *A*.

It is probable, indeed almost certain, that the shale between San Emigdio and Tacuya creeks is the equivalent to both the upper and lower divisions of the shale in the Temblor Range. The area in which the shale is exposed east of San Emigdio Creek is, however, so shattered by faults and contains so many huge landslides that it is quite impossible to interpret the structure and relations of the shales without spending a great amount of time—far more than the writer had at his disposal. On the map, therefore, the separation of the Maricopa shale into the upper and lower divisions is indicated in only a small area along the axis of the Pleito syncline.

The shale mapped as Maricopa in the hills due west of El Rincon is less indurated than the Maricopa shale in which the upper slopes of the Temblor Range are cut, is as a rule somewhat more sandy, and weathers to a light chocolate-brown rather than white. Carbonaceous matter is fairly abundant in it, and in a few places silicified wood and leaf impressions were found. The character of the exposures make an estimate of the thickness of the shale here impossible.

Near Muddy Creek is a narrow belt of outcrop of white diatomaceous shale which dips steeply northward, being almost vertical in places, and is overlain with marked unconformity by dark clay shale of the Etchegoin.

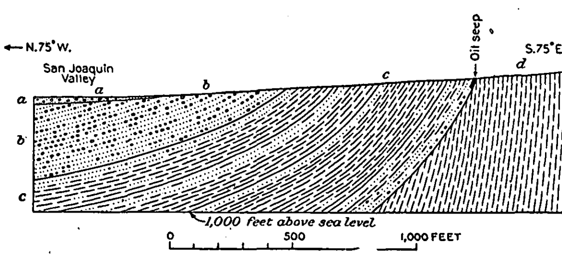


FIGURE 4.—Section of rocks exposed on Muddy Creek. *a*, Alluvium; *b*, Paso Robles formation; *c*, Etchegoin formation; *d*, Maricopa shale (lower two-thirds).

The shale itself is precisely like the typical Maricopa shale exposed near Pioneer, is highly siliceous, weathers almost pure white, and contains numerous yellowish-weathering calcareous beds. Its general character and the unconformable relation it bears to the overlying Etchegoin are well shown in the diagrammatic section given in figure 4.

UPPER DIVISION.

AREA NORTH OF CROCKER SPRINGS.

North of Crocker Springs the upper part of the Maricopa shale is exposed in several areas where erosion has removed the cover of gravelly beds of the McKittrick group. Although the beds included in the Maricopa shale in the different areas are sufficiently alike to make their correlation certain, yet they are by no means of constant type, and there is a gradual increase westward in the amount of coarse material.

Along the Shamrock anticline in secs. 27, 28, 29, and 34, T. 30 S., R. 22 E., the Maricopa shale is composed of soft, punky diatomaceous shale with very little interstratified sandstone and none of the lenses of coarse boulders so common farther west. It weathers easily to a very loose, fluffy soil, and its outcrops usually occupy an area of low relief, for the shale is much less resistant than the overlying sandy and gravelly beds of the McKittrick.

In the eastern part of the Telephone Hills the Maricopa shale is composed of clayey diatomaceous shale which is much more resistant to erosion than that in the Shamrock anticline and which, although stained pinkish, does not show so great impregnation by oil as the shale south of McKittrick. The Maricopa shale is here faulted up on the east against the coarse detrital beds of the Paso Robles and is overlapped on the west by beds of that formation in the syncline that trends northwestward through the center of the Telephone Hills.

Along the anticline trending parallel to the road south of the Santa Fe tank house in sec. 18, T. 31 S., R. 22 E., the Maricopa is chiefly very soft white diatomaceous shale. In the area exposed north of the tank house diatomaceous shale of this type is interstratified with coarse gravelly beds, composed largely of fragments of granitic rock and resembling closely the beds that form so prominent a part of the upper division of the Maricopa shale west of Midway. The coarse beds are in a general way so like those in the overlying Paso Robles that the separation of the two formations is very difficult, and much of the section here included in the Maricopa shale was mapped as McKittrick in the preliminary report.[1] Moreover, the rocks are broken by a great number of faults, making it difficult, indeed, in this area where the exposures are uniformly poor, to follow any bed for a considerable distance or to correlate the beds exposed in one gulch with those shown in another that lies but a few hundred feet distant.

AREA IN THE MIDWAY DISTRICT.

The upper division of the Maricopa shale that is exposed along the foothills between Crocker Springs and Spellacy Hill (Twenty-five Hill) is really the southward continuation of the belt exposed in the Telephone Hills, and as in that area it is composed largely of soft, punky diatomaceous shale which has a pinkish-brown color when fresh but weathers pure white.

[1] U. S. Geol. Survey Bull. 406, 1910.

The thickness of the upper division of the Maricopa shale exposed varies greatly owing to the unconformable relation of the overlying Paso Robles. The thickest section observed is that west of Fellows, where between the siliceous lower division of the Maricopa shale and the shale-pebble beds of the Paso Robles about 3,000 feet of diatomaceous shale, indurated sandstone, and coarse gravel is exposed.

The upper division of the Maricopa shale here may be divided into two main parts, the lower of which is composed predominantly of diatomaceous shale and the upper of interstratified diatomaceous shale, arkosic sandstone, and coarse boulder beds. The lower of these two parts corresponds to the Santa Margarita (?) formation as mapped in the preliminary report on the McKittrick-Sunset region, but the upper part was included in that report with the overlying McKittrick.

The lower part of the upper division has a maximum thickness of about 1,500 feet, but along most of the foothill belt it averages about 1,000 feet. The variation in thickness is due to the lenticular character of the beds, for the separation of the two parts is based upon lithologic differences and does not follow a stratigraphic line. The shale toward the base of the lower part of this upper division of the Maricopa shale closely resembles that in the underlying lower division, being well lithified, thin bedded, and brittle and in places highly silicified, porcelaneous, or even flinty in appearance. Like the underlying division it contains yellowish-weathering calcareous layers, but such layers are far less plentiful than in the lower division. Moreover, this lower part of the upper division of the Maricopa shale is much less indurated than the shale in the lower division, and the separation between the two is recognizable in the topography by a distinct flattening in the crest lines of the spur ridges that trend eastward from the higher part of the Temblor range and cut across the strike of the beds. The yellow-weathering calcareous beds which are so prominent in the lower division of the Maricopa shale and which occur sparingly in the basal beds of the upper division are lacking in the softer shale. Arkosic sandstones and pebbly beds like those that compose so much of the upper part of the upper division occur sparingly. They are best developed about 2 miles west of Midoil, where, in the NW. ¼ sec. 18, T. 32 S., R. 23 E., a pebbly zone may be traced for a distance of about half a mile.

The upper part of the upper division of the Maricopa shale is composed of interstratified diatomaceous shale, arkosic sandstone, and ill-sorted conglomerate. These beds are best developed west of Fellows, where their exposed thickness is about 1,500 feet. In secs. 1 and 2, T. 32 S., R. 22 E., where they are best exposed, the lower 100 to 200 feet is massive sandstones and gravel. These beds crop out just southwest of the summit of the 2,100-foot hill near the center of the NW. ¼ sec. 2. Immediately above them is a bed of soft white diatomaceous shale not over 100 feet thick that crops out in a narrow belt which may be traced from the 2,100-foot hill southeastward into the SW. ¼ sec. 1. Above this diatomaceous shale is about 500 feet of coarse granitic gravel and indurated arkosic sandstone, with a few thin beds of diatomaceous shale, most of them less than 20 feet thick. Above these predominantly coarse-grained beds is another zone of diatomaceous shale about 200 feet thick. This shale is made up very largely of the remains of diatoms that have been altered so little by crushing or by the addition of siliceous material that they are readily visible to the eye without the aid of a magnifying glass. This shale may be traced, on the south flank of the syncline that trends northwestward through secs. 1 and 2, from the SW. ¼ sec. 27, T. 31 S., R. 22 E., to the vicinity of the southeast corner of sec. 1, T. 32 S., R. 32 E.; and along the anticline that lies east of the syncline mentioned, from the northern part of sec. 35, T. 31 S., R. 22 E., to the west line of sec. 6, T. 32 S., R. 23 E. It is the uppermost shale formed largely of diatomaceous material that is exposed in the Midway region. The beds above it that are here included in the Maricopa shale consist of coarse granitic conglomerate and arkosic sand, some of which is well indurated and weathers to prominent outcrops. These beds are in lithologic appearance the exact equivalent of the sand and gravel bedded with the underlying diatomaceous shale. On this account, and also because some of the indurated sandstone contains pectens and oysters similar to those that were found in the upper division of the Maricopa shale farther south and in the lower division in the E. ½ sec. 13, T. 32 S., R. 22 E., the gravel and sand above the uppermost diatomaceous shale just described are included in the Maricopa shale. The sandstones in which the best fossils were found lie in the NE. ¼ NW. ¼ sec. 2, T. 32 S., R. 22 E. The only forms found here were *Pecten estrellanus* and a large oyster, probably *Ostrea titan*. Either of these fossils might occur in the lower part of the McKittrick group, but it is thought that the beds are more properly to be considered as part of the Maricopa shale, because the same species are found in rock of the same type at several horizons in the Maricopa shale in other parts of the area shown on the geologic map.

The sandy beds in the upper division of the Maricopa shale along the foothills west of Midway are impregnated with oil at many places, especially where they are in contact with the diatomaceous shales, and it is from these sands that some of the wells in the region about Fellows derive their oil.

AREA IN THE PLEITO HILLS.

In the east end of the Pleito Hills near Salt Creek diatomaceous shale, granitic sand, and boulder beds occupy the trough of the Pleito syncline. The beds are believed to be the equivalent of those forming the upper part of the Maricopa shale in the Temblor Range, and the separation of the Maricopa into upper and lower parts is shown equally well in both places although it is made entirely on lithologic grounds. The presence of these beds occupying the trough of the Pleito syncline in contact with the underlying Vaqueros formation must mean that in this part of the region the Maricopa shale is separated by an unconformity from the Vaqueros. Yet in spite of this evidence the fact still remains that in most of the region, particularly in the west end of the San Emigdio Mountains, the Maricopa shale and the Vaqueros formation appear to be perfectly conformable, and, as explained on page 41, the writer believes that the unconformity is local and that sedimentation continued uninterruptedly in most of the region during the time in which the Vaqueros and Maricopa were deposited.

IMPORTANCE WITH RELATION TO PETROLEUM.

The fine-grained diatomaceous shales in the Maricopa shale are considered the ultimate source of oil in the south end of San Joaquin Valley. These shales are formed largely of the remains of diatoms and foraminifers, but they contain also in places a considerable amount of carbonaceous material, probably derived from terrestrial vegetation. The oil is believed to have been formed mainly by the decomposition of the minute marine organisms, but very probably the decomposition of the terrestrial matter also furnished some oil. The oil has collected in part in sandy beds that are intercalated with the shale but chiefly in the porous beds of younger formations that rest unconformably upon the shale.

The Maricopa shale is therefore both the ultimate source and a present reservoir of oil, and in attempting to estimate the potential oil value of a certain region it is important to know the character and attitude of the beds composing this formation, and also the relation this formation holds to the younger formations that rest upon it, for it is in the younger formation that rests unconformably upon the diatomaceous shale that the petroleum is now chiefly contained.

SANTA MARGARITA FORMATION (MIDDLE MIOCENE).

GENERAL CHARACTER AND STRATIGRAPHIC RELATIONS.

In the western part of the San Emigdio Mountains are beds of coarse or even pebbly sandstone which are clearly littoral deposits and contain abundant invertebrate fossils. These beds are the near-shore equivalent of the diatomaceous shales that constitute the upper part of the Maricopa shale in the Temblor Range. They are shown separately on the geologic map (Pl. II), because they are of distinct lithologic type and because the fauna they contain permits a definite correlation with the typical Santa Margarita.

These sandy beds composing the Santa Margarita are nowhere exposed resting upon the diatomaceous shale that forms the lower part of the Maricopa shale but overlap that part of the section and rest unconformably upon the older Tertiary formations—the Vaqueros and Tejon.

The Etchegoin formation (upper Miocene and Pliocene) evidently rests unconformably upon the Santa Margarita in the San Emigdio Mountains, and the relations are best shown in the foothills between Santiago and San Emigdio creeks. At the seep on Muddy Creek the *Pseudocardium gabbi* beds of the Etchegoin rest upon the Maricopa shale, but only a little more than a mile south of this seep they rest upon the fossiliferous Santa Margarita in the north flank of a small anticline. The overlapping of the Santa Margarita in this vicinity is shown in the geologic cross section E–E′ (Pl. II).

LITHOLOGY.

In the foothills of the San Emigdio Mountains between Bitter and San Emigdio creeks the Santa Margarita is composed of very friable conglomeratic sandstone, usually white when fresh but weathering yellowish. The color of the weathered surface is not uniform, for the rock is stained deep yellow in small irregular areas or along irregular lines, and between these stains it is almost as light colored as it is in an unweathered outcrop. The weathered outcrops have therefore a mottled appearance when viewed closely, or a light-yellowish tone when viewed at a short distance. These beds form a rather sharp contrast to the prevailingly somber-colored beds of the upper part of the Vaqueros formation, upon which they rest. The sandstone is commonly formed of angular fragments whose average diameter is between one-sixteenth and one-eighth inch, but scattered through the sand are many well-rounded pebbles 2 or 3 inches in diameter of acidic granitic or porphyritic rock and of quartzite. Unlike the overlying upper Miocene beds the Santa Margarita contains no fragments of the fossiliferous sandstone of the Vaqueros formation or of the basaltic and andesitic rocks that occur in the Vaqueros in the San Emigdio Mountains. The fact that fragments derived from the Vaqueros formation and the lower part of the Maricopa shale are abundant in the McKittrick group and yet are absent in the Santa Margarita is another indication of the existence of an unconformity at the top of the Santa Margarita.

In this western part of the San Emigdio Mountains the Santa Margarita is exposed in a narrow belt, in the main not more than 1,000 feet across, that extends from the east bank of San Emigdio Creek nearly to Bitter Creek. The maximum exposed thickness is about 900 feet, but usually the formation as exposed is much thinner. West of Los Lobos Creek, where the Santa Margarita is folded into a closely compressed syncline, it is only about 500 feet thick.

Fossils are fairly abundant in the Santa Margarita between Santiago and San Emigdio creeks, and such characteristic forms as *Pecten estrellanus*, *Astrodapsis whitneyi* (?), *Tamiosoma gregaria*, and a large oyster, probably *Ostrea titan*, were collected at many places. The shells are particularly abundant near Los Lobos Creek.

IMPORTANCE WITH RELATION TO PETROLEUM.

The sandy beds composing the Santa Margarita formation in the hills between San Emigdio and Santiago creeks are of relatively little commercial importance so far as petroleum is concerned, for the region in which they occur is so broken that the beds can not form good reservoirs for retaining oil.

The Santa Margarita becomes finer grained westward toward the Temblor Range, and beneath the valley filling only a short distance north of the foothills of the San Emigdio Mountains it is evidently composed in part of diatomaceous shale. Where the formation assumes this shaly character it is really to be considered a part of the Maricopa shale, and the remarks on page 41 regarding the economic importance of the shale apply to it.

McKITTRICK GROUP (UPPER MIOCENE, PLIOCENE, AND PLEISTOCENE ?).

DEFINITION AND GENERAL FEATURES.

Resting upon the Maricopa shale in the Temblor Range and the Santa Margarita formation in the San Emigdio Mountains are the beds of gravel, sand, and clay that have been described collectively as the McKittrick formation.[1] These beds were laid down in part in marine or estuarine waters, but also in part in fresh-water lakes or even subaerially, in a manner similar to that in which the alluvial filling of the present San Joaquin Valley was deposited. Their unconformable relation to the underlying Santa Margarita formation and Maricopa shale is discussed in the descriptions of those formations (pp. 35, 42). With the overlying terrace deposits and alluvium the McKittrick group is perfectly conformable, and a separation of it from these deposits is not exact. With a single exception all the beds that have been folded or noticeably tilted are here included in the McKittrick group, and only those beds that now lie in practically the same attitude that they had when originally deposited are mapped as alluvium and terrace deposits. The only beds that are tilted to a considerable angle which are included with the Recent deposits are those about the mouth of San Emigdio Creek. The evidence showing that these tilted beds are Recent is discussed on page 52.

During the early part of the period in which the McKittrick was deposited the Sunset-Midway region was submerged beneath marine waters, but later it was gradually raised and during most of the last half of the period practically all of it was either dry land or was covered by fresh-water lakes, the condition approaching that which now exists in San Joaquin Valley. In consequence the beds in the lower part of the McKittrick group are in general finer and much more uniform in character than those in the upper half. The change in the conditions governing sedimentation did not take place suddenly, however, nor was it uniform throughout the region, for at one and the same time part of the region may have been submerged by marine waters and part by brackish or fresh waters, while other parts may have been raised above the surface of these bodies of water to form land. Moreover, the movements that affected the region seem to have been oscillatory, permitting the alternate advance and retreat of the sea, so that parts of the region were at one time covered by marine waters, at another raised above sea level and undergoing erosion, then occupied by bodies of fresh water, at still another time once more submerged beneath the ocean. In consequence the sedimentary beds that were deposited during this period show an exceedingly wide range in lithology.

But despite these local variations, which make it difficult to separate the McKittrick into definite formations that may be followed with precision throughout the field, it is possible in places to divide the group into two main parts. The lower part, comprising those beds that were deposited chiefly in marine waters, is correlated with the Etchegoin formation of the Coalinga region; the upper part, comprising those beds that were deposited chiefly under conditions much like those now existing in San Joaquin Valley, is correlated with the Paso Robles ("Tulare") formation. The Jacalitos formation, which in the Coalinga region was separated from the Etchegoin formation mainly upon paleontologic evidence, is

[1] U. S. Geol. Survey Bull. 406, pp. 74-90, 1910.

not recognizable in the Sunset-Midway region, although it may be and probably is represented by the lower part of the beds here described as Etchegoin.

The total thickness of the McKittrick group can not be estimated from the exposed beds, but from the records of the deep wells together with the data afforded by the outcrops it appears that the group is at least 5,400 feet and probably more than 6,000 feet thick. Of this the uppermost 2,300 feet of beds are certainly to be correlated with the Paso Robles ("Tulare"), and the lower 2,100 feet with the Etchegoin. Nonfossiliferous beds that aggregate about 1,000 feet may be either part of the Paso Robles or part of the Etchegoin.

IMPORTANCE WITH RELATION TO PETROLEUM.

The McKittrick group contains the chief reservoirs of petroleum in the Sunset-Midway district. Oil that has originated in the diatomaceous Maricopa shale has moved upward and collected in the porous beds in the lower part of the McKittrick group, where structural features, principally anticlinal folds, have tended to make it concentrate. The clayey beds and also the coarse-grained beds whose porosity has been reduced by induration through the addition of a cement that has filled the pore space between the grains evidently act as impervious barriers about the oil-saturated sands, retarding or perhaps preventing the further migration of the oil. The lenticular character of the formation is therefore of great importance in considering the distribution of the oil, both vertically and areally.

The stratigraphic position of the oil-bearing beds is not constant throughout the field, for the presence or absence of oil in a certain bed is dependent not upon the position that the bed holds in the stratigraphic column but upon its position in that particular part of the area with reference to the diatomaceous shales. In most of the field the Etchegoin formation is thick enough to offer sufficient storage space for all the oil that has moved up out of the diatomaceous shales, and oil is found in it but not in the overlying Paso Robles. In parts of the field, however, chiefly along the edge of the main Temblor Range, the Etchegoin is either absent or so very thin that the oil has collected in the Paso Robles. The Etchegoin formation is, however, the chief oil-bearing formation of the district. Natural gas, being more mobile than petroleum, has migrated farther and, even where the Etchegoin is thick, has concentrated very largely in the porous beds of the Paso Robles.

Finally, as the barren beds in the upper part of the McKittrick in any part of this field form a more or less thick blanket over the oil and gas bearing beds, it is important that the thickness of the group be known in a part of the region in which drilling is contemplated, in order that the accessibility of the productive sands can be estimated.

ETCHEGOIN FORMATION.[1]

STRATIGRAPHIC RELATIONS.

In the Etchegoin formation are included the beds in the lower part of the McKittrick group that were deposited chiefly in marine waters. These beds rest unconformably upon the Maricopa shale and also upon the Santa Margarita in the San Emigdio Mountains, where that formation is mapped separately. The relation of the Etchegoin to the Santa Margarita and to the Maricopa shale is described in detail on pages 35 and 42.

With the overlying Paso Robles ("Tulare") the Etchegoin is perfectly conformable, and the separation of the McKittrick group into its parts is not easy to make. The accuracy of this separation and the reasons for making it are discussed in the description of the McKittrick group (p. 43).

DISTRIBUTION AND LITHOLOGY.

The Etchegoin formation is exposed at several points along the eastern flank of the Temblor Range south of McKittrick and also in the north flank of the San Emigdio Mountains. Some of these outcrops are indicated on the map, but others, because the belt of outcrop is extremely narrow or because sufficient time was not available to trace out the separation between Paso Robles and Etchegoin, are not mapped separately, the beds of probable Etchegoin age being included with the overlying Paso Robles.

The Etchegoin, however, underlies practically the whole district beneath the cover of the Paso Robles and Recent formations, becoming gradually thicker toward the central part of San Joaquin Valley.

The beds comprised in the Etchegoin are almost wholly near-shore marine deposits,

[1] As here described this formation probably includes a representative of the Jacalitos formation.

mainly sand, gravel, and clay, which are usually only slightly consolidated but which in places are indurated by the addition of a calcareous cement. On the whole the Etchegoin is much finer and more uniform in grain than the Paso Robles. Also as a general rule the Etchegoin is finer grained where it lies at some little distance from the main Temblor Range than where it is exposed along the foothills of that range.

OUTCROPS IN THE SAN EMIGDIO MOUNTAINS.

The Etchegoin formation is exposed in the foothills of the San Emigdio Mountains east of Santiago Creek. On Plate II it is mapped separately in the area lying between Santiago and Pleito creeks. It is probably exposed in the central part of Wheeler Ridge, but it was not found possible to segregate the Etchegoin and Paso Robles in that part of the district, and on the geologic map all the exposures here are shown as Paso Robles. Between Santiago and Pleito creeks the Etchegoin is composed chiefly of greenish-gray fossiliferous clay shale, in places somewhat sandy, especially toward the base. It has a maximum exposed thickness of about 800 feet and rests unconformably upon the white sands and gravels of the Santa Margarita formation, as is shown by the complete overlapping of that formation near Los Lobos Creek. Near Muddy Creek, where the Santa Margarita is completely overlapped, the Etchegoin rests with marked discordance in dip upon the diatomaceous shale in the lower part of the Maricopa shale. (See Pl. X, *B*.) The upper limit of the Etchegoin in this part of the area has not been determined definitely, and for the present only the fossiliferous greenish clay shales and intercalated sandy beds are mapped with that formation. The overlying beds, which are mainly coarse granitic conglomerate and arkosic sands, are mapped as Paso Robles. It is possible that, although the upper part of the coarse beds is certainly to be correlated with the Paso Robles, the lower part may be of Etchegoin age, for the gravelly beds show every evidence of conformity with the underlying fossiliferous clay shales and are lithologically similar to the Etchegoin in the Temblor Range. However, the clay shales and the gravel have been mapped separately, because in that way the complicated structure of this region is much more readily interpreted. The close relation of the clay shale to the overlying gravelly beds is well shown east of Pleito Creek, where between the two formations is about 250 feet of brownish sand and fine gravel intermediate in character between the shale below and the coarse sand and gravel above.

The clay shale that makes up the major part of the Etchegoin in the foothills of the San Emigdio Mountains is almost black when fresh but weathers greenish gray. It is somewhat sandy throughout and, especially near the base, contains beds of fine-grained arkosic sandstone and a few pebbly beds. Semiangular fragments of white diatomaceous shale, evidently derived from the Maricopa shale, are scattered through both the clay shale itself and the interstratified sandy beds. West of Los Lobos Creek the lower 100 feet of the Etchegoin is in places somewhat more sandy than the overlying beds and contains a few well-rounded cobbles, 2 or 3 inches in diameter, of hard rocks evidently derived from the basal complex exposed in the central part of the range. This part of the formation is filled with fossils; the most typical form is *Pseudocardium gabbi*, which occurs in great abundance in a bed exposed in Muddy Creek near the seep. (See Pl. XI.)

The Etchegoin between Santiago and San Emigdio creeks, to judge from its lithologic character and from the fossils it contains, was evidently deposited in quiet but relatively shallow marine waters. East of San Emigdio Creek, however, no marine fossils were discovered in the clay, but a few fragments of bones of land animals were found. These were far too poorly preserved to be determined generically, but they show that at least a part of the Etchegoin here was probably deposited subaerially or in fresh-water lakes. In places the weathered slopes of the Etchegoin bear a striking resemblance to those of the less indurated facies of the Maricopa shale, and the soil from the two formations is strikingly similar. This fact, together with the presence of pebbles of diatomaceous shale throughout the Etchegoin, shows that that formation was derived in large part from a land mass composed principally of the Maricopa shale. The coarser, well-rounded fragments may have been derived directly from a land mass of crystalline rocks, but it seems probable that they were in part secondarily derived—that is, that these granitic fragments were plucked from another sedimentary formation, probably the upper part of the Maricopa shale, in which they had been deposited previously.

The predominantly clayey beds in the central part of Wheeler Ridge are probably to be correlated with the Etchegoin formation, but the lithology of the beds exposed in the ridge is too varied to permit a definite separation of them into two parts that may be correlated with the Etchegoin and Paso Robles formations. The section exposed in Wheeler Ridge is discussed in some detail in connection with the Paso Robles formation. (See p. 51.)

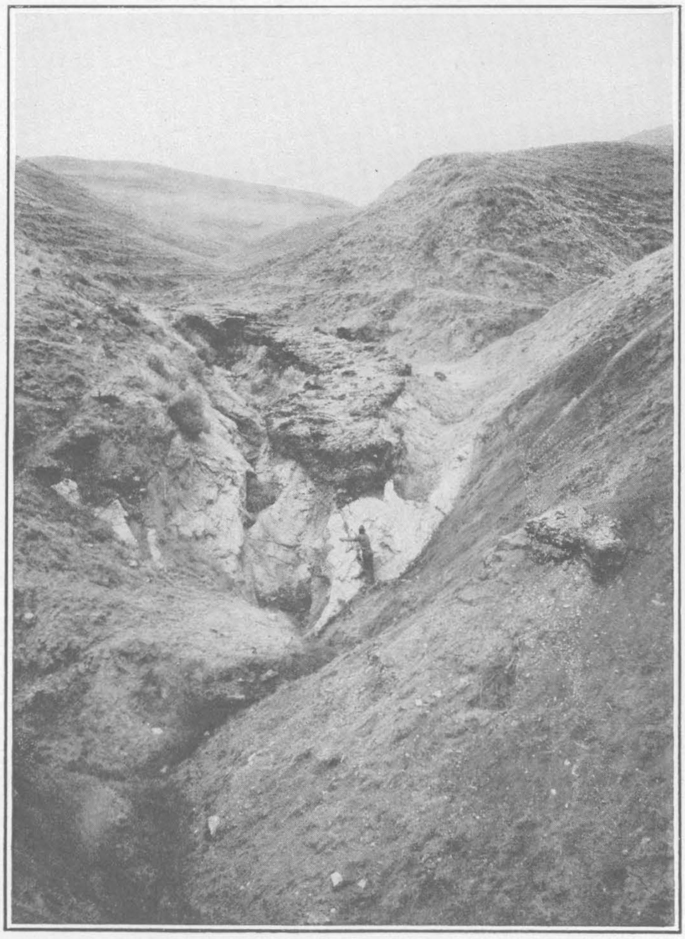
OUTCROPS IN THE TEMBLOR RANGE.

The northernmost outcrops of the Etchegoin formation within the Sunset-Midway district are those that lie on the flanks of the Shamrock anticline about a mile south of the town of McKittrick. Here the Etchegoin is exposed on both the north and south flanks of the anticline in a belt that is in few places more than 200 feet across. The formation is here composed chiefly of gray arkosic sandstone, locally indurated but for the most part only poorly consolidated. In the hill in the NE. ¼ sec. 29, T. 30 S., R. 22 E., the basal beds are coarse granitic sand with gravelly layers, above which is a pebble bed composed of fragments of granitic, quartzitic, and other hard rocks. These beds are overlain by clay or clay shale that contains fresh-water fossils and is mapped as the Paso Robles. On the west slope of the hill just mentioned a fine-grained grayish sandstone near the base of the Etchegoin is filled with marine fossils, almost wholly *Pecten eldridgei.* Similar fossils were found near the east end of the Shamrock anticline in the SW. ¼ sec. 27, T. 30 S., R. 22 E., here also in sands near the base of the Etchegoin. No marine fossils were found in the beds exposed on the south flank of the Shamrock anticline, but the grayish sands that crop out on that side of the fold from the NW. ¼ sec. 34 northwestward to the vicinity of the center of sec. 29 are evidently the equivalent of the fossiliferous beds just described.

Farther west the Etchegoin is overlapped by the Paso Robles formation, and in the Telephone Hills the Paso Robles rests upon the interstratified diatomaceous shale and coarse arkosic beds of the upper division of the Maricopa shale. The maximum thickness of the Etchegoin exposed on the flanks of the Shamrock anticline is not more than 200 feet.

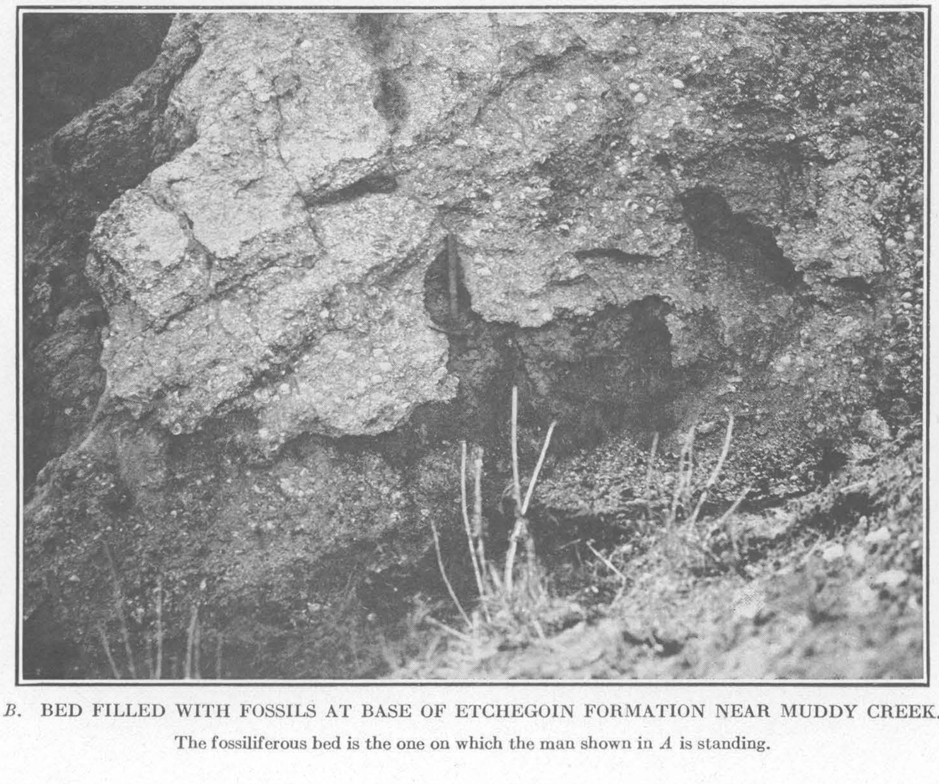
Along the foothills of the Temblor Range between Crocker Springs and Spellacy Hill (Twenty-five Hill) the Etchegoin has been recognized definitely at only a single point. This point lies just west of Fellows, where, near the center of the east line of sec. 1, T. 32 S., R. 22 E., a thin bed of limy arkosic sandstone filled with Etchegoin fossils is exposed resting upon the interstratified diatomaceous shale, sand, and gravel that are mapped as the upper division of the Maricopa shale. The fossiliferous bed is so thin that it has been grouped in the mapping (Pl. II) with the overlying Paso Robles. A fossiliferous bed of this type, probably the same bed that crops out west of Fellows, is encountered in several of the wells, notably in well 9 of the United Oil Co., in sec. 6, T. 32 S., R. 23 E.

West of Maricopa the beds mapped as Etchegoin are mainly fine-grained granitic sand and compact clay or clay shale. These beds are well exposed in the canyon that drains eastward from the Tannehill wells through sec. 27, T. 12 N., R. 24 W. Some of these beds are certainly Etchegoin, as is shown by the marine fossils that occur in the W. ½ sec. 33, T. 12 N., R. 24 W., but the line of separation indicated on the map between the Etchegoin and Paso Robles may not be the true one. It is, as has already been explained, simply a separation between the fine-grained sands and compact clay shales below and the coarse granitic sands filled with granitic cobbles and diatomaceous-shale pebbles above. Many of the coarser sandy beds in the Etchegoin, particularly those in the lower part of the formation, contain oil, and a study of the outcrops of these beds affords a very fair understanding of the way that oil occurs beneath the surface farther east. The most important characteristics to be noted are (1) that the oil is found in the coarser-grained beds; (2) that it is not restricted to the lower part of the formation, as might be inferred from a too literal interpretation of the statement that the oil sands occur in sandy beds that rest unconformably upon the diatomaceous-shale formations, but is found well up in the formation; (3) that the sandy beds which contain the most oil are those that are overlain and underlain by beds whose porosity is relatively slight. In some places these less pervious beds are compact clays, but in other places, notably near the Banner well of the Union Oil Co., in



A. BREA IN ARROYO NEAR MUDDY CREEK, IN SAN EMIGDIO REGION.

Note mass of brea occupying center of gulch above figure of man and small patch at right in foreground. The canyon has cut 10 or 12 feet below the level marked by this brea.



B. BED FILLED WITH FOSSILS AT BASE OF ETCHEGOIN FORMATION NEAR MUDDY CREEK.

The fossiliferous bed is the one on which the man shown in *A* is standing.

the N. ½ sec. 33, T. 12 N., R. 24 W., the impervious bed overlying the oil sand which crops out is an arkosic sandstone that is of much coarser grain than the oil sand but is indurated by a calcareous cement and thus rendered far less pervious than the fine sand. Below the oil sand is a conglomerate made up of fragments of diatomaceous shale embedded in a clayey matrix that is evidently composed chiefly of comminuted shale like that forming the larger fragments. It likewise contains much less pore space than the fine-grained oil sand and acts as an impervious barrier.

AREA WHERE THE ETCHEGOIN IS NOT EXPOSED BENEATH THE PRODUCTIVE OIL FIELD.

The Etchegoin reaches its maximum development in the region under discussion in the foothills northeast of the Temblor Range, where it is buried beneath the thick cover of the Paso Robles formation and the alluvium in the topographic basins. Its character and thickness in this part of the field may be judged only approximately from the rather imperfect record afforded by the deep wells. The formation is apparently composed largely of clay or clay shale, sandy clay, and sands, with some hard "shells" which are either indurated sands or moderately coarse boulder beds similar to those that crop out in the area mapped as Etchegoin west of Maricopa.

Along the west side of Midway a few of the deeper wells have been drilled through the Etchegoin and have entered the upper part of the Maricopa shale below. The thickness of the formation here is difficult to estimate, as few of the wells report any Paso Robles or "Tulare" fossils, and it is only from such reports that the position of the base of the Paso Robles may be estimated. The Etchegoin, however, is probably not much over 1,000 feet thick along the western edge of Midway Valley, but eastward from that locality it thickens greatly, and east of Midway Valley wells have been drilled in it for a distance of at least 2,000 feet and probably for 2,500 feet.

The Etchegoin in this area appears to be very largely fine sand or shale, probably of much the same character as the clay shale exposed in the foothills of the San Emigdio Mountains, and like that shale it is filled with fossils. Almost all the logs of deep wells in Midway Valley and in the Buena Vista and Elk hills report "sea shells" in the productive oil sands or in the immediately overlying beds. The widespread occurrence of these fossiliferous beds beneath the cover of the Paso Robles and their failure to crop out in the foothills of the Temblor Range except in local areas can best be interpreted to mean that the Etchegoin and Paso Robles formations were laid down in a basin that was continuously sinking and that the Etchegoin was not deposited in regions now occupied by the Temblor Range but only in the region of lower relief to the northeast. This interpretation seems much more reasonable than the assumption made in the preliminary report that the richly fossiliferous beds that are deeply buried beneath the Paso Robles are the equivalent of the coarse gravels and diatomaceous shales upon which the Paso Robles rests along the foothills of the Temblor Range. As has already been shown, these beds are considered in the present report as the upper part of the Maricopa shale.

PASO ROBLES ("TULARE") FORMATION.

GENERAL CHARACTER AND STRATIGRAPHIC RELATIONS.

The last formation to be laid down before the time when the most recent general movements affected the region was a thick terrane of gravel, sand, and clay with a very few calcareous beds. This formation is much like the underlying Etchegoin formation in lithology, differing chiefly in being somewhat coarser grained and in having been laid down in part in fresh or brackish water and in part subaerially but not in marine water. It corresponds to the Tulare formation as mapped and described in the report on the Coalinga district.[1] The older name Paso Robles is, however, used in this report instead of Tulare, which has been abandoned,[2] for the reason that the two names were applied to essentially the same beds.

The Paso Robles formation rests upon the Etchegoin formation with perfect conformity, and in the preliminary report the two formations were mapped and discussed together as the McKittrick formation. Although, as has already been shown, it is not possible to separate the two formations in an entirely consistent manner throughout the field, it is

[1] U. S. Geol. Survey Bull. 398, 1910.

[2] English, W. A., Geology and oil prospects of the Salinas Valley-Parkfield area, Calif.: U. S. Geol. Survey Bull. 691, pp. 219-250, 1918.

thought best to show the separation in certain places, even though it can not be more than approximately correct, for the late geologic history of the region may thus be understood more readily.

The separation between the Paso Robles and the overlying terrace deposits and alluvium is as indefinite as that between the Paso Robles and the underlying Etchegoin, for deposition has been practically continuous in the Sunset-Midway region from the end of the Paso Robles up to the present time. Except near the mouth of San Emigdio Creek, where recent stream terrace deposits have been deformed by faulting, all the beds of this series that show marked deformation have been grouped with the Paso Robles formation, and those that now have practically the same attitude as they had when they were deposited are considered Recent terrace deposits or alluvium.

In parts of the area, notably in the east flank of the Temblor Range west of Maricopa, in the outer foothills just south of the old refinery at Pioneer, and in the central part of Wheeler Ridge, the Paso Robles as mapped includes some beds of Etchegoin age.

THICKNESS.

As nearly as can be judged from the imperfect records furnished by the deep wells, the Paso Robles formation varies in thickness between 2,000 and 4,000 feet in the area northeast of the main Temblor Range. In the east end of the Elk Hills wells that start 1,000 feet below the uppermost beds of the Paso Robles exposed in the region penetrate beds containing fresh-water fossils at a depth of 1,300 feet, below which the beds are nonfossiliferous to a depth of 2,400 feet, where marine fossils taken to be characteristic of the Etchegoin occur. The Paso Robles is therefore at least 2,300 feet and possibly 3,400 feet thick here. At the east end of the Buena Vista Hills wells penetrate more than 3,500 feet of the Paso Robles, and on the west side of Midway Valley, northwest of Taft, fresh-water fossils are reported in wells at a depth of 2,700 feet. In the foothills near San Emigdio Creek the gravels and sands mapped as Paso Robles are not over 1,200 feet thick, but even in the outermost foothills of the San Emigdio Mountains the beds dip at a fairly high angle northward, and the formation evidently thickens greatly in that direction beneath the Recent valley filling.

LITHOLOGIC CHARACTER.

The Paso Robles was deposited under conditions that varied greatly from place to place, and the variations are reflected in the character of the beds. Likewise the conditions governing deposition did not remain constant in any part of the region for any considerable length of time, and the formation shows as great a range vertically as it does areally in the type of material laid down.

The general character of the upper part of the formation is well shown on the north slope of the Elk Hills, where it is composed of alternating beds of fine granitic sand, clay that is in places more or less sandy, and coarse gravel. The coarse gravel beds, although usually exhibiting no sorting of the fragments as to size, in many places show a remarkable segregation in the character of the material. For example, the formation for a stratigraphic thickness of 200 or 300 feet may be composed wholly of granitic débris—both fine sand and coarse gravel—interstratified with beds of compact greenish clay. Overlying these beds may appear a bed composed almost wholly of fragments of diatomaceous shale. This bed of detrital shale is so free from granitic débris and the underlying coarse beds composed of fragments of granitic rocks are so free from fragments of diatomaceous shale that in many places a sharp, almost knife-edge contact may be traced for a distance of several hundred feet. One who is attempting for the first time to map the areal geology of the region is liable to be led astray by the discovery of just such sharp contacts and to spend considerable time in a fruitless endeavor to divide the beds here comprised in the Paso Robles formation into several formations. But sooner or later it becomes apparent that these various lithologic phases do not mark stratigraphic divisions but rather only lenses, some large, some small, and that material of a given type may occur at almost any position in the Paso Robles from top to bottom.

Despite the fact that these variations in lithology can not be shown on the map, they must not be lost sight of nor their economic importance overlooked, for it is this very lenticularity, this segregation of material and the formation of porous and impervious masses, that gives the formation its power to hold the accumulations of fluid, either oil, water, or gas.

The fragments of diatomaceous shale in the "shale pebble" beds of the Paso Robles are almost invariably only slightly rounded and vary greatly in size, the largest noted being about 4 inches in length. They are embedded in a clayey matrix that looks much like that composing the clayey beds interstratified with the underlying beds of coarse granitic débris. The land mass that furnished the débris of which the Paso Robles in this part of the area is composed was probably formed of the earlier Tertiary rocks like those now exposed in the Temblor Range. Although some of the fragments of granitoid rocks may have come directly from the complex exposed in the mountains at the south end of San Joaquin Valley, it is probable that the main source of supply lay in the Temblor Range, to the west, which at that time must have had a considerably greater relief than at present. The granitic débris in the Paso Robles was probably derived from the coarse granitic sands and conglomerates in the Tertiary beds there, particularly those bedded with the diatomaceous shale in the upper part of the Maricopa shale. The sorting of the material and the absence of fragments of diatomaceous shale in certain beds are probably more apparent than real. It is entirely reasonable to suppose that in the denudation of a land mass made up of interstratified diatomaceous shale and coarse granitic débris, such as compose the upper part of the Maricopa shale, the soft diatomaceous shale would, during transportation, be so finely pulverized by the grinding action of the fragments of hard crystalline rocks that it would not be recognizable when finally deposited but would form compact clays precisely like those that are bedded with the coarse granitic débris in the Paso Robles formation. These clays are remarkably compact and fine grained, and even with a high-power hand lens it is with difficulty that any individual grains may be recognized. They must represent deposition in quiet waters, perhaps in large part of wind-blown material. Their close association with coarse gravel, although at first sight somewhat surprising, is really of the same sort as that shown by the material that is accumulating in the present-day deserts, where the fine dust deposited in intermittent lakes is mingled with the coarse material brought down occasionally by torrential streams.

Near the east end of the Elk Hills various clayey beds have been prospected in a more or less desultory manner as fuller's earth, and it is said that the clays give more or less satisfactory results in clarifying oil.

On the west slope of the Elk Hills the clayey beds are less conspicuous. The general character of the Paso Robles in the Elk Hills is shown in the following section, which is taken from the preliminary report:

Section of McKittrick formation [upper part, or Paso Robles] in the Elk Hills.[1]

	Feet.
Coarse gravel of considerable variety of rocks; maximum cobbles about 6 inches in diameter	175
Soft light yellowish-brown sandy clay with white efflorescent alkali	50
Gravel of equal parts of shale fragments and mixed colored pebbles; maximum diameter 3 inches	50
Soft light-yellowish clays like the second bed above	40
Gravel of shale fragments and colored pebbles, the latter predominating; 4-inch pebbles maximum	100+
Soft yellowish-brown sand with occasional streaks of shale and mixed pebbles	75
Soft yellowish-brown sand with greenish-drab clay stratum at base	60
Gravelly sand and clay, upper 15 feet of which is stained light purple by alkali; both sand and clay are very soft	100
	650

South of McKittrick the Paso Robles is exposed resting upon the Etchegoin on both flanks of the Shamrock anticline. The formation here is on the whole more sandy than it is in the east end of the Elk Hills, but the coarse beds of granitic cobbles are likewise less numerous. The following section, taken from the preliminary report, gives a good idea of the character of the formation here:

Section of McKittrick [Paso Robles] formation 1 mile southeast of McKittrick.[2]

	Feet.
Soft sandy or clayey beds and coarse soft sandstones below	380
Coarse-grained pink granitic sand with numerous waterworn shale fragments up to 3 inches long.	55
Soft sandstone with occasional layers of shale fragments, also brown sandstone and fine scattered shale fragments	35
Hard gray sandstone, some shale pebbles, occasionally brownish and apparently oil stained	80
Greenish and brownish clay shale with thin layers of interbedded sandstone	64
Clay shale and sandstone	18
Brown and pink coarse sandstone with shale fragments, also thin partings of shale, at some points stained by oil, and clay-filled mud cracks	145

[1] U. S. Geol. Survey Bull. 406, p. 81, 1910. [2] Idem, p. 80.

	Feet.
Coarse thick-bedded incoherent sandstones with numerous shale fragments	190
Largely shale and clay, alternate hard and soft layers; some sandstone and shale fragments; chocolate, pink, yellowish, and brown (color due to oil impregnation)	290
Green and brown shale with interbedded yellow sands, dark brown and heavily charged with oil	300±
Waterworn shale fragments forming a fine conglomerate	395
	1,952±

In the preliminary report these beds were described as the McKittrick formation. Part of the lowest division recorded may be Etchegoin, for fossiliferous beds of that formation are exposed a short distance to the west. Most of the section is, however, certainly Paso Robles, as fossils characteristic of the Paso Robles ("Tulare") were found a few hundred feet south of the point where the section was measured in sandy clays that are either the equivalent of the upper part of the lowest division recorded in the section or belong in the overlying green and brown shales.

In the northern half of the Buena Vista Hills the Paso Robles is of much the same character as it is on the western slope of the Elk Hills and in the hills south of McKittrick. The upper part of the formation exposed here contains somewhat coarser material than the lower part. Near the middle of the exposed section is a zone about 100 feet thick containing several beds of calcareous clay which weathers to conspicuous whitish outcrops that may be followed on the east slope of the hills from the vicinity of the east line of T. 31 S., R. 23 E., to the northwest quarter of that township and on the south slope of the hills in secs. 27, 34, and 35 of the same township. Most of these calcareous beds are not over 20 feet thick, and no one bed is traceable separately throughout the area outlined above, but as their outcrops aid in understanding the structure here, the approximate position of this zone has been indicated on the geologic map (Pl. II).

West of Midway Valley the Paso Robles is composed of clay, arkosic sand of variable grain, and conglomerate formed largely of fragments of diatomaceous shale. Its general character is shown by the following section, copied with a few alterations from the preliminary report:

Section of McKittrick [Paso Robles] formation in T. 32 S., R. 23 E.[1]

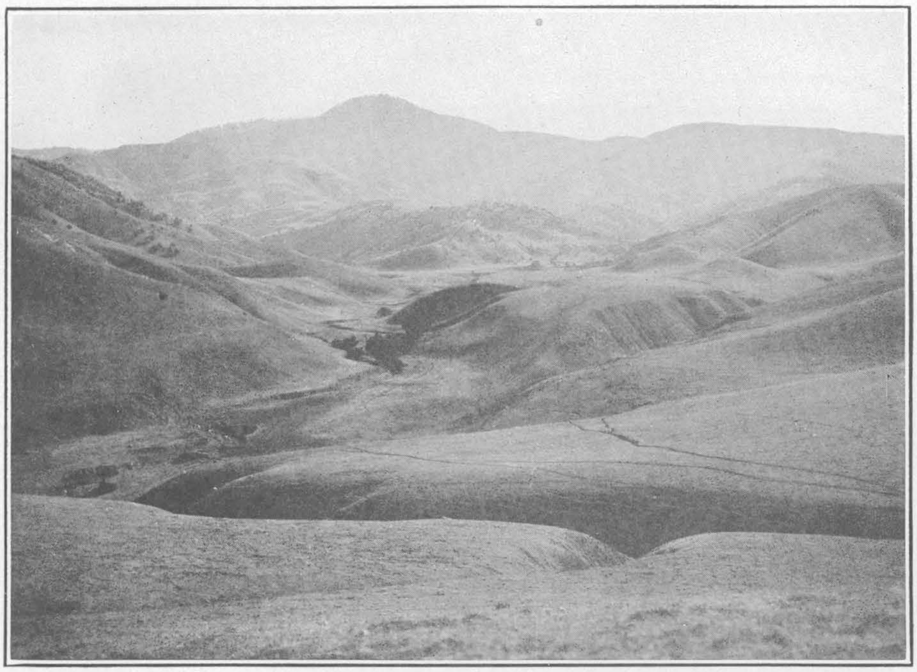
	Feet.
Superficial gravel dipping gently northeast and overlying beds of sand and gravel unconformably	25
Gravelly granitic sands with thin clayey layers	200
Light-green coarse and fine granitic sandstone with thin clay layers; also thin hard layers	75
Fine well-bedded yellow granitic sand with thin harder seams	100
Coarse gray sand with plentiful shale pebbles	200
Coarse and fine gray sand and greenish shales with shale pebbles	160
Gray and white sandstone with many shale pebble layers	100
Light gypsiferous sandstone with shale fragments; contains white porcelain shale layer	120
Oil sands with granitic cobbles at base, sands dark brown and coarse; rests on brown diatomaceous shale, strongly impregnated with oil (at anticlinal axis)	50–80
	1,060

South of Spellacy Hill (Twenty-five Hill), in sec. 35, T. 32 S., R. 23 E., the Paso Robles rests upon the highly siliceous Maricopa shale, and the basal beds are composed almost wholly of fragments of diatomaceous shale. In places these fragments have been cemented together by a siliceous cement, and although the rock is as clearly detrital as the overlying incoherent sands and gravels, it appears in hand specimens more like a fault breccia.

In the foothills of the San Emigdio Mountains the Paso Robles is composed mainly of coarse gravels and sand, with a relatively small amount of clay and fine sand. The conglomerate is for the most part ill sorted; the fragments in any bed show a wide range in size and are for the most part but poorly rounded. Besides the cobbles of granitoid rocks which compose the bulk of the formation and a relatively small number of angular fragments of diatomaceous shale, the Paso Robles contains numerous fragments derived from the Vaqueros formation—both of fossiliferous sandstone and of the basalt and andesitic agglomerate which occur in the upper middle part of the Vaqueros. Such fragments are rare, if they occur at all, in the Paso Robles exposed in the slopes of the Temblor Range and in the outlying foothills. The slight areal range of the different types of rocks that make up the Paso Robles shows that the conditions under which that formation was deposited must have been very local and that the land masses which furnished the detrital

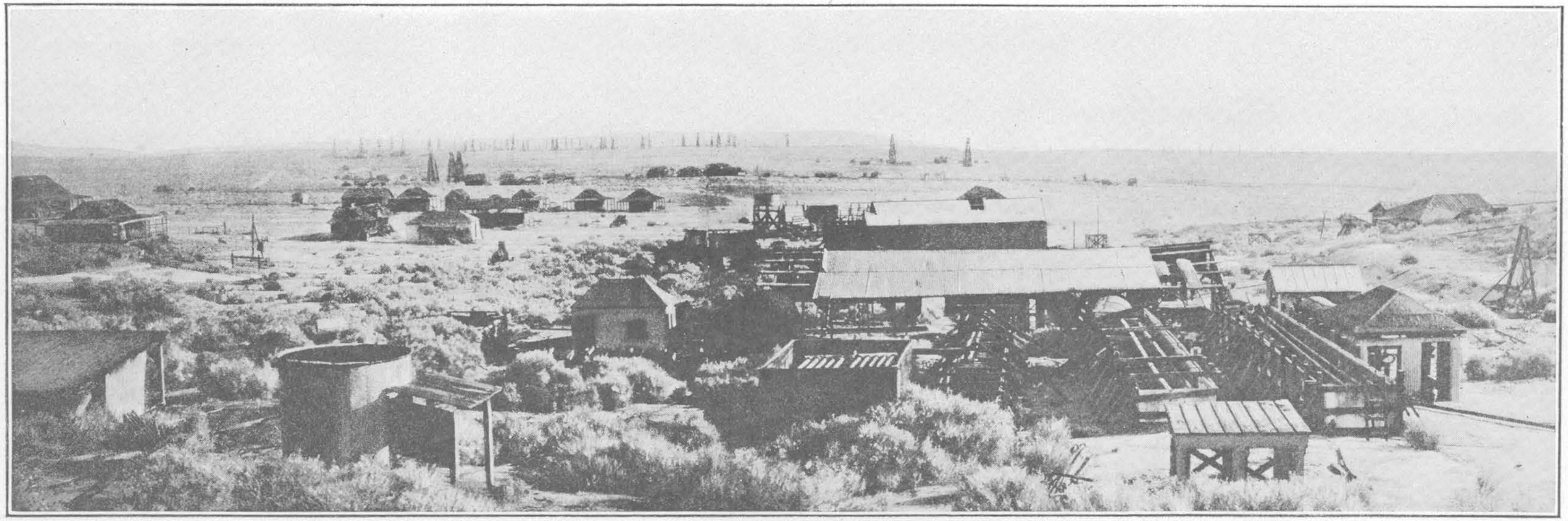
[1] U. S. Geol. Survey Bull. 406, p. 83, 1910.

A. TERRACES NEAR MOUTH OF SANTIAGO CREEK.



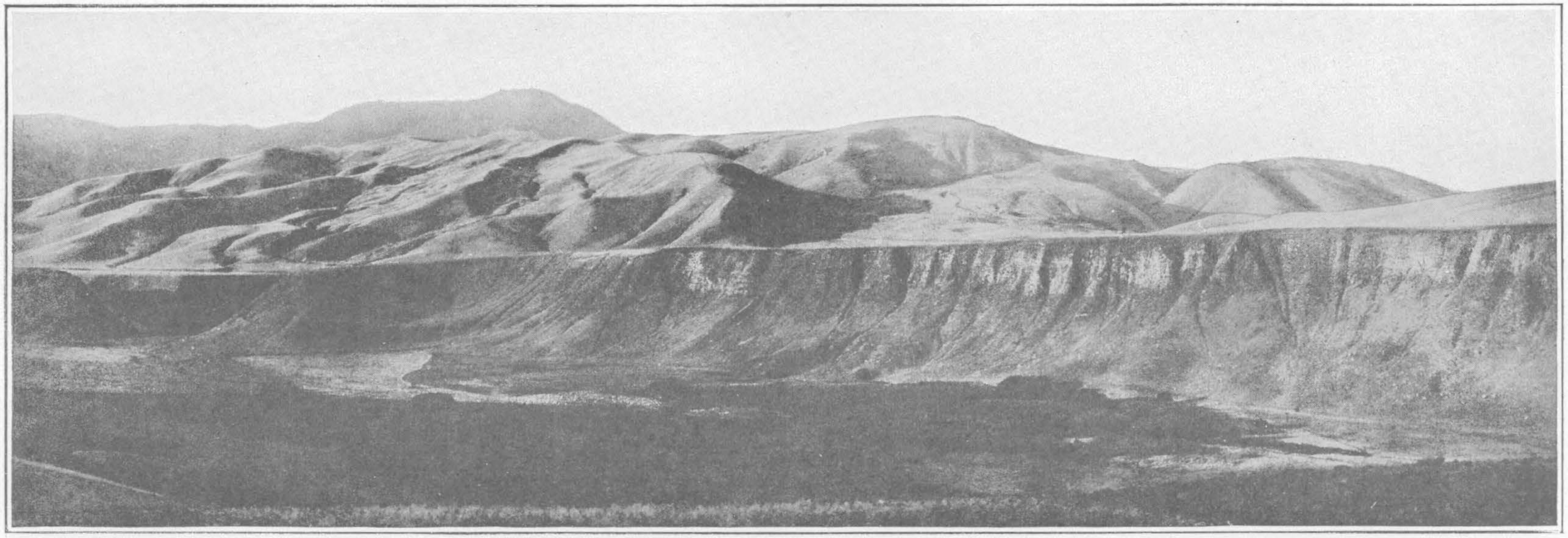
B. TERRACES ON LOS LOBOS CREEK.

Note terraces at several levels. The downward cutting below the lowest terrace shown at the extreme left has been accomplished mainly in the last 30 years.



A. OLD JEWETT & BLODGETT ASPHALT REFINERY SOUTH OF PIONEER.

Looking north from hill above refinery in sec. 13, T. 11 N., R. 24 W. Note wells in Maricopa Flat in distance.



B. TERRACE GRAVELS ALONG SAN EMIGDIO CREEK ABOUT 2 MILES FROM EDGE OF SAN JOAQUIN VALLEY.

Looking southwest across the canyon. The gravels here are almost 200 feet thick and lie horizontal. San Emigdio Mountain is the flat-topped mountain at the left of the center.

material were not far distant from the basins of deposition.

Wheeler Ridge is formed of coarse conglomerate, arkosic sand, and compact reddish and greenish-gray clay which are shown on the map as part of the Paso Robles formation. Most of the beds exposed are probably correctly correlated with the Paso Robles ("Tulare"), but some of the clays that crop out near the axis of the anticline are probably in the Etchegoin formation. The time available did not admit of mapping a dividing line between the two formations here, and from the character of the outcrops the writer doubts whether a satisfactory separation can be made. The total thickness of the beds exposed in Wheeler Ridge is between 2,500 and 3,500 feet. Most of the beds in the upper part of the exposed section are coarse conglomerate made up of fragments of all the types of rocks occurring in the central part of the San Emigdio Mountains. Fragments of granitic rocks predominate, but boulders of crystalline limestone, of fossiliferous sandstone, of basalt, and of andesitic agglomerate from the Vaqueros formation, and of siliceous diatomaceous shale from the Maricopa shale are very plentiful. The clay that is exposed in the central part of Wheeler Ridge, along the anticlinal axis, weathers to greenish gray or reddish gray and resembles closely the late Tertiary clays in the Kern River field.

QUATERNARY SYSTEM.

TERRACE DEPOSITS AND ALLUVIUM.

The conditions that governed the deposition of the youngest beds included in the Paso Robles formation have continued uninterruptedly up to the present time, and the sediments laid down since the end of Paso Robles time include the beds of intermingled sand, gravel, and clay that fill the larger valleys and cover the terraces.

In the Temblor Range and in the outlying foothills to the northeast only the almost flat-lying deposits that fill the structural basins occupied by Midway and Buena Vista valleys are mapped as terrace deposits and alluvium. The gently inclined gravels that occur higher on the range are considered a part of the Paso Robles. Despite its broad areal extent the thickness of this alluvial filling in Midway Valley is relatively small, probably nowhere exceeding 300 or perhaps 400 feet, except in the south end of Buena Vista Valley. South of the Buena Vista Hills the thickness of the valley filling almost certainly increases eastward toward the central part of San Joaquin Valley, and there the deposits bury so deeply the sands that are oil bearing in the productive field that they can not be reached by drilling methods now in vogue. Probably the thickness of the alluvial filling in San Joaquin Valley can never be accurately estimated, as its lithologic character is so like that of the Paso Robles that well records will not give data that are sufficiently accurate to permit a separation of the two formations.

In the San Emigdio Mountains remnants of stream terraces may be found up to altitudes of at least 2,500 feet above sea level, or 1,000 feet above the south end of San Joaquin Valley. Nearly all the larger streams show, especially in their lower courses, a succession of terraces, the lowest a few feet above the bed of the present stream and the upper well-marked ones 40 or 50 feet higher. The terraces near the mouth of Santiago Creek are well shown in Plate XII, *A*.

Besides these terraces in the outer foothills there are many isolated terraces in the upper parts of the canyons which record some local interference with the downward erosion of the stream. A good example of an isolated terrace of this type is Neasons Flat, in the canyon of Pleito Creek, where a small gently sloping area has been formed by a filling of terrace gravel and sand 20 to 30 feet thick. In the upper end of the flat Pleito Creek has intrenched itself in the terrace gravels to a depth of 8 or 10 feet, but at the lower end the creek has cut completely through the terrace deposit into the underlying Tertiary rocks and runs through a trench 40 to 50 feet deep.

The deposits that cover the stream terraces range from a veneer of sand and fine gravel only a few inches thick to masses of coarse gravel and sand 300 to 500 feet thick. The thickest deposits in the region are those in the canyon of San Emigdio Creek. In the lower 2 miles of its course this stream traverses a flat-bottomed valley about a quarter of a mile wide, bounded on the south by a precipitous wall of terrace gravel. In places these gravels lie more than 400 feet above the floor of the valley. The terraces on San Emigdio Creek are shown in Plate XIII, *B*. Remnants of a terrace comparable with the upper part of the terrace on San Emigdio Creek are easily recognizable as far westward as Santiago Creek and are best shown along the old road that leads from San Emigdio Creek to Santiago Creek through the southern part of the San Emigdio grant. The terrace deposit in the upper part of the canyon of Los Lobos Creek (Pl. XII, *B*) records a later period during which the upward movement of the region halted for a while. This terrace may be the equivalent of an extensive terrace west of Santiago Creek, the uppermost one shown in Plate XII, *A*.

In places the terrace deposits have been deformed by Recent movements. The best example of such deformation is shown by the terrace gravels in San Emigdio Canyon, which about half a mile from the edge of San Joaquin Valley change abruptly from the flat-lying attitude characteristic of them farther upstream and dip northward beneath San Joaquin Valley at an angle of about 25°. The deformation of these gravels apparently has been caused by a fault that lies somewhat north of the outermost foothills. A curious structure resulting from this faulting is shown in a small canyon about a mile west of the mouth of San Emigdio Creek. Here the Recent terrace gravels dip northward at an angle of 38°, and the white gravels (mapped as Paso Robles) upon which they rest are overturned, dipping southward at about 35°. The structure here is shown in the sketch in Plate XIV.

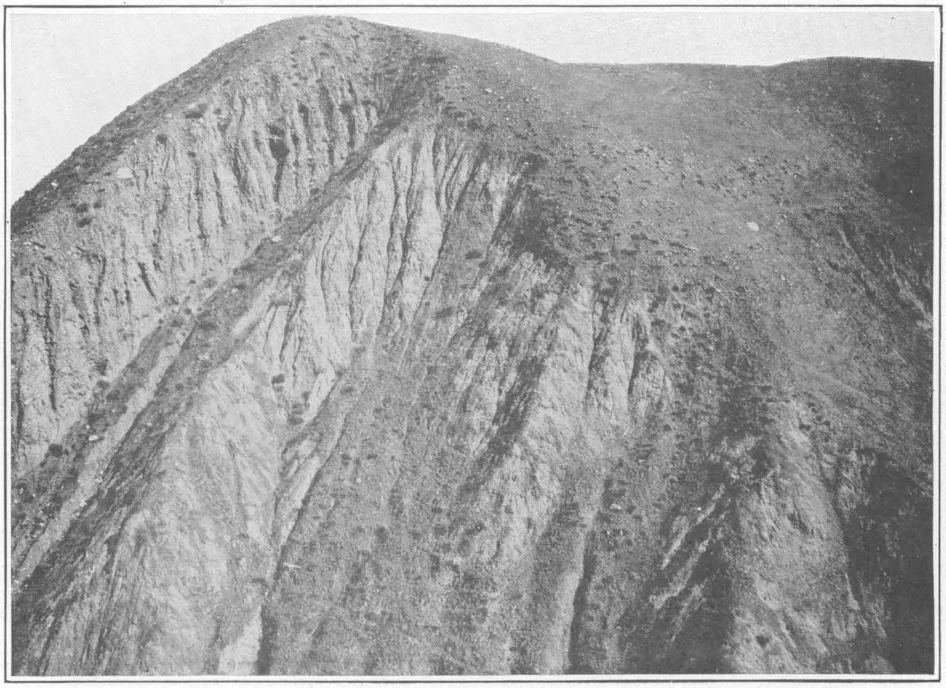
One of the most interesting features of the Recent terraces in this part of the region is the evidence they afford that this part of San Joaquin Valley is at present rising, apparently at no very slow rate. Most of the stream terraces, even those that lie 20 to 30 feet above the bed of the present stream, are bounded by clean-cut cliffs whose steep slopes have been concealed but little by talus. Moreover, if observations made by the inhabitants of the region are to be trusted, much of the downcutting below a terrace level that lies from 4 to 6 feet above the present stream beds has been accomplished within the last 30 or 40 years. On Tacuya Creek an especially instructive bit of evidence regarding this regional movement was obtained. Near the old adobe cabins that stand about a mile above the mouth of the creek water issues from a point in the bank a foot or two above the stream bed. About 8 or 10 feet vertically above this spring is an old pipe which, it is said, marks the location that the spring occupied some 40 years ago, when, as now, the spring was about 2 feet above the bed of the stream. Near this locality, at an altitude comparable with that of the old location of the spring, is the top of a well-marked terrace deposit through which the stream has cut a trench with almost vertical sides. It seems evident that most of the downward cutting represented by the change in position of the spring has been caused by a very recent regional uplift. It should be noted, however, that the resistant basaltic rock that lies in the upper part of the Vaqueros formation crosses Tacuya Creek a few hundred feet downstream from the spring, and it is probable that these rocks have halted the downward corrosion of the stream above the point where they cross it. The stream level between the basalt and the mouth of the creek has probably changed gradually, keeping pace with any regional uplift, but the basaltic rocks were probably broken through only during periods of excessively high water, and it was only after such periods that the upper reaches of the stream tended to assume what may be considered their normal gradient. Thus, although the change in the position of Tacuya Creek near the spring unquestionably records a recent uplift of the region, the rate of uplift is not necessarily recorded by the rate at which the stream has intrenched itself at this point.

The alluvial filling in San Joaquin Valley is composed of coarse gravel and sand brought down by the streams, the alluvial fans at the mouths of which coalesce to form a gently sloping apron along the whole hill front. Many of the streams, especially those that drain the San Emigdio Mountains, are torrential at times and carry huge boulders far out into the plains. One of the largest of these fragments lies more than a mile from the mouth of Tacuya Creek and must have traveled that distance over a slope of about 200 feet to the mile. The boulder is now partly buried in the fine alluvium, but the part visible measures roughly 20 by 11 by 7 feet. It is shown in Plate VI, *A*.

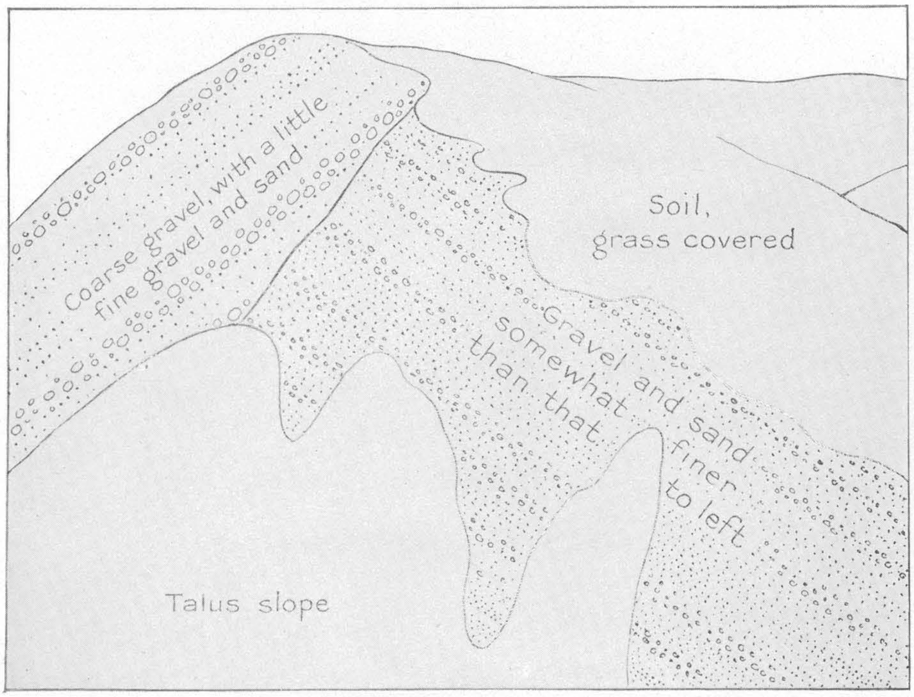
TERTIARY IGNEOUS ROCKS.

DISTRIBUTION.

In the north flank of the San Emigdio Mountains igneous rocks of two general types occur in the Tertiary section. The older of these



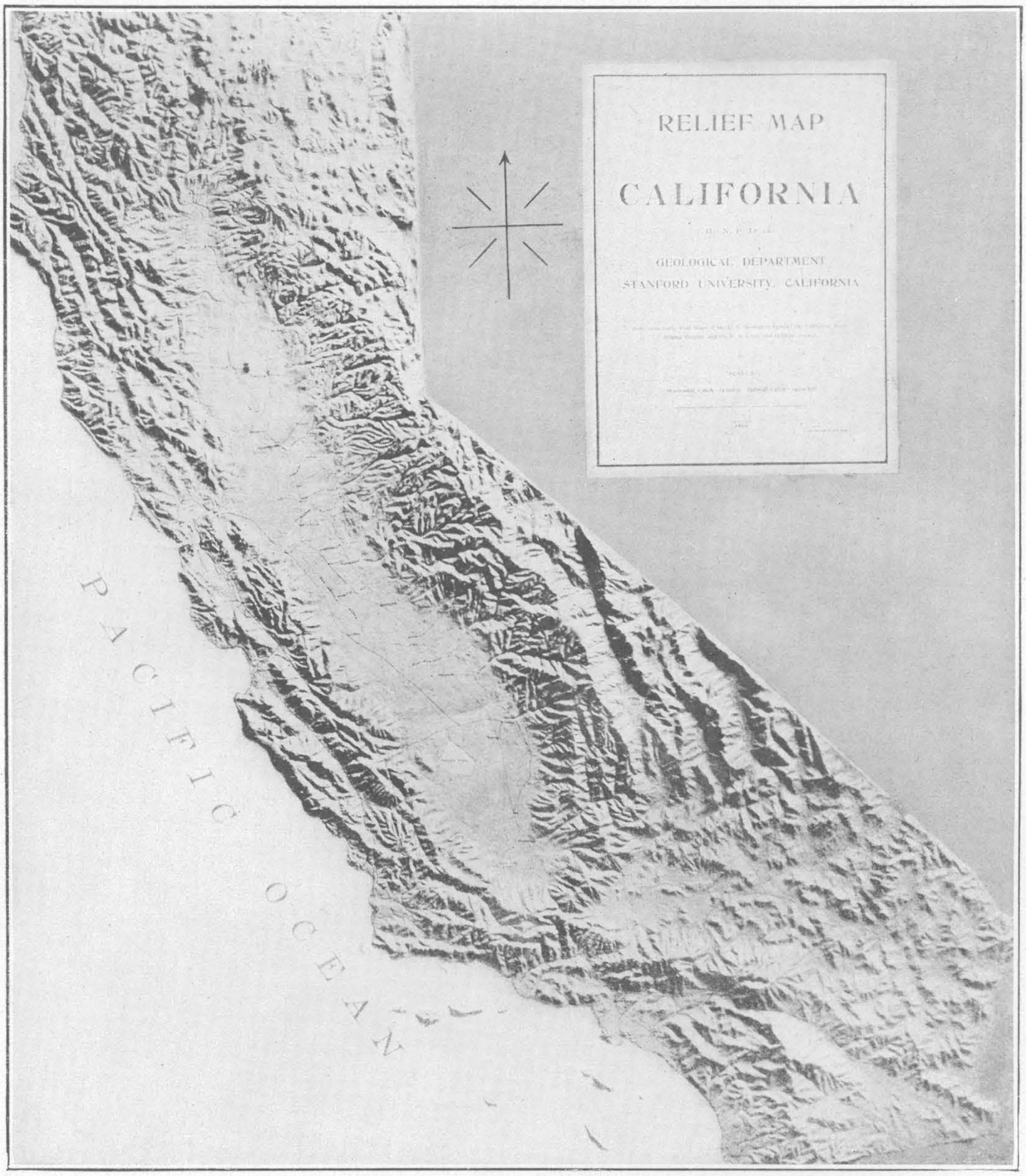
A.



B.

UNCONFORMITY BETWEEN LATE TERTIARY GRAVELS AND TILTED PLEISTOCENE OR RECENT GRAVELS IN SAN EMIGDIO REGION.

Looking east across first arroyo west of San Emigdio Creek.



RELIEF MAP OF CALIFORNIA.

rocks, which lie in the upper part of the Vaqueros formation, consist of tuff, andesitic agglomerate, and scoriaceous flows of basalt; the younger, which are in the uppermost part of the Vaqueros and in the overlying diatomaceous Maricopa shale, consist of basalt flows and sills. The older rocks are by far the more abundant, the younger occurring only in small isolated areas a few hundred feet in extent on lower Pleito Creek.

The older Tertiary igneous rocks consist of flows and agglomerates which do not yield readily to erosion, and their outcrops stand out in bold relief from those of the Tertiary sedimentary beds. Their weathered surfaces are highly and irregularly colored to various shades of brown, green, indigo, yellow, and black, which are markedly in contrast with the somber brown color of the sedimentary beds of the Vaqueros formation. These rugged and varicolored outcrops of the volcanic rocks form a very prominent feature of the landscape, giving to it in places a distinctly fantastic touch.

They are exposed in three areas within the region shown on the geologic map. The largest of these areas extends as a belt ranging in width from a few hundred feet to 2 miles between Tacuya and Pleito creeks; another lies at the crest of the San Emigdio Mountains, near the headwaters of Santiago Creek; the third area lies near the center of the W. ½ sec. 11, T. 10 N., R. 23 W., about 2 miles west of Santiago Creek. This last-mentioned area is so small that even though its representation on the geologic map has been very greatly exaggerated it might easily escape the reader's notice.

Flows of basalt, probably the equivalent of those exposed in the San Emigdio Mountains, occur in the middle part of the lower Miocene section in the canyon of Walker Basin Creek, on the east side of San Joaquin Valley. Also at the south end of the Carrizo Plain, which lies just west of the Temblor Range, basic igneous rocks, described by Fairbanks[1] as analcite diabase, occur in the Monterey group. These rocks crop out near the northwest corner of T. 10 N., R. 24 W., from which they may be traced northwestward for more than 25 miles. They are almost certainly the equivalent of the older Tertiary igneous rocks that are exposed in the San Emigdio Mountains.

Tertiary volcanic rocks occur also on the south slopes of Mount Pinos near the borax mines in Lockwood Valley interbedded with coarse detrital beds. It seems probable that these flows are also approximately the equivalent of the older Tertiary flows exposed on the north slope of the San Emigdio Mountains. If they are, their study may afford a correlation between San Joaquin Valley and the Great Basin province. The Tertiary igneous rocks in this general region will probably be of greater aid than any other feature in making a general correlation of the varied Tertiary sedimentary formations developed in different parts of the region.

STRATIGRAPHIC RELATIONS.

The basaltic and andesitic rocks that make up the older Tertiary igneous rocks on the north slope of the San Emigdio Mountains occur chiefly as flows in the upper part of the Vaqueros formation. Within the area shown on the map no vent was found from which the lava was extruded, nor were any dikes or sills recognized with certainty. The only point in the foothills along the south end of San Joaquin Valley at which these rocks are certainly intrusive into the Tertiary lies about 6 miles due east of the mouth of Tejon Pass (Cañada de las Uvas). Here a dike of basaltic rock, evidently a part of the main mass of igneous rock, cuts the lower part of the Vaqueros formation and the underlying Tejon formation (Eocene).

As has already been explained, the Vaqueros formation was deposited under varying conditions, part being laid down beneath marine waters and part subaerially. The igneous rocks likewise show evidence of having been formed under varying conditions. Thus the pyroclastic beds that form the lower part of the succession of igneous rocks were evidently deposited in water. Even some of the coarse tuffaceous material was deposited in marine water, for in the andesitic tuff west of Santiago Creek was found a specimen of *Turritella*, probably *Turritella ocoyana*, a mollusk inhabiting marine waters. Much of the massive basalt and even the scoriaceous lava were probably poured out on the surface of the land.

East of San Emigdio Creek, especially in the vicinity of Salt Creek and between Salt and Tacuya creeks, there is good evidence of uncon-

[1] Fairbanks, H. W., On analcite diabase from San Luis Obispo County, Calif.: California Univ. Dept. Geology Bull., vol. 1, pp. 273-300, 1895.

formity at the top of the igneous rock. The beds resting upon the basalt in this part of the region are almost barren of fossils, and there might be some question as to the propriety of classing them with the Vaqueros, on account of the unconformity that exists between them and the underlying basalt. The unconformity, however, is believed to be only of local importance and to occur within the Vaqueros. The true position of the lavas and tuffs is shown by the outcrops of these rocks on the headwaters of Santiago Creek near the southeast corner of T. 10 N., R. 23 W., and by the small outcrop of andesitic tuff in sec. 11 of the same township. The igneous rocks appear to be perfectly bedded with the overlying and underlying beds of the Vaqueros formation and occur at the top of what has been described as the lower division of that formation.

LITHOLOGIC CHARACTER.

No systematic microscopic study of the Tertiary igneous rocks from the San Emigdio Mountains has yet been made, and the following notes are based almost wholly upon field observations and examinations of hand specimens.

The older Tertiary igneous rocks are of two main types—one a light varicolored rock, largely fragmental and probably an acidic andesite, the other an almost black basalt varying in texture from a fine-grained compact rock showing few megascopic crystals to a rock containing phenocrysts several millimeters in length. Through most of the region the two types are fairly distinct and they have been mapped separately, although at the westernmost point where they are exposed along the axis of the Devils Kitchen syncline there seems to be a gradual change from the andesitic rock into the overlying basalt, and the separation is only approximate.

The andesite is almost wholly fragmental and ranges from a fine ash to a coarse agglomerate composed of angular blocks several feet in diameter. In places thin flows are bedded with the tuff. The flows contain abundant glassy phenocrysts of andesine, some of them as much as 1 centimeter in length, embedded in an aphanitic groundmass. The agglomerate is light colored, usually being bluish or indigo, though locally dark green, red, or light buff. The lowest beds are as a rule composed largely of ash, especially those exposed in sec. 30, T. 10 N., R. 24 W., where there is a perfect gradation downward from the agglomerate into the granitic gravel of the Vaqueros formation through a zone about 200 feet thick of intermingled ash and detrital material composed of fragments of granitic rock. The character of these transition beds is shown in the tabulated section given on page 32. The andesitic agglomeratic and tuffaceous beds vary greatly in thickness, reaching a maximum between 500 and 600 feet in the region between Pleito and Salt creeks. The agglomeratic and tuffaceous beds were in part deposited in marine water, as is shown by the presence of *Turritella ocoyana* in the agglomerate exposed west of lower Santiago Creek.

The basalt that overlies the andesitic agglomerate likewise has its greatest development near Pleito Creek. It is probably a little thicker than the andesite, although the fractured nature of the rocks prevents an accurate estimate of the thickness. The texture of the basalt varies greatly, in some places being dense and finely granular and in other places almost glassy. Almost everywhere the rock is somewhat scoriaceous, and in places it contains amygdules as much as an inch in diameter filled with natrolite, analcite, calcite, and less commonly with chalcedony.

STRUCTURE.

GEOLOGIC RELATIONS TO NEAR-BY REGIONS.

The chief geologic features of the Sunset-Midway district are on the whole of a type common to the central part of the Coast Ranges of California, but as the field is near the border of the Coast Range province, many of these features are in a measure modified, and reflect the complicated structure of the mountainous region that lies to the southeast. This region, embracing the San Emigdio and Tehachapi mountains, forms both a topographic and a structural connection between the Coast Ranges and the Sierra Nevada.

Even a cursory examination of the geologic map (Pl. II) reveals a difference in the character of the geologic structure of the Sunset-Midway district and the San Emigdio Mountains. It is impossible, however, from a study of so small a region, to appreciate the relations of the geologic features of the one area to those of the other, or to understand how these features fit into the structural scheme of this part of the State. In order that these relations may be better understood a brief outline of the salient features of the structure of the central part of California will be given in the following paragraphs. The accompanying relief map of California (Pl. XV) gives an excellent representation of the chief geographic features here described.

The central part of California—that is, the region between the latitude of Mount Shasta and that of Point Conception—embraces three major provinces that extend as elongated belts parallel to the trend of the coast. The eastern province consists of the Sierra Nevada, which is composed predominantly of granitic rocks and is essentially a block that has been faulted up along the eastern edge and presents a fairly even and gentle slope toward the west. The western province embraces the Coast Ranges and may be considered as an anticlinorium in which the rocks, in the main sedimentary and ranging in age from Jurassic to post-Tertiary, are greatly folded and faulted. Between these two regions of high relief is the tectonic trough known as the Great Valley of California, which embraces the Sacramento and San Joaquin valleys. Near its south end the Sierra Nevada diverges from its prevailing southeastward trend and, swinging to the southwest, forms in the Tehachapi Mountains a barrier separating San Joaquin Valley from the Mohave Desert, a part of the Great Basin. At Tejon Pass (Cañada de las Uvas) the Tehachapi Mountains abut against the San Emigdio Mountains, and this pass is commonly taken as marking the junction of the Sierra Nevada and the Coast Ranges.

South of San Francisco the Coast Ranges are composed of a number of ranges which, although approximately parallel to one another, trend somewhat more easterly than the mountainous belt as a whole and cut obliquely across it. In this part of the State the easternmost of these parallel ranges—that is, those which determine the position of the western boundary of San Joaquin Valley—are the Diablo and Temblor ranges. The Diablo Range heads near San Francisco Bay and, holding a course that diverges only very slightly from that of the Coast Ranges as a whole, extends southeastward almost 200 miles to a point somewhat south of Tulare Lake, where it descends through a narrow belt of foothills to the valley level. South of this point the western margin of San Joaquin Valley is formed by the Temblor Range, which heads several miles west of the point where the Diablo Range ends and which on the south joins the San Emigdio Mountains.

Both the Diablo and Temblor ranges are formed by what may be considered essentially great anticlines somewhat broken by faults along the southwestern flanks. They are by no means simple folds, however, but each is rather an assemblage of relatively small anticlines and synclines whose combined effect has been an uplifting or doming of the region. Moreover, just as the Diablo and Temblor ranges have a course somewhat more easterly than that of the Coast Ranges as a whole and thus cut obliquely across the mountainous area, so likewise these minor folds are not parallel to the course of the range in which they lie but in general have a somewhat more easterly trend. The chief obliquely trending anticlines along the western border of San Joaquin Valley are shown in figure 5.

These obliquely trending folds increase in size and in number southward from the north end of the Diablo Range. Between Mount Diablo and Coalinga, a distance of about 150 miles, the normal anticlinal structure of the Diablo Range is broken by only three well-developed oblique anticlines. South of Coalinga, however, the complexity of the folding increases greatly, and at the south end of the Temblor Range is developed the complicated system of folds that is shown in detail on the geologic map (Pl. II).

The obliquely trending anticlines appear very largely to govern the accumulation of oil on the west side of San Joaquin Valley, for practically all the large productive fields lie either near the axes of such anticlines or in areas in which they dominate the structure. A study of the position and character of these folds is therefore of prime importance in estimating the values of undrilled areas in this general region.

The structure typical of the eastern margin of the Coast Range terminates near Sunset Valley, at the south end of the Temblor Range, where the structure lines bend sharply from a southeastward to an eastward trend. Beyond this locality, along the southern margin of the valley, the obliquely trending folds so typical of the Coast Ranges to the northwest are not developed, but toward the east first the folding appears to become much more complicated and then faults come more and more to dominate the structure. Also rocks much older than those exposed in the Temblor Range reach the surface. All in all, there appears in the San Emigdio Mountains a fairly complete gradation between the structural features of the Coast Ranges and those of the Sierra Nevada.

GENERAL STRUCTURAL FEATURES OF THE SUNSET-MIDWAY DISTRICT.

The region shown on the geologic map may be divided by a northeastward-trending line drawn through Pioneer into two parts in which, although the larger structural features are much alike, the lesser features are very different. Northwest of this line lie the closely folded Temblor Range and the outlying more

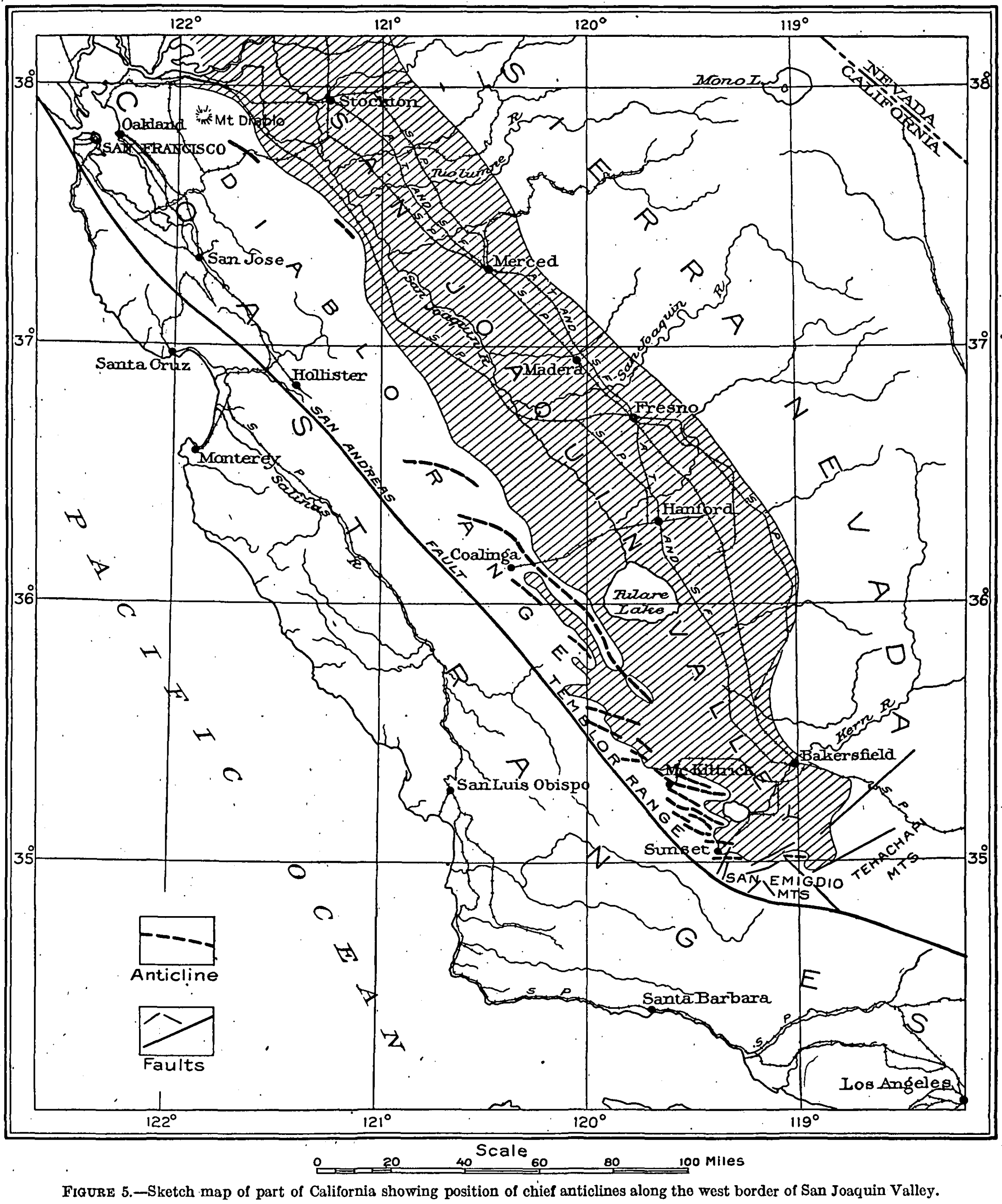


FIGURE 5.—Sketch map of part of California showing position of chief anticlines along the west border of San Joaquin Valley.

gently folded foothills, occupying a region in which the structural features are typically those of the Coast Ranges; southeast of the line are the complexly faulted and folded San Emigdio Mountains, occupying a region in which from west to east there is a fairly complete gradation between the structural features of the Coast Ranges and those of the Sierra Nevada. Some details of the structure are shown in the geologic cross sections (Pls. XVI–XXXI, in pocket).

TEMBLOR RANGE AND OUTLYING FOOTHILL RANGES.

GENERAL FEATURES.

The structure of the east flank of the Temblor Range, including the outlying foothill ranges, the Buena Vista and Elk hills, is essentially anticlinal, though it does not consist of a single fold, or even a few large folds, but rather of a great number of anticlines and synclines whose combined effect has been an upward folding of the strata along the lines now occupied by the present Temblor Range and the outlying hill groups.

Although the Temblor Range is bordered on the southwest by the San Andreas fault, along which profound movements have taken place, faults are rare in the east flank of the range near its south end. In the central part of the range the strata are very closely folded or even crumpled, but northeastward from this central area toward San Joaquin Valley the number of folds within a given area decreases, the folds themselves are more symmetrical, and the beds on their flanks are less sharply flexed. The variability in the character of the folding is probably due in part to the fact that the rocks exposed in the central portion of the Temblor Range are older than those exposed in the foothills to the northeast and were subjected to folding before the younger formations were deposited. However, the forces that have been the chief agents in producing the structure in this region were active in fairly recent geologic time and affected all the rocks in the area mapped except those of Recent age. The greater complexity of the structure in the central part of the range is therefore due mainly to the fact that it was here that the forces were chiefly active, and it is probable that in the outer foothills the older formations are but little more deformed than the younger formations which rest upon them and form the surface.

A striking feature of the structure, which has been pointed out repeatedly in the preceding pages, is the fact that, although the folds are approximately parallel to the course of the range, they are not exactly so but trend somewhat more eastward and as they extend into the valley plunge beneath the surface some distance from the main range. The angular difference in direction between the trend of these folds and the trend of the range increases toward the northeast, and the course of the outermost folds which form the Elk Hills differs about 35° from that of the Temblor Range. Not a single one of the folds in the foothills can be considered as a distinct and separate feature—that is, as a dome isolated from the structural features of the main range. They are all really but spurs that branch out from the major fold of the Temblor Range and overlap one another to a greater or less degree. The overlapping of the secondary anticlinal folds is well shown in the foothills of the Temblor Range west of Midway by the Midway, Spellacy, Thirty-five, and California Fortune anticlines; in the Buena Vista Hills by the Rudisill, Globe, and Sixteen anticlines; and to a less marked degree in the Elk Hills by the three small anticlines on the south flank of those hills. This oblique arrangement is characteristic of all the folds along the west side of San Joaquin Valley (see fig. 5) but is most marked toward its south end and is particularly well developed in the area shown on the accompanying geologic map (Pl. II).

The individual folds are short. Few are traceable for more than 15 miles, and most of them for less than half that distance. In the foothills the folds are usually grouped and a series of small anticlines taken together form a structural uplift. This grouping or bunching of the folds is particularly noticeable in the north half of the Buena Vista Hills. Here the strata are folded upward along two major zones—one extending from the southeast corner of T. 31 S., R. 23 E., northwestward to the middle of the west line of that township; the second from the middle of the east line to the northwest corner of the same township. Along each of these zones of uplift the strata are bent or puckered into several small parallel anticlines and synclines, with the main bending upward. It is probable that the individual folds are really surficial features and that at a depth of not more than a few hundred feet at most they merge to form two anticlines, one along each of the zones of uplift mentioned.

The longer anticlines are undulating, in some places pitching to the north or west and in other places to the south or east, thus fashioning the anticline into a series of domes. Most of the folds, however, pitch in but a single direction—usually south or east toward San Joaquin Valley.

Many of the small folds in the Buena Vista and Elk hills are sharp puckers, the strata that crop out only a few hundred feet from the axis of the fold being tilted very commonly as much as 30° and in places as much as 70° or 80°. As a rule, however, these sharp folds are the shorter ones and, as nearly as may be judged from the well records, the shallower ones. These small sharp folds are therefore isolated and not nearly so favorable for the accumulation of oil as the less sharply defined but broader and deeper folds. The fact that the smaller anticlines are really no more than surface wrinkles is well shown by the small anticline that lies just west of the main one—the Honolulu anticline—in the south half of the Buena Vista Hills. This small fold—the Sixteen anticline—affects the surface beds along a line that extends from the northern part of sec. 2, T. 32 S., R. 23 E., southeastward to the N. ½ sec. 8, T. 32 S., R. 24 E., and probably across the topographic depression in the central part of sec. 8 to the northeast corner of sec. 16. The position of the axis of this fold is shown on the geologic map (Pl. II). The producing oil sands that underlie the area at a depth of about 2,000 feet are, however, not folded into a single anticline but rather into a series of benches that extend out from the main Honolulu anticline. The structure of the oil sands is shown by the underground contours on Plate III.

The chief synclines in the foothills—that is, the synclines separating the zones of upward folding—are of course not so susceptible of study as the anticlines, for in them the bedrock is deeply buried beneath a thick alluvial cover. Analogy might suggest that these troughs are formed by a collection of small anticlines and synclines similar to those in the zones of uplift in the Buena Vista Hills but differing from them in that the downward folding rather than the upward folding is dominant. From the well records, however, it appears that these downward-arching folds are much more regular than the upward-arching folds and that most of them are simple troughs.

STRUCTURAL DETAILS IN THE FOOTHILLS.

The details of the structure are in the main sufficiently well shown on the geologic map (Pl. II) and the map showing the structure of the oil sands (Pl. III) to make a complete written description of them unnecessary, but one or two features, particularly those which have some direct bearing on the occurrence of petroleum that might otherwise escape notice, will be described here.

ELK HILLS.

The Elk Hills come as near to being an isolated dome as any other group within the area mapped, for the two anticlines that together form their dominant structural feature plunge not only southward beneath San Joaquin Valley but also northwestward, thus forming a structural saddle between the Elk Hills and the main range about McKittrick. These anticlines trend northwestward through the center of the hills. They are broad and low, the beds rarely being tilted more than 5° or 6° on either flank. Although the anticlines are separated at the surface by a shallow trough, it is almost certain that they unite at no great depth and form a single anticline. The trough separating them is so shallow—the dips on its flanks are in most places not more than 3° or 4°—that for all practical purposes the two anticlines may be considered one, even at the surface. In places one or the other of them is interrupted—for example, near the west end of the hills, for a distance of a mile or so, the strata dip northward from the axis of the more southerly fold to the north edge of the hills, thus interrupting the northerly fold.

Much of the south slope of the Elk Hills is approximately a dip slope, but the regularity of the structure is interrupted by three sharp puckers along which the strata are tilted in places to an angle of 50° or 60°. These folds are clearly only very minor features, and it is doubtful if they affect the strata that lie deeper than a very few hundred feet below the surface. That these folds are of no more than local importance is shown by the fact that the synclinal and anticlinal axes are very close together and by the narrowness and sharply outlined nature of the belt in which the beds are steeply tilted.

BUENA VISTA HILLS.

In the Buena Vista Hills there are two zones of upward folding—one connecting with the Shamrock anticline near the southeast corner of T. 30 S., R. 22 E., and extending southeastward to the middle of the east line of T. 31 S., R. 23 E.; the other connecting with the main range at the south end of the Telephone Hills and thence trending first eastward and then southeastward to the extreme southeast end of the Buena Vista Hills. In each of these zones or belts of upward folding there are a number of short parallel folds which overlap one another in an irregular way. Such short folds are most plentiful in the central part of the southerly belt, near the pass through the Buena Vista Hills at the southeast corner of T. 31 S., R. 23 E.

The southerly zone is the larger and the more important so far as the occurrence of oil is concerned. Although the strata are steeply tilted along the northerly zone of folding, the folds in that zone in many ways closely resemble the small folds which lie on the south flank of the Elk Hills and are to be considered as only short surface wrinkles. Toward its south end—that is, in the eastern part of T. 31 S., R. 23 E.—the folds comprised in this northerly zone probably do not greatly affect the strata that are buried more than a few hundred feet beneath the surface.

The southerly zone of upward folding, which extends from the vicinity of sec. 15, T. 31 S., R. 22 E., southeastward to the extreme southeast end of the Buena Vista Hills, is not a simple arch or even a series of small parallel anticlines, for the chief fold plunges alternately to the east and west, fashioning the anticline into a series of short anticlines or elongated domes that are separated from one another by structurally low points or saddles. The separate parts of the uplift are not very distinct at the surface, although the topography does in a measure reveal their presence, but at the horizon of the oil sands they are very marked, and they have a very definite influence upon the accumulation of the oil. The separate domes are therefore, in the present report, separately named, being called the Globe, United, and Honolulu anticlines. Their position is well shown by the underground contours on Plate III.

The pass that cuts through the hills in sec. 36, T. 31 S., R. 23 E., is as truly a reflection of the structure as the hills themselves. All the short folds that lie north of the pass plunge southward, and the Honolulu anticline and the northward extension of the Sixteen anticline, on the south of it, plunge northward. The northward plunge of the Honolulu anticline is particularly notable and is well shown by the contours in the structure map (Pl. III).

The north edge of the Buena Vista Hills, east of the pass through sec. 36, T. 31 S., R. 23 E., is well defined, the angle between the slope of the valley and slope of the hills being more sharply marked than it is in the Elk Hills. This, too, is a reflection of the structure, for the strata dip at angles of 15° to 20° in the outer part of the Buena Vista Hills, whereas at the edge of the Elk Hills the dip is rarely over half that much. Along the southwest flank of the Buena Vista Hills east of Taft there is a similar though less marked tendency for the dip to be slightly greater near the edge of Midway Valley than it is closer to the crest of the hills. A cross section across the south end of the Buena Vista Hills therefore shows the fold as a flat-topped arch, not a regularly shaped dome.

FOOTHILLS WEST OF MIDWAY VALLEY.

The chief structural features in the foothills of the main Temblor Range west of Midway Valley and south of the Globe anticline are the Midway, Spellacy, and Thirty-five anticlines. Each of these folds heads near the central part of the range but in trending southeastward each edges out into the outermost foothills and finally plunges beneath Midway Valley. The three folds have a step-like arrangement, each of the folds on the south commencing west of the point where its neighbor on the north plunges beneath the valley.

The beds near the crests of these three anticlines are a little less sharply flexed than those along the folds in the north end of the Buena Vista Hills, the dip here rarely being more than 30°. The decrease in dip on the northeast flank is regular, but on the southwest flank there appear various irregularities such as small faults, or breaks in the synclinal troughs that separate these three anticlines from the main range. These irregularities in structure are most numerous on the southwest flank of the Spellacy anticline.

The Spellacy anticline is somewhat broken near its northwest end, but the short anticline in the Maricopa shale 2 miles south of Fellows is really the northwest end of the Spellacy anticline, although not connected with it at the surface. Near the crest of Spellacy Hill (Twenty-five Hill) the Spellacy anticline changes its course rather abruptly from southeastward to eastward and passes through the central part of sec. 30, T. 32 S., R. 24 E. Near the center of the south line of sec. 25, T. 32 S., R. 23 E., a sharply marked anticline is traceable for about half a mile. This fold has frequently been taken as the southeast end of the Spellacy anticline, with which it is in almost perfect alinement. It is, however, really but a minor surface pucker, for the axis of the main fold clearly lies fully half a mile farther north. The relatively slight importance of this fold is indicated by the close approach of its axis to that of the syncline on the southwest, which is one of the chief secondary folds, and is here equal in size and parallel to the Spellacy anticline.

The California Fortune anticline may be considered the westward extension of the Thirty-five anticline—offset, it is true, and separated from that fold by the Phoenix syncline, but for all that the two are no more to be regarded as distinct structural features than the small anticline in the Maricopa shale 2 miles south of Fellows is to be regarded as a feature distinct from the Spellacy anticline.

SAN EMIGDIO MOUNTAINS.

GENERAL FEATURES.

In the San Emigdio Mountains the structure is dominated by faults and not, as in the east flank of the Temblor Range, by folds. In this region the granitic and metamorphic rocks underlie the Tertiary sedimentary rocks at a much shallower depth than in the Temblor Range and crop out in the central part of the San Emigdio Mountains, and the presence of this rigid mass of crystalline rocks so close to the surface may have been a large factor in causing the forces that produced the deformation to express themselves in faults rather than in folds. The chief reason, however, for the dominance of faults over folds is to be found in the fact that in this region the Sierra Nevada abuts against the Coast Ranges, and the forces causing deformation in both provinces have left their imprint upon the structure in this meeting ground. The action of these combined forces was evidently so intense that probably the sedimentary beds, though fairly flexible, could not simply by folding have adjusted themselves to the stresses set up, even if they had not been underlain at fairly shallow depth by a rigid foundation such as was afforded by the crystalline rocks.

In the western end of the mountains, where the Tertiary sedimentary rocks are thick, those beds are folded into an infinite number of short irregular folds and broken by a multitude of equally irregular faults. Many of these folds and faults are shown on the geologic map (Pl. II), but a great many others are of necessity omitted, and the structure there is even more complicated than the map indicates. East of Santiago Creek the folds are relatively few, and most of them are shown on the map. In contrast to those in the west end of the mountains, the folds here are mainly open, few are closely compressed, and only one or two small ones are even locally overturned. The faults are, however, increasingly abundant toward the east, and many of them have almost certainly been overlooked, for the outcrops do not preserve evidence of faulting for any great length of time.

One feature worthy of note in comparing the structure of the north flank of the San Emigdio Mountains with that of the Coast Ranges, to the northwest, is the fact that here in many of the blocks bounded by faults the strata are folded into both anticlines and synclines. The faults are apparently entirely independent of the folds in position, and many of them in direction. In the central part of the Diablo Range the anticlines are characteristically faulted, and in the fault blocks the sedimentary rocks are folded into synclines only. An excellent example of structure of this type is shown by the region about Priest Valley, at the heart of the range west of Coalinga. The structure in this area is mapped and described in an earlier paper.[1]

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

The largest single structural feature in the San Emigdio Mountains is the San Andreas fault, or the "earthquake line," as it is commonly known because of the fact that movements along this fault farther north were the cause of the San Francisco earthquake of April, 1906. This fault is traceable from a point north of San Francisco southeastward for several hundred miles to a point in the desert in the southeast corner of the State. Movements along the fault have been profound and in the area shown on the map have resulted in a vertical displacement that aggregates many hundred or perhaps several thousand feet. Some idea of the magnitude of the movements along this line may be obtained by a view of the section on the east branch of Santiago Creek near the southern edge of the area shown on the geologic map. Here the Mesozoic granite on the north side of the canyon is in fault contact with the Miocene sands and gravels on the south. (See diagrammatic section E–E′, Pl. II.)

Very little evidence was obtained as to the precise nature of the faults, for the rocks they cut are not well suited to retain such evidence very long in recognizable form. From the meager evidence available, however, it seems probable that most of the faults are normal and that the dip of the fault planes is usually high. Certainly there is no evidence here that any fault is a thrust with even a moderately low dip. The faults in the north flank of the San Emigdio Mountains appear to belong to two main systems, those of one trending between N. 40° W. and N. 75° W. and those of the other between N. 45° E. and due east. It may be that the San Andreas fault, which would fall into the first-named system, should really be considered separately, for it appears to have a slightly more westerly trend than most of the other large faults of this system.

The faults of the northwesterly system are represented in the area shown on the map (Pl. II) by the fault that parallels the main branch of San Emigdio Creek above its connection with Williams Creek, by the one that terminates on the west the granitic outcrop which lies north of the Devils Kitchen syncline, and by the one that passes through the hills just west of El Rincon. The faults of this system increase in size and in abundance toward the eastern edge of the area mapped, and in the Tehachapi Mountains, still farther east, they are far more plentiful than they are anywhere in the San Emigdio Mountains.

The faults of the easterly system are represented by the fault that crosses Santiago Creek near the southwest corner of the San Emigdio grant, by the one that parallels Williams Creek, and by the one that crosses San Emigdio Creek at its mouth.

DETAILS OF STRUCTURE.

AREA WEST OF SANTIAGO CREEK.

The strata in the foothills west of Santiago Creek are so crumpled and broken by irregular faults that about the only generalization which can be made regarding the structure here is that the complexity increases as the San Andreas fault is approached.

In the outer foothills are the Cienaga syncline and the Pioneer anticline, which with the Wheeler Ridge anticline are the most easterly of the folds typical of the Temblor Range. The Cienaga syncline is asymmetric, the beds standing almost vertical upon its south limb but dipping southward at only 10° or 15° on the north limb near its east end.

The Pioneer anticline is almost symmetrical, and east of the fault down Cienaga Canyon the beds are usually tilted not more than 20° on either flank. Both anticline and syncline plunge eastward beneath the valley, but it is probable that both continue to affect the Tertiary strata beneath the alluvial cover as far eastward as the east line of R. 23 W.

The exact position at which the fault that extends down Cienaga Canyon is drawn on the maps (Pl. II, III, and XLIV) is determined largely by the topography. There may be and probably are other faults in the Tertiary rocks about Old Sunset, but the cover of alluvium hides them completely. The Cienaga Canyon fault does not cross the Cienaga syncline, for although that fold makes a very abrupt bend, beds may be traced uninterruptedly across the canyon.

AREA EAST OF SANTIAGO CREEK.

The chief folds in the San Emigdio Mountains east of Santiago Creek are the Devils Kitchen syncline, the Pleito syncline, the unnamed anticline which separates these two troughs, and the Wheeler Ridge anticline. All these folds are fairly symmetrical and open.

The Devils Kitchen syncline is one of the most picturesque features of the whole region, for where San Emigdio Creek has cut a deep canyon directly across it the massive rocks in the lower part of the Vaqueros formation are clearly exposed, and one standing on the west side of the canyon may look across and follow with his eye some individual bed from the point where it dips northward at Eagle Rest fully around the trough of the syncline to the point on the north flank where it dips southward. An excellent view of the syncline is given in the photograph shown in Plate VIII.

East of San Emigdio Creek the syncline pitches directly eastward at an angle of about 20°, and on the opposite side of the hill shown in Plate VIII, the massive sandstone and conglomerate crop out in the center of the syncline and, weathering to rock slopes almost barren of vegetation in places, form a great rock trough.

The axis of the anticline separating the Pleito and Devils Kitchen synclines has been mapped for a distance of only 2 or 3 miles between San Emigdio and Pleito creeks. The fold continues westward beyond San Emigdio Creek, however, for it is along this fold that the granite exposed north of the Devils Kitchen syncline crops out. Some importance attaches to this fold, for along it, if anywhere on the north flank of the San Emigdio Mountains, the oil which may possibly have originated in the shales of the Tejon formation would be expected to collect. The possibility that oil has collected here is discussed in another part of the report (p. 170).

The Wheeler Ridge anticline is a slightly asymmetric fold that heads in an area of complicated structure just west of Coaloil Canyon and runs in a slightly curving course first eastward and then southeastward for some 6 miles, finally plunging beneath the valley. In a reconnaissance report on the south end of San Joaquin Valley Robert Anderson[1] described the Wheeler Ridge anticline as plunging westward west of Coaloil Canyon and likened the structure here to that of a dome. The swing in the course of the anticline near the Coaloil Canyon is, however, not due to a westward plunge. A cross fault passes through the hills just west of El Rincon, and although the field evidence is not quite clear as to whether the fault has cut the fold or whether the folding was subsequent to the faulting and only the beds east of the fault were flexed, it is certain that the change in the trend of the fold is caused by the fault and not by a simple plunge of the fold.

The northwestward-trending fault that passes through the low hills west of El Rincon and across Wheeler Ridge just west of Coaloil Canyon is one of the chief structural features of the region. It or a parallel fault evidently continues southeastward along the upper part of Grapevine Canyon (Cañada de las Uvas) at least as far as Castac Lake, which lies 4 miles southeast of the southeast corner of the area shown on the geologic map (Pl. II). In spite of the evident large size of this fault it is practically impossible to get satisfactory evidence in the field either as to its exact position in the foothills or as to the attitude of the fault plane. The shale that crops out in the area just west of El Rincon is so crumpled, and the whole area lying between the axis of the Pleito syncline and Wheeler Ridge is so complex a mass of landslides that the attitude of the outcropping rocks gives no clue as to the true structure. Even where the fault is supposed to cross the line of contact between the granite and the Tejon the surface is so covered with the granitic débris of rock slides from the higher parts of the range that the offset shown on the map is almost wholly hypothetical.

A fault paralleling the fault just described crosses Tejon Pass (Cañada de las Uvas) practically at its mouth, and other short parallel faults cross lower Salt Creek. Moreover, the steep northward slope of the shale hill lying north of the axis of the Pleito syncline and just west of the mouth of Salt Creek suggests that it too is determined by a break paralleling the larger one which lies a mile to the northeast.

Both the fault along the main branch of San Emigdio Creek and that up Williams Creek, or faults parallel with and close to these faults, almost certainly continue southward to the San Andreas fault, forming thus a triangular fault block of which San Emigdio Mountain is the highest point. The fault up the main branch of the creek is distinctly younger than the Devils Kitchen syncline and offsets the axis of that fold. This fault does not seem to cross the fault that passes down Williams Creek and is probably older.

The eastward-trending fault that passes through the Tejon rocks about 2 miles above the junction of Williams and San Emigdio

[1] U. S. Geol. Survey Bull. 471, pp. 123, 124, 1912.

creeks is a relatively small break. Its relation to the fault up San Emigdio Creek is not clearly shown.

PETROLEUM.

HISTORY OF DEVELOPMENT.

The presence of brea and seeps of heavy oil in the foothills of the Temblor Range at the south end of San Joaquin Valley has been known for at least 50 years, but owing in part to a lack of appreciation of the value of the petroleum resources of California as a whole, and especially to the lack of transportation facilities in this portion of the State, the Sunset-Midway district received scant attention until the nineties. Even then the first serious efforts to develop the resources of the region were concerned with asphalt rather than with petroleum, and the production of oil in the Sunset-Midway field may be said to date from 1900.

The pioneer work in the district was done by a company composed mainly of Bakersfield men, among whom were Solomon Jewett, J. A. Blodgett, John Hambleton, Judge J. O. Lovejoy, J. H. Woody, and W. P. Woods. This company located some 2,000 acres of land lying between the tar seeps at Old Sunset and the site of the present town of Maricopa and in 1889 prepared to drill for oil. The following account of the operations carried on before 1900 was written by Wallace Morgan, formerly editor of the Bakersfield Echo.[1] It describes so well the details of these first efforts that it is here given in his own words:

The first well sunk on this land and the first put down in the Sunset field was drilled by William DeWitt, then of Tulare and now justice of the peace at that place. DeWitt reached a depth of 300 feet on the SW. ¼ SE. ¼ sec. 2, 11–24, where he struck a strong flow of sulphur water. This well was located, like most of the early wells, in a bed of brea at the very outcropping of the oil-bearing strata. Less than half a mile to the east were drilled years later the productive wells of the Adeline Extension, and had DeWitt tried his fortunes a little farther from the hills the early history of the Sunset field might have been more rosy. However, when he struck the artesian flow of sulphur water the present Tulare judge pulled up stakes and moved his derrick to the SW. [NW.?] ¼ sec. 21, 11–23, about 5 miles to the southeast, where he found another bed of brea and where he drilled a well to a depth of 100 feet. The second venture was a little more encouraging, for a stratum of heavy oil was found, and the thick, black semifluid rose in the casing and oozed over the top.

Meantime Charles Barnard, who had operated in the Ventura oil fields, * * * secured a 20-year lease in conjunction with Jewett and Blodgett on the 2,000 acres held by the Sunset Oil Co. * * * Barnard brought from Ventura a standard rig with which he began operations on sec. 21, 11–23, near the site of DeWitt's second attempt. Before he had gone 300 feet he had lost three strings of tools in the well and decided to move to the SE. ¼ sec. 13, 11–24 * * * . Here, at 300 feet, he got sulphur water that flowed over the casing. He then sold out his interest in the lease to Jewett & Blodgett. * * *

Mr. Blodgett, who was the active member of the firm, had bought a standard rig from the Columbian Oil Co., which had abandoned drilling at McKittrick and was drilling along the break of the hills at Sunset, with indifferent success. He got oil in small quantities, but there was no transportation save by teams to Bakersfield, and the cost of hauling was prohibitive.

In 1891 Jewett & Blodgett began making asphalt at Sunset, quarrying the native product from the beds where the oil had seeped out and dried and melting it in open kettles with a small amount of crude oil for a flux. The hot asphalt was drawn off into boxes and the sediment of sand and dirt was shoveled out of the kettles in preparation for another batch. The asphalt was hauled to Bakersfield by big teams of 16 to 24 horses and shipped east by rail. There was no local market.

Of course the expense ate up the profits, and the men interested in the venture began an effort to secure rail transportation. H. F. Williams * * * took an interest in the project and * * * succeeded in bringing about an agreement between Jewett & Blodgett and the Southern Pacific Railroad by which the latter, in 1892, undertook to build a railroad to McKittrick in two years and one to Sunset in five years in return for assurances from Jewett & Blodgett that the traffic would be sufficient to pay the operating expenses. As a part of the agreement the Standard Asphalt Co. was organized, with Jewett & Blodgett and the railroad company as equal owners, and all the asphalt properties between Sunset and McKittrick were merged in the new concern. A little later the railroad offered an amendment to the agreement to the effect that it would at once construct the road to McKittrick if the building of the Sunset line was waived. The new arrangement was accepted and the McKittrick line was completed in 1893.

* * * *

The Standard Asphalt Co. took over the asphalt-making business of Jewett & Blodgett, but owing to the panic of 1893 the venture did not pay, even with the better transportation facilities, and the partnership was dissolved, the railroad retaining the name of the company and taking the McKittrick end of the business, while Jewett & Blodgett went back to their old firm title and took the Sunset end as their share.

In 1894 W. E. Youle, an oil-well driller from the Newhall and Puente fields, was placed in charge of the development work of Jewett & Blodgett at Sunset. * * *

Youle's first task was to pull the lost tools out of the old Barnard well on sec. 21, 11–23. Several wells were drilled, but they were all too near the outcroppings, as it later developed, and their product was not sufficient even to supply oil for the flux needed in clarifying the natural asphalt. Then the plan of sinking shafts to supply the deficiency was tried. * * *

[1] The Morning Echo, vol. 31, No. 117, Bakersfield, Cal., Feb. 28, 1911. A somewhat briefer account has been published by Mr. Morgan in his book entitled History of Kern County, Cal., Los Angeles, Calif., Historical Record Co., 1914.

There were difficulties, too, connected with the process of clarifying the natural asphalt in open kettles. In more ways than one it was like frying out lard, for a teaspoonful of water would make half a kettleful of hot asphalt boil over into the fire. Several plants were burned up in accidents like this.

In 1894 Jewett & Blodgett had 16 wells at Old Sunset, the combined product from which amounted to about 30 barrels a day, the material varying from a heavy tar to oil of 16° Baumé.

The following excellent description of the development of the Sunset field in 1894 was written by Watts,[1] who visited the region in that year for the State Mining Bureau:

Messrs. Jewett & Blodgett bored two groups of wells in the mesa lands of the Sunset oil district. One of these groups, * * * "group 1," * * * is in sec. 21; the other, * * * "group 2," is in sec. 28 [T. 11 N., R. 23 W.]. In group 1 there are 13 wells, one of these being 1,300 feet in depth, the remainder varying from 80 to 500 feet in depth. The 1,300-foot well yielded flowing water and much gas; the others yield a heavy oil by pumping. The 12 oil-producing wells are all situated within an area of about 400 feet in length and 30 feet in width. The 1,300-foot well was bored a short distance in a northeasterly direction from the most northerly of the oil-yielding wells. The 12 oil wells yield altogether about 15 barrels of oil every 24 hours. The specific gravity of this oil varies in the different wells from about 12° Baumé to a heavy liquid asphaltum that requires to be heated by steam, which is forced to the bottom of the well, before the heavy oil can be pumped. Six of these are dry wells and are sunk to a depth of from 80 to 100 feet. The stratum yielding the greater portion of the heavy oil is about 35 feet in thickness. The other six are drilled wells varying from 150 to 500 feet in depth. All these wells are sunk to a sufficient depth to form reservoirs at the bottom capable of storing the oil, which gathers during several days, for a few hours of pumping is sufficient to pump the oil accumulated during 24 hours. Each well is furnished with a pumping jack, consisting of knee and frame, which is securely anchored to the ground or mud sills. All these wells are pumped with lift pumps.

* * * *

The crude oil yields about 50 per cent of distillates, which have an average specific gravity of 20° Baumé. The heat is increased toward the end of the process to 700° F., in order to expel the heavier distillates and make the refined asphaltum hard. It is the intention of the Sunset Co. to treat these heavy distillates by fractional distillation, and at the time of the writer's visit these distillates were being stored in tanks for that purpose.

* * * *

In 1892–93 Messrs. Jewett & Blodgett bored three wells on the mesa lands in sec. 28, at a point a little more than a mile from Oil Wells, group 1, and in a southeasterly direction therefrom. [These are the wells of "group 2."]

* * * *

The oil yielded by the oil wells of group 2 is a dark-green oil and possesses a lower specific gravity than that yielded by the oil wells of group 1.

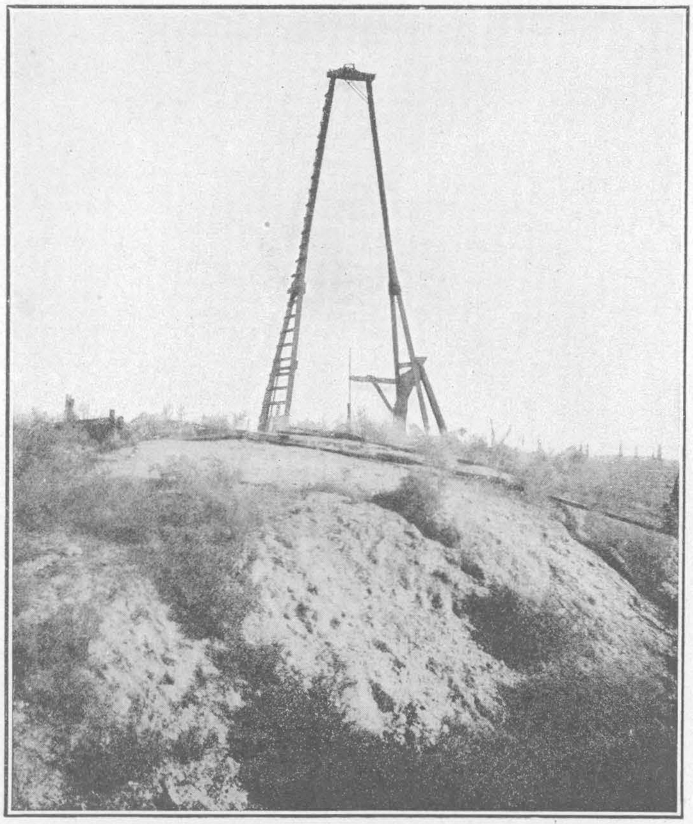
One of the wells drilled in the nineties is shown in Plate XXXII, *A*.

The operations about Old Sunset were abandoned shortly after 1894, and Jewett & Blodgett moved their operations to Sunset, or Pioneer, as it was later known, in sec. 13, T. 11 N., R. 24 W. In the later part of 1899 the Kern River field was discovered, and the success attained in the relatively shallow wells there gave a great impulse to the search for oil in the surrounding regions. Most of the land in the Sunset-Midway field was at this time located under the provisions of the placer-mining law, but owing to the distance from the railroad drilling was actually started on but few of the claims. In August, 1900,[2] there were between Old Sunset and the site of the present town of Maricopa 16 wells, which ranged in depth between 250 and 400 feet and yielded between 10 and 25 barrels of oil of 11° Baumé. Another well 875 feet deep had been drilled in sec. 18, T. 11 N., R. 23 W., east of the main group. Besides the wells of Jewett & Blodgett the only other productive well in the Sunset field at this date was one belonging to the Monarch Oil Co., in the NW. ¼ sec. 2, T. 11 N., R. 24 W., which flowed and was said to yield about 75 barrels of oil a day.

About this time an agreement was reached with the Santa Fe Railway to build a line from Bakersfield to Sunset, but before construction had been started an arrangement had been made between the Santa Fe and the Southern Pacific concerning joint ownership of feeder lines from points common to the two roads. The Sunset Railroad was to have been completed in 1901 but was not actually finished until 1902. This delay in the completion of the road had a serious effect on the field, for upon the announcement that a railroad was to be built to Sunset that field became the scene of great activity, all vacant land about Sunset and in what is now the Midway field was located, and drilling was started on many of the sections. Most of the wells about Sunset got small quantities of petroleum, but by the time the railroad was completed and adequate means for shipping the oil were provided the

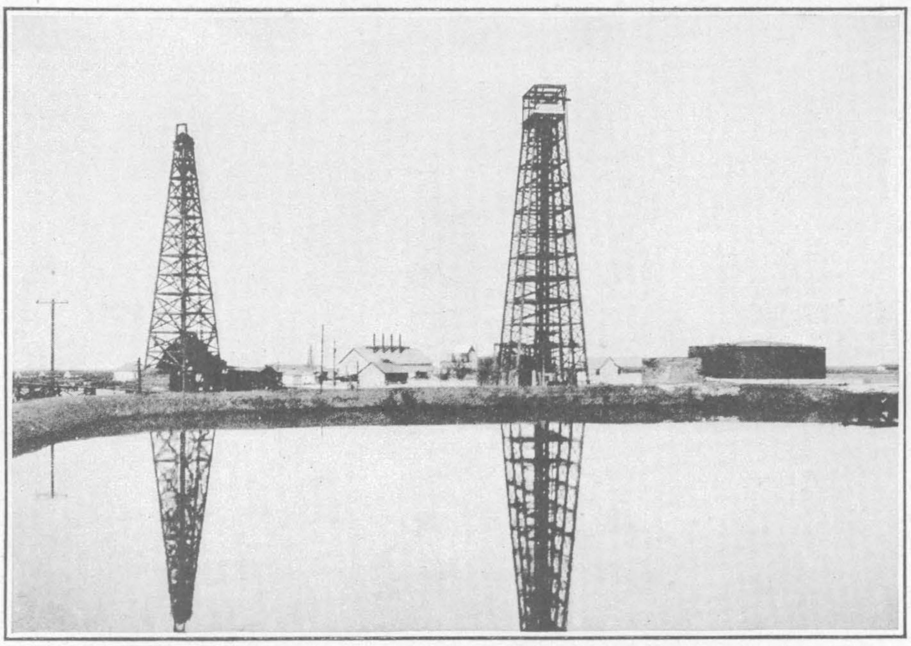
[1] Watts, W. L., The gas and oil yielding formations of the Central Valley of California: California State Mining Bur. Bull. 3, pp. 26–33, 1894.

[2] Watts, W. L., Oil and gas yielding formations of California: California State Min. Bur. Bull. 19, p. 123, 1900.



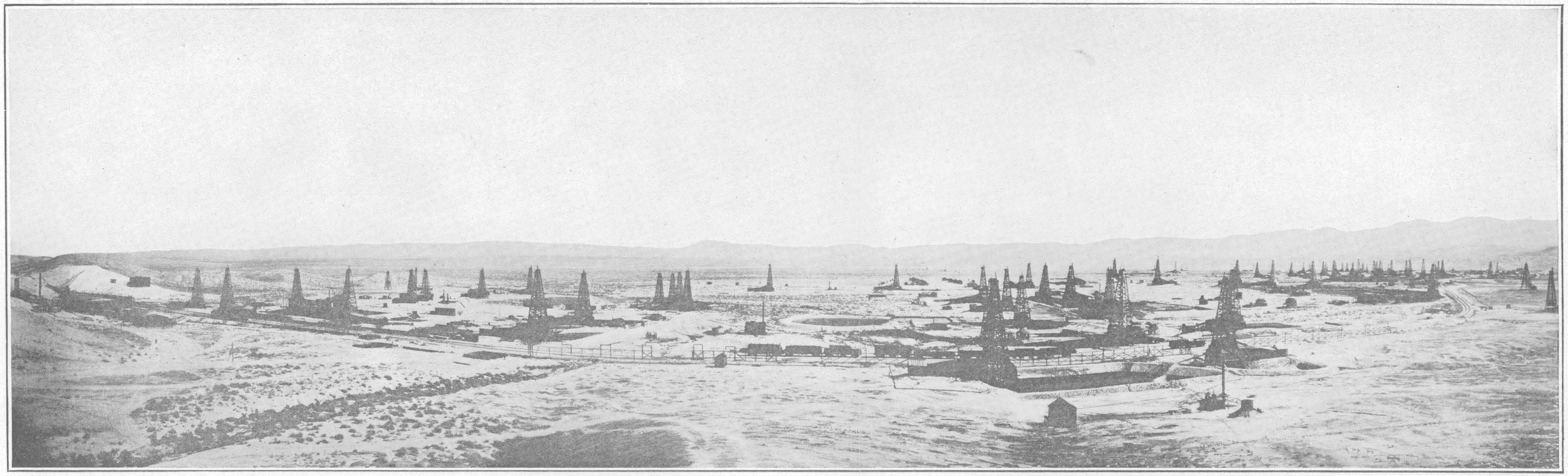
A. CRUDE DERRICK OVER A WELL DRILLED IN THE NINETIES.

This well furnished oil for the old refinery shown in Plate XIII, *A*.



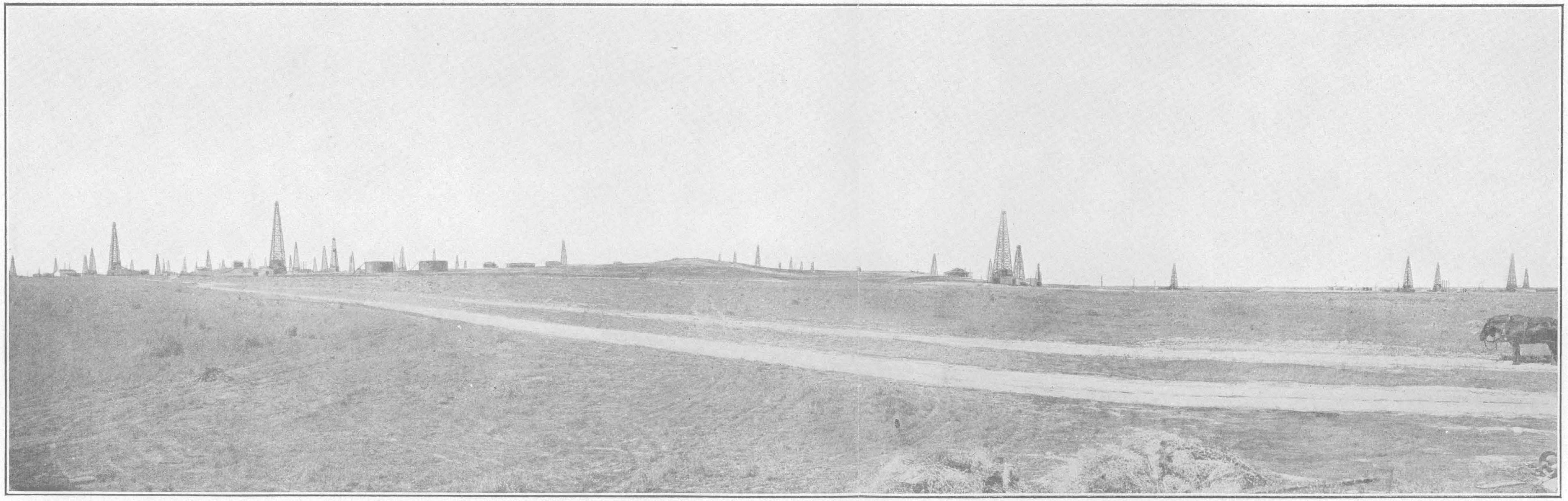
B. DERRICK AND GAS TRAP IN MARICOPA FLAT.

The derrick (at the left) is more than 100 feet high. Note the difference between it and the one shown in *A*.



A. SUNSET OIL FIELD IN OCTOBER, 1908.

Looking northeast, east, and southeast from Occidental property 1 mile northwest of Maricopa. Photograph by Ralph Arnold.



B. MARICOPA FLAT, SUNSET OIL FIELD, IN 1914.

Looking northward from center of sec. 5, T. 11 N., R. 23 W. The low hill in the center is the topographic expression of the Thirty-five anticline. Wells in sec. 4, T. 11 N., R. 23 W., are shown at the extreme right.

price for oil had dropped so low that few of the companies could live.

The drop in the price of oil affected the Midway field even more seriously, for it was at that time without proper transportation facilities, and all lumber, machinery, and fuel had to be hauled by team either from Sunset or from McKittrick. At first drinking and even drilling water had to be hauled from the Miller & Lux well far out in San Joaquin Valley. The difficulties under which the first operations were conducted here are described as follows in an article published in the Maricopa Oil News in July, 1914:

The first drilling in the [Midway] field was by the Oregon Midway, on sec. 4, 32–23, with a patent rig. Three wells were drilled, but with the rig 600 feet was the greatest depth to be reached. A standard rig was secured and a hole drilled to 1,000 feet. The drilling water had to be hauled by team from the Miller & Lux hog ranch. In 1901 the Producers' Guaranty Co., which guaranteed to strike oil in two years or refund the amount paid for stock, began drilling. On its first well the drillers were paid $5 per foot, the company furnishing all machinery, supplies, water, and fuel. On February 26, 1901, the machinery was hauled across the bed of Buena Vista Lake, which was then dry, no water having been in it for three years. On May 1, 1901, the first oil was struck, at 1,407 feet, the casing being 7⅝ inches. For this work the water cost $1.25 per barrel delivered at the well. After the water was delivered the company had to permit the 10-mule teams used to haul it to drink from it. They used about half the water hauled. Fuel oil was secured from Sunset, it requiring four days to bring a tank of oil. It cost $2.90 per barrel, and hauling cost $15 per day for the team.

On May 15, 1901, the first Midway oil sold was from the Producers' Guaranty to the Oregon Midway for fuel, they having been buying from McKittrick. Among other drilling companies was the C. C. M. Oil Co., the Bay City, the Mascot, the Judge, the Crump, and the Pittsburg. The Producers' Guaranty had a production of 250 barrels per day, though it was pumping but 12 hours a day. In 1902 Buena Vista Lake filled up and the Producers' Guaranty Co.'s four wells had water trouble. This disappeared two years later, when the lake went down. In 1903 the oil industry in the Midway "blew up," as there was no way to ship it, and Kern River oil was selling at 10 cents per barrel. This continued until 1907. In that year Boust and others formed the Knob Hill Co., and also leased land to other companies, which began work and are now among the producers.

In 1907, with the return of adequate prices for oil, the Sunset-Midway field started its tremendous growth that has continued up to the present time. (See Pl. XXXIII.) Prospecting gradually left the foothills along which it had hugged, spread boldly out over Midway Valley and the Buena Vista Hills, and in 1910 entered the Elk Hills. During this time the field passed through the period of speculation common to most new mining camps. Titles to mining claims changed hands many times in a few weeks, each time at an increase in price. The price for claims covering tracts several miles from any producing well increased from a few dollars to $1,000 or more an acre, and those holding a clear title to the land were able to command even higher prices. The maximum price attained was reached in 1910, just after the famous Lakeview No. 1 gusher started flowing, when $200,000 is reported to have been offered and refused for a tract of 20 acres lying close to that well.

Prior to 1909 the producing wells that had been drilled furnished oil by pumping or flowed moderately, but none had produced more than a few hundred barrels a day. In November, 1909, the Chanslor-Canfield Midway Oil Co. brought in a well near Fellows that flowed at a rate of about 2,000 barrels daily. This was the first of the big wells of the field. During the following year more than 25 flowing wells with an initial production of 1,000 barrels or more had been brought in, and up to the present time (1916) over 100 such gushers have been drilled.

The most famous of these wells was the first Lakeview gusher, in sec. 25, T. 12 N., R. 24 W., which came in March 14, 1910, and the following day produced approximately 18,000 barrels of oil. Within a few days the well was far beyond control. It continued to flow for 18 months, finally stopping September 9, 1911, after it had produced over 8,000,000 barrels of oil, about 6,000,000 barrels of which had been saved. The daily production of the well varied greatly, reaching a maximum of about 65,000 barrels. At first the product was practically clear oil having a gravity of 18° to 21° Baumé, but in a few weeks water and emulsion appeared and gradually increased in amount, forming some 60 per cent of the daily product on January 1, 1911.

The pipe lines leading from the field were inadequate to carry the product of the field while the Lakeview well was flowing, and much of the oil from that well was stored in earthen sumps constructed hastily by throwing dams across small canyons in the foothills. Here the oil stood for weeks or months exposed to the sun, and when finally marketed it had lost most of its lighter constituents.

About this same time a group of flowing wells in the North Midway field was attracting much attention. The first of these wells was that of the Mays Oil Co. (now the Consolidated Mutual), in sec. 30, T. 31 S., R. 23 E., which started to flow on March 7, 1910, at a rate of over 10,000 barrels a day. In close succession followed the wells of the St. Lawrence Oil Co.; those of the Pioneer Midway Oil Co. (now the Associated Oil Co.); well No. 2 of the Chanslor-Canfield Midway Oil Co., in sec. 36, T. 31 S., R. 22 E.; wells of the Mammoth and Eagle companies, in sec. 31, T. 31 S., R. 23 E., of the Midway Premier Oil Co., in sec. 5, T. 32 S., R. 23 E., of the Midway Premier Oil Co., in sec. 5, T. 32 S., R. 23 E., and of the United Oil Co., in sec. 6, T. 32 S., R. 23 E. The greatest of these North Midway wells was No. 79 of the American Oilfields Co., in sec. 36, T. 31 S., R. 22 E., which came in April 3, 1910, making 400 barrels of oil the first day. The production gradually increased until in June it was making over 1,000 barrels of oil. Late in July it broke loose and for a time produced at a rate of over 20,000 barrels daily. After a couple of months the tremendous gas pressure was exhausted and the production dropped to a rate between 1,000 and 2,000 barrels daily, which was maintained for more than three years.

Another group of flowing wells was obtained early in 1910 by the Standard Oil Co. along the foothills of the main range in sec. 30, T. 32 S., R. 24 E. These wells flowed under perfect control, two of them for a time individually producing as much as 7,500 to 10,000 barrels daily.

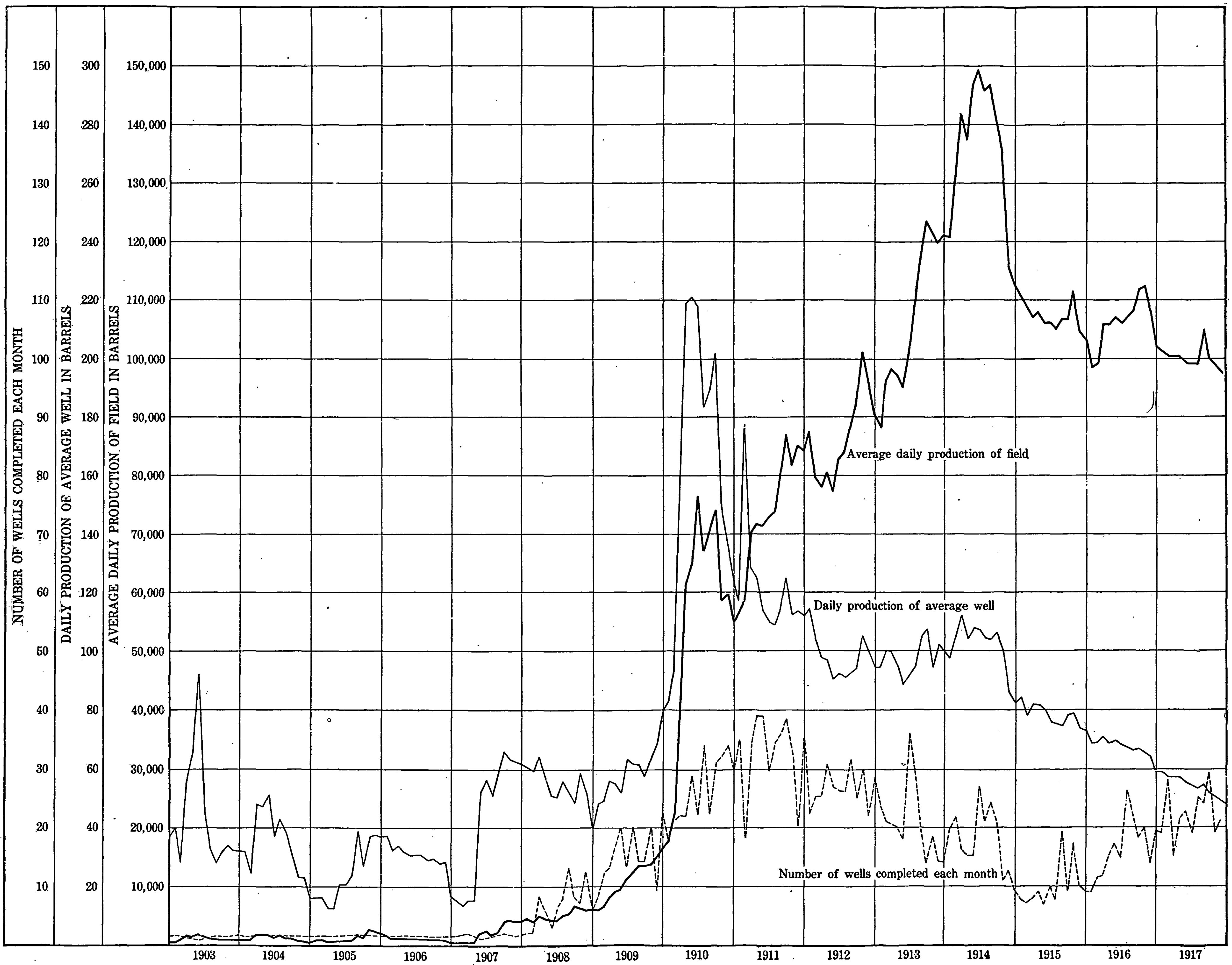
In the meantime drilling in the Buena Vista Hills had met with success. The pioneer well here was that drilled in sec. 10, T. 32 S., R. 24 E., by the Honolulu Consolidated Oil Co., which in 1909 obtained a strong flow of gas at a depth of a little more than 1,600 feet. The company was then entirely unprepared to handle gas under such heavy pressure, and the well ran wild for about two months. Eventually it was deepened more than 2,500 feet, and early in 1910 it produced light-gravity oil flowing at a rate of 2,000 or 3,000 barrels daily.

Later in the same year the company obtained large flows of gas from wells in secs. 4 and 6 of the same township. In the north end of the Buena Vista Hills the Standard Oil Co. obtained big gas wells in secs. 22 and 26, T. 31 S., R. 23 E., the first of which was brought in October 11, 1909. At first the gas found but little utilization other than to supply fuel for drilling operations on near-by properties, but in 1910 the Standard Oil Co. started to use it in its pumping station in Midway. Later the California Natural Gas Co. laid a line to the Elk Hills to serve drilling companies there and finally extended its lines to Bakersfield, first serving that place on December 29, 1911. As early as 1910 the project of piping gas to Los Angeles was considered, but it was not until November, 1911, that the Midway Gas Co. was incorporated for the purpose of constructing the necessary transmission main. In September, 1912, a 12-inch line 111 miles long was completed to West Glendale, near Los Angeles, and service was started April 28, 1913.

Since 1911 all parts of the field have shown steady growth, the greatest amount being in the Buena Vista Hills, in North Midway, and in Maricopa Flat. The last-named area attracted much attention during 1912, 1913, and 1914, having a group of flowing wells, among which were those of the Obispo, Spreckels, Miocene, Midland Oilfields, and General Petroleum companies. The most spectacular of these wells was that of the Lakeview No. 2 Oil Co., which came in May 10, 1914. Like the old Lakeview well, this well baffled the efforts of the company to control it, and soon the casing had been cut away and a crater-like hole about 60 feet across excavated about the mouth of the well. The well flowed until October 25, 1914, and the total amount of oil produced up to that time was roughly estimated at about 6,000,000 barrels. The rate of production varied greatly, but the well is said to have made as much as 50,000 barrels in a day. Like the old Lakeview, and indeed like most of the big flowing wells, this well produced at first practically clear oil, but water and emulsion soon appeared and, increasing in amount, came to form as much as 80 per cent of the total product.

PRODUCTION.

The following table has been prepared from figures furnished to the Survey by the operating companies. (See also Pl. XXXIV.)



CURVES SHOWING PRODUCTION OF SUNSET-MIDWAY FIELD.

Oil marketed in the Midway and Sunset fields, Cal., 1900–1918, in barrels.

Year.	Sunset.	Midway.	Total.
1900	a 12,000		12,000
1901	189,000	4,000	193,000
1902	133,000	5,000	138,000
1903	181,000	a 5,000	186,000
1904	a 276,000	a 8,000	284,000
1905	317,000	13,000	330,000
1906	563,000	(b)	563,000
1907	567,000	134,000	701,000
1908	1,556,000	410,000	1,966,000
1909	1,713,000	2,095,000	3,808,000
1910	c 7,157,000	10,436,000	17,593,000
1911	c 6,350,000	21,196,000	27,546,000
1912	c 6,509,000	23,928,000	30,437,000
1913	6,212,000	32,349,000	38,561,000
1914	9,242,000	37,863,000	47,105,000
1915	8,731,000	29,930,000	38,661,000
1916	7,358,000	31,840,000	39,198,000
1917	6,681,000	28,830,000	35,511,000
1918	7,432,000	32,517,000	39,949,000
			322,742,000

a Estimated.
b Included in Sunset field.
c Includes some from Midway field.

PIPE LINES.

Most of the oil from the Sunset-Midway field is delivered to the large pipe-line companies and by them pumped to tidewater. The lines leading from the field are described below.

OIL LINES.

Standard Oil Co.—Two 8-inch lines 32 miles long from Midway to Kern River, with 14 miles of 12-inch loop. At Kern River these lines join the main valley system of the company, that runs to Point Richmond, on San Francisco Bay. Capacity about 65,000 barrels daily.

Associated Pipe Line Co.—One 8-inch line 279 miles long from Sunset through the Midway field to San Francisco Bay. Capacity about 26,000 barrels daily.

Producers Transportation Co.—One 8-inch line 50 miles long from Sunset through the Midway field to Junction station, at the north end of the Temblor Range. Capacity about 30,000 barrels. At Junction this line meets the 8-inch lines from Coalinga and Lost Hills, and the oil is pumped through two 8-inch lines 74 miles westward to Port San Luis, which is on the coast about halfway from San Francisco to Los Angeles.

General Pipe Line Co.—One 8-inch line from Midway to Los Angeles, a distance of 156 miles. Estimated daily capacity of line about 25,000 barrels. A branch 8-inch line extends from Lebec, in the Tehachapi Mountains, 52 miles eastward to Mohave, where the oil is topped before shipping it by rail.

GAS LINES.

Midway Gas Co.—One 12-inch gas line from Midway to West Glendale, near Los Angeles, a distance of about 115 miles. In 1915 only about 15,000,000 cubic feet of gas was sent through the line daily, but it is said that 35,000,000 cubic feet of gas has been delivered in a day.

Valley Gas Co.—Line from Midway to Bakersfield, a distance of about 40 miles. Pipe of different sizes. Capacity about 1,800,000 cubic feet a day on a 4-ounce base.

WATER SUPPLY.[1]

The east flank of the Temblor Range contains no perennial streams and very few springs that flow, except during the wet season. Moreover, the ground water throughout the foothills is not potable, and all the water used in the Sunset-Midway field for domestic purposes and much of that for boiler supply and drilling purposes is piped in from sources outside the productive field.

The lack of a sufficient water supply severely handicapped the first operators in the field, and it was not until the Western Water Co. had completed its system that the field had an adequate supply. The first operators in the Sunset field were dependent for boiler and drilling water upon sulphur-water wells, chiefly those in secs. 12 and 13, T. 11 N., R. 24 W., and before the railroad was completed drinking water was hauled by wagon from springs in the west end of the San Emigdio Mountains. It is said that this water costs 10 cents a barrel at the springs and that it took a full day to make a round trip from Sunset. The Midway field was hardly more fortunate, as it was dependent upon the small supply furnished by the Chanslor-Canfield Midway Oil Co. and the Stratton Water Co. Drinking water for use in many of the camps and in the towns was hauled by the Sunset Railroad in tank cars from Kern River, on the east side of San Joaquin Valley.

In 1914 the field was supplied from a number of sources at an average price of about 3 cents a barrel. The chief supply is that furnished by the Western Water Co. from shallow wells at the north end of Buena Vista Lake. This water is used throughout the field for domestic and boiler water.

The Chanslor-Canfield Midway Oil Co. pipes water for its own use and for the use of some of the companies in the north end of the Midway field from Santa Maria Valley, west of McKittrick. This was one of the first supplies developed for use in the Midway field, and in the early days the water was sold for 21 cents a barrel. The water is used both for domestic purposes and in the boilers.

[1] Analyses and a discussion of representative waters used for industrial purposes are given in Part II of this report (Prof. Paper 117, Table 17, p. 78).

The Standard Oil Co. pipes water to its camps from the east side of San Joaquin Valley. With the possible exception of the water from the Wagy ranch and that from Santiago Creek used at the Western Minerals camp this is the best water in the field.

Sufficient water for domestic use in Maricopa is piped from the Wagy ranch, in sec. 12, T. 9 N., R. 24 W. The water here issued from Tertiary sedimentary beds in the bottom of Ballinger Canyon.

The camp of the Western Minerals Co. near Old Sunset is supplied with splendid water from springs in a faulted area on Santiago Creek in the west end of the San Emigdio grant. The water issues from early Tertiary sedimentary beds close to the granitic rocks, with which they are in fault contact.

Water so heavily charged with mineral salts as to be useless for domestic purposes is furnished as boiler and drilling water by a number of wells. The water is of varied character, some of it highly charged with sulphur or hydrogen sulphide, and some of it, chiefly that from the deeper wells, saline. The principal companies furnishing water of this type are the August Water Co., from wells in sec. 35, T. 32 S., R. 23 E., and sec. 31, T. 32 S., R. 24 E.; the Stratton Water Co., from wells in sec. 7, T. 32 S., R. 23 E.; and the Northern Oil Co., from wells in sec. 12, T. 11 N., R. 24 W.

The waters of Buena Vista Lake are controlled by a large land company and used for irrigation in the central part of San Joaquin Valley. Only a single company, the Honolulu Consolidated, uses this water in the oil field. This company maintains a pumping station in sec. 1, T. 32 S., R. 24 E., from which it pumps drilling and boiler water to its properties in Buena Vista Hills.

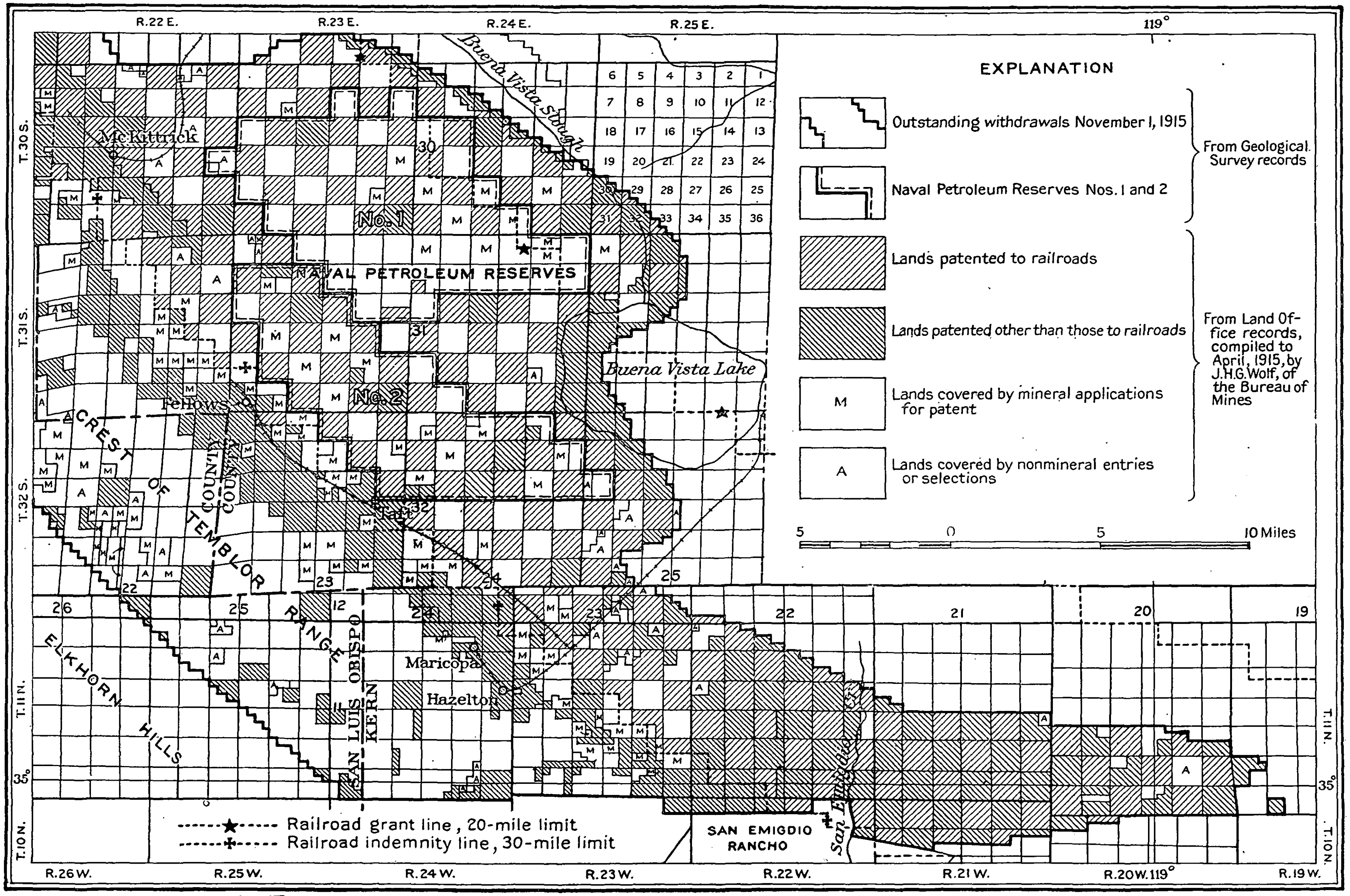
WITHDRAWALS.

Ever since the discovery of oil in the Midway field, but especially during the period of rapid development from 1900 to 1910, numerous conflicts have arisen between different persons who had one or another sort of claim upon the same tract of land. Such conflicts inevitably arise in any new mining district, but they have been especially numerous and especially troublesome in the oil fields of the public-land States, on account of the lack of satisfactory laws governing the disposition of oil and gas contained in the lands belonging to the Government.

When oil was first discovered in the Sunset-Midway region most of the land was still a part of the public domain, and application for title to it was made under the laws governing the disposal of the public lands. Not only were many tracts located according to the regulations prescribed by the mining laws, but application was made for these same tracts under the laws providing for the disposal of agricultural lands. Most of the land in the Sunset-Midway oil field is clearly without value for farming, and the sole purpose of most of the agricultural entries was to enable the applicants to obtain valuable deposits of oil and gas.

In order that the prospector might be protected as thoroughly as possible from these unnecessary conflicts, the lands thought to be valuable for petroleum were withdrawn from agricultural entry on September 14, 1908. (See Pl. XXXV.) Although this withdrawal was of great service in reducing the number of unnecessary conflicts and in protecting the prospector who was operating in good faith, the fact, which had long been known, that the placer-mining law is a sad misfit as applied to oil and gas lands, became increasingly apparent. This law was framed to apply to lands containing solid minerals that lay at or close to the surface, and the attempt to apply such a law to lands containing oil and gas that lay many hundred feet below the surface led to many difficulties, not the least of which was the necessity for making a discovery before patent could be granted. This requirement of an actual discovery of mineral upon the land made it necessary for the applicant to drill upon land to which he had no legal title nor could have until his well obtained oil or gas. In many places rival claimants drilled wells upon the same tract, the first to obtain oil or gas getting title to the land. Naturally the necessity for making the discovery as soon as possible under such conditions led to hurried and reckless drilling, and wells were put down without proper regard for the protection of the oil sands.

Bad as such a state of affairs is, the existing laws and customs foster a condition that is even more regrettable, for they make it practically impossible to regulate the production of oil in accordance with the demand existing for



MAP SHOWING PETROLEUM WITHDRAWALS AND NAVAL PETROLEUM RESERVES IN AREA COVERED BY GEOLOGIC MAP (PL. II).

it. As a result the fields have suffered many times from a tremendous overproduction, necessitating the storage of light-gravity oil in earthen sumps exposed to the sun, so that by the time the oil was marketed many of the lighter and valuable constituents had been lost by evaporation.

In order thoroughly to understand the reasons for this state of affairs the great difference between deposits of solid minerals and those of fluids such as oil and gas must be appreciated. In deposits of solid minerals a certain definite amount of the minerals is contained in a certain definite place and will remain there until it is mined out. On the other hand, no definite amount of oil or gas is attached to any particular tract of land, and even though no attempt is made to obtain the oil underlying a certain area by drilling wells upon that area itself, part of the oil lying beneath the surface of this tract or even, if the tract is small, practically all of it may be drained out by wells drilled upon adjoining lands; or such wells may so alter the normal conditions, as for example by letting water into the oil sands, that wells drilled later upon the tract itself can not obtain oil at a commercial profit. Moreover, the first well drilled into the oil sand has a great advantage over the near-by wells drilled later, for it gets the full benefit of the initial gas pressure, and in consequence its production during its early life is greater than the initial production of the later wells. Also it is evident that this first well establishes lines of drainage in the oil sand along which oil moves more readily than it does in other directions, for even though several wells are drilled on a tract of land, the first one will continue to drain a large area, part of which lies much closer to the later wells than to the original well. Commonly, therefore, other things being equal, the production of this first well continues to be greater than that of any of the later wells.

Thus it is apparent that a tract, particularly a small tract, of land lying within a producing oil field can not be considered to have a constant potential value as oil land, and the safest way to obtain the maximum yield of petroleum is to exhaust the oil sand as quickly as possible once it has been tapped.

Another factor that makes for the rapid development of an oil field, or indeed of any mineral deposit, is the interest upon the capital invested. Were the market price of the product constant, the most profitable method of handling a property would be the one that, without unduly increasing the cost of extraction, exhausts the property soonest. Of course, many conditions must be considered in determining the rate at which the property is to be developed, and a nice adjustment must be effected between interest on capital invested, on the one hand, and the market price or the demand for the product and the increased cost of production that attends an increase in the rate of production, on the other. With deposits of solid minerals this adjustment can be made with relative ease; for, as a rule, no irreparable injury results from closing down temporarily when the demand for the product is less than the supply. In an oil field, however, such an adjustment can not be made easily, for the policy adopted by one operator must of necessity influence that of his neighbor, and in many fields instead of temporarily closing down a property during periods of overproduction and consequent depression of price it is necessary to continue drilling new wells.

The conditions under which one producer is operating—perhaps the terms of his lease, perhaps his need for oil for his own use in other business, or to fill a contract—may make it necessary that he increase his production by drilling a new well. Now, in drilling a tract of land it is an almost universal custom to place the first wells close along the boundary of the property, with the avowed intention of drawing oil from as much of the neighboring land as possible. Where such a line well is drilled the owners of the adjoining property must either themselves drill a well to offset that drilled by their neighbors or sit idly by and allow oil to be drained from beneath their land. Should the first well be drilled in the corner of a tract where four properties join, three offsetting wells may be necessary, all of which may be drilled most unwillingly by the owners, and all further flooding an already overloaded market. Clearly, the law that cuts the field up into small units and then forces production upon each of these units is not a law that fosters conservation.

In view of these conditions, and also because of the advisability of reserving for the Navy an adequate supply of fuel oil, the Geological Survey recommended that certain tracts, which included practically the whole of the Sunset-Midway field, be withdrawn from entry, and on September 27, 1909, the Secretary of the Interior issued an order providing that

> In aid of proposed legislation affecting the use and disposition of the petroleum deposits on the public domain, all public lands in the accompanying lists are hereby temporarily withdrawn from all forms of location, selection, filing, entry, or disposal under the mineral or nonmineral public-land laws.

Since this first departmental withdrawal was made several Executive orders have been issued providing for the withdrawal of certain areas in the Sunset-Midway field and for the restoration to entry of areas which the field examination by the Geological Survey showed to be not oil bearing.

A full discussion of the objects for which the withdrawals of land in the California field were made and a history of these withdrawals would be hardly appropriate here, even if space would permit. One who is interested in this phase of the question will find an excellent account in a report by Ball.[1]

As yet (1918) no satisfactory method for the disposal of oil and gas upon the public lands has been evolved by Congress, and the ultimate purpose of the withdrawals has not been achieved. Those withdrawals have, however, accomplished two very definite things neither of which entered into the calculations of those who had to do with ordering the withdrawals. One of these results is so obvious as to be appreciated by everyone, but the other is more obscure. In the first place the withdrawal of September, 1909, was made so abruptly that "it knocked the breath, for the moment, from the California oil industry." The validity of the withdrawal was questioned by many, and work was continued despite it. Litigation that appears endless has arisen and bids fair to outlive the field itself. Many operators who with the best of intentions started development work on the public lands in the oil field have found their ventures anything but profitable. But, on the other hand, though the effect of the withdrawal on individuals has thus been harsh and for many almost ruinous, the effect on the oil industry of California as a whole has been distinctly beneficial, for these orders more than any other one thing served to keep down excessive drilling during the boom days when a great overproduction threatened. Had it not been for the retarding effect they had, it is probable that in 1910 the market would have been so flooded and the price of oil so reduced that many of the companies now operating would have been forced out of existence.

ORIGIN OF THE PETROLEUM.

The chief reservoirs of petroleum in the Sunset-Midway district are the feebly consolidated sandy beds of the McKittrick group, but the petroleum is believed to have originated not in these beds but in the fine-grained beds of organic origin that make up so large a part of the Maricopa shale and of the upper portion of the Vaqueros formation in certain parts of the region. These fine-grained beds are chiefly the so-called diatomaceous shales, which are composed in large part of the remains of minute plants and animals—diatoms and foraminifers—and it is from the decomposition and alteration of these organisms that the petroleum now found in the Sunset-Midway field results. In parts of the region the organic material contained originally in the fine-grained beds appears to be not so much the remains of diatoms as of larger terrestrial vegetation, and it is probable that part of the petroleum has been formed by the alteration of this coarser vegetal material. But in any case it seems clear that the ultimate source of the petroleum is the organic material originally contained in these beds.

There is nothing new or startling in the theory that the petroleum in California has been formed from the organic material contained in the diatomaceous shales, for those shales have long been considered the source of the oil. The reasons that they have been so regarded have recently been discussed somewhat in detail,[2] and anyone particularly interested in this phase of the subject is referred to that report, for the discussion will not be repeated here in detail. The chief reasons supporting the belief that the oil has had such an origin are, however, about as follows:

In the first place, the rocks in the vicinity of the oil field are sedimentary, igneous rocks being notably few, and, unless one holds to the belief that the oil has migrated from some source deep within the earth—and of such a migration there is not the least bit of evidence in

[1] Ball, M. W., Petroleum withdrawals and restorations affecting the public domain: U. S. Geol. Survey Bull. 623, 1916.

[2] Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Calif.: U. S. Geol. Survey Bull. 603, pp. 194–203, 1915.

the Sunset-Midway region—he is forced to the conclusion that the oil must have originated in the sedimentary rocks themselves. The diatomaceous shales and the shales that contain a large amount of carbonaceous matter are believed to be the beds in which the oil originated, because these beds are the only ones that contain or have contained material from which it is at all reasonable to expect that oil would form. There are no considerable amounts of limestone in the section, and the coarse detrital beds composed wholly of fragments of rocks of various types are hardly to be considered as a source of oil. Moreover, the field evidence supports the theory that the diatomaceous shales, or shales of similar type, are the beds in which the oil originated, for not only do practically all the oil fields in California lie in areas that contain considerable amounts of shale of this type, but the oil sands within the fields exhibit a notable tendency to lie either within the diatomaceous shale formations or immediately adjacent to them. Although the sedimentary beds in the oil field may be many thousands of feet thick, the oil sands are clustered in and about the relatively small part of the section occupied by the shale, and thousands of feet of beds that underlie and overlie the shale are, where not in contact with the shale, barren of oil.

Finally, it is of interest to note that at the south end of San Joaquin Valley the diatomaceous shale appears to be fairly pure—that is, the proportion of it composed of the remains of these minute organisms is large—and also that the formation is about as thick here as it is in any other part of California. For it is just here that the largest and most productive oil field in the State is located.

FACTORS INFLUENCING ACCUMULATION OF THE OIL.

In most regions where oil is found it is difficult to reach any very definite conclusion as to the exact material from which the oil was formed, or to determine precisely how or why the oil has concentrated in certain areas in sufficient amounts to form commercially valuable "pools." Although, as has been shown in the preceding section, the fact appears to be established that the oil in the California fields has originated from the organic material contained in the diatomaceous shales, the precise way in which the oil has concentrated, or, indeed, the reasons why it has concentrated at all, are no more easy to understand for these fields than for most other fields. Certain geologic features, however, appear to have played a large part in the determination of the location of the pool and of the position of the productive oil sand within the pool. The following brief description of the larger geologic features that control the accumulation of the oil along the west side of San Joaquin Valley is based upon a study which extended over several years of the geology of the Coast Ranges of California. Much of the material presented in this section has been published in an earlier report.[1] The section describing the lesser geologic features that control the position of the productive oil sand within the pool is based largely upon the writer's detailed study of the Sunset-Midway field, chiefly the study of the data made available by the drilling.

LARGER GEOLOGIC FEATURES DETERMINING THE LOCATION OF THE OIL FIELD.

The main geologic features of the east flanks of the Temblor and Diablo ranges are fairly constant, for not only do both ranges lie on the edge of the great structural trough occupied by San Joaquin Valley, but the rocks making up the two ranges are of the same general character and are bent and folded in the same general way. The oil fields within this region do not, however, form a continuous belt from one end of it to the other but are scattered through it irregularly, the position they occupy being determined by certain definite geologic features. Just what the chief of these features are it has been relatively easy to determine by a comparison of the productive oil fields with the nonproductive areas.

The chief geologic difference between the areas along the west side of San Joaquin Valley which contain commercial accumulations of oil and those in which oil, if present at all, is disseminated through the rocks, is that in or near the productive areas there are thick masses of diatomaceous shale and the rocks are bent into anticlines that serve as traps in which the oil is held; whereas the areas in which no commercial pools occur do not contain both the shale and the structural trap, although they may contain either one or the other.

[1] Anderson, Robert, and Pack, R. W., U. S. Geol. Survey Bull. 603, pp. 116-121, 1915.

This general statement holds good for the whole west side of San Joaquin Valley, for no oil field has been developed within this area that does not contain both the shale in which the oil has originated and the structural trap in which it has been held.

The importance of the obliquely trending anticline and of the deposits of diatomaceous shale as factors determining the position of commercial pools along the west side of San Joaquin Valley has been discussed in some detail in an earlier report,[1] from which the following quotation is taken:

The conclusion appears unavoidable that the dominant factor influencing the accumulation of oil along the eastern flank of the Coast Ranges is the presence of the anticlinal folds in the formations bordering the San Joaquin Valley and the corresponding synclines back of these anticlines. * * * In the whole region from the San Emigdio Mountains to Tesla not one of the well-developed folds that border the edge of the valley lacks evidences of the presence of oil either in or near it. On the other hand, there is no evidence of oil at any point not in the general neighborhood of one of these folds. It is not meant to be implied that oil occurs solely along the anticlines, for that is not true, but, as will be brought out below, oil invariably occurs either along such a fold or within an area believed to have been influenced by it. An examination of the province reveals the fact that in addition to seeps or evidence of oil obtained by wells along the anticlines that border the valley, similar indications occur almost invariably in the synclines and minor folds back of these anticlines at points along or in the foothills, whether the beds are or are not folded at such interior points in a way that would ordinarily be considered favorable for the retention of oil. On the other hand, where there is no anticline near the edge of the valley no sign of oil appears either at the edge of the hills or farther back, even though the character and attitude of the beds are practically identical with those of the oil-bearing beds at such interior points as are above mentioned. In other words, where an outlying anticline occurs the strata on the farther flank of the inlying syncline are oil bearing, even though they may be steeply tilted and truncated; whereas tilted and truncated beds facing the valley and not inclosed behind an outlying fold are barren. The conclusion is obvious that the anticlinal folds exert some kind of protecting influence on the strata in the foothills to the west. * * * Farther south, along the eastern flank of the Temblor Range, there is a fairly continuous series of oil-bearing outlying folds. Back of these, along the flanks of the corresponding synclines that separate the anticlines from the foothills, the indications of oil at the surface or in wells are numerous. * * * In this southern area the evidence of the protecting influence of the outlying folds is not quite so clear as it is farther north, owing to the more complicated character of the folds and to the fact that many of them are covered by Recent filling in the San Joaquin Valley. In general, however, the rule holds good that the outer folds are oil bearing and that they are followed on the west by a belt of irregularly tilted strata likewise rich in oil. A good example is afforded by anticlines in the Buena Vista Hills and the highly productive syncline of Midway Valley. It is very doubtful whether the west flank of the syncline would be so productive if it faced directly upon the San Joaquin Valley, without the intervening domes of the Elk and Buena Vista hills.

The relation of these obliquely trending anticlines to the larger structural feature—the great trough that is occupied by San Joaquin Valley—must not be forgotten. It is believed that in the central part of this trough a great mass of diatomaceous shale exists, and that this shale has furnished much of the oil which is now concentrated in the folds along the west side of San Joaquin Valley. Indeed, it is this shale which lies beneath the younger Tertiary rocks in the central basin that must be regarded as the chief source of the petroleum, and therefore those folds which lie along the border of the valley—chiefly those folds that trend out into the valley and, gradually sinking, plunge and are lost beneath the valley filling—have the most favorable structure for the accumulation of oil, for they are the traps located closest to the source of supply. Folds that lie in the higher parts of the range—such as those which occupy the center of the Temblor Range west of the Sunset-Midway field (see Pl. II) or as those which lie in the central part of the Diablo Range west of Coalinga—have no great feeding ground from which to draw their oil, and the beds along them are in consequence less likely to contain great quantities of oil than the beds along the folds on the border of the Great Valley. This fact can not be too strongly emphasized, for although the chief oil fields lie along the anticlines, it is along those anticlines which are located about the periphery of this great structural trough that the really large fields are found. A comparison of the location of the producing fields along the west side of San Joaquin Valley with that of the anticlinal folds there, as indicated in figure 5 (p. 56), will show the force of this statement.

The supposition that the oil now found along the edge of the valley originated in the shale in the central part of the valley means that the oil must have migrated laterally for great distances, and in order that this migration may have taken place either the avenue along which the oil has passed must have been

[1] Anderson, Robert, and Pack, R. W., op. cit., pp. 117-118.

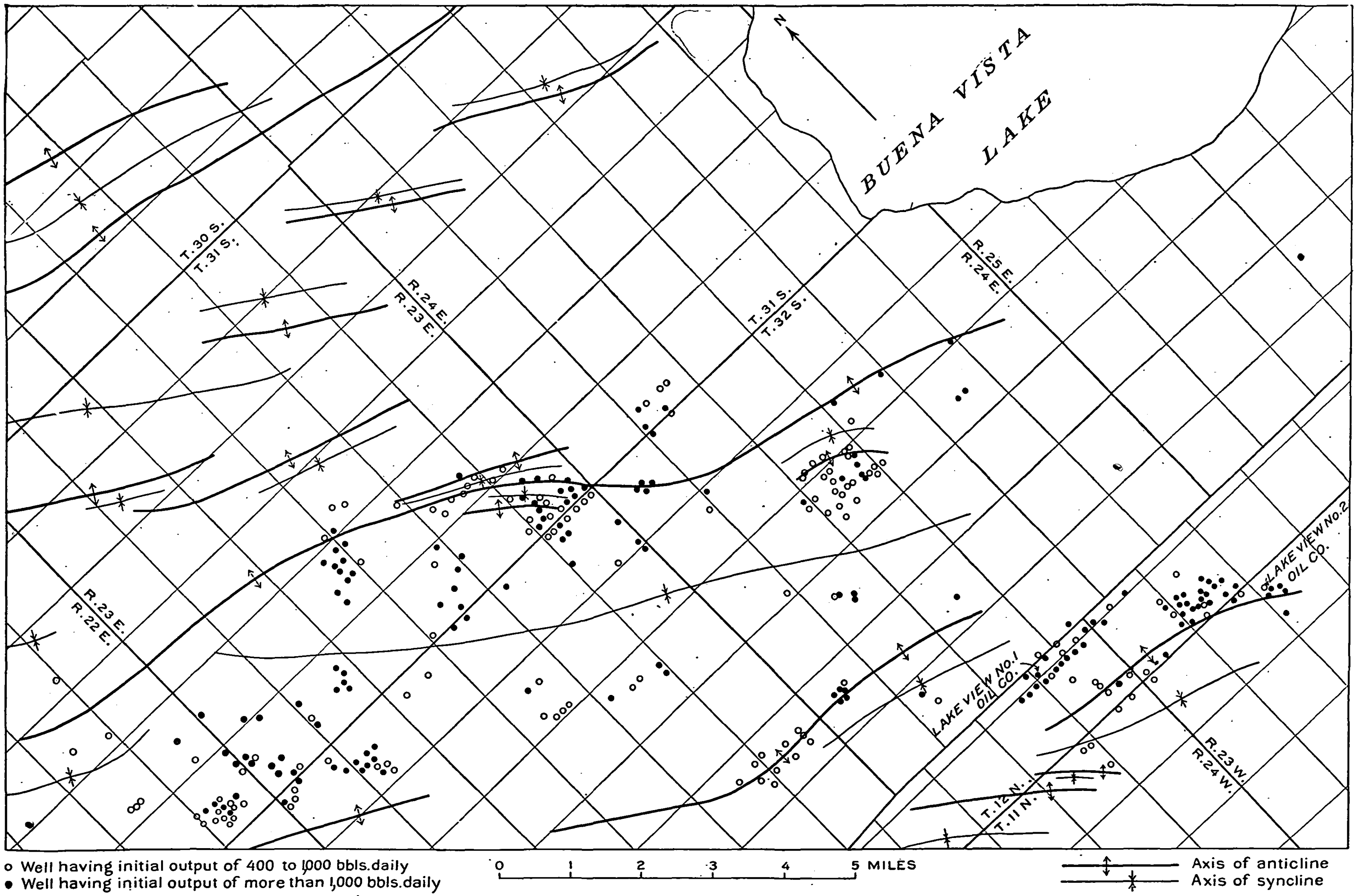


FIGURE 6.—Sketch map of Sunset-Midway oil field showing position with relation to structure of wells having high initial output.

so open that the passage of the oil was easy or else the pressure causing the oil to move must have been so great that even though the path was difficult the oil was forced to travel it for great distances.

It has frequently been urged that oil so heavy and so viscous as that commonly found in the California fields could never have moved into its present position through the fine-grained sedimentary beds in which it occurs. Such migration, however, does not appear to the writer to be at all unreasonable, for, (1) as is explained in the section describing the features which determine the position of productive oil sands within the fields, it is probable that the oil has changed in character since it first moved into the beds it now occupies; (2) the viscosity of petroleum varies tremendously with temperature, and moreover, as the variation is much greater for heavy oils than for light (see curves in fig. 7) oils of different gravity and at normal temperatures of widely different viscosity tend at a temperature of approximately 200° F. to become about equally viscous. Much of the oil which is now produced in the Sunset-Midway field has a fairly high temperature. None of it, of course, has a temperature as high as 200° F., for only rarely are temperatures of more than 115° or 120° recorded, but it is not unreasonable to suppose that the temperature of the oil when it moved into the position it now occupies may have been somewhat higher than it is at present, as it would have been were the oil sands buried somewhat more deeply than they are now. It would thus seem that the objection raised that California oil is too viscous to migrate through the fine-grained rocks is not particularly valid, for at fairly high temperatures it would move almost as readily as light-gravity oil.

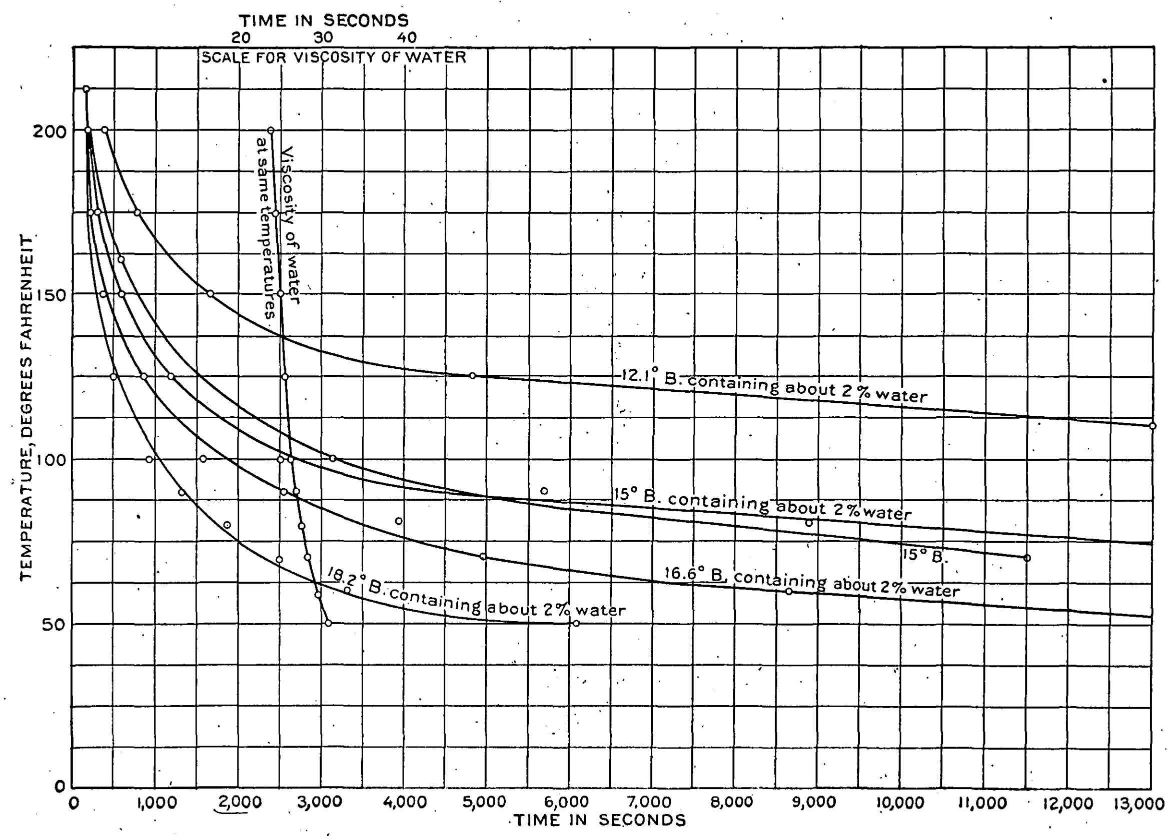


FIGURE 7.—Curves showing relation of viscosity to temperature in several crude oils.

The path along which the oil must have moved to its present point of accumulation has been a relatively open one, for the beds in which oil is found are fairly coarse grained. The most open path along which oil could move has probably been through the beds that lie at the base of the McKittrick group, close to the unconformity which separates that group from the underlying diatomaceous shale.

This unconformity between the shales in which the oil originated and the overlying beds that now contain the oil is almost as important a geologic feature as the attitude of the beds, so far as the accumulation of oil is concerned.

As to the exact nature of the forces that have caused the oil to move out of the shale, migrate for great distances through the rocks, and accumulate in small anticlines along the border of the trough, little can be said. Although the oil has concentrated along small anticlines, the conception—to which the term "anticlinal theory" is usually applied—that the sorting is caused entirely by the difference in specific gravity between oil and water does not appear to be at all reasonable. The hydraulic hypothesis of accumulation, which states that "moving water under either hydraulic or capillary pressure has been the direct agent of accumulation,"[1] seems more nearly to fit the observed facts in the fields along the west side of San Joaquin Valley. This hypothesis does not, however, explain adequately the causes for the hydraulic pressure of the moving water.

Recently an attempt has been made to describe the factors responsible for this hydraulic pressure, and under the designation "diastrophic theory" Marcel Daly[2] has described a possible mode of accumulation of oil. Daly's idea is essentially that the hydraulic pressure which has caused the migration of the oil is developed chiefly by the lateral pressure that caused the deformation of the strata in near-by regions. The forces of deformation, he believes, have transferred their effects not only through the solid material that makes up the beds but through the fluids contained in the pores in these beds.

LESSER GEOLOGIC FEATURES CONTROLLING THE POSITION OF THE OIL WITHIN THE FIELD.

The factors briefly outlined in the preceding section were probably dominant in controlling the movement of oil over wide areas in San Joaquin Valley, but these major factors have been to some extent modified and their effect perhaps increased, perhaps decreased, but certainly guided by an infinite number of lesser factors, which in the long run have been almost as important, for they have determined the position within the field and within the geologic section where the oil has collected in considerable quantity, the depth below the surface of the productive sands, and the position of the gusher sands, of the oil of light gravity and that of heavy gravity, and of water. A discussion of these secondary features is therefore of more immediate importance in the present report, for, as they control the distribution of the oil within the field, a correct and scientific development of the field must be based upon a proper understanding of them.

In the Sunset-Midway field these secondary features may, for the purpose of discussion, be grouped into three main classes—(1) those connected with the structure, (2) those connected with the lithology of the beds, (3) those connected with the character of the oil and with the chemical reactions between the oil and various substances in the water or in the rocks with which the oil comes into contact. The effects of all these different features are so intermingled that it is practically impossible to describe one without at the same time making considerable mention of nearly all the others, yet their importance may best be understood by focusing attention first upon one and then upon another of the classes outlined above.

EFFECTS OF THE SMALLER STRUCTURAL FEATURES.

UNCONFORMITIES.

The aid rendered by unconformities to the migration of oil in affording an open highway to the moving fluids has already been spoken of in the discussion of the larger geologic features. The effect of the unconformities is, however, felt even after concentration has to a very large extent been accomplished, for their presence gives the oil a fairly wide choice as to the sand in which it will finally lodge, and in many places a choice as to whether it will occupy one, two, or more sands lying one above another.

To understand these relations one must appreciate the conditions under which the beds that now contain the oil were laid down. These beds—alternating sands, clays, and gravels—were deposited in a body of water which at first occupied only San Joaquin Valley but which later, gradually enlarging and gradually deepening, encroached upon and finally submerged the high land that stood on the site of the Temblor

[1] Munn, M. J., The anticlinal and hydraulic theories of oil and gas accumulation: Econ. Geology, vol. 6, p. 523, 1909.

[2] Daly, Marcel, The diastrophic theory: Am. Inst. Min. Eng. Bull. 115, pp. 1137-1157, 1916.

Range. These beds were laid down in a nearly horizontal position. An individual bed, ending at the then existing shore line, really abutted against the land mass, and the series of horizontal beds lying one above another, each upper one overlapping the next lower and occupying a larger area, may be compared to layers of sand contained in a huge bowl with gently sloping sides, the layers lying horizontal and abutting against the sides of the bowl. San Joaquin Valley is the bowl, the Temblor Range is one side of the bowl, and the flat-lying beds that gradually mount higher and higher until at last they submerge the range are the layers of sand that fill the bowl.

The oil that has moved out of the diatomaceous shale that underlies the central part of San Joaquin Valley and collected along the plane of unconformity tends to move upward along this plane, or, in other words, along the inner surface of the bowl. This movement continues until the oil approaches the surface—that is, until it approaches the outcrop of the oil-bearing bed. Near this point the oil, as a result of natural fractionation or of reactions with minerals contained in the water or in the rocks, becomes heavy or tarry and very effectually clogs the pores of the rocks. When this happens the free movement of the oil upward along the plane of unconformity is retarded and finally stopped. The forces that caused the oil to move out from the center of the valley continue active, however, and the oil, blocked from outlet at the surface, seeks an outlet through one of the more sandy and more porous beds that abut against the plane of unconformity. As all the beds that overlie the diatomaceous shale abut against the unconformity at one place or another, the oil has a great number of beds from which to choose in picking a porous bed. Through this porous bed the oil moves outward, and in many places downward away from the plane of unconformity.

The distance that the oil moves away from the unconformity is probably not more than a mile or so and usually much less than that, for the sands that have so far been penetrated by the drill show a diminishing quantity of oil with increase in the distance from the plane of unconformity, and, moreover, they fray out into a number of small thin sands. But the real end of the movement of oil in this direction seems to be reached when the oil, owing to an encounter with mineral waters or with some mineral in the rocks, changes to a tarry product that clogs the pores and so seals up this highway, just as the outcrop was sealed up against further movement toward the surface. When this point is reached the oil, which is still being forced upward along the plane of unconformity, must seek another avenue of escape along some other porous bed.

The final result of all this is the impregnation with oil (1) of a sand or a group of sands along the plane of unconformity and (2) of a number of other sands that start at the plane of unconformity and extend out from it. When viewed in cross section this arrangement of the oil sands looks like a great branch from which minor branches or twigs extend out in one direction only, the sands along the plane of unconformity being the main branch and the sands that extend out parallel to the bedding of the strata being the twigs. Or perhaps the whole arrangement may better be compared to a great flight of stairs.

The position of the different oil sands that extend out from the plane of unconformity is very irregular, for the oil follows the more porous beds, and the lithology is extremely variable. In one part of the field there may be only a single thick sand, in another part one or two thin sands in addition to the thick sand, and in still another part two or three thin sands which are sharply distinct from one another. Within a distance of several hundred feet from the plane of unconformity the oil, so far as can be determined from the drill records, is not restricted to fairly well defined sands but is scattered more or less through the entire section. This lack of definition in the individual oil sands close to the unconformity is probably due very largely to the fact that in that vicinity all the beds are more or less coarse and irregularly grained. At least there is no such sharp difference between impervious clay and even-grained sand as there is in the beds farther removed from the unconformity. As all the beds in the area close to the unconformity have much the same degree of porosity, all are more or less equally filled with oil.

The arrangement of the oil sands described above will be better understood by reference to the diagrammatic section given in figures 8 and 13, or to the map that shows the conditions in Maricopa Flat (Pl. XLIII). The mode of occurrence of oil in this field can not be understood until it is realized that the oil-bearing sands do not lie as a great unbroken blanket beneath the surface and do not as a rule even lie parallel with the bedding but that they form a zone which as a whole is parallel to the plane of unconformity that marks the top of the diatomaceous shale.

A feature of great practical importance in the development of the field is the fact that the different sands that extend out from the plane of unconformity overlap. In any particular area there are therefore a shallow sand and a deep sand, or perhaps even several deep sands lying at different depths below the shallow sand. As all the oil sands that extend out from the unconformity are impregnated with oil for about the same distance, and as the plane of unconformity dips eastward, the uppermost sand is the first one to become barren toward the east. The sand does not, of course, become barren abruptly, nor even at a uniform distance from the plane of unconformity. The content of oil gradually diminishes, and the line marking the eastern limit of the area in which the wells derive their oil from a particular sand is very irregular. This irregularity is due in part to the natural irregularity in the oil content of the sand and in part to the difference in the attention paid to the sand by the different operators. Some of the operators, considering that even a small amount of oil in the sand is worthy of attention, attempt to recover it, whereas other operators drill through this sand without paying the least attention to it and get their oil from some deeper sand. It is this zone in which a sand becomes lean or barren and in which the handling of the wells is so diverse that the writer has called the "transition" zone or belt. The handling of the wells in such a zone is of great importance, for unless a uniform method is adopted, water is certain to be let into the sands that contain oil and to ruin more or less completely the rich oil sands that lie a considerable distance away.

SECONDARY ANTICLINES AND SYNCLINES.

Although the anticlines that extend out from the main range are of very great importance in the concentration of the oil inasmuch as they mark the points at which the oil tends finally to lodge, the secondary anticlines that make up most of these obliquely trending folds appear to have exerted very little individual influence on the concentration of the oil. It might be supposed that these small folds, as for example the small sharp anticlines on the south flank of the Elk Hills or the individual anticlines in the central part of the Buena Vista Hills, would be the most favorable points in the whole region for oil to collect. But the beds beneath the small folds in the Elk Hills are barren, and those that lie directly beneath the axes of the small anticlines in the Buena Vista Hills appear to be no richer in oil than those that lie beneath the axes of the small synclines in the same part of the hills.

The failure of these anticlines to affect the concentration of the oil is to be explained by the fact that they are really no more than surface wrinkles and do not as a rule appear as individual flexures in the oil sands. In considering the oil prospects of the outlying hills, therefore, it is necessary to deal with the folded belt or zone and not with the individual folds that make up this zone, the structurally highest part of the zone being regarded as the most favorable for the concentration of oil, and the anticlines that lie low on the flanks of the upward-folded zone being regarded as unfavorable, even though these folds are sharp and distinct at the surface. The difference between the structure of the surface beds and that of the beds that lie several hundred feet beneath the surface is well shown in Plates II and III. The failure to appreciate the fact that these folds are shallow has led to the drilling of a very considerable number of wells along the axes of sharp anticlines that stand almost at the edge of the folded zone—such folds, for example, as the small ones on the south slope of the Elk Hills. Such locations, although not entirely hopeless, can not by any means be said to be attractive, for it is the center of the whole anticlinal belt, which in the case cited embraces the whole of the Elk Hills, that is the most promising part.

The lack of importance attaching to the individual anticlines in the anticlinal zone or belt that embraces the Buena Vista Hills is excellently shown by the wells on the McNee lease of the Standard Oil Co., in sec. 36, T. 31 S., R. 23 E. On this lease are several of the largest wells in the whole Sunset-Midway field. The lease, which covers a square mile, lies almost in the center of the anticlinal belt of the Buena Vista Hills and is crossed by several small anticlines and synclines. It so happens that several of the largest wells are located along the axes of the synclines, not along the anticlines; and, conversely, several of the smallest wells on the whole lease are precisely on the axes of the small anticlines. The contour map (Pl. III) shows how greatly the small folds are flattened at the horizon of the oil sands, and thus why it is that they have had so little individual effect on the concentration of the oil.

In the section describing the effect of the unconformities (pp. 75–77) the stairlike arrangement of the oil sands in the western part of the field is discussed and the fact is pointed out that the oil has entered the sands it now occupies by moving chiefly first through the porous sands that lie along the plane of unconformity and then eastward parallel to the bedding through sands that abut against that plane. The entire movement of the oil has not, however, occurred in this manner, but in places as, for example, along the anticlinal belts of the Buena Vista and Elk hills the oil has quite evidently been able to move vertically upward through the strata. Along these belts the oil is now found in a number of sands through a stratigraphic thickness of 600 feet or more. Many of the sands that contain oil along these anticlinal belts do not contain oil in the synclinal basin that separates the belts from the main range on the west, and it appears very improbable that the oil could have moved eastward from the plane of unconformity clear across the intervening syncline to find a resting place in the higher parts of the outlying anticline without leaving some considerable trace in the beds in the syncline. There is also other evidence, such as the presence of the shallow tar zone in the vicinity of sec. 25, T. 31 S., R. 22 E., which shows that the hydrocarbons are able to move vertically through the strata. This evidence is discussed on page 88. It is important here to note that the vertical movement is most marked and perhaps is of practical importance only in the belts where the beds are folded strongly upward. The relation of the oil sands in the outlying anticlinal belts of the Buena Vista and Elk hills to those along the edge of the main Temblor Range is shown in the cross section in figure 8.

EFFECTS OF LITHOLOGY.

The lithology of the beds which overlie the diatomaceous shale and which now contain the oil in the Sunset-Midway field is, for several

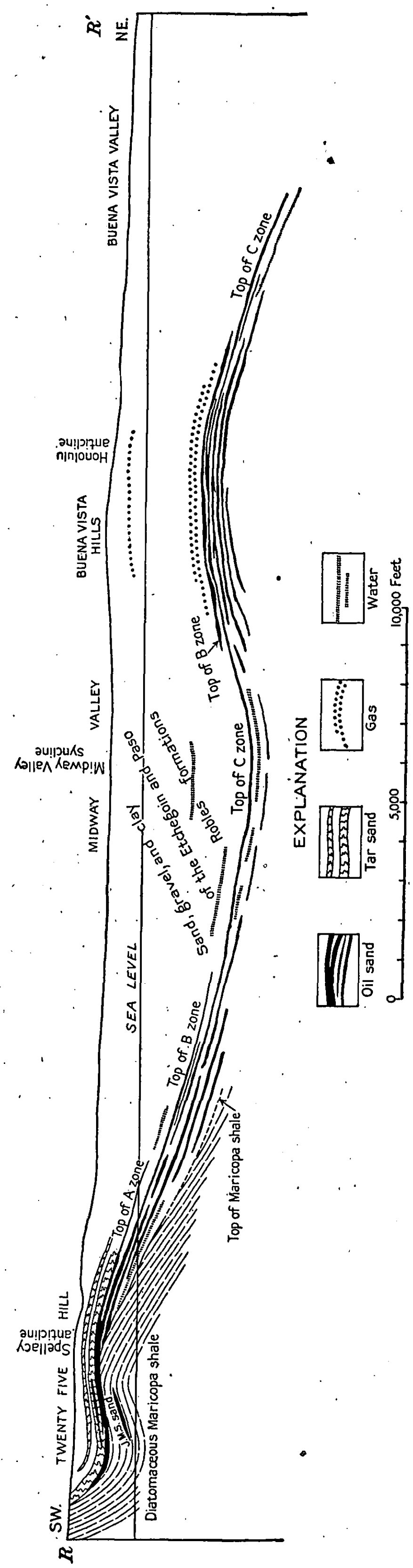


FIGURE 8.—Geologic cross section through Midway field along line R–R′, Plate III.

reasons, important in a consideration of the occurrence of oil. The porosity of the beds must be great enough to permit them to absorb a very considerable quantity of fluid; the open spaces in the rock—that is, the "voids"—must be of sufficient size to permit these fluids to move fairly freely through the rock; and finally the porosity of the different beds must be different, for otherwise there would be no particular tendency for the oil to concentrate in certain beds, but rather would it tend to disseminate through all the beds.

In the Sunset-Midway field the lithology of the beds overlying the shale is diverse to the extreme, the beds ranging from coarse conglomerate through almost every conceivable mixture of grain to the finest, most compact, and most impervious clay shale. This variation is not only vertical from bed to bed but also horizontal within a given bed. These beds, therefore, contain many admirable reservoirs in which the oil may collect, for many of the porous lenses are almost completely surrounded by the most impervious clay. The very lenticularity of the beds is, however, somewhat of a detriment, for the productive oil sands are not continuous, and the field is in consequence somewhat "spotted." The practically barren belt along the northeastern slope of Twenty-five Hill is an example of the control that the lithology exercises over the concentration of petroleum, for, as is explained in the detailed description of this area, the lack of oil here is due to the fact that there are in this area no suitable porous sands in which the oil might collect, and the oil has therefore collected in the immediately adjacent areas, where such sands are plentiful.

It may not be out of place here to point out that the porosity of a bed is, theoretically, in no way dependent on the size of the grain but rather upon the shape of the individual grains, the arrangement of the grains, and their regularity in size. Theoretically the porosity of a bed composed of spherical grains all of one diameter is equal to that of any other bed composed also of spherical grains of some uniform size, provided only that the grains are arranged in a similar manner in the two beds. It matters not at all whether the grains of one bed are large and those of the other small—a foot in diameter in one and a fraction of an inch in the other—if the grains are arranged in a similar manner in the two beds, and if the grains of one bed are all of one size and those of the other bed all of the other size, then the porosity of the two beds is the same.

The shape of the individual grains exerts a great influence over the porosity of the bed, for if the grains are of such shape that they may be fitted tightly together—as, for example, is the case with particles having large flat sides—the porosity may be very greatly decreased. Uniformity in the size of the grains is equally important, for if the bed contains a mixture of large and small grains the small ones will fit into the "voids" between the larger grains and thus reduce the porosity.

The size of the grain in incoherent sands such as those that are found in the Sunset-Midway field does not necessarily indicate the porosity of the bed, but it is a fair measure of the size of the "voids," for although beds that contain coarse fragments may have the size of the "voids" decreased by the addition of smaller fragments, the "voids" would hardly be larger than the grains if the bed is reasonably compacted. Therefore, other things being equal, the coarser-grained beds are the ones that offer the more attractive reservoirs in which the oil, particularly viscous oil, may collect. Porosity and coarseness of grain should not be regarded as synonymous terms, however, for they are not. Many very fine grained sands are much more porous than coarse-grained sands near by, and these fine sands offer by far the more attractive reservoir for light oils.

The reader interested in the factors that control the porosity of mixtures of sand will find excellent discussions of them in the writings of King[1] and Slichter.[2]

In the course of his work the writer had the opportunity to study the lithology not only of the outcrops of the oil-bearing beds but also of the oil sands penetrated by the producing wells, more than 400 samples from different parts of the field being obtained. This study showed clearly the following facts: (1) The beds close to the unconformity that marks the top of the diatomaceous shale are usually

[1] King, F. H., Principles and conditions of the movements of ground water: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 2, pp. 59-294, 1899.

[2] Slichter, C. S., Theoretical investigation of the motion of ground waters: Idem, pp. 295-384. See also U. S. Geol. Survey Water-Supply Papers 67, 110, 140, 141, 153, 184.

coarser grained than those that lie at a little distance from the shale, and not only do these beds contain coarser fragments but they are more uniformly coarse grained. (2) At a little distance from the unconformity the oil sands are not the beds that contain the coarser fragments but rather the fine-grained beds that are composed of fairly well rounded grains of uniform size. (3) In many parts of the field the oil sands are remarkably fine grained, many of the sands having more than 80 per cent of their grains smaller than 200 mesh.

The fact that the beds lying close to the unconformity are coarser grained than those that lie at a little distance from it is quite what is to be expected, for these beds were laid down close to the hills from which the detritus was derived, and, as is usual, the coarse fragments were deposited near the edge of the basin of deposition while the smaller and lighter ones were carried farther out toward the center of the basin. Clays that are very compact and in consequence very impervious occur near the unconformity, but they are not so common there as in the center of the valley. All the beds near the unconformity are therefore fairly coarse and also fairly porous, and any oil that works its way into these beds finds them all about equally attractive as reservoirs and so impregnates them all about equally. Thus there is formed in the beds that lie immediately above the plane of unconformity a thick succession of oil sands. Moreover, these beds, being fairly porous and also fairly coarse grained, are able to contain fairly thick and viscous oil such as that which is found in the western part of the field close to the outcrop of the oil sands. The character of the oil in this part of the field is of course due chiefly to the relation the sand bears to the surface and to surface waters, but it is very probable that if these beds were not coarse grained the oil would not be so heavy as it is, or at any rate that the thickness of the beds that contain the heavy oil would be very much less.

The fineness of the oil sands that lie at a little distance from the plane of unconformity is very striking, but even more striking is the fact that these sands are in many places underlain or overlain by beds that contain very much coarser grains than the oil-bearing sand itself. The selection of the finer-grained sand by the oil is of course due to the relatively greater porosity of that sand, but to understand why the finer sand is the more porous it is necessary to consider once more the conditions that governed the deposition of these beds.

The beds that now contain the oil are composed of detritus brought down into the San Joaquin Valley from high land that lay where the Temblor Range and the San Emigdio Mountains now stand. In all probability most of the débris came from the west—that is, from the area now occupied by the Temblor Range. The hills that made up this area of high land were composed of diatomaceous shale in which there were some beds of sand and coarse boulders, consisting almost wholly of fragments of granitic rocks. In other words, the range was then composed, much as it is to-day, of diatomaceous shale with lenses of coarse material. The coarse beds were so lenticular that quite naturally the detritus derived from the hills varied from place to place, here being almost entirely fragments of shale, here entirely fragments of granitic rocks, and here a mixture of the two. Moreover, the character of the material brought into the basin at a given spot varied from time to time, for as a lens of conglomerate became worn away the detritus obtained changed from fragments of granite to fragments of shale. There is thus a very great variation in the lithology of the beds, both vertically and horizontally.

The coarse débris that was derived from the lenticular masses in the diatomaceous shale was so heavy that most of it was dropped fairly close to the edge of the basin of deposition and thus forms part of the succession of coarse beds near the unconformity at the top of the shale, but the finer particles were carried farther out and now form the fine-grained sands that are found in the central part of the valley. On the other hand, the diatomaceous shale in weathering tends to break up into needle-like splinters, into flattish particles of fair size, and into a fine dust or mud. The larger fragments of shale are on the whole of considerably greater size then the rounded grains of granitic material that were carried out into the valley, but nevertheless because of their light specific gravity the shale particles were carried well out into the valley. It is very common, therefore, to find that the beds in the central part of the valley that contain the coarser fragments are composed of a very compact clay shale—the dust or mud derived from the diatomaceous shale—in which there are set a greater or less number of flattish shale fragments of fair size. It is evident that a bed composed of such detritus from the diatomaceous shale can not be as porous as a bed composed of well-rounded particles of approximately the same size, and thus it is that the fine granitic sands in the central part of the valley are the beds that now contain the oil even though they are in places exceedingly fine grained.

The control that lithology exercises over the porosity of the bed and therefore over the distribution of the oil is excellently shown in the vicinity of the northeast corner of sec. 25, T. 31 S., R. 22 E., a short distance north of Fellows. This area has proved to be one of the most spotted in the whole field, for here wells that flowed at the rate of many thousand barrels daily are situated among wells that produce so little oil that it hardly pays to pump them. Moreover, the large and the small wells obtain oil from the same sands. An examination of samples of the oil sand from the wells in this area showed quite clearly that the variation in the productiveness of the wells was due to the variation in the lithology of the beds, for without exception in the samples at the writer's disposal the sands from the flowing wells were made of well-rounded grains of granitic material—small grains, perhaps, but free from clay or detritus from the diatomaceous shale—whereas the sands from the wells that produced only a little oil were all very "muddy." The most productive sand in this area was of very fine grain but also of remarkably even grain, and, as the grains were about equally light and dark, it looked much like a mixture of finely ground pepper and salt.

In considering the possibilities of undeveloped portions of the field a great deal of attention has frequently been given to the size of the grains making up the bed, and certain areas, as, for example, the Elk Hills, have been condemned, for it was believed by many geologists that the sands there were too fine grained to permit them to act as reservoirs. It is remarkable, however, just how fine grained some of the producing oil sands really are, and the writer believes that no portion of the whole Sunset-Midway field lacks beds porous enough to make satisfactory reservoirs for the oil. Small areas, as, for example, the northeastern slope of Twenty-five Hill, lack porous beds, or at least the beds in these areas are much less porous than those in the immediately adjacent areas, but no large area seems to be without adequately porous beds. A large proportion of the oil sands that the writer examined were very fine grained, 50 to 80 per cent of many of the samples passing through a 100-mesh screen and some of the samples containing an equally large amount of material that passed through a 200-mesh screen. In these sands there was very little indeed that would not pass through a 60-mesh screen. These sands are in reality little more than the finest sort of dust, yet it is just such fine dust that seems to contain the oil in the parts of the field where the producing oil sands do not lie immediately adjacent to the unconformity that marks the top of the diatomaceous shale.

The writer believes that in this region any isolated anticline in which the formations above the diatomaceous shales are present is to be regarded as a possible reservoir of oil, provided, of course, that the beds in which the oil would normally occur—that is, those closely overlying the diatomaceous shale—are within reach of the drill. By an isolated anticline is meant one that is separated from other structurally high areas by structurally low areas, or synclines.

Those who have condemned parts of the field because of the lack of coarse-grained sands forget that (1) coarseness of grain is not necessarily an indication of porosity, but that fine-grained beds may be very porous; (2) the thick tarry oil found in the western part of the Sunset-Midway field is not characteristic of the field as a whole, and the normal oil is fairly fluid and can readily occupy very small pore spaces; (3) it is vastly more important, so far as the concentration of oil is concerned, to have beds of different porosity than to have coarse-grained beds, for unless there is a distinct difference in the porosity there can be no concentration of the oil in certain beds and thus no formation of commercially valuable "pools."

An especially instructive example of the character of the oil sands was seen in the hills west of the producing field at Maricopa. Here there is exposed in the sides of a deep gulch an oil sand that forms part of the zone from which the wells in the field to the east obtain their oil.

This sand, which is 1 or 2 feet thick, is underlain by a conglomerate composed of fragments of diatomaceous shale embedded in a sticky clay that is also composed of detritus derived from the shale. This conglomerate, despite its coarse grain, is practically impervious and contains no trace of oil. The oil sand is overlain by a grit in which the grains are on the average 2 or 3 millimeters in diameter, but the grit, too, is practically impervious, for it is tightly cemented, nearly all the pore space being filled with a calcareous cement, and it also contains no trace of oil. The oil sand itself is exceedingly fine grained, more than 90 per cent passing a 200-mesh screen and all of it passing an 80-mesh. One could hardly imagine a finer-grained sand, yet this sand is filled with oil.

Upon the lithology of the bed depends to some extent the character as well as the quantity of the oil, for the gravity of the oil varies with the grain of the bed in which it occurs, the lightest oil being found in the fine-grained beds and the heaviest in the coarse conglomerates. As described in Part II of this report the character of the oil depends largely upon its distance below the surface or from mineralized water; yet there is a very distinct difference between the oils in the shaly beds and those in the coarser sands, where other conditions are apparently the same. This difference, however, is natural, for the thick tarry oils are too viscous to move freely through the finer sands. Nor is it likely that the character of all the oil in a pool would be changed by the reaction with mineral waters, for such reaction would probably result in the alteration of the oil only along the very outer edge of the pool, because to change the oil throughout the pool there would of necessity be some considerable movement of the heavy oil—the result of the reaction—through the fine pore space. Moreover, as there is less opportunity for the oil to move freely through the very fine grained beds, so there is less opportunity for it to fractionate and for the lighter portions to leave.

The difference in the character of the oils in the coarser sands and in the very fine clays is readily recognizable, and the term "shale oil" is in common use among the operators to describe the oil obtained from the clays or shales. These beds are truly clays or shales, for, as is shown in the preceding pages, many of the most productive sands are exceedingly fine grained, a large proportion of the particles composing them being small enough to pass through a 200-mesh screen. The beds yielding the "shale oil" are still finer grained. Very frequently the shales when first drilled into yield a large amount of oil daily, and, moreover, the oil is under a very heavy pressure. Usually, however, the pressure decreases rapidly, and soon the well must be pumped or perhaps refuses to yield more than a mere dribble of oil. The rapid decline in the production of the wells that obtain oil in such fine shaly beds means of course that the oil can not move through the fine beds freely enough to permit the rate of production to be maintained, but the original pressure is of interest, for this pressure is apparently more or less localized and seems to have been built up from within the pool, not from without. In another section of this report the writer has advanced the idea that the pressure is caused by reaction within the pool after the oil has been more or less completely sealed up by the tarry oil formed about the edge of the pool as a result of other reactions, and it is of interest here to note that the pressure is more localized and exceptionally high in the finer-grained beds, for these beds are more readily sealed up by such tarrification of the oil.

EFFECT OF THE CHEMICAL AND PHYSICAL CHARACTER OF THE OIL.

Besides such physical factors as the lithology, position, and attitude of the beds containing the oil, there are other factors that exercise a control over the concentration of the oil. Among the most important of these other factors are the chemical character and the relative chemical instability of the oil, which cause it to react with mineral substances in the strata or in the mineralized water contained in the strata to form various heavy compounds that serve to seal the outcrops and to make closed pockets in which the unaltered and lighter oil may collect and remain.

The factors causing the alteration of the oil are outlined on page 87 and are discussed somewhat fully by Mr. Rogers in Part II of this report (Professional Paper 117). The mechanical effects upon the concentration of the oil of this chemical change in the oil are discussed in the section dealing with the importance of the unconformities as agencies aiding concentration (pp. 75–77). The subject is merely mentioned here, simply to emphasize the fact that the chemical character of the oil has quite as great an influence in controlling concentration as the physical features of the beds in which the oil is contained. It is therefore not necessary to do more here than to point out the fact that were it not for this tendency of the oil to oxidize readily and so to clog the outcropping beds and thus prevent the remainder of the oil from escaping, there would probably now be very little if any oil in the part of the Sunset-Midway field lying west of the axis of the Midway syncline, but all the oil that had not escaped at the surface would probably be that which is contained in such structural traps as the anticlines in the Buena Vista and Elk hills, where the oil sands are completely buried.

In other fields, where the oil is not of an asphalt but of a paraffin base, and where no such heavy tar is formed either at the surface or at depth close to mineralized waters, the concentration of the oil is governed more completely by the lithology, the attitude, and the position of the strata, and it is only in the upper parts of the anticlines or in the porous lenses in the strata that the oil is concentrated and retained. In relatively steeply tilted outcropping beds such as those along the west side of the Midway syncline light, mobile oils that do not oxidize readily would soon escape at the surface, leaving almost no evidence that they had formerly been present in the beds in considerable amount.

The influence of the character of the hydrocarbons upon the concentration and retention of the oil is shown also in the relative position of the oil and gas. Throughout the field the dry gas lies above the oil, and in the Buena Vista Hills the beds containing the dry gas are distinct from and lie several hundred feet above those containing the oil. The position of this dry gas so far above the oil is due, of course, to the greater mobility of the gas and to the ability it possesses to move in a general vertical direction through the strata that are impervious to the thicker oil. But besides this dry gas, there is a very considerable quantity of wet gas in the same strata with the oil. This wet gas is contained in a given stratum more or less throughout a large area, but it is most abundant in the higher parts of the anticlines. All the small folds in the Buena Vista Hills are more or less undulatory, and it is in the upper parts of these folds—or one might say in the domes—that most of the gas is contained, whereas the stratum that contains gas in the domes contains oil where it is downfolded in the saddles of the anticlines.

The most striking example that the writer has noted of this segregation of oil and gas in the same stratum, according to its position with relation to the structure, is that shown in the south-central part of the Buena Vista Hills, for the oil sands that compose the upper part of the oil zone in the McNee lease, in sec. 36, T. 31 S., R. 23 E., contain gas in the area farther south, and it is from these sands that many of the deeper gas wells of the Honolulu Consolidated Oil Co. derived their gas in 1916.

The segregation of the oil and gas within the same stratum is evidently due in part to the greater mobility of the gas but chiefly to the difference in specific gravity of the two fluids. The result is therefore in a way an example of concentration according to the anticlinal theory by which oil, gas, and water are presumed to concentrate in the anticlinal folds and to arrange themselves in more or less definite layers according to their specific gravities, the lightest fluid (gas) above, the heaviest (water) below, and the fluid of intermediate gravity (oil) in the middle.

Although in the example cited the oil and gas are evidently arranged more or less according to their specific gravities, the writer believes that the arrangement is not a primary one, but only a secondary readjustment after the fluids as a whole have collected along the axis of the anticline. In other words, the difference in the gravity of the two hydrocarbons or of the hydrocarbons and water has not been the factor that caused the hydrocarbons to accumulate and to remain where they are now found, but once they had collected there, the difference in their specific gravities caused a readjustment whereby the different fluids came finally to occupy more or less definite layers.

PRESSURE UNDER WHICH OIL EXISTS IN THE POOLS.

In practically every part of the field the oil is under a pressure considerably greater than atmospheric pressure, and in consequence many or perhaps most of the wells flow when first brought in. The pressure varies greatly, but in many of the wells it was, during the early life of the wells, 1,000 pounds to the square inch (66 atmospheres) or more, and in one well it has been reported as 2,000 pounds to the square inch (133 atmospheres). As a whole the pressure, particularly in the Buena Vista Hills, was considerably greater than hydrostatic pressure—that is, it was greater than the pressure exerted by a column of water equal in height to the distance the particular sand was buried beneath the surface.

The cause of this pressure has been the subject of a great deal of speculation, and many ideas have been advanced to explain it, for any theory that really seeks to explain the mode of accumulation of oil in the earth must explain, directly or indirectly, the pressure under which the oil is now found. Practically all the theories of oil accumulation explain this pressure as the result of the forces that have caused the concentration of the oil, regarding it as the resistance built up in the pool at the time of concentration to the forces that were causing the oil to collect, and, as the oil is now at rest, regarding this resistance as being able to offset these forces and therefore equal in amount and acting in the opposite direction to them.

For example, the anticlinal theory, which relies upon the difference in the specific gravity between the hydrocarbons and water to supply the force that causes the petroleum to move and to collect, explains the pressure now existing in the pool as purely and simply hydrostatic pressure. The hydraulic theory dodges the question and explains only the segregation of oil and water and gas, given the initial condition of moving fluids. The diastrophic theory recently advanced by Marcel Daly[1] definitely states that the pressure now existing in the pool has been built up in resistance to the forces that caused the initial movement and collection of the oil, these forces being the same that have caused earth movements or diastrophism in some area in the vicinity, though not necessarily immediately adjacent to the area in which the oil has collected.

The central idea about which all these "theories" are grouped—that the pressure now existing in the oil fields is intimately related to the forces that have caused the concentration of the oil, or, as some of the more definite and positive of the "theories" state, is quantitatively equal to the pressure that caused the fluids to migrate, or more correctly to the pressure developed by the forces causing migration—seems to the writer to be entirely unjustified. To assume that it is true only makes the interpretation of other phenomena connected with the oil more difficult.

For example, why is it, if the pressure is the resistance built up to the forces that caused the migration of the oil, that the oil is not forced back over the path it once traveled as soon as the forces that caused the original migration are no longer active? How is it that the oil remains concentrated and still under this pressure which caused it to concentrate—a pressure the writer is tempted to call "fossil pressure," as it is so clearly a relic of the past and of an earlier and very different condition of things.

In other fields—as, for example, those of northern Louisiana—where the pressure in the oil sands bears a more or less constant relation to the depth that the oil sands lie beneath the surface, the pressure may reasonably be termed hydrostatic, for it is roughly the same as that of a column of water that is equal in height to the depth that the oil sand is buried. But in parts of the Sunset-Midway field, where no such relation exists and the pressure in the oil sands is characteristically greater than hydrostatic, some other explanation must be looked for.

To the writer it appears evident that (1) the pressure under which the oil is now held is very largely independent of the forces that caused the original concentration of the oil; (2) the pressure was probably built up very largely within the pool after the oil had been collected.

A possible and to the writer the most probable explanation of the way in which the pressure under which the oil is held was built up is that the oil, after having been collected in a certain area in a more or less definite pool, is held under a pressure which may be very moderate indeed and which has been built up in opposition to the forces that caused the oil to migrate originally and to collect where it has. After the concentration has been effected, the oil reacts more or less with the mineral substances with which it comes into contact—those making up the rocks or those in the water. The extent to which such reactions take place and the nature of the products formed is at present very largely a matter of conjecture, for very little is known as to the exact chemical make-up of the petroleum as it exists in the ground, of the exact chemical

[1] Daly, M. R., The diastrophic theory, a contribution to the study of the mechanics of oil and gas accumulation in commercial deposits: Am. Inst. Min. Eng. Bull. 115, pp. 1137-1157, July, 1916.

changes that it undergoes, or of the products formed by such changes. There is, however, abundant evidence that one of the products of the reaction between the petroleum and the mineral substances in the waters that occur in the Sunset-Midway field is a thick, heavy oil or tar. Now it so happens that in nearly every oil pool the oil is normally in contact with water at the edges of the pool, for usually water occurs in the oil sand down the dip from the area in which the oil occurs. At the point where the oil and the water are in contact, therefore, a tar plug is formed that stops up the porous reservoir sand, preventing the further encroachment of the water and incidentally preventing the oil from moving out of the reservoir. After this plug has been formed the oil is held in a tight reservoir bounded above and below by the impervious beds that overlie and underlie the porous sand and on the sides by the tarry plug that fills the pores of the sand.

Once the tight reservoir has been formed any reaction that results in the formation of light or gaseous hydrocarbons will cause an increase in the pressure under which the oil is held, for the pressure can not be relieved by a simple pressing back of the oil and water over the path that they have traveled in effecting the original concentration. As to the possible reactions that might cause the formation of gaseous hydrocarbons the writer can offer no suggestion, but he is convinced that such reactions are not at all improbable, and when one considers the unstable nature of the hydrocarbons that compose the petroleums and the ease with which just such changes can be effected in the laboratory, they seem quite to be expected.

There is no question that a thick tar is characteristically formed where oil and mineralized waters of certain types are in contact. This has been shown time and again to be true by wells drilled in pretty nearly every part of the field. Invariably where tar has been found at depth it has been found either in beds that immediately overlie water-bearing beds or, if in the main oil sand, at the outer edge of the pool and wells drilled still farther out have encountered only water in the sand. As the tar or tarry oil is remarkably viscous it is equally evident that only a small quantity of it would be necessary to seal a porous sand completely and make of that sand a very perfect and tightly closed reservoir. Just what changes take place in the oil that is inclosed in the reservoir is a problem that is well worth detailed study—a study that must involve a great deal of careful chemical work. At present far too little is known as to the true nature of the oil or of the possible reactions that might take place to venture any definite statements, for very little work has been done on the chemistry of petroleum that will throw light on the subject.

As has been pointed out above, there is no definite relation between the pressure and the depth that the sand lies beneath the surface. The pressure is greater in the parts of the field where the sands lie deeper, it is true, but the increase in the pressure is not proportionate to the increase in depth. Rather it appears that the pressure bears some sort of relation to structure, for it is far greater in the Buena Vista Hills, where the beds are strongly upfolded, than in the central part of the Midway Valley, where the oil sands are even more deeply buried than they are in the Buena Vista Hills but where they are downfolded into a syncline.

It is quite apparent that variation in the hydrostatic pressure can not have been the cause of this variation in the pressure in the oil sand in the two areas of opposite structure, nor is it reasonable to think that if the pressure in the oil sands is a reflection of the pressure that caused the accumulation of the oil, the pressure would vary so greatly in areas so close together. The writer believes that this variation is due to the fact that along the anticlines there is greater opportunity for the formation of more perfectly sealed reservoirs than there is along the synclines, for, as will be seen from an inspection of figure 13 (p. 115), on account of the unconformity between the diatomaceous shale and the overlying sands, the oil has opportunity to work its way into a very considerable number of sands before it is finally sealed completely in all of them. This movement of the oil is explained more completely in the section that deals with the effect of the unconformity on the accumulation of the oil (pp. 75–77). The oil is pretty thoroughly sealed in by the formation of tar in the oil sand on both flanks of the anticlines, and the oil is thus prevented from working its way into other beds when the pressure in the original reservoir becomes fairly great.

EXPLANATION OF THE "GUSHER SANDS."

The theory has been advanced that the reason for the exceptional richness of the oil sand in certain spots in the field is that at these spots the oil sand in the moderately tilted beds of the McKittrick group rests directly upon the truncated edge of an oil sand in the steeply tilted diatomaceous shale formation. The well therefore supposedly has a much greater reservoir from which to draw and in consequence yields much more oil.

This theory has been a very popular one, but it appears to the writer to be entirely untenable, for (1) it necessitates the supposition that peculiar and really very unusual conditions exist in innumerable places in the field; (2) in many places the large "gushers" are not so deep as the neighboring wells and get their oil either from "stray" sands that lie above the main productive zone found in surrounding wells or in the very uppermost part of the zone. A few of the large wells that derive their oil from relatively shallow sands are Associated (Pioneer Midway) well No. 2, in sec. 30, T. 31 S., R. 23 E.; Kern Trading & Oil well 39, in sec. 1, T. 32 S., R. 23 E.; American Oilfields well 79, in sec. 36, T. 31 S., R. 22 E.; and Honolulu (Hawaiian) well 10, in sec. 31, T. 31 S., R. 23 E. All the big flowing wells in sec. 32, T. 31 S., R. 23 E., got their oil from beds that lie above the deep sand encountered in Alaska Pioneer well 9 and G. P. well 6 (Fellows 32), and even the two last-named wells derived their oil from beds in the lower part of the McKittrick.

It seems much more probable that the true explanation for these exceptionally rich parts of the sand is either that where they occur the sealing up of the reservoir has been more complete, or that the formation of the light hydrocarbons in the petroleum trapped in the reservoir has been more extensive; or perhaps both factors have been operative. This explanation is in a measure supported by the fact that a large number of the big flowing wells yield oil of slightly lighter gravity than the wells immediately surrounding them.

CHARACTER OF THE OIL.

The oil ranges in gravity from less than 11° to 32° Baumé (0.9929 to 0.8641 specific gravity). The average gravity of the oils from sands near the outcrop is between 14° and 18° Baumé (0.9722 and 0.9459 specific gravity), and that of the oil from sands in the Buena Vista Hills and other parts of the field where the oil sands lie deep is 21° to 28° Baumé (0.9271 to 0.8860 specific gravity).

As to the chemical character of the oil very little can be said other than that it is asphaltic, for the published work on the true nature of the oil is very meager indeed. Almost the only work the results of which have been published that has been done in determining the exact nature of the hydrocarbons that compose the oil is that of Peckham and Mabery, and their work was done with so few and so scattered samples that it will hardly serve as a basis for any very definite conclusions. Moreover, none of the samples that they examined came from the sands in the deeper parts of the Sunset-Midway field, where the oil is probably much more nearly in what might be termed its original state than it is in the sands near the outcrop—that is, in the sands from which the samples that were analyzed came. The results of analyses and other chemical studies of the oils of the region are reviewed by Mr. Rogers in Part II of this report (Professional Paper 117).

It is hopeless to expect that any great permanent advance will be made in the study of such problems as the origin of the oil, its alteration, or even its accumulation until some serious and systematic study of the chemical nature of the oil is made. The ordinary "analyses" that show the fractional distillation of a sample of oil, the viscosity, the gravity, and perhaps the amount of sulphur and of unsaturated hydrocarbons are of only a very little use to the geologist in his study of these problems. What is needed is the determination of the exact nature of the hydrocarbons that compose the oil in a number of specially selected samples taken at different parts of some such field as the Sunset-Midway field. Samples that are typical as nearly as possible of the original oil, of oils that have been altered by interaction with various mineral substances, and of others that are altered owing to oxidation should be analyzed before we can do more than speculate in a most general way as to the general nature of the oil, of the way in which it is collected, or of the changes that it undergoes.

But until such information is available it may not be out of place to point out one or two things regarding the variation of the gravity of the oil, for the gravity varies considerably and seems to bear some relation to the structure, to the presence of water, and to the depth of the oil sand beneath the surface.

Along the west side of the field—in the Spellacy anticline (Twenty-five Hill), in the field about the town of Maricopa, and along the foothills of the main range as far as the north end of the field—the oil is fairly heavy, thick, and tarry. Its character here is probably due to the oxidation of the oil upon its close approach to the surface, or to the action of surface waters.

In the parts of the field where the oil-bearing beds lie deeper the main oil sand is in places underlain by tar, which by its proximity to water-bearing sands indicates clearly that the reaction of the oil and the water have been the cause of the formation of the tar.

Also in the Buena Vista Hills the lightest oil in a given sand is apparently that which occurs in the highest structural position. The reason for this difference is probably to be found in the fact that lighter and more mobile hydrocarbons have moved to the highest parts of the folds.

Finally, there is a decided difference in the gravity of the oil in the coarse-grained sands and that in the very fine and compact shales.

A large number of distillation tests and determinations of gravity and other physical features of the oils from the Sunset-Midway field have been recorded in bulletins published by the Bureau of Mines.[1] However, all the available chemical and physical information will be found in Part II of this report, where it is summarized and discussed by Mr. Rogers.

EFFECT OF MINERALIZED WATERS ON THE OIL.

In 1910 Mr. E. A. Starke, then chief chemist for the Standard Oil Co. of California, called the writer's attention to the fact that the surface waters of the California oil fields appeared to react fairly readily with the oil. These surface waters are primarily sulphate waters, and by the reaction with the hydrocarbons they are reduced, giving rise to free sulphur or to hydrogen sulphide. At the same time the hydrocarbons are oxidized, giving rise to carbonates. Just what reactions take place can not be told, for the exact nature of the hydrocarbons that make up the oil is not known, but the general type of reaction is expressed by the subjoined formula, although as methane is a fairly permanent gas this reaction itself may never take place to an appreciable extent:

$$CaSO_4 + CH_4 = CaCO_3 + H_2S + H_2O$$

The carbonates formed by reactions of this type remain dissolved in the water, and the waters close to the oil are thus changed from sulphate to carbonate. But the sulphur or the sulphides unite more or less with the oil to form thick and tarry products.

The discovery of the tendency of the oil to react in this manner was turned to advantage in a very practical manner by Mr. Starke, for he held that as the tendency for this reaction was evident and pronounced, sulphate-bearing waters could not exist in the vicinity of oil and that in the oil zone, therefore, only carbonate waters would be found. In drilling "wildcat" wells a careful examination was made by his company of the water encountered in the various water sands, and as long as they showed abundant sulphates it was considered that oil did not exist in the vicinity; but as soon as the sulphates disappeared and carbonates appeared great care was taken to examine all the sands penetrated to determine the presence or absence of oil or gas. Remarkable success was had with this procedure so long as care was taken to obtain samples of water really typical of that contained in the bed penetrated. The method is of course adaptable only to those regions where the surface waters are filled with sulphates, as they are in the California fields.

Some years later G. S. Rogers,[2] of the United States Geological Survey, while investigating the chemical relation of the oil and water in the California fields, elaborated this theory and built upon it a classification of the waters encountered in these fields.

In the previous sections of the present report the writer has pointed out that the reservoirs containing the oil are sealed up by tarry oil or tar which is formed by the interaction of the mineralized waters and the hydrocarbons that compose the oil. It is a reaction of the type described above—the reduction of sulphate water to form sulphides and the addition of the sulphur or sulphides to the oil—

[1] Allen, I. C., and Jacobs, W. A., Physical and chemical properties of the petroleum of the San Joaquin Valley, Calif., with a chapter on analysis of natural gas from the southern California oil fields, by G. A. Burrell: Bur. Mines Bull. 19, 1911. Allen, I. C., Jacobs, W. A., Crossfield, A. S., and Matthews, R. R., Physical and chemical properties of the petroleums of California: Bur. Mines Tech. Paper 74, 1914.

[2] Rogers, G. S., Chemical relations of the oil-field waters in San Joaquin Valley, Calif. (preliminary report): U. S. Geol. Survey Bull. 653, 119 pp., 1917.

that the writer believes is responsible for the formation of this tarry plug.

In general these reactions that result in the formation of tarry products may be divided into two classes, or perhaps more properly the zones in which reactions of this type take place may be divided into two parts—that close to the surface and that at greater depth, in many places at the very base of the oil zone, below the beds containing the productive oil sands.

The reactions that take place close to the surface, particularly along the outcrop of the oil-bearing beds, result in sealing up the outcrop and preventing the escape of the oil at the surface. The extent to which the oil undergoes alteration is evidently far greater near the surface than it is at depth, for the deposits of tar and of sulphur are greater there. This is to be expected, for the surface water characteristically contains more sulphates than the waters at greater depth, and moreover the oxidation of the oil is aided to a large extent by other oxidized products in the rocks that lie close to the surface, or by exposure to the air itself. Not only are the oils at or near the surface changed more or less completely to tar, but the sulphate waters are changed so completely that great quantities of free sulphur are formed, and deposits of native sulphur such as the one occurring south of Old Sunset result. Sulphur is widely scattered along the foothills in which the oil sands crop out, but such extensive deposits of sulphur as those near Old Sunset are found only locally, where they have accumulated for some reason. The cause of the sulphur deposit at Old Sunset appears to be the concentration of oil and sulphate water along a fault zone.

An interesting bit of evidence as to the depth to which the oxidizing effect of the surface water extends is shown in the wells north of Fellows, near the east line of sec. 25, T. 31 S., R. 22 E. Here the wells encounter a persistent tar zone between 800 and 1,000 feet below the surface. This zone appears to lie more or less parallel to the surface and not to correspond exactly to the structure, although the dip is so low here that it is difficult to be certain that the tar bed is not exactly parallel to the bedding. In the beds some 600 or 800 feet thick below the tar zone and above the top of the productive C zone no other notable oil or tar sand occurs. The sands that contain the tar are not filled with oil to the west but lie above the productive zone there as well. To the writer this tar is explicable only as marking the depth to which the surface waters extend. At this depth they encountered hydrocarbons of some type, probably gaseous, that were making their way more or less vertically upward. One can hardly believe that natural fractionation of the oil has caused the formation of the tar at this particular depth, for why if the tar is the result of a gradual fractionation should not the underlying beds between this tar zone and the productive C zone contain tar also? Were the tar the result of natural fractionation there should be a gradation from the oil sand below to the tar sand above, in the amount and character of the oil or tar contained.

The effect of the deeper waters on the oil is not so extensive as that of the surface waters, but it is evident none the less, for in place after place where water is found in the oil sand a deposit of tar or heavy oil separates the portion of the sand occupied by oil from that occupied by water. The reason for the lesser effect of the deeper waters and thus for the smaller amounts of tar in the deeper sands is evidently the fact that the waters in the deeper sands contain normally a far smaller amount of sulphate than the surface waters. According to the views of the writer the deeper waters are not by any means to be considered as truly connate waters—that is, the waters in which the sediments composing the beds were laid down, still retaining the same chemical character as they had at the time of deposition. For it is evidently quite unreasonable to believe that these waters have remained quietly in the beds, retaining unchanged their original character, while other fluids, such as the petroleum, have entered the beds and filled completely the pore spaces in some of them.

DETAILS OF THE PRODUCTIVE FIELD.[1]

DOHENY PACIFIC-CARNEGIE AREA.

[Southwestern part of sec. 1; secs. 2, 3; eastern part of sec. 4; northeastern part of sec. 9; secs. 10, 11, 12; northern part of sec. 13, T. 31 S., R. 22 E.]

LOCATION AND OPERATORS.

The Doheny Pacific-Carnegie area lies north of the main part of the North Midway field that is now productive and south of the Mc-

[1] These detailed descriptions of parts of the productive field and the conclusions expressed are based on data made available by the drilling done up to July, 1916.

Kittrick field. In 1916 it contained but few productive wells. In the extreme southeastern part, in sec. 12, are the producing wells of the Midland Oilfields Co. and General Petroleum Co. (Oakburn); and in the extreme northern part, in sec. 3, are those of the Doheny Pacific Petroleum Co. In sec. 34, just north of the Doheny well, are the old and now abandoned wells of the Associated and Mammoth companies.

GEOLOGY.

The geology here is complicated, resembling that of the McKittrick field, which lies just to the north, and this area may be considered as the extreme south end of the region controlled by the structure appearing in the McKittrick field. The chief structural features here, from southwest to northeast, are (1) the fault along the eastern edge of the Telephone Hills; (2) the North Midway syncline; (3) the Belgian anticline, in sec. 2; (4) the small syncline crossing the north line of sec. 2; and (5) the Rudisill anticline.

Movement along the fault in the Telephone Hills has been considerable near the north line of T. 31 S., R. 22 E., where beds of the McKittrick group on the east have been dropped and abut against the diatomaceous shale and gravel in the upper part of the Maricopa shale. The displacement along this fault gradually lessens toward the southeast, and in sec. 15 the fault merges with the Globe anticline. In the Telephone Hills, in the extreme western part of the area here discussed, the beds are considerably fractured on both sides of the fault, and the line shown on the map marks only the center of this zone of fracture. On account of the large amount of fracturing and the meagerness of the data furnished by the surface exposures and by the few wells drilled here it is impossible to contour the oil zones in this area.

The North Midway syncline is a shallow fold that plunges rather abruptly toward the east and is almost if not entirely lost near the east line of sec. 13. On the east flank of the fold the beds are highly tilted, in places to angles of 40° or 50°. The irregularity in tilting is evidently due to the presence here of small faults similar to those so abundant in the west flank of the same syncline—that is, along the east edge of the Telephone Hills.

The anticline that trends southeastward and crosses the north line of T. 31 S., R. 22 E., just west of the northwest corner of sec. 2 is termed the Belgian anticline in the preliminary report on the McKittrick-Sunset region [1] and is shown on the map accompanying that report as making an abrupt double bend in the middle of sec. 34, T. 30 S., R. 22 E., adjoining the Shamrock anticline. There is, however, no direct evidence that the two anticlines join in this manner, but rather they appear to be separate folds that overlap like the folds in the Buena Vista and Elk hills. The Belgian anticline is short, probably not continuing southeastward much beyond the point in sec. 2 where it disappears beneath the alluvium. The beds close to the axis are flexed rather sharply, however, and at its north end diatomaceous shale in the upper part of the Maricopa shale is brought to the surface.

The syncline lying between the Belgian anticline and the Rudisill anticline is likewise short, plunging eastward abruptly. The Rudisill anticline is a well-marked fold, and the beds near its axis are tilted steeply. The fold plunges southeastward but probably not so abruptly as the North Midway syncline. The structure in this region is shown on the geologic section (Pl. XVI).

OIL SANDS.

In the western part of the area here described—that is, the part forming the west limb of the North Midway syncline—the sand which offers most promise of yielding oil is comparable to the B sand of sec. 15, T. 31 S., R. 22 E., just to the south, and of the area along the foothills still farther south in the same township. Little can be said regarding the position and character of the oil sands here, as only a few wells have penetrated them. The wells drilled west of the axis of the North Midway syncline that have penetrated the sand which is productive in sec. 15 have found it either dry or filled with tar or with water. Most of these wells have been drilled into the Maricopa shale, which immediately underlies the sand from which oil is to be expected, and have found oily shale, streaks of oil sand, and water sand. The Carnegie water well obtains water [2] from a deep sand in the Maricopa shale, at least 3,000 feet and probably 3,400 feet below the base of the McKittrick group. This sand is said to contain some oil, the estimate being made that 5 to 10 barrels is brought up

[1] U. S. Geol. Survey Bull. 406, p. 136, 1910.
[2] See analysis in Table 24, Part II (Prof. Paper 117).

daily with the water. In all, about eight wells have been drilled in this western part of the area, and they have shown that, although the beds in the lower part of the McKittrick contain some oil, the amount is small and it is doubtful whether enough oil will be found, except in small isolated areas, to make drilling profitable. The absence of oil here is probably to be explained by the facts that there is in this area no dominant structural feature along which oil would tend to collect, and that between this area and the Great Valley are numerous anticlines that would act as traps to intercept any oil moving westward from the shale lying beneath the valley.

The oil-saturated sands which rest upon the diatomaceous shale that is exposed along the crest of the Belgian anticline near the center of the north line of the NE. ¼ sec. 3 are at the base of the McKittrick and correspond to the B zone. These sands may be productive along the axial part of the Belgian anticline to a point at least as far southeastward as the center of sec. 2, where the anticline disappears beneath the alluvium.

The B zone, however, will probably not be productive for more than a short distance down the flanks of the Belgian anticline, for the dips are fairly steep, and in other parts of the field where the beds are highly tilted—notably along the foothills southwest of Fellows—the belt beneath which any particular zone is oil bearing is narrow. Therefore on either the east or the west flank of the Belgian anticline beyond a narrow belt that occupies the crest of the fold oil should be looked for in beds corresponding to the C zone, for if oil occurs there at all it is probably in this zone. Sands in the C zone have yielded the oil obtained in the Midland Oilfields wells 1, 2, and 3, and the General Petroleum Co. (Oakburn) well 1.

In the southeastern part of the area here described the C zone is about 100 feet thick and is underlain by a water sand, just as it is in the southeastern part of T. 31 S., R. 22 E. In this part of the area the B zone contains water, the water sand apparently corresponding to the water sand encountered near the southwest corner of sec. 13 and lying about 100 feet above the top of the C zone.

SUGGESTIONS FOR FUTURE DEVELOPMENT.

Much of the area lying west of the axis of the North Midway syncline and north of the north line of secs. 14 and 15 will probably prove nonproductive. The oil sands here are badly fractured, abundant opportunity has been given for the oil to escape, and the sands are probably occupied chiefly by tar and water. Moreover, on account of the presence of numerous faults, it is difficult to predict the exact position at which the sands will be encountered. Oil will probably be found in commercial amount in some parts of the area, but the oil sands are unquestionably discontinuous, and search for them will be expensive.

In the central part of the syncline in sec. 3, the southwestern part of sec. 10, and the northwestern part of sec. 11 the sands will probably not yield a great quantity of oil, as they appear here also to be fractured. However, the cover in this area is greater and the opportunity for the escape of the oil less, and doubtless wells drilled here would yield a small quantity of oil.

Farther down the plunge of the syncline—that is, in the southeastern part of sec. 11, the northern part of sec. 13, and the southern part of sec. 12—the productive sands are in the C zone, the B zone being occupied by water or tar. In this area wells similar to Midland Oilfields No. 1 and General Petroleum (Oakburn) No. 1 can probably be obtained, but the sand here is probably not so productive as it is farther south, closer to the crest of the Globe anticline. In this area it will be necessary to case off the B sand, which contains water, and also to avoid drilling into the bottom water, which probably is only slightly below the C zone. The C zone here is probably not more than 100 feet thick.

So far little prospecting has been done along the axial part of the Belgian anticline. The only well that had been drilled here at the date of writing (August, 1916), is the gas well of the Section 3 Oil Co., which encountered a flow of gas estimated at 18,000,000 cubic feet. The gas is evidently derived from sandy measures in the diatomaceous shale in the upper part of the Maricopa shale not far from the base of the overlying McKittrick group. The Belgian anticline plunges southeastward, and because of the abundant evidence of the presence of oil afforded by the seep in the canyon that crosses the north line of sec. 3 about a quarter of a mile west of the northeast corner of the section, the gas encountered in the well, and the gas blowout in the NE. ¼ sec. 2, the southeast end of this anticline offers one of the most promising parts of the North Midway field for future drilling. Wells here will probably not be "phenomenal gushers," but practically all the southwestern part of sec. 2 and much of the surrounding area offers promise of yielding a fair quantity of oil.

ENGINEERS-COALINGA MONTEREY AREA.

[SW. ¼ and southwestern part of NW. ¼ sec. 13, E. ½ sec. 14, NE. ¼ sec. 23, and NW. ¼ sec. 24, T. 31 S., R. 22 E.]

LOCATION AND OPERATORS.

The Engineers-Coalinga Monterey area lies in the northeastern part of the North Midway field and embraces the land lying on the northern flank of the east end of the Globe anticline. (See geologic sections, Pls. XVI and XVII.)

The companies operating here in 1916 were the Doheny Pacific, Oakland Midway, General Petroleum (Dabney, Bear Creek), Engineers, Onisbo, Stockton Midway, Kern Trading & Oil, Pacific Midway, and Coalinga Monterey.

GEOLOGY.

This area lies at the crest and on the north flank of the Globe anticline and extends as far northward as the axis of the North Midway syncline. The Globe anticline is here a broadly rounded fold, which plunges abruptly eastward, and a short distance east of the center of sec. 24 the arching effect is almost completely lost. This anticline is essentially the western continuation of the United anticline, in the north end of the Buena Vista Hills, but the two folds are separated in sec. 19, T. 31 S., R. 23 E., by a saddle that forms the north end of the Midway Valley syncline. This syncline may be regarded as separating the structural features which form part of the Temblor Range from those which form the outlying Buena Vista and Elk hills, the Globe anticline belonging to the main range and the United anticline to the outlying foothills. Both the North Midway syncline, on the north side of the Globe anticline, and the Twenty-six syncline, on the south side, plunge steeply eastward. The steep plunge is shown on the map (Pl. III) by the underground contours, which bend only very slightly for any one of the three folds.

OIL SANDS.

In sec. 13 the oil sands are very fine grained, being virtually sandy shales. Sand of this character is found in the Doheny Pacific and Oakland Midway properties. The C zone along the east line of the NE. ¼ sec. 23 is described as gravel and coarse sand and is filled with fossils. The pebbles making up the gravel beds are said to be well rounded, black (probably quartzite), and from a quarter to half an inch in size, and the sand grains to average between an eighth and a quarter of an inch in diameter. In one well log the upper part of the C zone is reported as an indurated gray sand, but in all others it is recorded as loose sand.

The upper sands in the western part of the area are in the Etchegoin or possibly in part in the Paso Robles formation. The lower or C zone is certainly in the Etchegoin, as is shown by the abundant fossils it contains along the east line of the NE. ¼ sec. 23. The C zone is probably the basal part of the Etchegoin, although, as only a very few wells have been drilled through the water sand that underlies the productive C zone, its position can not be stated with certainty. The distance between the top of the B zone and the top of the C zone increases greatly eastward, ranging from about 200 feet near the north-south center lines of secs. 14 and 23 to about 500 feet near the east lines of those sections.

In its western part this area includes a portion of the so-called transition belt, where oil occurs in the lower sands (the C zone) and also in small quantities in beds that in the area still farther west are productive—that is, in the B zone, which yields oil in sec. 15 and the W. ½ sec. 14. In the eastern part of this area, however, these upper sands contain only tar and a little water, the main production coming from the lower or C zone.

The "transition" belt extends roughly along the north-south center lines of secs. 14 and 23 to the vicinity of the middle of sec. 23. In this belt some wells are perforated for the upper sand, but in many the upper sands are cased off with the water string. In the "transition" belt the maximum thickness of the zone in which oil sands occur is about 500 feet, and of this thickness the lower 100 to 200 feet constitutes the C zone.

The C zone varies in thickness, the maximum being about 200 feet. In this measurement are included both the oil sands and the intercalated barren beds, for the productive sands themselves are in few places more than 100 feet thick. Usually not over 50 feet of oil sand is recorded or provided for in perforating the casing.

BEDS ABOVE THE B ZONE.

Above the B zone occurs the usual mixture of clay, gravel, shell, and shale. There is nothing very notable in the character of these beds unless it is that they are somewhat coarser grained than most of the other beds along the western margin of the productive field.

Tar sands are fairly abundant up to a level within 200 or 300 feet of the surface and are thickest along the axis of the Globe anticline, in the NE. ¼ sec. 23 and the NW. ¼ sec. 24. Near the center of the west line of sec. 13 a tar zone about 100 to 200 feet thick lies 600 to 800 feet above the top of the B zone. Neither above this tar zone nor below it for a distance of 400 feet is much tar sand recorded. This thin tar zone has been recognized also in some of the wells along the south line of sec. 13.

In the western part of this area, however, the B zone is really the bottom part of a thick tar zone, tar sands continuing above it for 250 to 300 feet. Water is abundant in this tar sand near the center of the west line of sec. 13.

WATER SANDS.

Bottom water.—The C zone is underlain by a very persistent saline water sand which up to the middle of 1916 had been penetrated by about 15 wells in this area. There is very little record of the flow of water from this sand, but it is reported that in one well a 3-inch pump running at full capacity could not exhaust the flow.

This water sand is very persistent, closely underlying the C zone is much of secs. 23 and 24 and almost all the water trouble in this part of the field has come from drilling into it. Near the center of the north line of sec. 23 the water is so near to the C zone that it can only with great difficulty be shut off properly once it has been entered, and several of the wells in this general locality have let and are possibly now letting water from this sand into the oil sands of the C zone.

Only one well in this area has been drilled through this water sand into the underlying strata. In this well numerous other water sands were encountered in a distance of more than 500 feet below the water that lies just below the C zone.

Top and edge water.—In the western part of sec. 13 water sand occurs with the tar sands that either form the uppermost part of the B zone or immediately overlie that zone. This water is recorded in the logs of several of the wells in the southwestern part of sec. 13, the southeastern part of sec. 14, and the northeastern part of sec. 23 and is the same as that which was designated the "lower top water" in the W. ½ sec. 14. It is so close to the top of the B zone (if it is not actually in that zone) as to be practically edge water for the upper part of the B zone. This water has been somewhat troublesome in the "transition" belt.

Another and still more troublesome water sand is found below the top of the B zone and above the top of the C zone. It is recorded in the logs of several wells near the southwest corner of sec. 13. This water has been cemented off from the C zone in all these wells but is quite free to enter the upper or B zone. It becomes more and more prominent toward the southeast, on the south flank of the Globe anticline, and is recorded in the logs of several of the wells in the SE. ¼ sec. 23. The approximate position of this water sand is shown in the geologic section (Pl. XVI).

PRODUCTION.

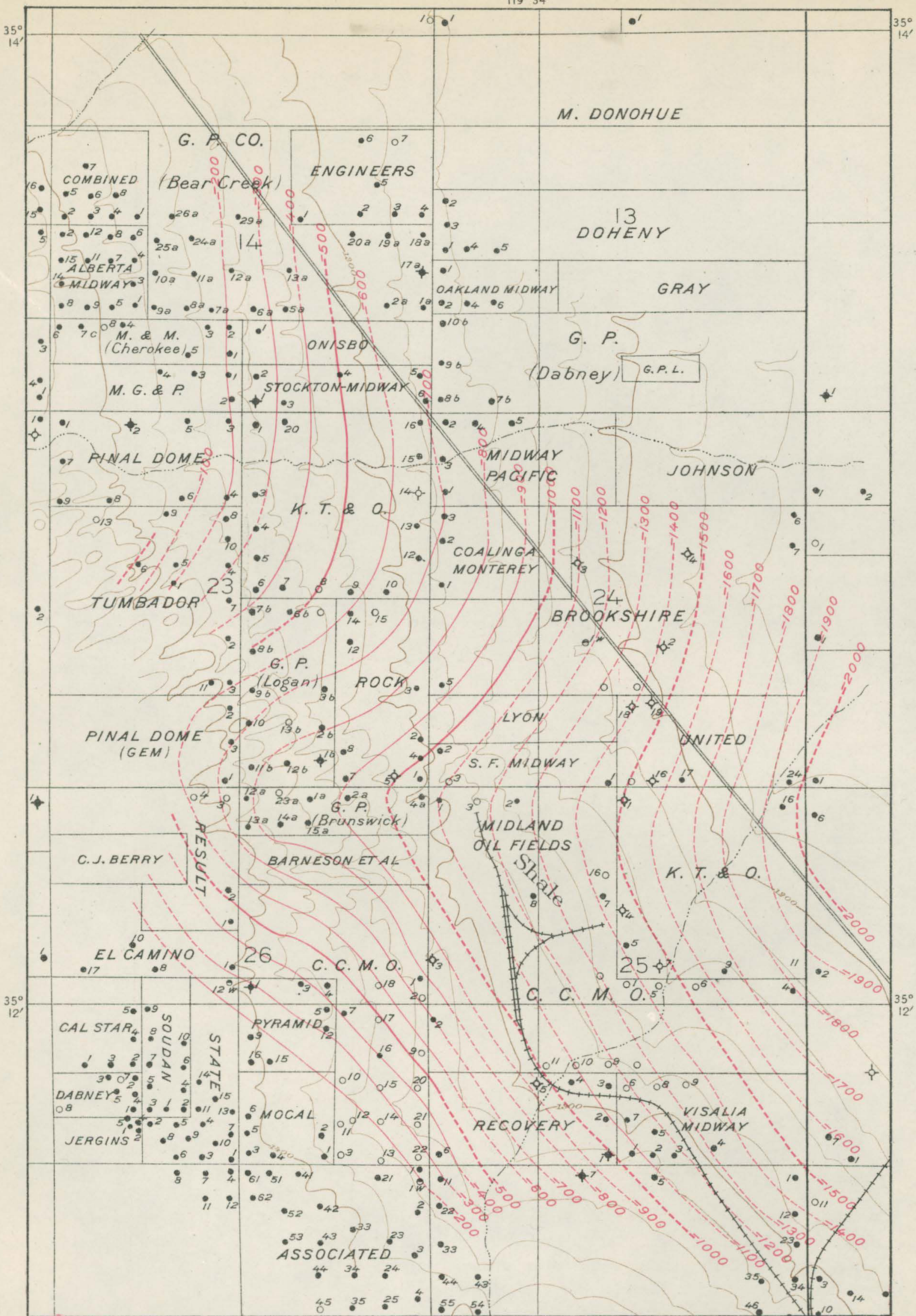
For the most part this area contains no wells that had a very high initial production. One well is said to have had an initial production of 1,000 barrels daily and to have produced an average of 650 barrels daily for the first month. A few other wells, about five in all, made at first 200 to 500 barrels a day.

The rate of decrease here is rather high. One group of five wells is said to have lost 25 per cent of its "settled" production in one year. Another group of 15 or 16 wells is said to have lost two-thirds of its "settled" production in one year.

In 1914 the daily production of individual wells in this area ranged from 10 to 150 barrels, and the average daily production of wells near the west line of sec. 13 was about 60 barrels. In the southeastern part of the area here discussed the wells averaged about 25 barrels daily.

CHARACTER OF THE OIL.

The gravity of the average oil in the C zone is about 20° or 21° Baumé, but the oil obtained in the wells ranges from about 16° to 21°



SKETCH MAP SHOWING BY STRUCTURE CONTOURS THE UPPER SURFACE OF THE BOTTOM WATER SAND IN THE SOUTHEASTERN PART OF T. 31 S., R. 22 E., CALIFORNIA

Wells are those shown on Plate III

Scale $\frac{1}{24,000}$

0 — ½ — 1 Mile

Surface contour interval 20 feet
Structure contour interval 100 feet
Datum is mean sea level

Baumé. Most of the heavier oil comes from the western part of the area, and the increase in specific gravity (decrease in degrees Baumé) of the oil toward the west is evidently due to the fact that the oil produced there is derived in part from the B zone. The wells that are troubled with bottom water yield oil 2° Baumé or so heavier than that which is normally obtained from the C zone.

SUGGESTIONS FOR FUTURE DEVELOPMENT.

Deeper drilling.—It seems probable that throughout this area the C zone is in the basal part of the Etchegoin formation and that the success of deeper drilling depends upon the presence of oil sands in the Maricopa shale. A few wells have been drilled through the water sand that underlies the C zone, and these wells show that below this bottom water there are no further oil sands on the south flank of the Globe anticline near the east-west center line of secs. 23 and 24. It is doubtful if any greater success will be attained on the north flank of this same anticline. Any deep drilling must be carefully done in order that the water that lies just below the C zone shall be successfully cased off. A well to test the deep sands on the north flank of the fold should be placed a considerable distance east of the "transition belt." It would therefore have to case off top water above the C zone, the C zone, and water below the C zone.

Exclusion of water from oil sands.—In two or three places in the "transition belt" where tar and water sands begin to appear in the B zone considerable trouble has been experienced in handling top water because of the fact that in adjacent wells the water strings have been set at very different horizons. One of the areas where this trouble has occurred is near the southwest corner of sec. 13. Here a water-bearing sand occurs within the B zone; its position is shown in the geologic section on Plate XVI. Drillers of some wells here have reported this water and have cased off below it, thus casing this sand off with the upper part of the B zone. Drillers of neighboring wells, however, have not recognized this water sand and have set their water string at about the top of the B zone.

It may be that this sand contains water in only a few places and that in the wells whose logs have not reported water the sand is actually dry. However, as conditions now stand water is free to enter the sands in the upper part of the B zone in the wells that have been cased off below the water sand and to appear in the wells that have been cased off above the B zone. Even though water has not yet appeared in the last-mentioned wells, it may do so later, when the oil has been partly extracted from the sand.

A condition that is similar to that just described and is concerned with either the same water sand as that causing the trouble near the southwest corner of sec. 13 or with a sand at about the same horizon exists near the center of the west line of sec. 24. In some of the wells near the center of the S. ½ sec. 14 the water string has been set below the top of the B zone, whereas in neighboring wells the water string is set much higher and the oil string is perforated to provide for the uppermost sands in the B zone. Top water is thus free to enter the top of the B zone, although there is no record of its actually having done so yet.

In at least one well near the crest of the Globe anticline the water string has been set exceptionally low, apparently below the top of the C zone. It is possible that top water is thus permitted to enter the C zone, and several of the wells in the vicinity of the well in which the casing is so set are troubled with water. The source of this water can not be stated definitely, however, for in this same area bottom water was reached by the drill and it may not have been plugged off successfully.

The sand that yields the most water in this area is the one that closely underlies the C zone. The approximate position of the top of this sand is indicated by the contours on Plate XXXVI. These contours are of necessity only a rough approximation of the location of this sand, for the wells furnishing information as to its position are few and scattered. However, any well that is drilled below the horizon indicated by these contours is in grave danger of encountering bottom water. The position of this sand is shown also on the geologic cross section. (Pl. XVI.)

GLOBE-BEAR CREEK AREA.

[Sec. 15; W. ½ sec. 14; northwestern part of sec. 22; and NW. ¼ sec. 23, T. 31 S., R. 22 E.]

LOCATION AND OPERATORS.

The Globe-Bear Creek area includes the extreme northwestern part of the North Midway field that was productive in 1916. (See geologic sections, Pls. XVI and XVII.) The companies operating here in 1916 were the Elliott, Bankline, Dominion, Potter, General Petroleum (Globe and Bear Creek), Kern Trading & Oil, Hondo, Midway Peerless, M. & M. (M. H. & M. and Cherokee), Security, Combined, Alberta Midway, M. G. & P., Pinal Dome, and Tumbador.

GEOLOGY.

The chief structural feature in the N. ½ sec. 15 is the fault that determines the eastern front of the Telephone Hills. This fault dies out near the south end of those hills, and in the S. ½ sec. 15 the beds are bent into several small folds and broken by several small faults. Near the southeast corner of the section the structure is more simple, and the beds are folded upward regularly, forming the fairly broad Globe anticline.

The chief structural features in the S. ½ sec. 15 are (1) a gentle upward fold along a line passing diagonally through the section and connecting the northwest end of the Globe anticline with the southwest end of the fault zone along the east front of the Telephone Hills; (2) a slight downward fold along a parallel line extending from the center of the west line to the center of the south line of the section and probably continuing into the NE. ¼ sec. 22; (3) a very slight upward fold along a parallel line that lies between the shallow syncline just described and the Twenty-six syncline on the south. These two last-mentioned folds are, however, so small and so broken by faults that individually they do not appear to have had much effect upon the accumulation of oil, and the upward fold that extends diagonally through the central part of sec. 15 may be considered as the chief one of these minor structural features.

The rocks of the whole area from sec. 15 northward and westward to the outcrop of the diatomaceous shale in the Telephone Hills and in the vicinity of the Santa Fe tank house in sec. 17 are much fractured. Apparently there is here an abrupt twisting in the strike of the beds from the northwestward trend they have in the foothills southwest of the Telephone Hills to an almost westward trend through the center of T. 31 S., R. 22 E. It may be that a northeastward-trending fault of considerable size determines the low pass in the Diablo Range near Crocker Springs, but it is more probable that the beds only bend abruptly about the ends of the plunging folds that pass through secs. 6 and 7, T. 31 S., R. 22 E.

OIL SANDS.

The chief oil sands in this area lie in the lower part of the Etchegoin formation, but it is probable that the upper part of the productive zone, or at least the lower part of the tar zone that overlies the productive oil sands, is in the Paso Robles formation. Only one or two wells have been drilled completely through the Etchegoin into the underlying Maricopa shale, and the logs of all these wells record oil sands mixed with shell and brown shale, or "broken oil sand," for a distance of about 200 feet below the base of the Etchegoin.

The oil sands vary in grain from very fine sandy shale to pebbly coarse-grained sand but slightly indurated. "Shells" are not very abundant, but the clays in the lower part of the tar zone are thick enough to afford good landings for the water string.

In the western part of this area, in sec. 15, the productive zone varies in thickness but reaches a maximum of about 400 feet. The upper limit of the productive zone can not be recognized definitely from the well records, for the productive sands lie at the base of a thick zone whose upper part is occupied by tar sands, and not only does the impregnation of the different sands vary considerably from place to place, but the drillers differ as to what should be considered a productive oil sand. Consequently, the bed recorded in the different well logs as the top of the productive zone is not everywhere the same. Usually more care was taken to test the upper part of the zone in the first wells drilled than in the wells drilled later, which were put down hastily to the most productive sand reached by the neighboring wells. The logs of most of the wells in sec. 15 record an almost unbroken oil sand; few of them record less than 200 feet, and most of them between 200 and 300 feet.

Toward the east the upper part of the productive zone becomes more and more tarry, and wells recently drilled near the east line of sec. 15 record only tar sands in the B zone. However, as far eastward as the center of sec. 14 the B zone has proved productive in spots, and some of the first wells in this section originally obtained their oil exclusively from it.

Were the B zone everywhere tested adequately it might even now yield a small quantity of heavy oil throughout the western part of sec. 14. The chief oil sands underlying the W. ½ sec. 14 are, however, in the C zone, and in the wells recently drilled the water strings have been set near the base of the B zone, so as to produce oil from the lower sands.

Two wells have been drilled about 200 feet below the base of the main oil sands of the Etchegoin in the western part of the area, penetrating the Maricopa shale. The logs of these wells record thin oil sands, shale, and shell, but apparently no water was encountered. The oil sands have not proved to be productive. These sands, together with the interstratified brown shales, have a total thickness of about 100 feet and are separated from the base of the main oil zone in the Etchegoin by about an equal thickness of barren clay and shale.

BEDS BELOW THE MAIN PRODUCTIVE ZONE.

Only three wells have certainly gone below the Etchegoin, or, in other words, been drilled completely through the main productive zone. Below this zone were encountered numerous shells and brown shales mixed with lean oil sands. These beds form the upper part of the Maricopa shale, which here is coarse grained and of much the same character as it is where exposed in the hills west of Fellows.

WATER SANDS.

Top water.—Top water has not proved troublesome in the western part of this area—that is, in most of sec. 15—and only a few of the wells, most of them in the eastern part of the SE. ¼ and the W. ½ sec. 14, record top water. This water sand is interstratified with tar sands and lies about 400 feet below the surface and 300 feet above the top of the B zone.[1] The water in one well is said to be practically fresh and is evidently only surface drainage.

Near the east line of sec. 15 top water appears lower down, apparently occupying sands in the upper part of the tar zone—that is, in the uppermost part of the zone that is productive in sec. 15.

In general the top water encountered in the western part of sec. 15 is largely surface drainage and should not be troublesome, for it is far enough above the top of the productive zone to be cased off easily. A lower top-water sand encountered in sec. 14 and in part of the E. ½ sec. 15, about 600 feet below the one just mentioned, is found at the top of the B zone and, it is said, has not been shut off properly in some of the wells, probably not being recognized in many of them.

The chief trouble from water is, as usual, in the so-called transition belt that lies between the area in which oil is obtained from the lower sand (the C zone) and that in which it is obtained from the top of the B zone, for it invariably happens that in this belt the water strings are not set uniformly in the different wells.

The very little top water recorded in the NW. ¼ sec. 23 comes from a sand lying about 200 feet above the top of the C zone. The correlation of this sand is not very good, but it may be the equivalent of the lower sand that is as troublesome in the eastern part of sec. 14. (See p. 92.)

Bottom water.—Bottom water has not been encountered in any well in sec. 15, even in the deep wells that have entered the Maricopa shale. It has been struck, however, in some of the wells in the W. ½ sec. 14, particularly in several wells near the center of the south line of sec. 14. This water is discussed in detail in the part of this report describing the E. ½ sec. 14, the NE. ¼ sec. 23, etc. (p. 92). Its approximate position is shown by the contours on Plate V and in the geologic section (Pl. XVIII).

CHARACTER OF THE OIL.

Most of the oil obtained in sec. 15 ranges in gravity from about 12° Baumé to about 16° Baumé, but in places a little oil of relatively light gravity (17° to 18° Baumé) is recorded in sands that lie at the very top of the productive zone. The oil from the bottom sand is in much of the area exceedingly heavy, and in many places it has been found difficult or almost impossible to drill through this tar sand with standard tools. The logs of many of the wells record alternating oil sands and tar sands. It is probable that the variation in gravity is caused by the fractured nature of the beds and their variation in grain, rather than by the presence of water, the very coarse beds retaining only the tarry oil, whereas in the

[1] See analysis 7, Table 14, Part II (Prof. Paper 117).

fine-grained and less fractured beds fractionation is less complete and the lighter oil is found. It is also probable that along the faults only tarry oil remains, the lighter constituents having left.

In the western part of sec. 14 and the NW. ¼ sec. 23 the oil is slightly lighter, the lightest gravity recorded being between 20° and 23°. This oil, however, probably comes in part at least from the lower or C zone.

PRODUCTION.

Most of the wells in sec. 15 came in as pumping wells, making 100 to 300 barrels. They are fairly long-lived, or at least the rate of decrease is not very great for the first two or three years. In the western part of sec. 14 and the NW. ¼ sec. 23 many of the wells flowed originally and have made 300 to 400 barrels or more a day. The period during which they flowed, however, was not very long and the decrease is much more rapid than for the pumping wells in sec. 15. The reason for this difference is to be found in the fact that in sec. 15 the productive zone is thick, whereas in the eastern part of the area the sands yielding oil are much thinner and either the casing has not been perforated for the upper part of the zone found to be productive in sec. 15 or else this part has been shown to be a tar sand that will yield no oil. It is probable that if the upper part of the productive zone had been more carefully tested in the western part of sec. 14, it might have yielded a considerable amount of heavy oil.

Near the outcrop in sec. 15 the tar sands and even some of the sands containing heavy oil are so sticky that drilling with standard tools is slow and unsatisfactory, and consequently many of the new wells have been drilled with the rotary rig. This in a measure accounts for the difficulty in making satisfactory correlations from the drill records, for it is notoriously difficult to keep an accurate log of a rotary drilled well.

A few of the wells in sec. 15 use but a single string of casing. This is safe only near the western edge of sec. 15, for many of the wells near the center of the E. ½ SW. ¼ get a top water which, although only surface drainage, should be kept out of the productive sand. In most of the other wells a water string is set just above the top of what is considered the productive zone. This method would be all right if the drillers' ideas were all alike, but unfortunately in some wells in the W. ½ sec. 14 the casing has been set above the lower of the two top-water sands described above, and in neighboring wells below this water sand.

SUGGESTIONS FOR FUTURE DEVELOPMENT.

Deeper drilling.—On the whole it seems foolish to drill deep wells here in the hope of getting oil from sands that lie below the zone that is now productive, especially in the western part of the area—that is, in sec. 15. The zone that is now yielding oil appears to be almost if not quite at the base of the Etchegoin. The Maricopa shale, upon which the Etchegoin rests, is made up of diatomaceous shale with intercalated lenses of granitic sand and gravel. The coarse lenses may yield some oil, yet the opportunity for the oil to have migrated into the overlying Etchegoin is so great, owing to the unconformable relations existing between the Etchegoin and the Maricopa shale, that the coarse beds in the Maricopa shale are rather unpromising.

As the Etchegoin thickens toward the east, owing to the unconformity at the base of that formation and the inclusion in it of older beds than those present closer to the outcrop, it is possible that eastward from the vicinity of the east line of sec. 15 a deep sand may lie below the zone which is now yielding oil. The productive zone is, however, underlain in this part of the field by a persistent sand carrying saline water, and in drilling through this water sand great care must be exercised to prevent the infiltration of the water into the overlying productive oil sands.

Although the Etchegoin thickens eastward, the rate of thickening is not very great, and inasmuch as wells in the E. ½ sec. 15 that have been drilled through the productive zone have not encountered a deeper sand, it would seem best, if the drilling of a deep well in sec. 14 were contemplated, to place that well somewhere in the E. ½ sec. 14 or even in sec. 13, where a sufficient thickness of beds to contain a workable oil sand may have wedged in below the present productive zone and above the Maricopa shale. The prospect of obtaining deeper sands in this general area is discussed in the section dealing with the E. ½ sec. 14, the NE. ¼ sec. 23, etc. (p. 93).

TRAFFIC-STARLIGHT AREA.

[Sec. 16; eastern part of sec. 17; northeastern part of sec. 20; all of sec. 21 except the southwest corner; and all of sec. 22 except the northeastern part, T. 31 S., R. 22 E.]

LOCATION AND WELLS.

The Traffic-Starlight area lies at the extreme northwest end of the North Midway field, just west of the south end of the Telephone Hills. It extends from the outcrop of the basal beds of the McKittrick group eastward to the vicinity of the area in sec. 15 which in 1916 was producing oil. There are no producing wells in this area, but there are several idle or abandoned ones, in some of which oil was encountered. Chief among these are the wells of the State Consolidated and Corrigan oil companies in sec. 17, the Durango Oil Co. in sec. 20, and the Starlight, K. & C., and Chanslor-Canfield Midway Oil companies in sec. 22.

GEOLOGY.

The dominant structural feature in this area is the Twenty-six syncline, which trends diagonally northwestward through sec. 22 from a point a little south of the center of the east line of that section and is continued by a general synclinal structure through sec. 16. This syncline appears to be a well-defined trough in sec. 22, with fairly steep dips on both north and south flanks and, near the east line of the section, a strong plunge toward the east. Toward the northwest, however, the regularity of the trough is broken by faults, and in sec. 16 no line marking the center of the trough can be drawn.

The axis of the Globe anticline passes close to the northeast corner of sec. 22, but it is here not the dominating feature that it is farther to the southeast, for it commences to break up into a number of small folds and faults. The anticlines and synclines occupy the western part of sec. 17 (see geologic map, Pl. II), plunge rather abruptly eastward, and do not affect the structure markedly in the W. ½ sec. 16. They probably have no particular influence on the accumulation of oil in this area.

OIL SANDS.

In this area only a single thick productive zone can be recognized. The C zone, which is productive in the E. ½ sec. 23, either forms the lower part of this zone or, more probably, is absent, the sands forming it having been cut out along the plane of unconformity that marks the base of the Etchegoin. It may be that the C zone extends as far west as the center of the east line of sec. 22, for the lower part of the productive zone encountered in the Chanslor-Canfield Midway Oil Co.'s well No. 2 in that section corresponds in general position fairly well with that zone.

The conditions encountered in the SE. ¼ sec. 15 (see pp. 93-96) probably prevail as far west as the center of the SE. ¼ sec. 16, for here the productive zone is about 150 feet thick. The sands become markedly thinner, however, westward from this locality, probably owing to the unconformity at the base of the Etchegoin, and in sec. 17 the zone containing sands is not much over 100 feet thick, of which less than 50 feet is probably truly oil sand. Toward the southwest, in the N. ½ sec. 21, thick oil sands are reported. They evidently contain very heavy oil and will probably not prove very productive, as there is in that vicinity no dominant fold along which oil would tend to collect.

One or two of the wells in this area have been drilled completely through the main oil zone of the Etchegoin into the underlying Maricopa shale and in this formation have found irregular lenses of sand, some containing a little oil and some containing water. The chief water sand reported seems to underlie closely the main oil zone at the base of the Etchegoin.

FUTURE DEVELOPMENT.

Much of the area lying northeast of the outcrop of the Maricopa shale in secs. 21 and 22, possibly a very small part of sec. 20 and of the SE. ¼ sec. 17, and a considerable part of the S. ½ sec. 16 will probably prove productive. In the SE. ¼ sec. 16 the oil will be found in the thick oil sands under much the same conditions as are encountered in the SW. ¼ sec. 15, but the productiveness of the sand will probably decrease westward from the vicinity of the wells now producing in sec. 15.

On the south flank of the Twenty-six syncline, in the area passing diagonally through the S. ½ sec. 22 and probably extending into the N. ½ sec. 21, the oil sands will probably be found to have much the same character as those in the SW. ¼ sec. 26—that is, they are 100 to 300 feet thick, are coarse grained, and will yield a heavy oil. The most promising part of this belt lies about midway between the outcrop of the McKittrick group and the axis of the Twenty-six syncline. Close to the outcrop the productive zone contains chiefly tar sands, whereas near the axis of the syncline water will probably appear in the productive zone. Wells drilled in this part of the area will almost certainly not be so productive as those in the SW. ¼ sec. 26, for in general the south flank of the Twenty-six syncline becomes less promising northwestward from the west line of sec. 26.

There is but little probability that the Maricopa shale contains extensive productive oil sands. Oil may occur in isolated lenses in this formation, but the wells that have been drilled into it have found only water sand and a few very poor oil sands.

On the whole, wells drilled in this area will probably yield only a small amount of heavy oil. The most promising parts of the area lie along the flanks of the Twenty-six syncline and probably also along the axis of that syncline near its west end, in secs. 21 and 16.

BROOKSHIRE-GEM AREA.

[S. ½ sec. 23; SW. ¼ and E. ½ SE. ¼ sec. 24; NW. ¼ and W. ½ NE. ¼ sec. 25; NE. ¼ and northeastern part of NW. ¼ sec. 26, T. 31 S., R. 22 E.]

LOCATION AND OPERATORS.

The Brookshire-Gem area includes the southern part of the North Midway field, extending from the westernmost part of the field that was producing oil in 1916 as far eastward as the deep wells north of Fellows, along the west line of T. 31 S., R. 23 E. (See geologic section, Pl. XVII.) The companies operating here in 1916 were the Tumbador, Pinal Dome (Gem), Rock, General Petroleum (Logan and Brunswick), Brookshire, San Francisco Midway, United, Coalinga Monterey, Kern Trading & Oil (secs. 23 and 25), Midland Oilfields (Ltd.), Chanslor-Canfield Midway Oil (secs. 25 and 26), Result, El Camino, and Pyramid.

GEOLOGY.

This area lies along the central part of the Twenty-six syncline and extends up the north flank of that syncline nearly to the crest of the Globe anticline. The Twenty-six syncline is a regular, fairly narrow trougn as far southeast as the vicinity of the center of the north line of sec. 26, but eastward from that locality it plunges rather abruptly and swings from a southeasterly trend to an almost easterly one, thus paralleling the Globe anticline. Near the northeast corner of sec. 25 the syncline has almost flattened out, as is shown by the very slight embayment made by the underground contours (Pl. III).

The Twenty-six syncline is really the western of the two branches of the Midway Valley syncline. It may almost be considered as the main arm of this branching trough, for the saddle between the Globe anticline and the United anticline is probably so high as practically to terminate the north arm of the Midway Valley syncline in sec. 19, T. 31 S., R. 23 E.

OIL SANDS.

The chief production in this area is obtained from the C zone, the upper or B zone being dry in most of the area. The C zone is entirely in the Etchegoin, as is shown by the fossils, which are very plentiful in the producing sands, especially along the east line of sec. 23.

The beds containing oil range from a pebbly sand in which the largest fragments are between a quarter and half an inch in diameter to a very fine sand or sandy clay. One of the most productive wells in this area obtains its oil from a "pepper and salt" sand in which the grains are of exceptionally uniform size and well rounded. Most of the wells, however, including all that have yielded only a small quantity of oil, obtain their oil from a very uneven-grained sand which contains a large amount of clay and in which the free-pore space is evidently small.

The C zone is the chief producer, the upper or B zone being recognized and the casing perforated for it only in the SW. ¼ sec. 23 and the NW. ¼ sec. 26. The C zone varies in thickness; the maximum is about 200 feet, including interstratified barren clays and sands. The oil sands themselves are usually less than 100 feet and in places only 10 to 25 feet thick. On the average about 30 to 40 per cent of the C zone is recorded as oil sand.

The "transition belt" that marks the easternmost extension of the area beneath which the B zone contains some oil extends roughly along the north-south center line of sec. 23 to the vicinity of the south line of that section. There it swings slightly to the west and, bending about the Twenty-six syncline, trends southeastward practically through the center of sec. 26. In the "transition belt" the productive beds have a maximum thickness of 450 feet, the lower part of this embracing the C zone. "Stray" oil sands occur in the B zone as far east as the north line of sec. 25, where a sand containing some oil lies about 200 feet above the main C zone. This "stray" sand is remarkably coarse grained, being very much coarser than the sands in the C zone beneath.

Along the east line of the NE. ¼ sec. 23 the B zone is 70 feet thick and is separated by 200 feet of clay from the C zone, which is here 120 feet thick. The B zone here contains tar, not oil, but may be recognized definitely. Near the east line of sec. 25 the beds in the upper part of the C zone become less productive, the main production coming from the lower part, although one or two wells are a notable exception to this general rule, for they apparently get their oil from the very top of the C zone.

BEDS ABOVE THE B ZONE.

The beds above the B zone consist of the usual mixture of clay, sand, and gravel. All the wells were drilled with rotary tools, and the upper parts of many of the logs are not intelligible. It seems, however, that the beds as a whole are somewhat coarser grained than usual. Also it is certain that tar sands are more abundant here than in other parts of the field that contain the oil sands buried at an equal depth, for they are almost as thick here as they are in sec. 15 of the same township, where the productive zone is buried under much less cover.

Tar sands are remarkably thick along the east-west center line of sec. 23, where about half the beds that lie between the top of the B zone and a point 700 feet above that zone are saturated with tar. In two of the wells tar sands are reported within 200 feet of the surface. Along the south line of sec. 23 the tar sands are much thinner than they are in the center of that section. Here they may be grouped roughly into two zones. The upper tar zone is 150 to 200 feet thick and its top lies 600 to 800 feet below the surface. The top of the lower tar sand lies 300 to 600 feet below the bottom of the upper sand and extends down to the top of the B zone. This lower zone includes, of course, a great many barren clays, hardly 40 per cent of the beds being recorded as tar sand.

In the northern part of sec. 25 the logs of only a few of the wells record a thick tar sand, and most of them record only irregular tar sands; but these sands occur within 600 feet of the surface, even where the productive oil sand lies at a depth of fully 2,400 feet.

BEDS BELOW THE C ZONE.

The C zone is in the basal part of the Etchegoin formation probably throughout the area and certainly in the northern and western parts of it. A few wells that have been drilled several hundred feet below the base of the C zone have entered the Maricopa shale, and their logs record shale and numerous shells (many of which are recorded as "lime shells") and abundant water sands. One of these wells encountered an oil sand in the Maricopa shale but never produced from it, the sand being shut off on account of water trouble.

WATER SANDS.

Bottom water.—The C zone is underlain by water sand throughout the area. The top of this sand is shown approximately by the contour map (Pl. XXXVI). The sand is the same as that encountered by many wells in the southern part of sec. 14. However, in the area under discussion it is separated from the bottom of the C zone by a somewhat greater thickness of clay than it is in sec. 14, for in general, as is shown in the geologic section (Pl. XVI), this bottom water sand seems to diverge slightly from the C zone toward the southeast. For example, near the center of the north line of sec. 23 the bottom of the C zone is practically in contact with this water sand, whereas near the center of sec. 23 some 50 feet or so of clay separates the oil sands from the underlying water sand. Near the center of sec. 26 the water sand is barely 100 feet below the top of the C zone and there is very little clay between the two, the conditions here practically duplicating those near the center of the north line of sec. 23. Near the the center of the east line of sec. 23 the water is fully 120 feet below the top of the C zone, which is there 50 feet thick. At the center of the east line of sec. 26 the C zone rests practically upon the water sand.

Top water.—Top water is not troublesome in the western part of this area, practically the only water encountered there being either distinctly surface water or so far up in the tar sands that it is always cased off. There are very few data as to the strength of flow or quality of this water, but it is said to be "sulphur water." Water appears in the upper part of the B zone in the eastern half of the area; and in the easternmost part practically all the B zone is occupied by water.[1] A line drawn from the Kern Trading & Oil Co.'s well No. 12, in sec. 23, and trending S. 25° W. to the vicinity of General Petroleum (Brunswick) No. 1–A, in sec. 26, separates roughly the area on the southeast in which the B zone is occupied, wholly or in part, by water from that on the northwest in which no water is recorded in that sand. On the south limb of the Twenty-six syncline the line marking the western limit of the area in which the B zone contains abundant water trends southeastward and passes just south of the Chanslor-Canfield Midway Oil Co.'s well No. 2, in sec. 25. The log of only one well northwest of this line shows water in the B zone, but this log is not very reliable, and water may not actually have been encountered. This top water is what was called the "lower top water" in the description of the southwestern part of sec. 13, and its position is shown on the geologic section (Pl. XVI).

CHARACTER OF THE OIL.

The oil ranges in gravity from 16° to 23° Baumé, and the lightest oil comes from the very top of the C zone near the eastern edge of this area. The heaviest oil is almost invariably that obtained from wells which either are in bottom water themselves or are adjacent to wells that are. The normal oil from the C zone appears to run about 21° to 23° Baumé. In the eastern part of sec. 25 the top of the C zone is either dry or contains only a little oil, the production coming from the lower part, and the oil from this part of the C zone is several degrees heavier than that in the uppermost part.

PRODUCTION.

This area is one of the most spotted in the whole Sunset-Midway field. There is nothing in the structure of the area that makes it a specially favorable locality for the concentration of oil, for it lies along the axial part of a well-marked syncline, and oil would tend to migrate either to the north toward the crest of the Globe anticline or to the southwest into the beds on the steep north flank of the Midway anticline. As is described above, the grain of the oil sand is variable, the sand being in some places very porous and in others clayey and of a low degree of porosity. It is this variable porosity that appears to govern the accumulation of oil, which is trapped in the coarser lenses. About four large wells were obtained in this area, and these are scattered through it. Between them were brought in wells which made less than 100 barrels a day initially. In 1914 the average production per well per day was about 30 barrels for the northern half of the area and about 60 barrels for the southern half.

FUTURE DEVELOPMENT.

Except in the northwestern part of this area the success of all future development is dependent upon the C zone, for it is improbable that any deeper sand occurs here except possibly in the very easternmost part. Even there such deep sands are probably to be considered as nothing more than the lower part of the C zone, for that zone thickens toward the east owing to the unconformity at the base of the Etchgoin and the wedging in of beds above the diatomaceous shale and below the lowest Etchgoin present in the western part of the area. In the northern part of the area, on account of the fact that the water sand so closely underlies the C zone in the Globe anticline, it is risky to drill deeper than 100 feet below the top of that zone. In the southeastern part of the area the water sand is separated from the C zone by a greater thickness of clay, and the margin of safety is greater. (See Pl. XXXVI for approximate location of this water sand.) In drilling for lenses in the Maricopa shale care must be taken before testing such lenses to case off top water, the C zone, and the persistent water sand that lies just below the C zone.

In the eastern part of the area the upper or B zone is occupied wholly or in part by water and must be cased off. Only in the northwestern part of the area may oil be obtained from this zone.

EL CAMINO-PIONEER MIDWAY AREA.

[Central part of sec. 26; N. ½ S. ½ and southern edge of N. ½ sec. 25, T. 31 S., R. 22 E., and west-central part of sec. 30, T. 31 S., R. 23 E.]

LOCATION AND OPERATORS.

The El Camino-Pioneer Midway area extends from the extreme western edge of the present productive field to a point about a

[1] See analysis 40, Table 21, Part II (Prof. Paper 117).

mile northwest of the town of Fellows and forms a belt 3,000 to 4,000 feet wide far down on the north limb of the Midway anticline, or, in other words, on the south flank of the Twenty-six syncline. The companies operating here in 1916 were the El Camino, Pyramid, State, Soudan, Chanslor-Canfield Midway Oil (secs. 25 and 26), Kern Trading & Oil, and Associated (Pioneer Midway).

GEOLOGY.

This area lies well down on the north flank of the Midway anticline, where the beds usually dip less than 10°. The Twenty-six syncline, whose axis lies just north of this area, plunges abruptly eastward and is lost near the east line of the area—that is, near the east line of T. 31 S., R. 22 E.—there merging with the main structural depression of the Midway Valley syncline.

The southeastern part of sec. 25 more closely resembles the area lying farther southeast—that is, the northeastern part of sec. 36 and the northwestern part of sec. 31—and it is described in detail in the discussion of those areas (pp. 106–110).

OIL SANDS.

The producing oil sands in this area occur in the lower part of the McKittrick group in the Etchegoin formation. Some oil sands have been encountered in the underlying Maricopa shale in one or two of the deep wells, but so far these sands have not yielded much if any oil.

The western part of the area embraces what has been described as the "transition belt," where the chief production is obtained from the C zone but where the overlying B zone contains oil, as well as tar and water. The total thickness of beds from the top of the B zone to the base of the C zone is about 300 feet, and of this approximately the lowest 100 feet constitutes the C zone. In places the oil sands reported in the C zone are very thin, some of the wells reporting not more than 20 feet of them.

In the eastern part of sec. 25 the B zone contains no oil, the productive sands occurring entirely within the C zone, which is here about 200 feet thick. The sandy beds included in this zone in this part of the field are very lenticular and probably of much the same character as those composing this zone near the north line of sec. 25, as described on page 98. The general character of the C zone here is about as follows:

General section of C zone in E. ½ sec. 25, T. 31 S., R. 22 E.

	Feet.
Blue sandy shale containing numerous "shells" and some lenses of sand which have yielded the oil produced by the larger wells here. These lenses are, however, of small areal extent	50
Blue shale barren of oil	50
Oil sand	10
Sandy shale; contains some oil in small lenses	70
Oil sand	30

Most of the wells here derive their oil from the two lower sands.

BEDS ABOVE THE B ZONE.

In the western part of the area the B zone is overlain by thick tar sands which are reported to extend within 500 or 600 feet of the surface. The total thickness of the zone containing them is between 700 and 1,000 feet, of which the sands saturated with tar form less than 20 to 40 per cent, the remainder being clay, etc. In the eastern part of the area tar sands are reported to occur about 800 feet or so from the surface, but strangely enough below this upper tar zone very few tars are reported down to the C zone. It may be, of course, that, as many of these wells were drilled with rotary tools, tar sands were not reported, but the difference in the records of the tar sands encountered in the wells drilled in the eastern part of sec. 25 from those in the western part of the area is striking.

BEDS BELOW THE C ZONE.

Only one well has been drilled for a considerable depth below the C zone, but several of the wells have been drilled into the water sand which immediately underlies that zone. The log of the deep well records brown shale, shell, and sandy shale below the C zone and an oil sand about 300 feet below the top of that zone. This oil sand is clearly a sandy lens in the Maricopa shale, which here seems to be considerably more sandy than usual, and resembles the beds that crop out in the upper part of the Maricopa shale west of Fellows.

WATER SANDS.

Bottom water.—Throughout the area the C zone is underlain fairly closely by a water sand, into which eight or nine wells have been drilled.[1]

[1] See analyses in Table 21, Part II (Prof. Paper 117).

In the eastern part of sec. 26 this water sand lies about 100 feet below the top of the C zone and in some places is reported immediately below the oil sand, whereas in other places about 50 feet of shale is reported between the oil and water sands. Toward the east the barren strata separating the water sand from the lowest productive oil sand in the overlying C zone increases in thickness, and near the east line of sec. 25 the top of the water sand, as nearly as may be judged from the very meager data available, is between 200 and 300 feet below the top of the C zone. The location of the top of this water sand is shown approximately by the contour map (Pl. XXXVI).

Top water.—Top water is reported in most of the wells several hundred feet above the productive C zone. Water sands are reported also either in the top of the B zone or just above it, in wells near the center of sec. 26, in the "transition belt."

CHARACTER OF THE OIL.

In the western part of the area, where most of the oil is obtained from the B zone, the oil is much like that found in the southern part of the SW. ¼ sec. 26, higher up the flank of the Midway anticline, ranging in gravity from 14° Baumé or a little heavier to about 18° Baumé.

In the eastern part of the area, where the C zone furnishes the production, the oil has an average gravity of about 22° Baumé. In places, notably in the easternmost part of the area, where the oil comes from the lower part of the C zone, it is somewhat heavier—18° to 19° Baumé. The upper part of the C zone here apparently contains light oil, where it contains any oil at all, and has yielded the gusher flow in the Associated well (Pioneer Midway No. 2). The heavy oil in the lower part of the C zone may indicate the presence of bottom water close below, or it may be that the lower beds are somewhat coarser grained.

PRODUCTION.

The production of wells drilled in this area varies greatly, the reason probably being that the oil sands are lenticular and in much of the area are so clayey that they do not contain much oil. Certain coarse lenses, however, contained great quantities of oil, and one of the largest producing wells in the field (Pioneer Midway No. 2) is near the eastern margin of this area. Several other wells had a "settled" production between 100 and 400 barrels daily.

SUGGESTIONS FOR FUTURE WORK.

Water sand underlies the productive zone throughout this area and in the western part appears to be very close beneath it. In the eastern part of the area bottom water has not been reached, but heavy oil in the lower part of the C zone may indicate that the water is not far below. In any case it is risky to drill more than 100 feet or so below the top of the C zone.

On the whole it appears probable that the average production of wells drilled in the future in this area will be low, but that wells having a fairly large daily production may be obtained in a few places. On account of the lenticular character of the oil sands, it is probable that the big wells here will have less effect upon one another than in most parts of the field, and that wells of fairly high pressure will be obtained even after the field is pretty well drilled up. However, the life of these wells will not be long.

STATE-AMERICAN OILFIELDS AREA.

[Southwestern part of sec. 26; northeastern part of sec. 27; northeastern part of sec. 35; southwestern part of sec. 36, T. 31 S., R. 22 E.; north edge of sec. 1, T. 32 S., R. 22 E.; southwest corner of sec. 31, T. 31 S., R. 23 E.; and northwest corner of sec. 6, T. 32 S., R. 23 E.]

LOCATION AND OPERATORS.

The State-American Oilfields area extends from the outskirts of the town of Fellows westward to the western edge of the developed field and embraces a belt about 4,000 feet wide just northeast of the outcrop of the main oil sands. (See stereogram, Pl. XXXVII.) The chief companies operating here in 1916 were the El Camino, California Star, State, Mocal, Pyramid, Associated, Chanslor-Canfield Midway Oil, American Oilfields, United, Eagle Creek, and Mammoth.

GEOLOGY.

The dominant structural feature here is the Midway anticline, which trends almost due southeast through the center of sec. 35 and takes a somewhat more easterly course through the N. ½ sec. 1 into sec. 6. At the surface the fold is fairly sharp; the basal beds of the McKittrick group, which crop out near the axis of the fold, being tilted to angles of 25° or 30°, and the underlying Maricopa shale, which is exposed in places along the axis of the fold, even more steeply. The belt of steep dip is narrow, however, extending in few places more than 500 or 1,000 feet northeastward from the axis of the fold, and beyond it to the northeast the beds dip at angles of 10° or less.

Like most of the other folds in the foothills, the Midway anticline flattens greatly at a depth of a few hundred feet, and the oil sands are not buckled nearly so sharply as the beds that crop out. The Midway anticline extends a short distance farther northwestward than is shown on the maps (Pls. II and III). In secs. 26, 35, and the northwestern part of sec. 1 the crest of the Midway anticline appears to be about horizontal, but eastward from that locality the fold plunges abruptly to the southeast.

OIL SANDS.

The chief productive sands in this area lie entirely within the Etchegoin formation, as is shown clearly by the fossils that they contain from top to bottom. The Paso Robles formation contains tar but no productive oil sands. The Maricopa shale has been penetrated by one or two wells and is reported to contain a few oil sands, but these appear to be lenticular, small, and unimportant and have yielded a very small fraction of the total production. Although most of these lenses are practically negligible as a commercial source of oil, the Maricopa shale contains commercial amounts of oil in certain places, for where its uppermost beds are sandy they form the lower part of the main productive zone.

The fossiliferous beds of the Etchegoin crop out in secs. 35, 36, 1, and 6, this being one of the few places where the Etchegoin is exposed in the Midway field. The belt of outcrop is so narrow that it has not been shown on the geologic map (Pl. II), but its appropriate position is indicated on the map showing the underground contours (Pl. III). The fossiliferous beds that crop out are evidently the beds from which the oil in the northwest corner of sec. 6 is obtained, many fragments of fossiliferous sand having been blown out of the United Oil Co.'s well No. 9 when it first entered the sand.

The oil sands here range from pebbly sandstones in which the larger fragments are half an inch or so in diameter to fine sand or sandy shale. Some of the beds, particularly those in the south end of the area, where the fossiliferous beds described above occur, are indurated by a lime cement. For the most part the oil sands in the western half of the area are fairly fine grained, but they seem to be relatively free from clay. Very few samples of sand contain grains that will not pass a 20-mesh sieve, and a very large part of each sample passes an 80-mesh sieve. In places the sand contains fragments of a quarter of an inch in diameter, but these fragments are not common and it is notable that the samples in which they occur usually contain a large proportion of clay. The sands yielding the most oil usually are even-grained "pepper and salt" sand in which the grains are well rounded. The lower part of the productive zone—that is, the basal part of the Etchegoin—does not appear to be markedly coarser than the upper part.

The productive zone is thickest in the northeastern part of the area, where it is usually about 300 feet thick, although in one or two wells oil sands are reported through a zone fully 400 feet thick. The lowest oil sands encountered in the wells recording this maximum thickness are, however, probably in the Maricopa shale, which is in certain places very sandy near the top. In most of the wells, the greater part of this zone is recorded as oil sands, some of which are more and some less productive; in many wells barely 5 per cent of the whole is said to be entirely barren of oil. It is therefore impossible to separate the zone into parts comparable with the B and C zones of the area farther from the outcrop.

Within 1,200 or 1,500 feet of the outcrop the productive zone is not over 100 feet thick, and the productive well closest to the outcrop usually encounters only 40 to 50 feet of oil sand. The decrease toward the outcrop in the thickness of the productive zone is caused by two factors—the wedging out of the basal beds of the Etchegoin along the plane of unconformity and the replacement of the oil by tar in the upper part of the productive zone. This condition of affairs is well shown in the stereogram of sec. 36, T. 31 S., R. 22 E. (Pl. XXXVII), and is discussed in the part of this report dealing with the general mode of occurrence of oil in the field (pp. 75–83).

EXPLANATION OF PLATE XXXVII.

The stereogram was constructed to show the structure and the interrelationship of oil, tar, and water-bearing beds in an area near the outcrop of the B zone. This figure is not a perspective drawing and in consequence has a somewhat distorted appearance. It is, however, so drawn that the three reference lines are exactly to scale and on this account it can be used as a working drawing. The vertical scale of this block, however, is larger than the scale in other directions, as explained below. The method of constructing such a figure is briefly as follows:

A drawing of a block is constructed, as in figure 9, which represents the block as seen from above, AD representing the width, DC the depth, and AE the height of the block, each drawn to scale. The rectangular face ADHE is represented as in the plane of the paper and therefore is of true shape and size. The rectangular side DCGH of the block, which in reality is at right angles to the plane of the paper, is shown diagonally, so that the right angle CDH of the side of the block appears in the drawing as 120°. The

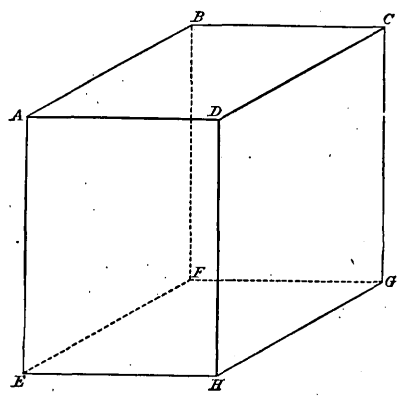


FIGURE 9.—Diagram explaining method of constructing stereogram in Plate XXXVII.

right angle ADC of the top of the block is similarly distorted in the drawing to 150°. The sides AB and AD are of the same length and are drawn on the same scale; the vertical dimension is made somewhat longer for convenience in drawing but is drawn on the same scale.

The intersection of the plane representing the surface of the ground with the sides of the reference block is shown in figure 10 by the lines IK, KL, LM, and MI. The part of the block below the plane representing the surface of the ground is considered as opaque, for it represents a block of the earth; the part of the block above the surface plane IKLM is considered as transparent, for it is simply a construction block. On the sides of the solid block the edges of the strata that form the block are shown. The representation of these strata on the plane IMHE is therefore a geologic cross section drawn true to scale, for that plane is in the plane of the paper. The representation of the intersection of the strata with the plane MLGH, however, is slightly distorted, for that plane which is in reality at right angles with that of the paper is shown diagonally and all angles are distorted. The intersection of the upper surface of the zone containing productive oil sands (the B zone that is contoured on Pl. III) with the two front sides of the block is shown by the lines ST, TU. The outcrop of the upper surface of the sand is represented by the line RS.

In figure 11 the block is supposed to be separated along the upper surface of the B zone—that is, along the plane

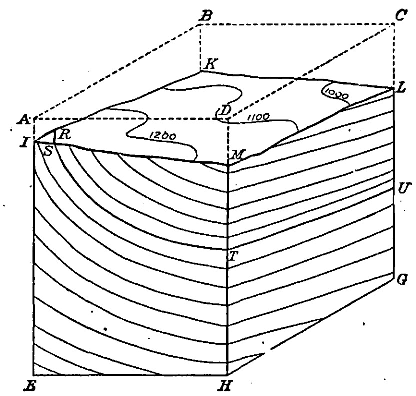


FIGURE 10.—Diagram explaining method of constructing stereogram in Plate XXXVII.

that is contoured on the map (Pl. III)—and the upper part of the block is supposed to be lifted so that the upper surface of the B zone is visible. On both the warped plane IKLM that represents the surface of the ground and the warped plane RSTUV that represents the upper surface of the B zone contour lines are drawn showing

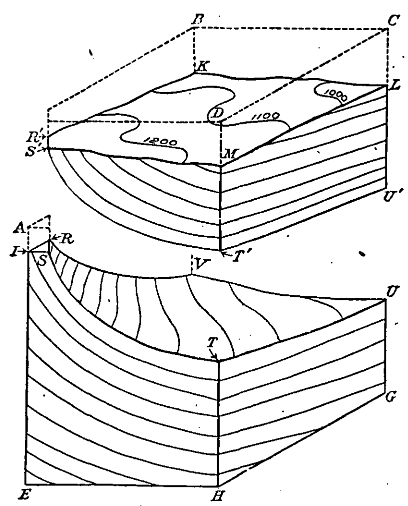
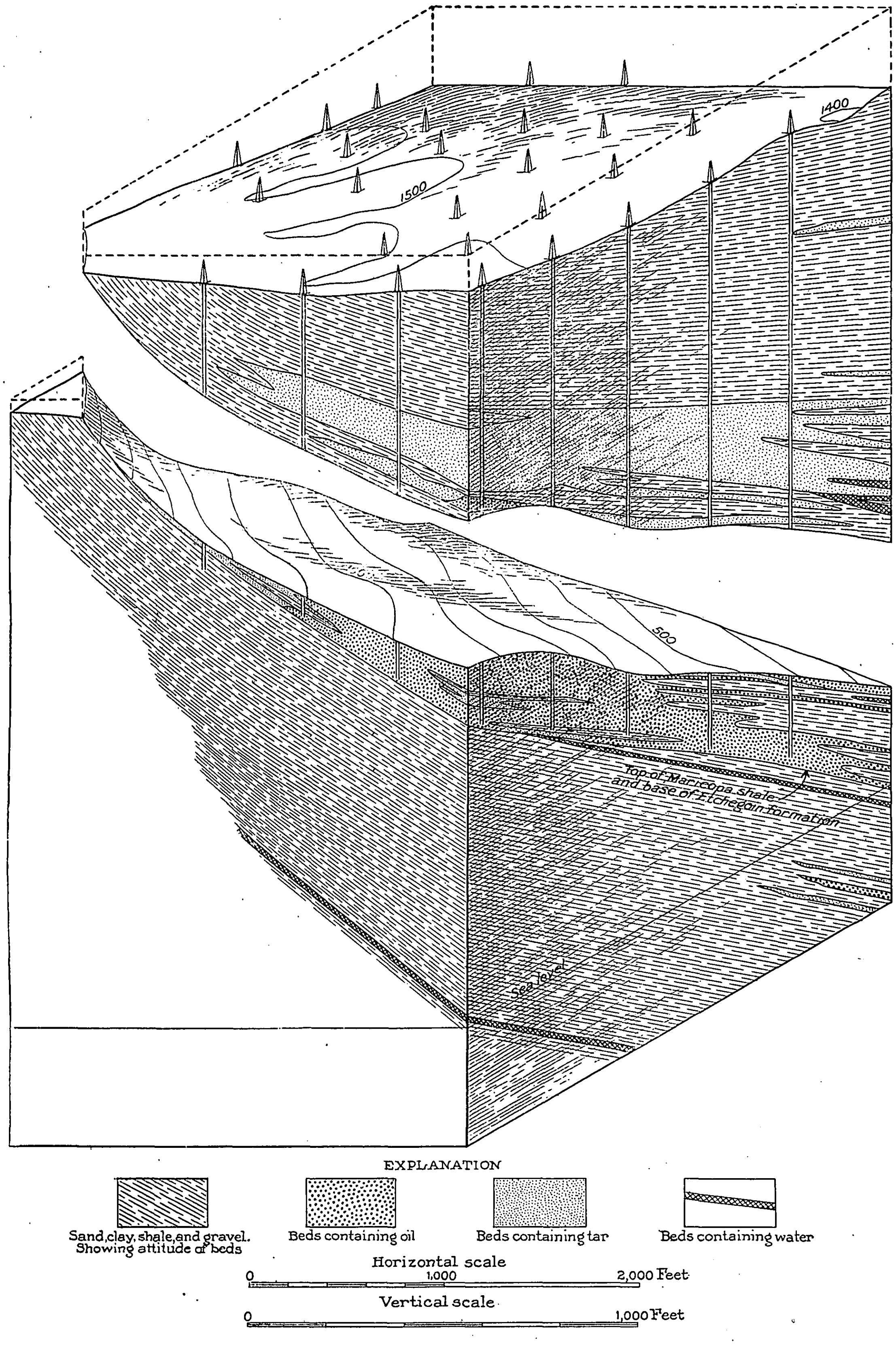


FIGURE 11.—Diagram explaining method of constructing stereogram in Plate XXXVII.

the elevation of these planes above sea level. These contour lines correspond with part of those that are shown for the B zone on the map of the field (Pl. III).

In order to show the structure of the strata more clearly the vertical scale in the stereogram is made twice that of the horizontal scale, which makes the dip of the beds steeper and thus distorts the structure somewhat.



STEREOGRAM SHOWING STRUCTURE OF OIL SANDS IN SEC. 36, T. 31 S., R. 22 E.

BEDS ABOVE THE B ZONE.

The B zone is overlain directly by a zone averaging about 300 feet in thickness in which tar sands are abundant. Here as in other areas that lie fairly close to the outcrop, the separation between the oil and tar zones can not be made very definitely, on account of the irregular distribution of oil in the beds and also because of the lack of uniformity in the ideas of the different drillers as to just what constitutes oil sand and what tar sand. Near the northeastern edge of the area tar sands as a rule occur abundantly up to a level within 400 feet of the surface.

BEDS BELOW THE PRODUCTIVE ZONE.

Some 9 or 10 wells in this area have been drilled into the Maricopa shale, one of them penetrating it for 2,000 feet. Without exception, these wells have failed to encounter any considerable amount of oil, although practically all have struck coarse lenses that contained some petroleum.

The Maricopa shale penetrated by these wells is chiefly brown shale (probably diatomaceous shale) with numerous "shells" and sandy or even gravelly beds. Both the well records and the outcrops higher in the foothills indicate that the Maricopa shale is in this area filled with sandy lenses that ought to make excellent reservoirs in which the oil could collect. The tests of the formation which these wells have given show that, although oil may occur in commercial amounts in certain isolated lenses, these lenses are not numerous and that prospecting for them will have to be done blindly and will be costly, for the percentage of dry holes will be very large.

WATER SANDS.

Top water.—In the western part of the area northwest of the center of sec. 36 top water is rarely found in wells drilled within 1,500 or 2,000 feet of the outcrop, practically the only water reported being clearly surface drainage. In the east end of the area, however, top water lies very close to the top of the B zone, probably immediately above the top of the "stray" oil sand that locally lies just above the B zone. In some of the wells in this area the casing seems to have been set too low, and probably water from this sand has entered the top of the B zone. Almost certainly the "stray" sand is flooded by this time. This water sand is the one that lies so close above the productive B zone near the center of sec. 36.

Bottom water.—The persistent bottom-water sand[1] that so closely underlies the C zone in the southeastern part of T. 31 S., R. 22 E., continues as far southwest as the center of sec. 26 and the northwest corner of sec. 36. The approximate position of the top of this water sand is shown on Plate XXXVI. Near the northwest corner of sec. 36 this water sand lies between 300 and 400 feet below the top of the productive zone. Water occurs also at approximately the same distance below the top of the productive zone in the center of sec. 36. The position of this bottom water in the center of sec. 36 is shown in the stereogram (Pl. XXXVII). Near the southeast end of the area water does not seem to underlie the productive zone quite so closely. The Maricopa shale, however, contains numerous water sands, and drilling far below the base of the Etchegoin is not safe in any part of the area.

CHARACTER OF THE OIL.

In the western part of the area the oil ranges from 13° to 19° Baumé. The gravity of the oil does not seem to bear any particular relation to the distance from the outcrop, for some of the lightest oil is obtained in the wells that are closest to it, whereas wells near the northeastern edge of the area and consequently 3,000 to 4,000 feet from the outcrop yield heavy tarry oil.

In the central part of the area the oil ranges from 14° to 24° Baumé; the average is about 20°.

In the east end of the area the oil is even lighter, usually ranging between 22° and 24° Baumé, although certain wells, in general those that are troubled by water, yield heavy oil, some as heavy as 14° Baumé.

In much of the area, particularly in the western part, where water sand closely underlies the productive zone, the sands in the lower part of the productive zone contain a very heavy oil, in many places almost a tar. Many wells close to the outcrop have yielded a rather larger amount of gas than is usually obtained from wells so close to the outcrop, where the opportunity for the escape of the

[1] See analysis 54, Table 24, Part II (Prof. Paper 117).

lighter constituents of the gas is relatively great. It seems, therefore, that the sealing of the beds must be rather more perfect here than is usual, and that the oil has suffered rather less than the ordinary amount of natural fractionation.

PRODUCTION.

This area has proved to be one of the richest in the Midway field, certainly the richest that is so close to the outcrop. In the western part of the area many of the wells had an initial production of 200 to 600 barrels daily and a "settled" production of 150 to 200 barrels. The largest wells, however, are in the east end of the area, where several wells flowed many hundred barrels daily for several months. The largest of these wells were American Oilfields No. 79 and United No. 9.

A remarkable feature of the production of this area is the fact that there is no gradual decrease toward the outcrop in the productivity of the wells. Up to 600 or 800 feet from the outcrop the production of the wells is about equal to the average of those within 2,500 feet of the outcrop, but at a distance of 300 feet or so from the outcrop the sands are much poorer and wells drilled there produce only a few barrels of oil or are dry.

SUGGESTIONS FOR FUTURE WORK.

In the western part of the area the productive zone is limited to a thickness of less than 400 feet, and within 1,000 feet of the outcrop it is less than 100 feet thick. Water is not present close below the productive zone in the southern part of the area west of the center of sec. 36. Deep drilling here is therefore not particularly dangerous to the productive sands, but it probably will not prove profitable, for although stray sands are to be expected in the upper part of the Maricopa shale, such sands are not persistent and probably could not materially increase the production. Bottom water is present near the northwest corner of sec. 36 and also both northwestward and southeastward from that point at approximately equal distances from the outcrop. Drilling in the part of the area lying northeast of this line should therefore not be continued below the base of the productive sands of the Etchegoin.

In the northwest corner of sec. 6 the area is practically drilled up, and future work is concerned with the proper handling of the wells already drilled. The chief troubles here are abundant top water and some bottom water, which has been reached by several wells. In casing off the top water it will probably be necessary to case off the stray oil sand also, for that has already been done in many of the wells, and the sand must be by now pretty well flooded. In the southwestern part of the area the productive zone is not over 300 feet thick, and to drill more than 300 feet below the top of the zone is dangerous, for bottom water is abundant in the underlying Maricopa shale.

MOCAL-HAWAIIAN AREA.

[South edge of sec. 25; southeast corner of sec. 26; NE ¼, northeastern part of NW. ¼, and northeastern part of SE. ¼ sec. 36, T. 31 S., R. 22 E.; southwest corner of sec. 30; western part of NW. ¼ and northeastern part of SW. ¼ sec. 31, T. 31 S., R. 23 E.]

LOCATION AND OPERATORS.

The Mocal-Hawaiian area comprises the northern part of what may be termed the Fellows field, extending from the thickly drilled area in and near sec. 26 that was first developed by the State Consolidated Co. eastward to a point about three-quarters of a mile northwest of the town of Fellows. (See geologic sections, Pl. XVIII.) The companies operating here in 1916 were the Recovery, Visalia Midway, Chanslor-Canfield Midway Oil (secs. 26, 31, and 36), American Oilfields, Associated (Pioneer Midway), Honolulu Consolidated (Hawaiian), and Mammoth.

GEOLOGY.

This area lies on the north flank of the Midway anticline, pretty well down the flank, where the dip is fairly low. On the north is the Twenty-six syncline, and on the east the Midway Valley syncline. Both of these synclines show their effect in the structure of this area, for the strike of the beds in the northern part of the area is somewhat more easterly than that of the beds in the eastern part of the area. The strike of the beds therefore makes a curve very gently convex toward the northeast, and the structure may be regarded as that of a very slight or broad anticline plunging steeply northeastward. This structure seems to have had considerable influence in the concentration of the oil, however, for this part of the field has thus had an unusually large area from which to draw the oil now contained in it. Oil occurring in the basin of the Twenty-six syncline, to the north, would tend to move southward, and that formed in the Midway Valley syncline would tend to move westward up the dip, to collect high on the flank of the Midway anticline. It is probable that a slight fold such as this would not have had so great an effect on the accumulation of oil were it farther from the outcrop, but here the sealing of the beds near the outcrop by asphalt and tarry oil has been nearly perfect, and the fold with this sealed end has been a better container for oil than the coarse lenses surrounded by impervious clays such as occur throughout the section. It is noteworthy that this area and the area just to the west contain practically all the big wells in the Midway field that are close to the outcrop.

OIL SANDS.

Practically all the oil obtained in this area comes from sands near the base of the Etchegoin formation, but one or two wells were drilled into the underlying Maricopa shale, and in their logs oil sand is reported 300 to 400 feet below the base of the main productive zone. There is very little evidence as to the extent of these sands in the Maricopa shale, but they are probably lenticular and will probably not prove very rich.

Near the center of sec. 36 the total thickness of the combined B and C zones is about 400 feet, but toward the northeast the thickness increases greatly, and near the northeast corner of the section it is about 750 feet. Of this, however, only about 250 feet is recorded as oil sand. This variation in thickness is evidently caused by the unconformity at the base of the Etchegoin and the wedging in of older beds toward the northeast. The angular discordance in dip between the Etchegoin and the underlying Maricopa shale appears therefore to be considerable and is apparently greater here than in the other areas occupying a similar position along the foothills of the main ridge.

The uppermost part of the B zone contains a remarkably persistent oil sand which has been recognized as far toward the northeast as the SW. ¼ sec. 30, T. 31 S., R. 23 E. Near the northeast corner of sec. 36 it is about 20 feet thick and is separated from the underlying C zone by some 200 feet of barren strata. It is rather remarkable that this sand should be so persistent, for usually the upper part of the B zone becomes nonproductive at a point closer to the outcrop than that at which the lower sands in the same zone become dry. Near the east line of the NE. ¼ sec. 36 the oil sands in the C zone are separated by barren clays almost equal in thickness to the barren measures lying between the upper sand of the B zone and the top of the C zone. These clays in the C zone are lenticular, however, and can not be followed so definitely as the clay overlying that zone.

In most of this area the productive zone may be divided readily into the B and C zones, but near the southwest edge of the area these zones are not separable and together form a thick zone of oil sands with relatively little interstratified barren clay, shells, etc.

Along the south line of the NE. ¼ sec. 36, the upper part of the productive zone is not recorded uniformly in the logs of the wells. Many of the logs do not record the upper part of the B zone, and, indeed, many of them do not record anything as oil sand above the C zone. The top of the B zone, however, contains oil here, and it should not be cased off with the top-water sands.

Several of the big flowing wells near the center of the east line of sec. 36 have obtained their oil from a sand that lies at the base of the B zone—that is, within 60 feet of the top of the C zone. This sand occupies approximately the same position as the sand that yielded the large flow of oil in Pioneer Midway well No. 2, about a mile to the north, but in the intervening area no oil sand occurs at this horizon. It is evident, therefore, that these sands are very lenticular, but their lenticularity is probably the chief reason why the oil in them is originally under such high pressure. Near the center of the east line of sec. 36 this sand has been recognized under an area of perhaps a square mile.

In this same part of the area a stray sand about 10 feet thick is reported in one well about 60 feet above the top of the B zone. This sand yielded heavy oil for a short time at a rate of about 80 or 90 barrels a day, but it was apparently soon exhausted and has not been recognized in the neighboring wells.

BEDS ABOVE THE B ZONE.

In the southwestern part of the area tar sands are scattered through the beds from a point between 600 and 800 feet below the surface down to the top of the B zone. In the northeastern part of the area tar sands are encountered at about an equal distance below the surface and also close to the top of the B zone, but in the intervening strata they are not abundant. The upper tar sand here is usually between 200 and 400 feet thick. The lack of tar in the beds fairly close to the top of the productive sand in the part of the area where the sand lies deeper is probably more apparent than real, for many of these wells are drilled with rotary tools and no attention is paid to character of the beds so far above the pay sands. However, the regularity with which the upper tar sand is recorded suggests that it is especially heavy.

WATER SANDS.

Top water.—Throughout the area the B zone is closely overlain by water sands, and in most of it the water string should be set very close to the top of the B zone. The exact position of these top-water sands is not known, for they are reported as scattered through the beds that lie between 200 and 300 feet above the B zone. Near the center of the north line of sec. 36 top water has been especially troublesome and seems to be separated from the B zone by only a very few feet of clay. In the northeast corner of the area water is present in the uppermost part of the B zone. The position of these sands is shown in the geologic section (Pl. XVIII, *B*). However, except in this extreme northeast corner of the area and in the vicinity of the center of the north line of sec. 36, where the water sand so closely overlies the B zone, top water should not be troublesome, for there appears to be sufficient clay beneath it in which to shut it off.

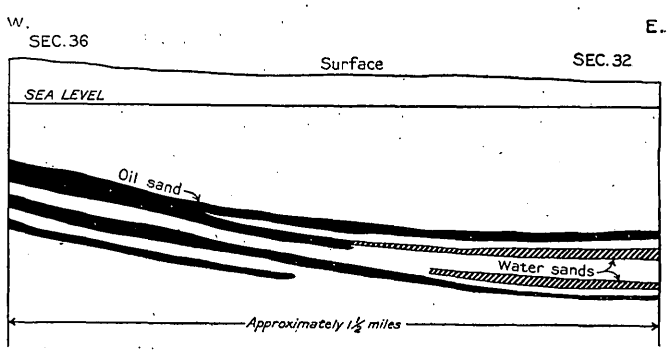


FIGURE 12.—Diagram showing relation of water sands in sec. 32, T. 31 S., R. 23 E., to those in the northeastern part of sec. 36, T. 31 S., R. 23 E.

Bottom water.—Bottom water has been encountered by some of the wells in three parts of the area, all in sec. 36—near the center, near the northwest corner, and near the center of the north line of the section. The water found near the center and near the northwest corner occurs either in the basal bed of the Etchegoin formation or in the Maricopa shale. The Etchegoin rests with marked unconformity upon the Maricopa shale, and along a belt that extends in a northwesterly direction through the center of sec. 36 the Etchegoin appears to be thinned considerably, probably because along this belt the Maricopa shale, upon which it rests, is somewhat higher than normal. The explanation of the occurrence of water here that best fits the known facts seems to be that a water sand in the Maricopa shale reaches the plane of unconformity along this belt and that water from it has entered the basal bed of the Etchegoin and flooded that bed along a belt that probably extends from a point north of the northwest corner of sec. 36 nearly if not quite to the southeast corner of the section. This belt is narrow, however, and does not extend to the northeast down the dip. The sands now occupied by water lie 200 or 300 feet below the top of the productive zone and apparently are not separated by much barren clay from the base of that zone. Care must be exercised here in order to avoid drilling too deep. In those parts of the area where water occurs very close below the productive zone, the lowest oil sands contain heavier oil than those in the upper part of the zone, and the presence of such oil will serve as a warning to stop drilling.

Near the east line of the NE. ¼ sec. 36 the deep wells that have been drilled 500 feet or more below the top of the C zone have not certainly encountered water. One well may have encountered bottom water, but the record is not entirely satisfactory. Although the wells in this area do not find any water in the C zone, water is present in both the upper and lower parts of that zone only a short distance to the east, and it is probable that as oil is extracted from the sands near the east line of sec. 36 water will work westward into the parts of the sand that now contain oil. The general conditions here are shown in figure 12 and Plate XVIII, *B*.

The persistent water sand that immediately underlies the gusher sand of sec. 32, T. 31 S.,

R. 23 E., is probably the sand most to be feared. In sec. 32 it lies within 100 feet of the top of the C zone.

In the northern part of the area the C zone is closely underlain by the persistent water sand that extends over so much of the southeastern part of T. 31 S., R. 23 E. The approximate position of the top of this sand is shown on the sketch map (Pl. XXXVI).

In several parts of the area more or less water has been encountered, but it does not appear to come everywhere from the same sand. The chief water trouble in the northern part is clearly from top water. Near the center of sec. 36 the chief trouble is probably from bottom water, although top water may have contributed. Near the northwest corner of sec. 36 any water so far obtained probably came from a bed below the C zone, but with exhaustion of oil edge water in the C zone will probably appear.

CHARACTER OF THE OIL.

The oil in this area is fairly uniform in gravity where water is not troublesome, ranging from about 20° to 25° Baumé. Where water is troublesome the oil seems to run 17° to 19° Baumé. The oil does not appear to get heavier regularly toward the outcrop, but there is a very distinct difference in gravity between the oil from the B zone and that from the C zone in the northeastern part of the area. The upper sand is said to furnish oil of about 17° Baumé, whereas the oil from the lower zone, or perhaps a mixture from both upper and lower zones, runs 20° to 25° Baumé.

PRODUCTION.

In this area are many of the largest wells of the Fellows field—wells that were originally spectacular gushers. The biggest wells here were Honolulu Nos. 1, 10, and 12; American Oilfields Nos. 34 and 56; and Mammoth No. 2. Visalia Midway No. 2 was also a flowing well for two years but did not flow wild. Most of the wells except those along the extreme southwest edge of the area have had a settled production of over 100 barrels daily, some of them 200 to 300 barrels. With a few exceptions the wells produced 60 barrels or more daily in 1914.

FUTURE DEVELOPMENT.

It is practically certain that further exceptionally large flowing wells can not be expected in this area, but much of the area gives promise of wells with a settled production of 100 barrels or more daily. This is particularly true of the northeastern part of the area—that is, the part in which the oil-bearing strata lie deeper. It is probable that the southwestern edge, particularly near the center of sec. 36, will yield a much smaller production. The uppermost part of the productive zone near the south line of the NE. ¼ sec. 36 is not properly tested by many of the wells, although top water does not seem to be especially dangerous here, and the upper sands could probably be tested without danger to the productive sands. The oil in these sands, however, is heavier than that furnished by the lower sands. In the northeastern part of the area the upper sand becomes much thinner and contains heavy oil, of about 17° Baumé. It is probable that edge water now occupies part of this sand and that any new wells near the northeast corner of sec. 36 will find it profitable to case off this sand and produce only from the lower ones. This statement may apply also to wells drilled as far southwest as a line drawn from the vicinity of the American Oilfields No. 5 to Mammoth No. 2.

Drillers of wells in the vicinity of the center of the north line of sec. 36 should use exceptional care in shutting off top water, as it seems to be very close to the top of the productive zone. It may be that the upper part of the productive zone should be cased off here, as this has already been done in some of the wells, and it is possible that the upper part of the productive sand is now flooded.

Bottom water appears to lie fairly close to the productive zone in the center of sec. 36. As suggested before, it may be that in this vicinity the presence of heavy oil will give an indication of the proximity of bottom water. In the northeast corner of sec. 36 bottom water apparently lies close below the productive zone, but here that zone seems to be fully 700 feet thick—that is, the lowest productive sand lies a little more than 500 feet below the sand that forms the uppermost part of the C zone, which is really the chief producing sand here. Somewhat farther east the individual oil sands making up the C zone are separated by water sands, and here also the chief oil sand lies at the very top of the C zone. As the oil is exhausted water will work its way up the dip and appear in the wells near the northeast corner of sec. 36. The chief water which is to be feared is that which lies immediately below the upper oil sand in sec. 32—that is, the sand which forms the uppermost part of the C zone. (See the description of that area, p. 112, and geologic section, Pl. XXI.)

PIONEER MIDWAY-MIDWAY CONSOLIDATED AREA.

[Southwestern part of sec. 29; southeastern part of sec. 30; NE. ¼, northeastern part of NW. ¼, and northeastern part of SE. ¼ sec. 31; sec. 32; and SW. ¼ sec. 33, T. 31 S., R. 23 E.; northwest corner of sec. 3; northwestern part of sec. 4; and northeastern part of sec. 5, T. 32 S., R. 23 E.]

LOCATION AND OPERATORS.

The Pioneer Midway-Midway Consolidated area includes the eastern part of the Fellows field, forming a belt about 1 or 1¼ miles wide that extends from a point approximately 1½ miles due north of the town of Fellows southeastward, parallel to Midway Valley, to a point about 1½ miles east of the town. It lies entirely on the flat, extending from the edge of the foothills of the Temblor Range to the center of Midway Valley. (See geologic sections, Pls. XIX–XXI.) The companies operating here in 1916 were the Kern Trading & Oil, Associated, Consolidated Mutual, Honolulu (Hawaiian), Columbus Midway, California Midway, Buick, Olig Crude, General Petroleum (Fellows 32), Pacific Crude, Alaska Pioneer, Chanslor-Canfield Midway Oil, Mammoth, Eagle Creek, Canadian Pacific, Midway Consolidated, Wilkes-Head, Vancouver Midway, California Counties, and Standard (Equitable).

GEOLOGY.

Most of this area lies fairly well out toward the axis of the Midway Valley syncline, where the Tertiary beds are hidden under a cover of alluvium, which is thin near the foothills but which is probably a few hundred feet thick in the central part of Midway Valley. The north end of the area lies near the point where the Midway Valley syncline ceases to form a single trough and frays out into two minor folds, one of which, the Twenty-six syncline, extends northwestward through T. 31 S., R. 22 E., and the other, the larger one, northward through sec. 19, T. 31 S., R. 23 E. This main branch of the Midway syncline may terminate in the eastern portion of sec. 19, but even if it does, its effect is shown by the presence of the low arch or saddle that separates the Globe anticline from the United anticline.

The dip of the beds is low throughout the area, rarely being over 6° or 7° along the extreme southwestern edge. The strike is regularly northwestward, except of course along the axial part of the fold of the Midway Valley syncline, where the beds start to swing about the axis of the plunging fold. This syncline plunges southeastward, but, except possibly in the extreme northwestern edge of the area, the plunge is not more than 1° or 2°. At the extreme northwest corner of the area, where the Midway Valley syncline forks, the beds show a very slight tendency to aline themselves with the trend of the Twenty-six syncline.

The Midway Valley syncline appears to be a rather flat-bottomed trough, the lowest part of which forms a zone that extends for about a mile toward the southwest from the axis of the fold. In much of the area the dip increases rather abruptly along a line trending parallel to the axis of the syncline and lying approximately a mile or a mile and a quarter southwest of it. This line may be considered to separate the synclinal portion of the field from the portion that is more closely allied with the Midway and other small anticlines along the flank of the Temblor Range anticline. In the part of the area north of the township line separating Tps. 31 and 32 S. no such sharp division may be noted, for the dip increases gradually from the synclinal part of the field toward the axis of the Midway anticline; but in secs. 5 and 8, T. 32 S., R. 23 E., the separation is well marked. The line along which the dip changes abruptly trends southeastward from the northeast corner of sec. 6 to the center of sec. 5 and thence to the center of the south line of sec. 4. This difference in the degree to which the beds are tilted, although slight, seems to have had a marked effect upon the accumulation of oil, for in the northern area—that is, the area of low dip—the upper part of the zone that is productive in the foothills, where the structure is dominated by the Midway anticline, contains oil closer to the axial part of the syncline than it does in the southern area, where the dip is higher and the change in attitude is more abrupt. In this southern part of the area, where the dip is high and then changes abruptly to form the floor of the syncline, the upper part of the zone that is productive near the axial part of the Midway anticline remains productive approximately to the line along which the dip changes, but east of that line it is almost if not quite barren of oil and usually contains water. Between this line and the axis of the Midway Valley syncline the productive sands are limited to the lower part of the zone that is productive close to the axis of the Midway anticline.

OIL SANDS.

The oil sands in this area are entirely in the Etchegoin formation, for marine fossils are reported both in the deepest sands yet encountered and in beds which overlie the uppermost productive sands. No well here has yet been drilled deep enough to penetrate all the Etchegoin and enter the Maricopa shale. To judge from the results of the deep wells drilled farther west the Maricopa shale would probably not prove productive in this area.

The productive sands here lie chiefly in the C zone, but the B zone contains oil in places along the southwestern edge of the area, particularly near the northeast corner of sec. 5. The general character of the productive zone in the different parts of the area may be summarized about as follows:

In a narrow belt along the southwestern margin of the area the B zone contains oil in sandy lenses that have a somewhat irregular extent. In this same part of the area the C zone is probably about 500 feet thick. The best oil sands lie near the top of the C zone, but less rich sands are scattered through the zone from top to bottom. No water occurs within the C zone here.

In the eastern part of the area the total thickness of the C zone is probably a little greater than it is near the southwestern margin, but here the chief oil sand is thin and lies at the very top of the C zone, and water sands are abundant in the zone, separating various sands reported to contain oil.

The B zone is usually 150 to 200 feet thick and is productive about as far north as the center of the east line of sec. 31, beyond which it is occupied by water. As is usual along the outer edge of the "transition belt," the oil sands in this zone are irregular and may only with difficulty and uncertainty be correlated between wells. No persistent oil sand comparable with that which occurs at the top of the B zone near the northeast corner of sec. 36 has been found here.

In the area just northwest of that here described, near the east line of the NE. ¼ sec. 36, T. 31 S., R. 22 E., the C zone is composed of interstratified oil sands and barren strata that have a total thickness of about 500 feet, and of this zone about half is usually recorded as oil sand. Eastward for half a mile or so from this area the oil in the C zone is restricted more and more to a few thin sands that are separated from one another by barren clays. Farther east the oil sands are still thinner, and water sands appear in the barren clays that separate the oil sands. The conditions existing here are shown in figure 12.

The character of the productive zone is best known in sec. 32, for here the upper part has been pretty thoroughly drilled. Its character is shown graphically in the geologic sections (Pls. XIX–XXI). The chief features of the productive zone here are described below:

The upper part, usually 20 to 30 feet thick, is oil sand (the chief producing sand in this section), below which is about an equal thickness of clay; then a water sand 10 to 20 feet thick containing salt water (the troublesome bottom water encountered in so many of the wells). Lying between 270 and 330 feet below this water sand is another sand said to yield flowing water. Between these two water sands various oil sands are reported, but these have not been thoroughly tested, and their position is not accurately known. The lowest water sand reported is probably not over 50 feet thick and may be only 10 feet thick. Beneath it oil has been reported, but the extent or productivity of this sand is not known.

The sand forming the uppermost part of this zone is the one that has yielded the largest production, and almost all the wells in sec. 32 penetrate only this upper sand. Its thickness as reported in the record of wells in the eastern part of sec. 32 ranges from 10 to 30 feet. There appears to be very little regularity in the variation in thickness reported for this sand, and the difference is evidently more a personal factor dependent on the driller than a natural dependent on the position of the sand.

For a distance of 200 to 300 feet above the top of this sand—that is, in the beds that are equivalent to the B zone of the western part of the area—traces of oil and gas occur, and showings of gas are reported still higher. These showings, however, evidently do not indicate deposits of commercial value, and the water string may safely be set in a short distance above the top of the C zone.

BEDS ABOVE THE PRODUCTIVE ZONE.

So many of the wells in this area have been drilled by rotary tools that any general statements regarding the character of the beds above the productive zone are not very reliable. It seems, however, that here as elsewhere in the field the uppermost tar zone is encountered at a depth of less than 1,000 feet below the surface, showing again that either this thickness of strata is insufficient to prevent the fractionation of the oil and the total loss of the light constituents, thus resulting in the deposition of the tar, or else the highly sulphate surface waters are encountered at about this depth, with the consequent oxidation of the hydrocarbons and the addition of sulphur. The probable relation of surface waters and the upper tar zone is shown by the fact that practically all the wells that record top water record it either in or just below this tar zone. Usually below this water, or below this combined tar and water zone, no more water or tar are recorded until the position of the B zone is approached.

WATER SANDS.

The position of several of the water sands has already been described in the section describing the oil sands. Top waters are scattered through the beds from the surface of the ground down to the top of the B zone; edge water occurs in the B zone; and water sands are interstratified with the oil sands of the C zone in the eastern part of sec. 32.

Top water.—The water in the sands that lie above the top of the B zone is, for the most part, not under heavy pressure and is cased off by the water string, which in the western part of the area is set above the top of the B zone, or in the parts of the field where the sands lie deeper, above the top of the C zone. Probably the most regular of these water sands is the one which lies at the base of the tar zone, encountered at a depth of less than 1,000 feet below the surface.

Edge water in B zone.—The B zone contains oil only in the southwestern part of the area, chiefly near the southwest corner of sec. 32. Northeast of this point the upper part of the B zone is occupied chiefly by water.[1] Many of the wells in sec. 32 do not record top water within 300 or 400 feet above the oil sand, but the other wells show that in the northeastern part of the section there is a persistent water sand that lies between 230 and 300 feet above the C zone. This water sand is probably in the B zone, and the water is thus true edge water for that zone. The logs of a few of the wells in sec. 32 record a lower water sand which lies only about 100 to 125 feet above the top of the C zone. This water sand may be the same as the water sand noted a similar distance above the C zone in the northwest corner of the section. In any case, in the NE. ¼ sec. 32 it is safest to set the water string somewhat less than 100 feet above the top of the C zone.

In sec. 4, except in the northeast corner, top water appears to be farther above the C zone than in sec. 32, but the records of it here are not very reliable. A sand yielding a heavy flow of water is recorded as lying about 300 feet above the top of the C zone, but other water sands are recorded, one of them lying only 15 feet above the top of the C zone. In the southwestern portion of sec. 4 water occupies the upper part, though not necessarily the uppermost part, of the B zone, occurring between 175 and 227 feet above the top of the C zone in the three wells whose logs record top water.

Water in the C zone.—The water sand that has given the most trouble in this area is the one that lies immediately below the oil sand which has yielded the chief production in sec. 32—that is, the thin oil sand at the very top of the C zone. The water from this sand is commonly termed bottom water. This water sand lies between 35 and 85 feet below the top of the C zone, the average being about 50 feet. Inasmuch as the oil sand at the top of the C zone is reported to be between 10 and 50 feet thick there, it has been difficult to penetrate the oil sand without also penetrating the underlying water sand.

The water sand that lies about 300 feet below the top of the C zone in sec. 32 has been penetrated by only one or two wells, and as no productive oil sands lie close to this sand water from it has probably not yet been a source of danger to the oil sands. The position of both the above-described water sands in the C zone is shown on the geologic sections (Pls. XIX–XXI).

[1] See analysis 44, Table 22, Part II (Prof. Paper 117).

CHARACTER OF THE OIL.

The oil produced in this area in 1914 ranged in gravity from about 22° to possibly 28° Baumé, the average being about 25°. Very little of the oil is lighter than 26.5° Baumé. The gravity of the oil produced by the first wells drilled here was 1° to 2° Baumé lighter than oil produced by the same wells in 1914. This decrease (increase in specific gravity) was shown most notably by the big flowing wells that were first drilled in the section.

There is a distinct difference in gravity between the oil in the upper part of the productive zone and that in the lower part. The B zone, which forms the upper part of the productive zone in a narrow strip along the southwestern edge of the area in sec. 31, furnishes oil of 17° to 20° Baumé. A mixture of this oil with oil from the C zone ranges from 20° to 23°. Wells that have had water trouble or are near wells that have had such trouble yield heavier oil.

PRODUCTION.

This area contains a number of wells that have had a very high initial production, several of them as much as 10,000 barrels or more daily. The settled production of many of the wells has been more than 1,000 barrels daily for periods of several months. These big wells are not grouped in any particular part of the area but are scattered through it from the north end nearly to the southeast corner of sec. 32. The whole area is, however, "spotted," and between the big wells are many wells which have never produced more than 100 barrels a day. The smallness in yield of these wells may of course be due in part to faulty drilling or more probably faulty methods of bringing the well in, but the lenticular character of the beds is probably the chief cause of the variation in size of the wells.

After the first big flow the output of the wells has decreased rather rapidly, and in 1914 most of them were making less than 100 barrels and probably less than half a dozen in the whole area made more than 200 barrels daily.

FUTURE DEVELOPMENT.

So far as sec. 32 is concerned (and probably much of this discussion will apply equally well to the southwestern part of sec. 33 and the northeastern part of sec. 4), the uppermost part of the C zone has yielded the oil so far produced. The productive sand is thin and apparently decreases in thickness from the southwest toward the northeast—that is, as it approaches the axis of the syncline. This thin sand has contained oil under tremendous pressure and has yielded big flows of oil when first tapped by the drill. The initial production of wells which may in the future be drilled into this sand, even at some distance from present wells, will evidently not be nearly so great as that of the first wells, for the gas pressure has been very greatly reduced throughout the area. Thin sands such as this can not be expected to yield wells that will be very long-lived, and the great decrease in productivity shown by the wells which have been drilled is quite what is to be expected.

The water sand underlying the productive sand that forms the upper part of the C zone in the eastern part of the area occurs so close to the oil sand that it has very naturally been drilled into, and much of the oil sand is now flooded with water and doubtless ruined.

This part of the area shows some promise of yielding oil from sands which lie below the water sand just mentioned. Such oil sands as those recorded between the two water sands encountered in the wells that have been drilled in sec. 32 may yield considerable oil, as may also the still deeper sand recorded below the second "bottom water." It seems as if the conditions here in a measure duplicate those that occur in Maricopa Flat (sec. 32, T. 12 N., R. 23 W.)—that is, that here there are a number of interfingering oil and water sands. The exact position of either the water or the oil sands can be determined only by drilling, but testing for these sands is well worth while. This area is not, however, nearly so favorable as Maricopa Flat, as there is here no well-developed anticlinal fold along which the oil would tend to collect.

Testing for lower sand should be carried on with due care for the protection of the upper sands. Thus in testing for the deepest sand said to have been encountered it would be necessary to set the following casings: (1) The water string above the top of the C zone (corresponding with the water string set in the wells now drilled); (2) the string below the top oil sand of the C zone, to protect that sand from "bottom water;" (3) a string below the "bottom water" which lies just below this upper oil sand, to enable the sands that occur between this water and the lowest water to be tested; (4) if these sands are productive another string between them and the top of the second "bottom water" sand; and (5) a string below this second water sand, to enable the deep sand underlying it to be tested.

Probably none of the wells that have been drilled in sec. 32 for a considerable distance below the top of the C zone have given the beds at lower horizons an adequate test. All of them have been troubled with bottom water, both the water which immediately underlies the upper member of the C zone and the water which occurs some 250 feet lower.

In considering the possible value of the lower sands in this area the character of the lower sands in the area just to the west should be considered. In that area several wells have been drilled 300 feet or more below the top of the C zone. Although many of them derive some oil from the lower sands encountered, the best production in most of them is recorded as coming from the upper part of the C zone. Thus, although one would naturally expect the basal beds of the Etchegoin formation to be the most productive, it is entirely possible that bottom water has forced the oil out from the lowest beds of that formation and that the oil has accumulated only in the very persistent coarse bed which occurs some distance above the base of the formation in the axial part of the syncline. It appears, however, to be well worth while to make a careful test of these lower sands in sec. 32.

MAMMOTH-ST. LAWRENCE AREA.

[Southwestern part of sec. 31, except the extreme southwest corner, T. 31 S., R. 23 E.; northeastern part of sec. 6; southwestern part of NW. ¼, W. ½ SE. ¼, and SW. ¼ sec. 5, T. 32 S., R. 23 E.]

LOCATION AND OPERATORS.

The Mammoth-St. Lawrence area embraces the southern part of the Fellows field, extending from a point about half a mile north of the town of Fellows southeastward to a point within half a mile of the old Chanslor-Canfield Midway Oil camp in sec. 8. (See geologic section, Pl. XXII.) The companies operating here in 1916 were the Chanslor-Canfield Midway Oil, Kern Trading & Oil, Midway Premier, Midway Five, Kalispell, St. Lawrence, Hale McLeod, Eagle Creek, and Mammoth.

GEOLOGY.

This area lies on the north flank of the Midway anticline, near the place where that fold plunges southeastward. The beds dip northeastward, usually at angles between 10° and 15°, but nowhere within this area do they show a tendency to bend around the end of the Midway anticline, the strike remaining approximately southeast to the southern edge of the area.

Besides the Midway anticline there is probably another fold in this area which has had some effect upon the accumulation of oil. This fold is indicated by a slight topographic rise near the eastern edge of sec. 6, passing about through the Chanslor-Canfield Midway Oil Co.'s well No. 3. The dip of the beds can not be made out from the surface exposures, and the fold can only be inferred from the topographic evidence.

The angular discordance in dip between the Etchegoin formation and the underlying Maricopa shale is considerable, and in consequence the lower part of the zone that is productive in the northeastern part of the area is wedged out abruptly toward the southwest.

OIL SANDS.

The chief oil-bearing sands here, the B and C zones, are in the basal portion of the McKittrick group. The sand described as the A zone (which corresponds to the upper part of the zone described as zone B by Arnold and Johnson [1]) may be in the Paso Robles formation, for no fossils have been found in it. This sand, however, does not form an important part of the productive zone in the area described, being productive only in the extreme southwest corner of sec. 5 and possibly in a part of the E. ½ sec. 6. Oil has been found also in some of the deep wells that have penetrated the upper part of the Maricopa shale.

The productive oil sands may be grouped into three divisions, the A, B, and C zones. The three zones are not productive throughout the area nor is it possible in all parts of the area to recognize a line of separation between some one of these and the overlying or underlying zone, for to the west the three zones merge. The general steplike arrangement of the productive oil sands is shown diagrammatically in figure 13.

[1] Arnold, Ralph, and Johnson, H. R., U. S. Geol. Survey Bull. 406, p. 144, pl. 3, 1910.

Along the southwestern margin of the area the productive sands with interstratified clays form a zone that averages about 400 feet in thickness, which can not here be divided into any definite parts. Toward the northeast, however, the productive zone thickens somewhat, reaching a maximum of 600 or perhaps 700 feet, and in the southern part of the area, northeast of a line drawn between the Chanslor-Canfield Midway Oil Co.'s well No. 17, in sec. 6, and St. Lawrence No. 3, in sec. 5, the productive sands may be grouped fairly definitely into the B and C zones. In this part of the area the B zone is approximately 200 feet thick. It has yielded oil in most of the area, but near the northeastern edge the oil sands in it become very thin, rarely being over 60 or 70 feet and in places only 10 or 20 feet thick, and the uppermost part of the zone is occupied by water.

In the northern part of the area, near the center of the W. ½ sec. 31, the uppermost 10 to 30 feet of the B zone contains heavy oil, and from this sand a few wells have obtained oil for a short time. This sand is evidently the equivalent of the persistent sand at the top of the B zone near the northwest corner of sec. 36. It does not everywhere contain oil, however, but in places contains gas under considerable pressure. Below this sand are barren beds approximately 100 feet in thickness, beneath which is a rather irregular oil sand that is recognized only in about half of the wells. This sand is about 70 to 100 feet thick and rests directly upon the C zone, forming, with that zone, a continuous productive zone in the center of the W. ½ sec. 31. It is from this sand that the gusher production in one or two of the wells just north of this locality was obtained.

The C zone varies greatly in thickness on account of the unconformity at the base of the Etchegoin. Near the southwestern edge of the area the lower 200 feet or so of the productive zone is probably to be correlated with the C zone. Near the center of sec. 5 the C zone is about 250 feet thick and its top lies about 300 feet below the top of the B zone. The variation in thickness is shown in the geologic section (Pl. XXII).

BEDS ABOVE THE B ZONE.

In most of the area, certainly in the southwestern part and probably as far northeast as a line drawn from northwest to southeast through the center of sec. 5, it is possible to recognize approximately the A zone, which is productive in the axial part of the Midway anticline in sec. 8. The A zone is not productive in this area but is represented by a tar zone—frequently recorded as "oil sand" or "heavy oil sand"—which has a thickness of about 100 or 150 feet. The top of this tar zone lies 400 to 500 feet above the top of the B zone. Water occurs both in this tar zone and in the beds between it and the top of the B zone, in most of the area outside of that in which the A zone is contoured. (See map, Pl. III.)

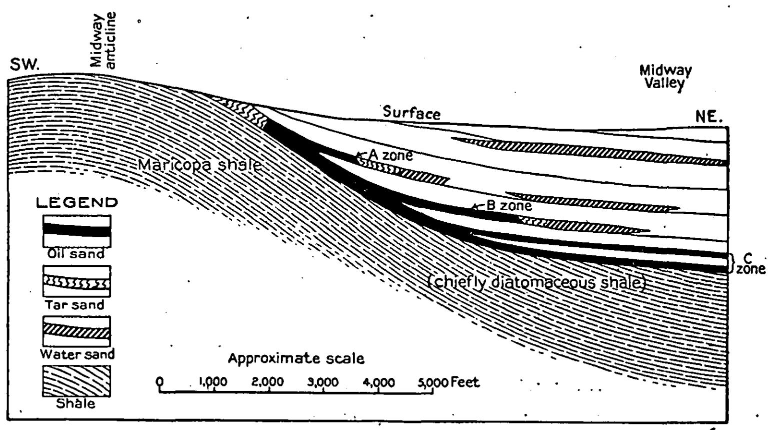


FIGURE 13.—Diagram showing relations of productive oil zones in the vicinity of Fellows.

Besides the tar sands in the A zone, tar sands are recorded up to levels within 600 or 800 feet of the surface. The uppermost tar sand recorded in this area lies somewhat deeper than the uppermost tar sand in the area between Fellows and the axis of the Twenty-six syncline, where the productive oil sands lie deeper than they do here. It seems strange that there should be this difference in the relative position of the oil and tar sands in the two areas, for one would expect the tar sand to bear a more or less constant relation to the oil sand and thus to lie deeper where the oil sand lies deeper beneath the surface.

BEDS BELOW THE C ZONE.

A considerable number of wells, both in this area and in sec. 8, just to the south, have been drilled deep and have entered the Maricopa shale. Most of the deep wells in sec. 8 and many of those in this area have encountered bottom water, but a few have found lenses containing considerable oil.

WATER SANDS.

The records of the wells indicate that the productive sands in this area are singularly free from water. The water is encountered in the A zone, in the northeastern part of the area, but that zone is not productive in this area, except possibly in the southwest corner, and the water sands in it are easily shut off by setting the casing somewhat less than 100 feet above the top of the B zone. In one well near the center of the west line of sec. 5 a water sand lies barely 100 feet above the top of the B zone, but in most of the other wells in the southwestern part of the area the lowest water sand lies somewhat higher.

Near the center of sec. 5, however, the upper part of the B zone contains water, or else a water sand rests immediately upon that zone. This water sand will prove and possibly has already proved troublesome, for many of the drillers of wells near this locality have disregarded the B zone and have drilled down for the C zone, setting their water strings far below the water sand just noted. The relation of edge water to the B zone here is probably the condition of chief importance at present, for until the position of this water is appreciated there is serious danger that by the incorrect handling of some well the upper part of the productive zone will be flooded.

What may be termed true bottom water—that is, water in a sand which immediately underlies the C zone—does not seem to be present here, but water is plentiful in the Maricopa shale not far below the C zone, as is shown by the deep wells in sec. 8 and the Stratton water wells.

About half a mile to the north the C zone is composed of a few oil sands separated by barren clays and water sands. (See description of that area, pp. 110–114, and geologic sections, Pls. XIX–XXI.) So far, however, no water sands have been encountered in the area under discussion, although it is probable that as oil is extracted water will work its way up the dip and may later appear here in the C zone. As the chief water sand in the area to the north, in sec. 32, T. 31 S., R. 23 E., lies near the top of the C zone, it is in this part of the zone that edge water will probably first appear in the area now under consideration as the oil becomes exhausted.

CHARACTER OF THE OIL.

The oil here ranges in gravity from about 18° to 26° Baumé. The average gravity of the oil obtained in wells which penetrate both the B and C zones and which are not near wells that make water, seems to be about 22° Baumé. Wells in which the casing is perforated for only a part of the C zone yield oil of about 26° Baumé. The wells that yield heavy oil are chiefly those in which water is troublesome. One well at first produced oil of 16° Baumé from the B zone but on being deepened to the C zone yielded oil of 22° Baumé.

PRODUCTION.

This area has been one of the best producing sections of the field, many wells having had an initial production of 1,000 to 3,000 barrels, coming in wild and being very difficult to handle. The gas pressure even now, after the area is so thoroughly drilled, is notably high. Many of the wells have had a daily production of over 1,000 barrels for periods of many weeks. The field is somewhat spotted, however, and some wells that yield only a small amount of oil are very close to those that have had large initial flows. The dividing line between the area on the northeast in which the B and C zones have yielded considerable oil, and the area on the southwest in which these sands are absent or contain no oil is fairly sharp and extends from the vicinity of Chanslor-Canfield Midway Oil well No. 20, southeastward to the vicinity of the center of the north line of sec. 8.

This area had its best day in 1911. The production in 1914 was relatively small, the average daily production for the wells being very much less than 100 barrels, and several of the companies were putting the wells on jacks. It is probable that new wells drilled not too close to the wells already producing will show a fairly high gas pressure, but big gushing wells are not to be expected. The initial pressure will probably fall off very rapidly in future wells, and their daily production will probably settle down to less than 100 barrels within a year.

SUGGESTIONS FOR FUTURE WORK.

In the area southwest of the dividing line mentioned under the preceding heading the wells will derive whatever oil they may obtain from the A zone or from lenses in the Maricopa shale. This zone will probably yield a very small production, indeed, and the wells will be similar in character to those in sec. 8. The oil will be heavy. The area lying northeast of this line may be further divided by a line drawn from northwest to southeast through the center of sec. 5. Southwest of this line and northeast of the line first described both the B and C zones are productive and water is not troublesome. Northeast of this line the upper part of the B zone contains edge water, and great care should be exercised in setting the water string below this zone and yet not so far below it as to permit water to enter the productive sands that lie in the lower part of the B zone.

Enough deep wells have been drilled here to show that the Maricopa shale does not contain many oil sands, although some wells have produced commercial amounts of oil from lenses in it.

Water may prove troublesome in the northeastern part of the area in the basal part of the C zone or just below it, for such water has been found in some of the wells drilled in sec. 4, just to the east, but how far to the west these water sands continue can not be determined in any other way than by drilling.

CALIFORNIA COUNTIES-CONTINENTAL AREA.

[Southwest corner of sec. 2; southern part of sec. 3; southern part of sec. 4; southeast corner of sec. 5; NE. ¼ sec. 9; sec. 10; all of sec. 11 except northeast corner; southwest corner of sec. 12; W. ½ sec. 13; all of sec. 14 except southwest corner; northeastern part of sec. 15; northeast corner of sec. 23; northern part of NW. ¼ sec. 24, T. 32 S., R. 23 E.]

LOCATION AND OPERATORS.

The California Counties-Continental area extends from Taft northwestward to the vicinity of the California Counties camp, in the center of sec. 4, and embraces a strip about 1½ miles wide lying just west of the center of Midway Valley. The companies operating here in 1916 were the Kern Trading & Oil, Standard (Continental, Equitable, sec. 10, sec. 12), California Counties, Chanslor-Canfield Midway Oil, Union (Equitable, Alvarado, Regal, Bedrock), Empire Fuel & Gas, National Pacific, Kanawha, S. K. D., Marion, Brad, North American Consolidated (sec. 2, Oskaloosa), Visalia Nonassessable, and General Petroleum (Continental).

GEOLOGY.

The structure of the area is simple, for no minor folds break the regularity of the west limb of the Midway Valley syncline, upon which this area lies. The beds strike northwest throughout the area and dip to the northeast at a low angle, being tilted not more than 10° or 12° in the extreme southwestern part of the area and rarely over 3° or 4° in a belt at least half a mile wide lying just west of the axis of the syncline.

The angular unconformity between the Maricopa shale and the Etchegoin formation is considerable here, as is shown by the abrupt way in which first the C zone and later the B zone wedge out westward from the axis of the Midway Valley syncline.

OIL SANDS.

The productive sands lie entirely in the Etchegoin formation, the Paso Robles containing tar but no productive oil sands. No well in this area that has penetrated the Maricopa shale has obtained commercial amounts of oil from it. In the northwest corner of sec. 13 and the southwest corner of sec. 12 the chief oil sands lie considerably above the base of the Etchegoin, for in deep wells here Etchegoin fossils have been found in beds 400 feet or so below the chief oil sands.

The beds of the B zone are relatively fine grained throughout this area, and in consequence wells relying upon sands in this zone are small producers, for the oil has tended to accumulate in the coarser beds below. This area forms the northeast end of the belt that stretches along the east flank of Twenty-five Hill in which the B zone is made up of fine-grained material and in which very few wells have been commercially successful.

The productive sands in this area lie chiefly in the C zone, although the overlying B zone contains a little oil in the southwestern part. The northeastern limit of the area in which the B zone contains oil is very irregular. It appears to be oil bearing in the southwestern part of sec. 10 and in the NE. ¼ sec. 14, two areas which lie not more than three-quarters of a mile from the axis of the Midway Valley syncline. On the other hand, in sec. 4, which lies about an equal distance west of the axis of the syncline, the B zone is barren of oil, except perhaps in the SW. ¼. A line from a point a little south of the northwest corner of sec. 10 through the center of the section and thence to a point a few hundred feet south of the center of the east line of sec. 14 marks roughly the eastern limit of the area in which the B zone contains much oil.

Near the center of the south line of sec. 10 the total thickness of the productive zone from the top of the B zone to the base of the C zone is about 500 feet. Approximately an equal thickness of oil sands has been penetrated in the NE. ¼ sec. 14, but here the drill has probably not yet gone through the full thickness of the C zone.

The northeastern part of the area is still too sparsely drilled to permit any very definite statements as to the character of the oil sands there, except that all the productive sands lie below the top of the C zone. It is probable that the conditions here approximate in a general way those in sec. 32, T. 31 S., R. 23 E., and that oil occurs in thin sands scattered through the beds between the top of the C zone and the base of the Etchegoin formation, and water sands occur between the several oil sands. There is, however, no reason to believe that the oil sands will yield oil in amount comparable with that obtained in sec. 32, for the wells so far drilled have shown that the oil in these sands is not under nearly so heavy pressure as it was in sec. 32 when the sand there was first tapped.

WATER SANDS.

Top and edge water.—Various water sands are recorded above the B zone, but the records are so imperfect that no general conclusion can be reached regarding them.[1] In the southwestern part of the area they may all be cased off by setting the water string a short distance above the B zone. The chief trouble from top water is that which is caused by the water sands that form the edge water for the B zone. These sands contain water near the center of sec. 10 and in the NE. ¼ sec. 14. Here, as in other parts of the field where the B zone commences to contain water or tar sands, the casing in some wells is perforated for it, and other wells go down to the underlying C zone, all the sands in the B zone being cased off with the water sands. Unless uniformity in setting the water string is established, water trouble is bound to occur here, if it already has not done so.

In the S. ½ sec. 4 the B zone contains water, and there seem to be no stray oil sands between the thin sand near the top of the B zone and the C zone; therefore the custom of setting the water string pretty close to the C zone is followed.

Near the center of sec. 10 water is reported between 50 and 150 feet below the top of the B zone, but the reports are so variable that no more exact estimate of the position of this water sand can be given. In one well the water sand has been mistaken for true bottom water, and the lower part of the well was plugged and the upper part of the B zone developed. In neighboring wells, however, both the water sand and the upper oil sand in the B zone, from which this well produces, are shut off, and oil is obtained from the C zone.

Bottom water.—Bottom water is encountered by relatively few wells in the part of this area where the sands lie deeper, and it here appears to lie at least 200 or 250 feet below the top of the C zone.[2]

Along the southwestern edge of the area a water sand lies about 400 feet below the top of the B zone. From that locality westward this water sand approaches closer and closer to the top of the B zone, and near the southwest corner of sec. 15 water occupies practically the top of that zone. As is explained in the description of the SW. ¼ sec. 15 (p. 126), this water sand is believed to mark approximately the plane of unconformity between the Maricopa shale and the overlying Etchegoin formation, and the reason that it appears to lie at a higher horizon toward the west is that the Etchegoin, in which the B zone lies, wedges out in this direction.

CHARACTER OF THE OIL.

There is a distinct difference in the gravity of the oil found in the different sands in sec. 10, and probably a difference in the gravity in the same sand in different parts of the area. This area is about the easternmost in which the B zone contains oil, and as some of the

[1] See analysis 33, Table 20, and analysis 59, Table 24, Part II (Prof. Paper 117).

[2] See analysis 48, Table 22, Part II (Prof. Paper 117).

wells produce only from it and others only from the C zone, a fairly definite comparison of the oil contained in the two zones may be made.

In the wells in the central part of sec. 9 the casing is perforated for both the B zone and the top of the C zone, and the gravity of the oil obtained ranges from 20° to 23° Baumé, except in one well, which is probably troubled by water and from which heavier oil is obtained.

Near the center of the south line of sec. 10 the top of the B zone does not seem to be very productive and most of the wells derive their oil either from stray sands that lie in the lower part of the B zone or from the C zone. Many of them have been drilled to a very deep part of the C zone, in which the oil is heavy. In general in sec. 10 the gravity of the normal oil from the C zone is about 24° to 27° Baumé. The average oil from the B zone runs 20° to 22° Baumé, but closer to the hills, in sec. 15, the B zone seems to yield oil of 14° to 16° or 17° Baumé. In the lower part of the C zone near the south edge of sec. 10 the gravity of the oil is 15° to 17° Baumé. This sand is underlain by a sand containing water, to the presence of which the heavy gravity is probably due. This heavy oil has not been reported in the center of sec. 10. It may underlie the sand yielding 26° oil there, or it may be that the sand containing tar in the south edge of sec. 10 contains water in the center of that section.

In sec. 14 the difference between the oils in the different sands is not so well marked as it is in sec. 10. Many of the wells have casings perforated practically throughout the B and C zones and yield an oil that ranges in gravity from about 21.5° to 25° Baumé. However, in the southwestern part of this area the B zone yields oil of 22.5° Baumé.

In the extreme north end of the area the C zone yields oil ranging from 26° to over 28° Baumé.

PRODUCTION.

This area is somewhat spotted, and wells located fairly close together in which the casing is perforated for the same sand yield very different quantities of oil.

The bulk of the oil comes from the C zone; the B zone yields oil in the southwestern part of the area, but wells depending upon sands in this zone are usually small producers.

A few wells have had initial productions of 500 barrels or more, and in 1914 12 wells had a daily production of 100 barrels or more. The average production in 1914 was about 75 barrels daily. The decrease in production here does not seem to be very great for the deep wells that produce from the C zone, but it is rather high for those in the B zone.

SUGGESTIONS FOR FUTURE WORK.

The area may be divided by lines running from northwest to southeast into three belts in which the conditions are fairly constant.

Along the southwest edge, in a belt about one-third of a mile wide in sec. 15 and slightly narrower in the northern part of sec. 9, the sands from which oil must be expected are included within the B zone. This zone is usually composed of fine-grained sands, and wells deriving their oil from it will probably have small yields.

The central belt is about half a mile wide. Its northeastern edge lies along a line drawn southeastward from the vicinity of the southeast corner of the California Counties property, passing a little north of the center of sec. 10 and thence to a point a little north of the center of the east line of sec. 14. In this zone the chief production is obtained from the C zone. The B zone, however, yields oil, and some of the wells rely entirely upon it for their oil, but in the northeast edge of the belt the B zone contains water. This, the "transition belt," is the critical one for this area, for if the water is not properly handled here it will flood the productive sand to the west. Even though the sands in the upper part of the B zone are not productive they should be protected from the water sands lying above and below them, for they are the chief productive oil sands in the western part of the area.

The third belt lies northeast of the one just described and extends to the axis of the Midway Valley syncline. In this belt the C zone yields the oil, the B zone being dry or containing water. The C zone here appears to contain a number of oil sands, which are probably separated by water sands, the whole zone being comparable with the productive zone in sec. 32, T. 31 N., R. 23 E. The upper part of the C zone appears to contain most of the oil, and it is safe to case off all sands above it. It is probable that near the axis of the Midway Valley syncline the whole C zone is barren of oil or filled with water.

Although the deep wells close to the axis of the Midway Valley syncline have tested the lower part of the C zone fairly well and have shown that the oil sands here are very lean, that part of the zone has not been tested so thoroughly half a mile or so to the west, and here prospecting for sands that lie between 250 and 400 feet below the top of the C zone offers some promise of reward.

STRATTON WATER-LOCKWOOD AREA.

[Northeastern part of sec. 7; sec. 8; SW. ½ sec. 9; NW. ½ sec. 16; northeastern part of sec. 17, T. 32 S., R. 23 E.]

LOCATION AND OPERATORS.

The Stratton Water-Lockwood area includes the south end of the Fellows field and extends from the old Chanslor-Canfield Midway Oil camp in sec. 8 southeastward to the North American camp in sec. 16. The companies operating here in 1916 were the Stratton Water, Chanslor-Canfield Midway Oil, Hale McLeod, Traffic, Midland, and North American Oil Consolidated.

GEOLOGY.

The area lies in the outer foothills of the main Temblor Range, on the east ends of the Midway anticline and the Midoil syncline. These folds are in the outer edge of the foothills and west of Fellows trend parallel to the north end of Midway Valley for a distance of about 4 miles, but in the area here discussed they swing slightly toward the east and plunge fairly abruptly beneath the valley, both dying out so far as their effect upon the surface rocks is concerned. To the south the marginal structural features similar to these folds are the Spellacy Hill anticline and the syncline lying just southwest of it. The relation of the Midway anticline to the Spellacy Hill anticline is not quite clear, for there is considerable faulting and fracturing of the rocks in the southwest corner of sec. 16. The faulting is probably rather minor, however, and the two folds may overlap in the manner characteristic of these small folds throughout the general region.

At the surface the beds dip at a rather low angle even near the axis of the Midway anticline, rarely being tilted over 10° anywhere in the NW. ¼ sec. 8. A second very small anticline probably lies just north of the Midway anticline, crossing the SW. ¼ sec. 6 and trending parallel to the Midway anticline. This fold is not shown in the outcropping beds, but it is indicated by a small topographic rise near the Chanslor-Canfield Midway Oil Co.'s well No. 3 in the SE. ¼ sec. 6, and by the flattening of the dip of the oil zones both along the east line of sec. 6 and along the north line of sec. 8. In the southern corner of the area, at the northwest end of the Spellacy Hill anticline, the beds are steeply tilted, standing in places at an angle of 40°. The dip flattens rather abruptly, however, and near the center of the west line of sec. 16 is not over 15°. Neither the Midway anticline nor the Midoil syncline is very deep, for, although the anticline affects the surface rocks as far southeastward as the center of sec. 8, the oil sands do not make a complete fold, but the anticline and syncline together have resulted only in the bending of the rocks from a northwesterly to practically a northerly strike in the northwestern part of sec. 16 and the northeastern part of sec. 17. This effect is recognized in the oil sands as far eastward as the center of sec. 15, being shown by a broad bending, convex to the southwest, of the underground contours. (See Pl. III.) It should be noted here that the Midoil syncline is not so deep as the Twenty-six syncline, which lies northeast of the Midway anticline, and in consequence the Midway anticline is more closely allied to the Spellacy Hill anticline than to the Globe anticline. Although the oil sands in the Midoil syncline contain some water they do not seem to carry nearly as much as the sands in the Twenty-six syncline.

The angular unconformity between the Maricopa shale and the McKittrick group appears to be considerable here and to be especially marked along the axial part of the Midway anticline. The lower sands—that is, those of the B and C zones—wedge out rather sharply on the northeast flank of the anticline, and over a very considerable area the only productive sands are those contained in the A zone.

OIL SANDS.

Position.—The chief productive sands in this area lie in the basal part of the McKittrick group, and in much of the area, especially along the axial part of the Midway anticline, they seem to lie practically at the base of the McKittrick. The B and C zones are certainly in the Etchegoin formation and the basal part of the A zone is also in that formation, for fossils have been found in this uppermost zone in one well. The upper part of the A zone may, however, be in the Paso Robles formation. A small production of fairly light oil—20° Baumé—is also reported from beds that are clearly in the Maricopa shale.

Divisions.—The oil sands in the McKittrick group may be grouped into two main divisions. The upper division, which corresponds to the A zone, has yielded oil in the central and northwestern parts of sec. 8, the northeastern part of sec. 17, the southeast corner of sec. 9, and the western part of sec. 16; the lower division, which is the equivalent of the B and C zones, has yielded oil in the northeast corner of sec. 8, the central part of sec. 9, and probably the northeast corner of sec. 16. The oil occurs here about as irregularly as in any other part of the field, its distribution being especially irregular in the axial part of the Midway anticline. This irregular distribution is probably due in part to the irregular surface of the Maricopa shale and consequently an irregular distribution of the sandy beds that serve as reservoirs for the oil but also to the fact that this formation appears to contain considerable water.

Sandy lenses in the Maricopa shale have yielded oil in the several wells near the axial part of the Midway anticline, but these lenses are irregular, and as many of them contain water rather than oil, they do not promise to be a source of much oil. Deep wells at a distance from the axial part of the anticline have not found oil in commercial amount in such lenses.

A zone.—In the northwestern part of the area, along the axial part of the Midway anticline in sec. 8, the A zone varies in thickness and reaches a maximum of about 100 feet, but in much of the area the thickness reported in the wells is considerably less than 50 feet. The productive zone is overlain by a zone about 300 feet thick composed of oil sands, tar sands, and water sands interstratified with barren clay. In one or two of the wells the beds lying in this upper zone have yielded some oil, but most of the oil has come from the thinner underlying zone mapped as the A zone.

In the southeastern part of sec. 8 the A zone has an average thickness of approximately 200 feet and a maximum of a little over 250 feet, and of this about 50 per cent is usually recorded as barren. Here the A zone is overlain by a zone of tarry sands whose average thickness is about the same as that of the A zone but which has a maximum recorded thickness of about 400 feet. In places the beds in this zone are recorded as oil sands but have yielded no oil and are probably heavy tar sands. They are comparable with the mixed oil, tar, and water sands overlying the A zone in the NW. ¼ sec. 8.

In sec. 17 and the northwestern part of sec. 16 the A zone has a thickness of about 250 to 350 feet, in places as much as 400 feet. Of this 40 to 80 per cent is barren of oil. The A zone here is overlain by no thick tar zone comparable with that in the SE. ¼ sec. 8, but irregular and thin tar sands are recorded up nearly to the surface. The difference between the tar sands here and those in sec. 8 is pronounced. In the eastern part of this area the A zone appears to be thinner than in the western part and to be overlain by a somewhat thicker tar zone; also the water sands appear in the tar zone here in much the same manner as in the NW. ¼ sec. 8.

The A zone probably contains oil as far east as the center of the SW. ¼ sec. 5. A few of the older wells have reported oil in it, although those drilled more recently have gone through the A zone for the richer sands in the underlying B and C zones. In the extreme south end of this area, near the center of the west line of sec. 16, the A zone is irregular in thickness and apparently contains a considerable amount of tar sand. Its irregularity in content and thickness is probably due to the faulting.

B and C zones.—Although the B and C zones are contoured separately in the northeastern part of the area (see Pl. III), they really form a fairly continuous zone, the different contours being shown only in order that the relation between the sands in this area and the deep sands in the area to the northeast may be brought out more clearly. The top of the B zone lies about 400 feet below the top of the A zone, but the distance varies somewhat, the two zones being closer in the southwestern part of the area than in the northeastern part. The maximum total thickness of the combined B and C zones is perhaps 400 feet. The logs of some of the wells report a continuous succession of beds containing oil and gas, but most of them record separate thin oil sands, 10 or 20 feet thick, with a few 50 feet thick, interstratified with barren shale. The beds reported to be oil bearing usually form less than 40 per cent of the whole zone. For the most part the upper beds in this zone—that is, those which would be correlated with the B zone—do not appear to contain much oil, and several of the wells, especially those in the eastern part of the area, have been drilled through them without finding oil. This area lies at the north end of the belt that extends northwestward from Spellacy Hill through the outer foothills, in which the B zone contains very little oil or is barren. This barrenness is believed to be due largely to the fine grain of the beds that compose the B zone in this part of the field. The combined B and C zones are wedged out rather sharply by the unconformity, and it is probable that they do not underlie much of the territory lying west of the area where they are contoured on the map (Pl. III).

Oil sands in the Maricopa shale.—A considerable number of wells have been drilled below the productive sands in the McKittrick group. According to reports, some of them have found oil in the underlying Maricopa shale, and a few have made a definite production from these sands. It is not possible to recognize any regularity in the distribution of these sands, and it seems certain that they are lenticular masses in the Maricopa shale which have no very great areal extent. The lenses that have so far yielded commercial amounts of oil are located along the axial part of the Midway anticline.

Grain.—The productive sands range in character from coarse gravelly sand in which the fragments are as much as a quarter of an inch in diameter and possibly even some larger down to fine clays. In places the sands are composed chiefly of shale pebbles embedded in a mass of clay, but wells encountering "sand" of this type yield a very small production and many of them have been abandoned. Some of the sands in the Maricopa shale are remarkably even grained granitic sands composed of fragments 1 or 2 millimeters in diameter.

WATER SANDS.

Top water.—Top water is rather troublesome in the northern part of the area, in the N. ½ sec. 8, being especially so in the wells that depend on the A zone for their production. As has been described in the discussion of the A zone, the productive sand here is overlain by a zone of oil, tar, and water sands 300 feet thick. The water encountered is distinctly a sulphur water and in at least one well has yielded a considerable flow.[1] These water sands are reported to occur within 50 or 80 feet of the top of the A zone. A somewhat similar condition prevails near the center of the west line of sec. 16, although the water sands there do not seem to be so abundant nor so troublesome as in the N. ½ sec. 8. They are reported, however, to occur as low as 50 feet above the top of the A zone.

Edge water.—The A zone contains edge water in the outer part of the area in which it is contoured on Plate III, edge water appearing not only in the uppermost part but also practically in the central part of the zone. In a belt that extends through the N. ½ sec. 16, the southwestern part of sec. 9, and the N. ½ sec. 8 edge water will probably prove troublesome in the A zone. East of this belt the edge water in the A zone may be considered as top water for the B and C zones. There, however, water sands occur very low in the A zone, and water should be shut off a short distance above the top of the B zone. Nowhere in this area does the B zone appear to contain water.

Bottom water.—In the western part of the area—that is, in the area where the A zone furnishes the oil—many wells have encountered bottom water below the productive zone, at various horizons in the Maricopa shale.[2]

CHARACTER OF THE OIL.

The A zone yields oil that ranges in gravity from about 12.2° to 17.9° Baumé and averages between 13° and 14°. The B and C zones yield oil that ranges from 18.5° to 23° and averages a little lighter than 21°. One well, in sec. 8, gives 18° oil from the deeper zones, but it is close to a deep well that got bottom water.

PRODUCTION.

No well in this area ever had a very large daily production, and although some wells at first yielded 200 to 400 barrels daily, most of them have yielded less than 100 barrels. The average production in 1914 was between 15 and 20 barrels per well per day. Although the oil sands are relatively close to the surface near the northeast corner of sec. 17, the wells there have produced about as much oil as any of the

[1] See analysis 35, Table 20, Part II (Prof. Paper 117).
[2] See analyses, Table 24, Part II (Prof. Paper 117).

wells elsewhere within the area, and this decrease in production is rather less than that of the wells which draw their oil from the sand where it is more deeply buried.

SUGGESTIONS FOR FUTURE WORK.

In the area in which only the A zone is contoured on Plate III small wells will prove the rule from now on, for the gas pressure, which caused some of the wells to give a considerable production originally, has now been greatly reduced, and it is to be expected that the production of the new wells will be approximately the same as the present production of the old wells. Deep drilling in this part of the field, except possibly along the axial part of the Midway anticline, will probably not prove profitable, for although the Maricopa shale evidently contains some lenses saturated with oil, these lenses are so irregularly distributed that prospecting for them will be very costly and the percentage of failure large. Moreover, these lenses do not seem to contain very much oil, certainly not in amount at all comparable with that in the McKittrick group.

Top water is troublesome in this area, being especially so in the northern part of sec. 8, and should be shut off by setting the casing only a short distance above the top of the A zone. Along the outer margin of the area where the A zone is contoured edge water appears in that zone.

In the area which lies east of a line drawn from a point near the center of the north line of sec. 8 to one a little south of the southwest corner of the Traffic property and thence southeastward to a point somewhere between North American wells Nos. 67 and 71 in sec. 16 sands in the B and C zones yield the oil produced, and the A zone either is dry, is filled with water, or contains tarry oil or asphalt. In order to protect the B and C zones from the water in the A zone the water string should be set only a short distance above the top of the B zone.

The B and C zones have been drilled completely through in only a single well. This well shows that the combined zones are probably not much more than 350 feet thick and that below them the Maricopa shale is of about the same character as it is near the Midway anticline. It is therefore probable that wells drilled deeper than 350 feet below the top of the B zone will not yield much oil in the eastern part of the area. Bottom water does not seem to underlie the C zone very closely, however, although it was encountered in the Maricopa shale in the deep well just mentioned.

LOCKWOOD-TALARA AREA.

[Southwest corner of sec. 14; SW. ¼, NW. ¼, and all of S. ½ except the northeast corner sec. 15; SE. ¼ sec. 16; NE. ¼ sec. 21; all of sec. 22; all but northeast corner of sec. 23; SW. ¼ and S. ½ NW. ¼ sec. 24; and northeast edge of sec. 27, T. 32 S., R. 23 E.]

LOCATION AND OPERATORS.

The Lockwood-Talara area occupies a belt about 1½ miles wide on the outer edge of the foothills of the main Temblor Range southwest of Taft and embraces the north end of the Twenty-five Hill field. It is bounded on the southwest by the topographic depression that lies on the southwest side of Spellacy Hill (Twenty-five Hill) and on the northeast by the edge of Midway Valley. The companies operating or holding land here in 1916 were the Visalia Nonassessable, North American (Oskaloosa, sec. 16, and Lockwood), Marion, General Petroleum (Foxtail, Sybyl, and B. A. T.), Brad, Oleum, Jade, Chanslor-Canfield Midway Oil, Union (Alvarado), Fairbanks, Burk, Combination Midway, Wilbert, Buena Fe (Amador Usona, Alpine, Amador West 40, Amazon, and Mountain Girl), Indian & Colonial, Producers Guaranteed, Griffith, Knob Hill, Babcock, Palmer Union, Traders, Cheney Stimson, and Jamison (Talara).

GEOLOGY.

The general geologic features in this region are identical with those in secs. 25 and 26, just to the southeast, and the productive zone in the two areas is practically the same. The two areas differ, however, in that in the northern one, here under discussion, the productive sands in the McKittrick group are virtually restricted to the northeastern flank of the Spellacy Hill anticline, whereas in the southern area the McKittrick sands are productive both on the northeast and on the southwest flank of that fold. On this account the two areas are described separately.

The dominant structural feature here is the Spellacy Hill anticline, which trends in a southeastward direction through the central part of the area. Southwest of the axis of this fold is the shallow and irregular syncline that determines the topographic depression in the northeastern part of sec. 27, the southwestern part of sec. 22, and the northeastern part of sec. 21, on the southwest side of Spellacy Hill. Farther southwest, beyond the axis of this trough, rises the higher part of the Temblor Range, in which are exposed the older Tertiary formations that lie below the beds that have yielded oil in the Midway field. The Spellacy Hill anticline is a well-marked fold that extends from the southwest corner of sec. 16, T. 32 S., R. 23 E., to the western part of sec. 30, T. 32 S., R. 24 E. Near the northwest end the fold is broken by a considerable number of minor faults, and its relation to the Midway anticline, which lies to the north, is not clearly shown. It is probable, however, that the two folds overlap in a manner similar to that shown by the small folds in this general region, although possibly the Spellacy Hill anticline is really joined to the Midway anticline by an arch that trends north through the eastern part of sec. 17 and the western part of sec. 16. The faults that affect the beds near the southwest corner of sec. 16 are probably not deep nor of great throw, but they have so broken the beds that the oil occurs in an irregular zone.

The Spellacy Hill anticline is slightly asymmetric. The southwest flank is short, for in most places the axis of the adjoining syncline lies only about a quarter of a mile from the axis of the anticline, and the dips here decrease abruptly from a maximum of about 25° near the axis of the anticline. The northeast flank is longer and the dips on that side decrease less abruptly. Near the axis of the anticline the beds are tilted to angles of 25° or 30°, but at the edge of the hills, about three-quarters of a mile northeast of the axis, the dip is about 15°. Farther northeast the beds are not exposed, but the attitude of the oil sands, as inferred from the well records, shows that the dip decreases rather abruptly here, the beds assuming the very low dip characteristic of them beneath other parts of the valley. In the foothills the attitude of the beds near the surface is not exactly like that of the underlying oil sands, for in general the oil sands here, as in other parts of the area along the foothills of the main range, appear to be less steeply tilted than the surface rocks.

The syncline southwest of the Spellacy anticline is not regular but is broken into two parts by a small anticlinal fold near the northeast corner of sec. 27. This interruption is minor, however, and the two parts may really be considered a single trough.

The surface rocks here all belong to the McKittrick group, except in the center of sec. 22 and in an irregular strip along the southwestern edge of the area, in which the soft diatomaceous shale of the underlying Maricopa shale is exposed. It is difficult to determine whether the lower part of the McKittrick, which crops out here, is Etchegoin or Paso Robles. The Paso Robles formation certainly crops out near the center of the north line of sec. 22, for fresh-water fossils were collected there, but between that point and the outcrop of the diatomaceous shale of the Maricopa nothing was found in the arkosic sands, gravel, and clay which crop out along the creek that would aid in determining the formation to which they belong.

Except at the northwest end of the Spellacy anticline, near the southwest corner of sec. 16, the area seems to be free from faults. The irregularity in the distribution of the oil sands in parts of this area has been thought by many persons to be due to faulting, but this irregularity is really caused chiefly by the lenticular bedding and by the fact that the oil sands that are productive along the axial part of the Spellacy Hill anticline are not productive for more than a very short distance down the north flank of the fold, for on this flank a sand wedges in below the sand that is productive along the Spellacy Hill anticline and above the top of the Maricopa shale, and it is this sand that furnishes the oil.

OIL SANDS.

The productive sands in this area are those embraced in the A and B zones, the deep C zone not being present.

The A zone is by far the more important, for from it comes the oil that is obtained in the area that extends along the axial part of the Spellacy Hill anticline and for a distance of about half a mile down the northeast flank of that fold.

The B zone furnishes the oil produced in the southwestern part of sec. 15, the northeastern part of sec. 22, the northeastern part of sec. 23, and the southwestern part of sec. 24. In these areas the A zone is productive in places, but the main yield comes from the lower sands. On the map the B zone is contoured well into the central part of sec. 22, but in this section it really forms with the overlying A zone a thick succession of oil sands and barren strata that are not readily divisible into definite parts.

A zone.—In the extreme northern part of this area (sec. 16) the A zone averages about 200 to 250 feet in thickness, and in most of the well logs fully half of this thickness is recorded as oil sand.

In sec. 21 the productive zone has a maximum thickness of almost 700 feet, of which usually half or more is recorded as oil sand. The upper 200 to 250 feet is probably in the McKittrick group; the lower part is almost certainly in the Maricopa shale.

In the northwestern part of sec. 22 the productive zone seems to be less than 300 feet thick, and usually at this depth below the top of the A zone water is encountered. Many of the wells penetrate only 150 to 200 feet of strata in this zone. In the central part of sec. 22 the water that is encountered near the NW. ¼ sec. 22 is not recorded, and a few of the wells here have been drilled as much as 500 feet below the top of the A zone without encountering water. The logs of these wells record oil sands through a thickness of 300 to 350 feet, and many of them record at least 70 per cent of this thickness as oil sand.

In the NE. ¼ sec. 22 the maximum thickness of the productive zone is about 300 feet. The productive zone here commences to show a considerably greater amount of interstratified barren clay than is shown nearer the axis of the Spellacy Hill anticline. In the southwest corner of the section the same condition prevails as in the NW. ¼, but farther east edge water appears in the A zone.

In the SE. ¼ sec. 22 the productive zone is somewhat thicker than it is in the NE. ¼, probably because the lower measures lie in the Maricopa shale and not because the McKittrick group is thicker here.

In the southeast corner of sec. 23 the conditions are much the same as in the SE. ¼ sec. 22. The A zone here has a maximum thickness of about 400 feet. The upper 100 to 150 feet near the axis of the anticline in the extreme southwest corner is in places called tar sand. The productive zone is progressively thinner northward, and near the north line of the quarter section it contains only about 150 feet of beds. This thinning is probably a thinning at the top and not at the bottom—that is, the top of the zone containing oil does not mark a stratigraphic plane but a plane that toward the north cuts lower and lower into the stratigraphic section.

B zone.—In the northeastern part of sec. 23 and the southwest corner of sec. 24 the productive zone splits up into distinct oil sands which are separated from one another either by barren strata or by sands containing water. In the eastern edge of the area just outlined the total thickness of the productive zone is approximately 700 feet, of which the upper 300 feet forms the A zone and consists of alternating oil sands, water sands, tar sands, and barren strata. Below this comes the B zone, which has yielded the oil obtained here. The B zone is approximately 200 feet thick near the southwest corner of sec. 24 but reaches a maximum of about 400 feet near the center of the section. Only about 25 per cent of this thickness, however, is labeled oil sand in the drill records.

The B zone appears to be rather fine grained in most of the area and not to contain very much oil, and wells in the part of the area that is dependent upon this sand for its oil have not been large producers. The belt in which this condition prevails is about a mile in width and extends along the east flank of Spellacy Hill (Twenty-five Hill) from the vicinity of the north line of sec. 25, T. 32 S., R. 23 E., northward at least as far as sec. 9 of the same township.

Throughout the part of the area in which it is contoured on the map (Pl. III) the B zone is usually at least 250 feet thick.

Grain of the oil sand.—The sands contained in the zone are variable in grain; some of the beds contain cobbles and boulders several inches in diameter, but most of them consist of medium to fine grained sand.

The B zone is very fine grained in places, notably in the central and southeastern parts of sec. 23, where it is called "shale" in the drill records and the oil is said to be "shale oil."

The difference in character between the productive sands along this northeastern part of the area (the B zone) and the productive sands along the axial part of the anticline (the A zone) has been noted by the drillers and explained by them as due to a fault which trends northwest a little northeast of the crest of the hill. There appears to be no necessity for assuming the presence of such a fault, and there is no direct evidence of its existence.

WATER SANDS.

Top water.—True top water is not troublesome anywhere in this area. Along the axial part of the anticline the only top water reported is purely surface water occurring within a short distance of the surface.

Edge water.—The chief trouble with so-called top water is concerned with what is really edge water in the A zone. Water is encountered in this zone in the southern part of sec. 15 (below the true top water just noted), in the northern and southeastern parts of sec. 23, and the southwestern part of sec. 24. In secs. 23 and 24 the A zone is composed of thin oil sands which

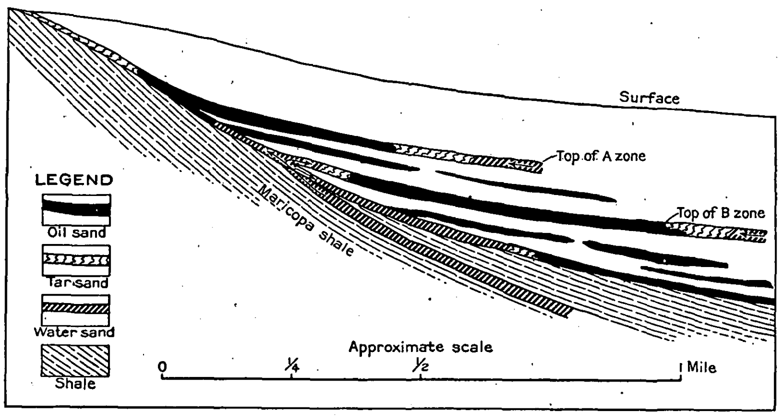


FIGURE 14.—Diagram showing possible explanation for occurrence of water in the B zone in the northwestern part of sec. 15, T. 32 S., R. 23 E. Arrows indicate direction of movement of edge water.

contain heavy oil and which in many well logs are recorded as tar sands, together with water sands and interstratified barren clays. The lowest water sand recorded here lies about 80 feet above the top of the B zone. There is hardly a well in this area that does not record water in the A zone. It seems very doubtful whether the A zone will prove or has proved productive much farther east than the line marked by the +400-foot contour on this sand. (See Pl. III.)

Bottom water.—A persistent water[1] sand underlies the productive oil sands in the central part of the area, in a belt marked roughly on the southwest by a line drawn between the center of the W. ½ NW. ¼ sec. 22 and the northeast corner of the Cheney-Stimson property and on the northeast by an approximately parallel line drawn through the center of the south line of the SW. ¼ sec. 15. Southwest of this belt water does not occur close below the productive sands, and wells have been drilled several hundred feet into the underlying shale without encountering water. The top of this "bottom-water sand," or zone containing water sands, lies between 250 and 400 feet beneath the top of the A zone, the thickness of strata separating them being dependent upon the position in the area. Thus, near the center of the north line of the NW. ¼ sec. 22 the top of the "bottom-water sand" and the top of the A zone are some 275 feet apart, whereas in the SE. ¼ sec. 22 they are between 330 and 400 feet apart. Near the southeast corner of sec. 16 the bottom water is hardly 250 feet below the top of the A zone and seems to occupy practically the position of the top of the B zone. The most reasonable explanation of this occurrence is that water from a sand in the Maricopa shale has worked its way out of the truncated beds of that formation along the plane of unconformity into the overlying oil-bearing beds of the McKittrick group. It is probable that wells a short distance northeast of this locality which rely upon the B zone for their production will be troubled by water in a rather peculiar manner—that is, edge water will work down the dip from the southwest as well as up the dip from the northeast. This condition of affairs is shown diagrammatically in figure 14.

In places this sand affords an extremely strong flow of water, and it is said that from one well more than 5,000 barrels of water a day was lifted without making any impression upon the water level. At present, however, a considerable number of the wells are raising oil and water with air lifts, and it is said that a very considerable lowering of water level is observable.

The belt beneath which bottom water occurs closely below the productive zone continues both northwestward and southeastward beyond the limits of the area here described, but the water sand is probably more troublesome here than in the neighboring areas. The approximate position of the top of the water-

[1] See analyses, Tables 24 and 25, Part II (Prof. Paper 117).

bearing zone is shown by the sketch contours on Plate XXXVIII.

BEDS ABOVE THE A ZONE.

In the northwest end of this area a tar zone, about 150 to 200 feet thick, rests immediately upon the A zone. In a few of the wells stray tar sands are recorded within a few feet of the surface, but on the whole the chief tar seems to extend less than 200 feet above the top of the A zone. This general condition prevails in secs. 16, 21, and 22. In the southeast end of the area, in the SE. ¼ sec. 23 and the southwest corner of sec. 24, the tar sands occur in thin streaks scattered through the beds for a distance of several hundred feet above the A zone. In this part of the area the A zone really takes the place of the tar zone resting upon the productive sand—that is, the B zone.

BEDS BELOW THE PRODUCTIVE ZONE.

Along the axial part of the Spellacy Hill anticline the deep wells entering the Maricopa shale have found that sandy lenses in the upper part of that formation contain oil, and also that the deeper sands usually contain water, but that water does not seem to lie close to the base of the A zone anywhere in this part of the Twenty-five Hill field. The Maricopa shale here seems to be composed chiefly of brownish shale, doubtless diatomaceous shale, with some beds of sand, a few beds of boulders or cobbles, and also some limestone shells. In the east end of the area the Maricopa shale is recorded as chiefly brown sand, with relatively little shale. This difference in the records may be due simply to the fact that they were made by different drillers, but it is so marked that probably the Maricopa shale here is really much more sandy. Moreover, the Maricopa shale in the east end of the area contains much more water than it does close to the axis of the Spellacy Hill anticline.

CHARACTER OF THE OIL.

A zone.—Oil in the A zone ranges in gravity from about 12° to 15° Baumé; the average of the oil produced in 1914 ran about 13.5°. The original oil, although somewhat lighter, was rarely lighter than 15° Baumé. The increase in the specific gravity (decrease in degrees Baumé) is doubtless due in part to the decrease in the quantity of gas in this area, but it is also due in part to the infiltration of bottom water.

B zone.—In the southeast end of the area the B zone yields oil between 17° and 20° Baumé, or possibly as light as 23° Baumé; the average is a little less than 20° Baumé. To the fine grain of the beds here is probably in a measure due the light gravity of the oil as contrasted with the heavier gravity in the A zone, but the greater thickness of the cover is also one cause.

In sec. 15 the B zone has yielded oil that ranges in gravity between 14° and 16.5° Baumé and averages 15°. This oil is somewhat heavier than that in the B zone in secs. 23 and 24, and it is possible that some of the wells may derive a part of their oil from the A zone and the product thus not be characteristic of the B zone. However, water sand underlies the B zone very closely here and the nearness of the water may account for the greater specific gravity.

PRODUCTION.

Along the axial part of the Spellacy Hill anticline the A zone originally contained oil under considerable pressure, and many of the wells first drilled had an initial production between 200 and 400 barrels daily, but the field is now so thickly drilled that in most of the wells the pressure is practically negligible and in 1914 the average daily production per well was between 30 and 40 barrels.

No well in this area produced from the C zone alone, although some of the wells in the very eastern edge may have obtained part of their oil from this deeper zone.

In the southeastern part of sec. 23 and the southwestern part of sec. 24 the wells were mainly small producers, although one or two have had an initial production of 200 or 300 barrels daily. These larger wells evidently produced from small lenses of sand inclosed in the sandy shale. Most of the wells here get their oil from fine sandy shale characteristic of the B zone, and, although small producers, they show a rather slow rate of decrease.

SUGGESTIONS FOR FUTURE WORK.

The area near the axis of the Spellacy Hill anticline is practically drilled up so far as oil sands in the McKittrick group are concerned. The wells farther southwest—that is, southwest of the wells now producing but still on the north flank of the Spellacy Hill anticline—will probably obtain very little if any oil in the A zone.

Wells drilled on the southwest side of the axis of the anticline will probably find that zone entirely dry of oil. New wells drilled in the central part of the area will doubtless have an initial production practically equal to the present yield of the wells now producing in the immediate neighborhood.

In the outer or northeastern edge of the area in which the A zone is contoured that zone contains water and probably will not yield much if any oil. The exact position of the southwestern limit of the area beneath which edge water occurs in this zone varies from place to place, but it is outlined roughly by a line drawn southeastward from a point near the center of the north line of sec. 22 to the center of the east line of that section and thence to a point a short distance east of the center of the south line of sec. 23.

The B zone, from which the production is to be expected in the northeastern part of the area, is rather fine grained and has so far proved very spotted. This zone does not appear to be underlain very closely by water sand except in the southwestern part of the area in which it is contoured. It seems as if the sands of this zone here are truncated or rather wedge out at the unconformity, and water which has probably come from sands in the Maricopa shale has worked its way into the top of the B zone. Thus there is here a peculiar condition of edge water working into that sand from the southwest, as well as the ordinary edge water which occupies the sand on the northeast. (See fig. 14.) This fact, together with the fact that the sands in the B zone are very fine grained, explains the presence of the barren belt that extends northwestward from the north end of Spellacy Hill, in sec. 24, to the vicinity of Midoil, in sec. 9. The fine grain of the beds and not the presence of water, however, is probably the chief factor determining the lack of oil in this belt.[1]

The sands encountered in the lower parts of the deep wells that have been drilled near the axial part of the Spellacy Hill anticline lie in the Maricopa shale. This formation, however, does not appear to contain any considerable quantity of oil except along the axis of the fold, and here only in its upper part. Deep drilling either here or elsewhere in this area for sands in this formation will probably not be found very profitable. Oil sands like those encountered by the deep wells of the J. M. S. and Californian Amalgamated companies are about the best that should be expected from the Maricopa shale here.

The chief water troubles of this area are those concerned with the water sand which underlies the A zone and into which so many wells in the axial part of the field have been drilled. The water from this sand has entered the overlying productive sand and has even flooded many of the wells that have not been drilled deep enough themselves to encounter bottom water. A comparison of the depth of the wells in this part of the field with the sketch contours, shown on Plate XXXVIII, indicating the approximate position of this bottom water in secs. 22 and 23, is instructive. Any well that has been drilled below the depth at which, as indicated on this map, bottom water is to be expected should be critically examined, for if the well did not encounter bottom water when it was drilled it is possible that water may make its appearance later.

Much of the northeastern part of this area has virtually been condemned on account of the dry holes scattered through it. It is practically certain, however, that a very considerable quantity of oil occurs here in the B zone, and that, although this sand is so fine grained that no large wells will be obtained here, with the increase in the price of oil this area will prove profitable ground for prospecting more thoroughly.

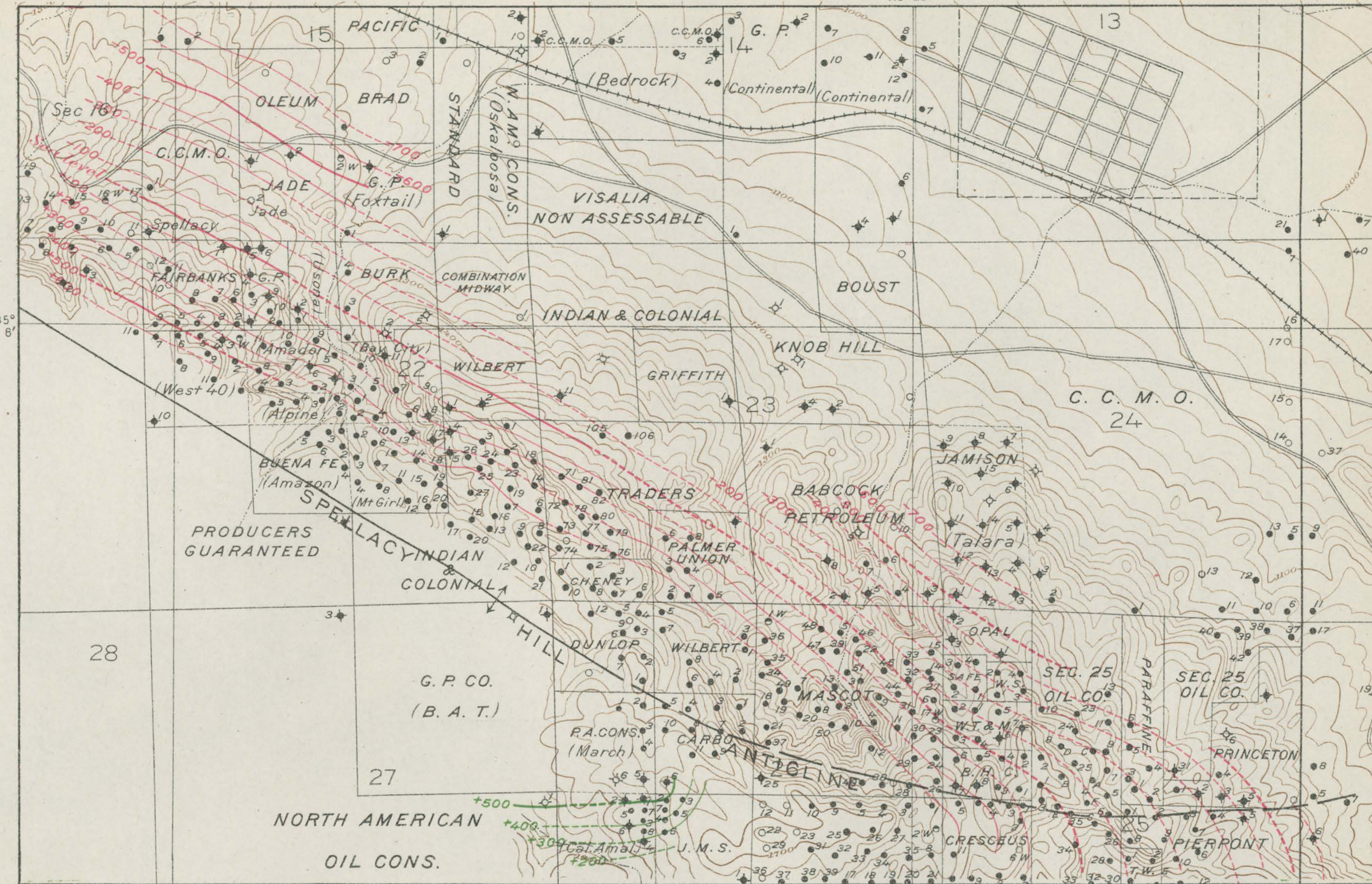
DUNLOP-SECTION TWENTY-FIVE AREA.

[All of sec. 25 except the northeast corner; sec. 26; NE. ¼ sec. 27; N. ½ sec. 35; N. ½ sec. 36, T. 32 S., R. 23 E.]

LOCATION AND OPERATORS.

The Dunlop-Section Twenty-five area includes the southern part of the Twenty-five Hill field, embracing the crest, the south flank, and a strip on the southwest side of Spellacy (Twenty-five) Hill. (See Pl. XXXIX.) It was one of the first parts of the Midway field to be prospected and is now more thickly drilled than any other part of the field. The companies operating here in 1916 were the Opal, Safe, West Side, W. T. & M., B. H. C., Cresceus,

[1] By fineness of grain is meant not the real size of the grain but the relative size compared with the grain of the adjacent beds. As a matter of fact these barren beds along the flank of the Spellacy anticline are no finer than the rich oil sands in the Buena Vista Hills. There is this difference, however, that the oil sands in the Buena Vista Hills are surrounded by beds of still finer grain, whereas the fine-grained beds that compose the B zone along the flank of the Spellacy anticline are adjacent to beds of much coarser grain in which the oil has, quite naturally, collected.



MAP OF NORTH END OF TWENTYFIVE HILL, SHOWING BY SKETCH STRUCTURE CONTOURS THE UPPER SURFACE OF THE BOTTOM WATER SAND AND OF THE J. M. S. SAND, T. 32 S., R. 23 E., CALIFORNIA

Scale $\frac{1}{24,000}$

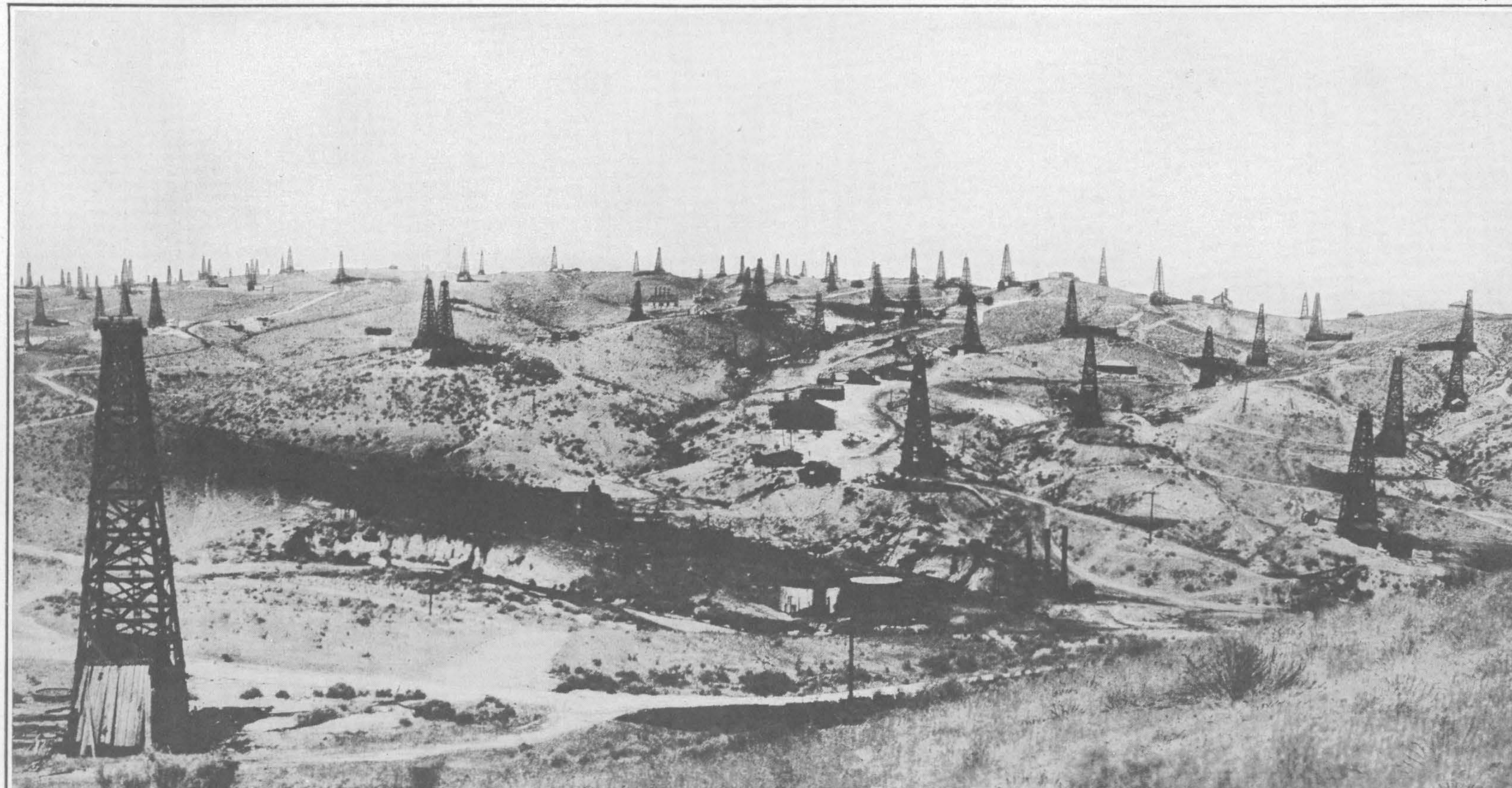
0 — ½ — 1 Mile

Wells are those shown on Plate III

Bottom water sand

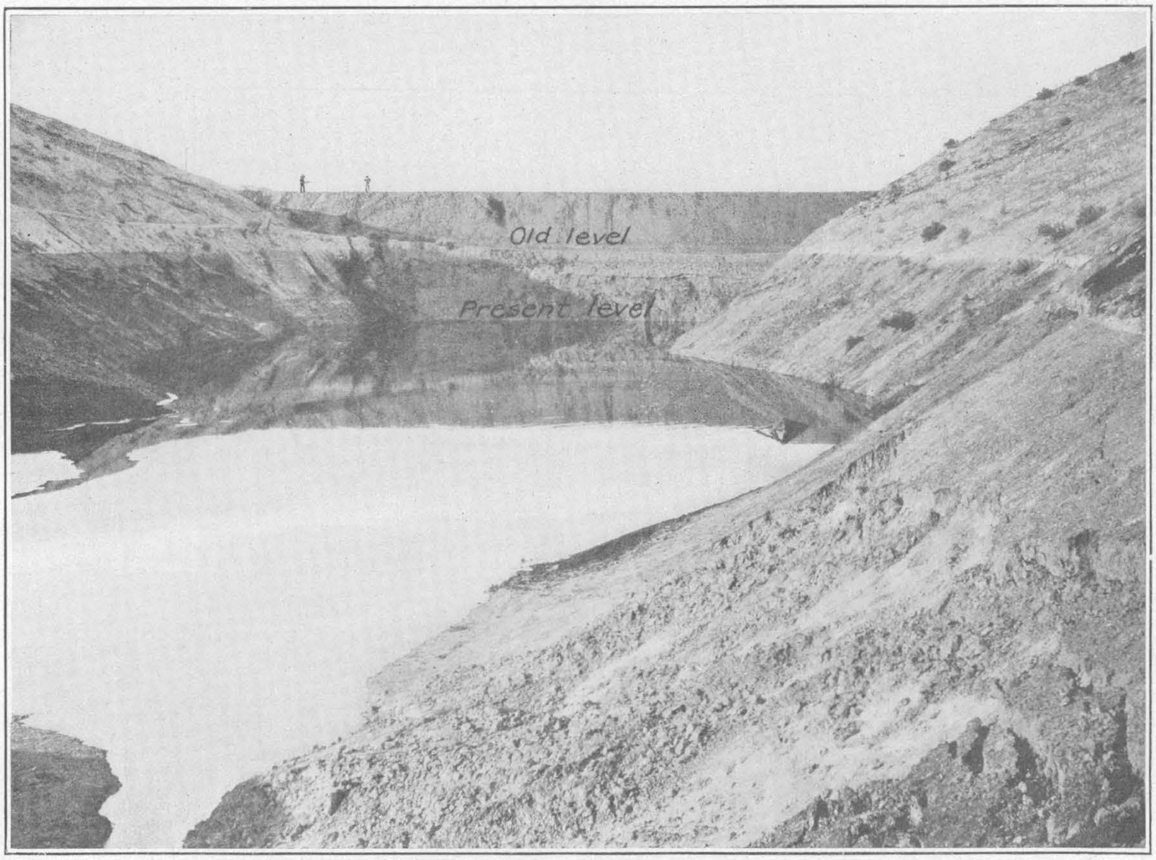
J. M. S. sand

Surface contour interval 20 feet
Structure contour interval 100 feet
Datum is mean sea level



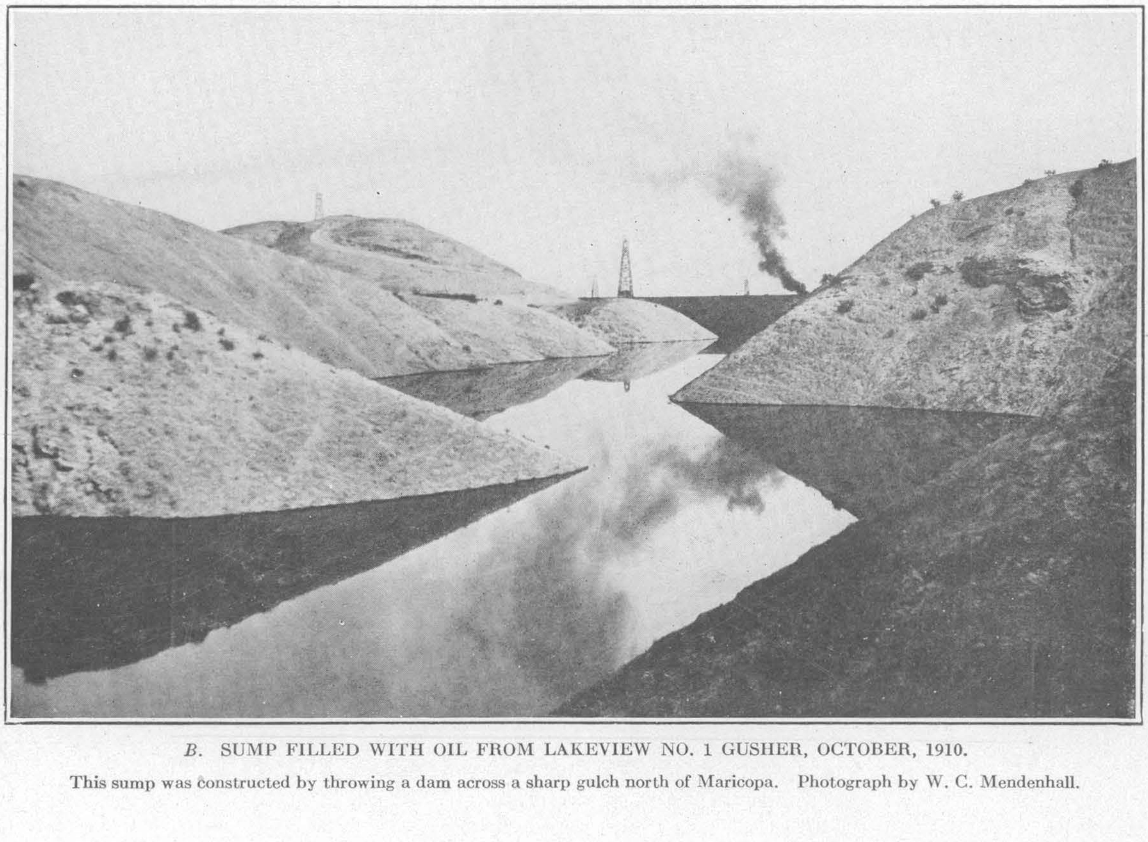
SOUTH END OF TWENTY-FIVE HILL, MIDWAY FIELD.

Looking north from point near Los Pozos well, in sec. 36, T. 32 S., R. 23 E.



A. SUMP IN FOOTHILLS FILLED WITH OIL FROM MIOCENE NO. 1 WELL IN 1914.

Note the old "high-water" mark made by oil of Lakeview No. 1 gusher, as shown in *B*.



B. SUMP FILLED WITH OIL FROM LAKEVIEW NO. 1 GUSHER, OCTOBER, 1910.

This sump was constructed by throwing a dam across a sharp gulch north of Maricopa. Photograph by W. C. Mendenhall.

General Petroleum (Nevada Midway, Scrongo, and Bankline), Section Twenty-five Oil, Seaboard, Paraffin, Princeton, Pierpont, T. W., Millie Francis, Tamalpais, Elkhorn, Pozos, Mascot, Carbo, Wilbert, Dunlop, March, Californian Amalgamated, J. M. S., Malayan Crude, Union (Pebble), Victor, and North American (Mount Diablo).

GEOLOGY.

The chief structural feature here so far as the occurrence of oil is concerned is the Spellacy Hill anticline. This fold is the central one of the group of small folds that lies along the west side of Midway Valley and like all these small folds it trends somewhat obliquely to the course of the main range. It heads near the southwest corner of sec. 16 and extends almost due southeastward for about 3 miles to a point near the center of the east line of sec. 26, where it changes to a more easterly trend and continues through the central part of sec. 25, T. 32 S., R. 23 E., into sec. 30, T. 32 S., R. 24 E. East of the center of sec. 25 the fold plunges rather abruptly, and it dies out in the central part of sec. 30. The true form of the east end of the fold is not very well shown in the outcrops. The axis of the main fold may be traced at the surface as far southeastward as the center of the NW. ¼ sec. 26, but from that point eastward it is difficult or even impossible to recognize a southward dip in the outcropping beds anywhere in the south-central part of sec. 26 or the southern part of sec. 25. The structure of the productive zone shows, however, that the axis of the main fold trends almost directly eastward through the central part of sec. 25 and northeastward through sec. 30. If the structure is viewed as a whole, the east end of the fold may be considered a broad anticline which plunges fairly abruptly toward the east and whose axial part lies in the central part of sec. 25. Although the axis can not be traced in the surface outcrops it parallels approximately the syncline that lies somewhat to the south.

A small anticline may be traced in the outcrops from a point near the middle of the south line of sec. 25 eastward to a point about a quarter of a mile south of the northeast corner of sec. 36, east of which the effect of this small fold can not be recognized at the surface; but a small topographic rise in the northeast corner of sec. 31 suggests that it continues approximately that far. This fold is, however, but a minor feature on the south flank of the main Spellacy Hill anticline, for it can not be traced into a connection with the main fold near the northwest corner of sec. 26. So far as its effect on the oil sands is concerned it may safely be disregarded. The near approach of the syncline, which is here really a major structural feature, to the small anticline shows the minor importance of the anticline.

On the north flank of the Spellacy Hill anticline the dips are regular and vary between 10° and 15°. In sec. 26 the axis of the syncline which separates the Spellacy anticline from the main range lies more than half a mile to the southwest, and in this section the dips are fairly low and regular from the axis of the anticline southwestward to the axis of the syncline. Near the southwest corner of sec. 25, where the axis of the syncline swings rather abruptly to an easterly trend and toward the east approaches more and more closely the axis of the small anticline described above, the dips are somewhat irregular and in places as much as 30°. The syncline is a fairly sharp fold, for the beds turn abruptly and only a few hundred feet west of the synclinal axis are tilted to angles of 30° or more.

The surface rocks in this area are in the McKittrick group and probably entirely in the Paso Robles formation except for the beds that crop out in a narrow belt in the southern part of the N. ½ sec. 35 and in the southern part of the N. ½ sec. 36. In this belt the beds are believed to be in the Etchegoin formation. The approximate line of separation between the Etchegoin and Paso Robles is indicated on the geologic map (Pl. II).

Many of the operators working in this part of the field believe that the beds are much broken by faults, and that one particularly large northwestward-trending fault lies just northeast of the crest of Twenty-five (Spellacy) Hill. They point out, in support of the idea of the existence of such a fault, (1) that southwest of the line along which this fault is supposed to pass the oil sands are coarse grained and thick, but northeast of it the sands are uniformly fine grained, thin, and irregular, and (2) that the oil sands on opposite sides of this line do not appear to be connected. The true explanation for these differences is that the line marks not the position of a fault but the position of the northeastern edge of the area beneath which the A zone is productive. Southwest of this line are the coarse-grained producing sands of the A zone; northeast of it are the fine-grained sands in the stratigraphically lower B zone.

The presence of the deep sand that furnishes the oil in the J. M. S. and Californian Amalgamated properties in sec. 26 is also explained by a fault which, it is supposed, has dropped the main productive zone several hundred feet. This hypothesis is clearly erroneous, for the main zone here is represented by tar sands which occur in quite their normal position and are encountered in the upper parts of the wells of the J. M. S. and Californian Amalgamated companies. The sands from which these wells derive their oil is evidently a lens in the Maricopa shale.

OIL SANDS.

Position.—The chief productive sands lie in the basal part of the McKittrick group mainly in the Etchegoin formation, although it is possible that in places the basal part of the Paso Robles formation may be productive. It is probable that near the crest of the anticline the uppermost part of the Maricopa shale is impregnated with oil and that the lower part of the main productive zone is in this formation. Also in places the coarse lenses in the Maricopa shale are impregnated with oil, and such a lens yields the oil produced by the J. M. S. and California Amalgamated wells.

Grain.—Part of the oil sands in the A zone are coarse grained, and in places they contain gravel and cobbles several inches in diameter. The B zone is finer grained, being particularly fine near the northwest corner of sec. 25, where it is usually recorded in the well logs as shale. It is probable that the B zone is uniformly fine grained in the eastern part of sec. 25, although the greater production from it here suggests that it is coarser grained than it is in secs. 22 and 23.

Zones.—In this area there are three main oil zones—(1) the A zone, which is the chief source of oil along the axial part of the anticline and indeed in all of this area except the northern and eastern parts of sec. 25 and a small area near the center of the W. ½ sec. 26; (2) the B zone, which is separable from the A zone in the eastern edge of the area but which in the western part simply forms the lower portion of the thick productive zone; (3) irregular lenses in the Maricopa shale. The position of these lenses is not known except that of the one which yields the oil in the J. M. S. and Californian Amalgamated wells and which is here termed the J. M. S. sand. Its position is shown approximately by the contour lines on Plate XXXVIII.

A and B zones.—In the western part of the area the A zone is a thick succession of oil sands and tar sands with relatively small amounts of interstratified barren shale. In the NW. ¼ sec. 26 the maximum thickness of this zone is 500 feet. The upper part, probably the upper half, is usually either nonproductive or yields a very little heavy oil and is in many of the well logs recorded as tar sand. In relatively few of the wells is the casing perforated for this upper part of the zone, but one or two of them that have been drilled less than 250 feet below the top of the A zone and therefore rely upon this part of the zone for their oil have yielded as much as 400 barrels a day initially. In general, however, most of the oil is found in the lower half of the A zone.

In the eastern part of sec. 26 the A zone has a maximum thickness of a little more than 400 feet near the crest of the anticline. Many of the wells have been drilled less than 150 feet below the top of the A zone, and these wells have yielded a very fair production. In the northeast corner of sec. 26 the A zone commences to thin out, and the upper part probably contains edge water. Certainly the uppermost part is much less productive than it is somewhat closer to the axis of the anticline, and the zone itself is composed more largely of barren shale. This area is really part of what is here called the "transition belt" lying between the area which is dependent upon the A zone for its oil and that which is dependent upon the B zone. In the SW. ¼ sec. 26 the A zone seems to be slightly thinner than it is near the axis of the anticline, the average thickness drilled through being about 200 feet, and to judge from the information afforded by the few deep wells here most of the wells seem to have been drilled almost if not quite to the bottom of the productive zone.

The productive zone in the SW. ¼ sec. 25 lies entirely within the A zone, which has a maximum thickness here of about 400 feet and is apparently of much the same character as in the SE. ¼ sec. 26. However, just north and east of this locality, in the west-central part of sec. 25, the A zone begins to fray out into a number of individual sands separated by barren strata. The boundary of the belt in which the A zone splits up may be outlined roughly on the west by the 400-foot contour on the top of the A zone (Pl. III) and on the east by a line drawn from the northwest corner of sec. 25 to the middle of the east border of that section and thence to a point near the middle of the SE. ¼. East of this line the productive sands are in the B zone, and although the A zone contains some oil farther east, especially along the axial part of the anticline in the central part of sec. 30, it has nowhere yielded oil in commercial amounts. The B zone is apparently about 100 to 200 feet thick and seems to be closely underlain by water.

J. M. S. sand.—The J. M. S. sand, from which the wells of the J. M. S. and Californian Amalgamated companies derive their oil near the center of the W. ½ sec. 26, is a sandy lens in the Maricopa shale. This lens has a small areal extent and is probably pretty well outlined by the wells already drilled. Its top lies about 600 to 800 feet below the top of the A zone, and its thickness is reported as from 100 to 200 feet in the wells that have entered it. The approximate position of the top of this sand is shown by the sketch contour lines on Plate XXXVIII.

The sand seems to have a somewhat greater dip than is shown by the sands of the overlying A zone. This difference may be truly a structural feature and represent the difference in the amount to which the Etchegoin formation and the Maricopa shale are tilted, but more probably it simply shows the shape of the sandy lens that contains the oil. It is probable that other sandy lenses in the Maricopa shale are impregnated with oil in various parts of the area, particularly along the axial part of the anticline. Their position can not be predicted in advance of drilling from conditions shown by other deep wells drilled along the foothills.

WATER SANDS.

Top water.—In the NW. ¼ and probably also in most of the SW. ¼ sec. 26 top water is either absent or else present in so small amounts as to be negligible. Many of the wells here, especially those along the axial part of the anticline, have been drilled with only a single string of casing and have had no water trouble.

In the E. ½ sec. 26 water sands are scattered through the tar sands that rest upon the A zone. The records of these water sands are rather discordant, and no single sand or thin zone seems to persist throughout the area. Some water is reported as close as 50 feet to the top of the A zone.

Edge water.—In a belt occupying the central part of sec. 25 and bounded approximately on the west by the 400-foot contour on the A zone and on the east by the sea-level contour on that same zone, the upper part of the A zone is occupied by true edge water,[1] the productive sands here being limited to the lower part of the A zone and to the underlying B zone. This edge water has proved especially troublesome, for many of the wells have been cased off above it and others below it, and in consequence the upper part of the productive zone here is flooded. Water sands in this position have given more trouble than any other water sands on Spellacy (Twenty-five) Hill, being even more troublesome than the bottom water which has been encountered in one or two of the wells.

Bottom water.—In the northeastern part of sec. 26 and the northwestern part of sec. 25 the same conditions exist as prevail in the SW. ¼ sec. 23 and the central part of sec. 22—that is, the A zone is closely underlain by a persistent water sand.[2] The approximate position of the top of this water sand is indicated on Plate XXXVIII.

In the northern part of sec. 26, along a line drawn from northwest to southeast through the center of the north line of that section, this water sand lies between 350 and 400 feet below the top of the A zone, but northeastward from this line the distance between the two gradually increases. Southwestward from this line water sands do not so closely underlie the A zone, and those sands which have been encountered in the deep wells seem to occur well within the Maricopa shale. Such deep water sands have been encountered between the bottom of the A zone and the top of the J. M. S. sand, the water there being under considerable pressure. The chief water which is found closely below the A zone in the northern part of the section

[1] See analysis 16, Table 14, Part II (Prof. Paper 117).
[2] For analyses see Tables 25 and 26, Part II (Prof. Paper 117).

may be regarded as edge water in the B zone, similar to that in secs. 22 and 23—that is, edge water which is working into the B zone from the west. (See sketch, fig. 14, showing conditions in sec. 22, p. 126.)

BEDS ABOVE THE PRODUCTIVE ZONE.

In practically all of sec. 26 tar sands occur scattered through the strata above the A zone, almost if not quite to the surface. They reach the surface or within a very few feet of it in the northeast corner of the section; whereas in the SE. ¼ they are about 600 feet thick and their top reaches within 300 feet of the surface. A separation between the A zone and the overlying tar sands in the NW. ¼ sec. 26 is very largely a matter of personal observation, and what is recognized as the top of the productive zone by one driller is not at all certain to be recognized by another driller who puts down a well only a few hundred feet distant. The tar sands in this section are somewhat thicker and are said to be somewhat more filled with tar than are those in sec. 22.

CHARACTER OF THE OIL.

A zone.—In sec. 26 the A zone furnishes an oil of rather uniform grade that ranges in gravity from 12.5° to 15° Baumé and averages 14°. In any part of the area the heaviest oil from this zone is found in the uppermost sands. The gravity of the oil, however, shows a slight variation with the position in the area from which it is obtained, the oil close to the outcrop being somewhat heavier than that farther from it. The southernmost wells drilled yield oil of about 12.5° Baumé.

The variation in gravity shown by the oil from different wells in this area is caused for the most part by one or both of the following reasons: (1) All the wells are not perforated for the same part of the productive zone; some produce from the uppermost heavy oil sands, and others are perforated only for the lower part of the zone, these upper sands being regarded as tar sands. (2) Some of the wells produce a considerable amount of water, derived either from water sands they have penetrated themselves or from oil sands that have been flooded by water from adjacent wells. Such "wet" wells invariably yield heavier oil than wells drilled under similar conditions and yielding no water.

In sec. 25 the character of the oil is about the same as that described for sec. 26 except in the northern and eastern parts of the section, where the oil is produced both from the A zone and from the underlying B zone. The 400-foot contour on the A zone may be considered as marking approximately the eastern limit of the area from which oil is produced only from the A zone.

B zone.—In the northern and eastern parts of sec. 25—that is, the area bounded approximately on the south and west by the 400-foot contour on the A zone—oil is produced from both the A zone and the B zone. The B zone yields the entire production in the northeast corner of the section, just outside the area here described, and also in several wells between that corner and the 400-foot contour line mentioned. The oil produced in this area ranges in gravity from 16° to 20° Baumé. It is probable that the oil in the B zone itself has a gravity of approximately 20° Baumé and that the heavier grades produced are mixtures of this oil with that from the A zone.

J. M. S. sand.—The stray sand in the Maricopa shale which yields the oil produced in the Californian Amalgamated and J. M. S. properties furnishes oil that ranges in gravity from 13.5° to 14.5° Baumé. Other lenses in the Maricopa shale would probably furnish oil of similar character.

PRODUCTION.

A and B zones.—The initial production of many of the wells that produce from the A zone in the western part of the area—that is, in the part lying west of the line marked approximately by the 400-foot contour on the A zone—was more than 150 barrels daily and in two wells was reported to be as great as 500 barrels daily. The area is somewhat spotted, and a few wells never produced more than a very few barrels daily. However, these "dry" wells are few, and if they are disregarded the average initial production was probably between 100 and 125 barrels daily. In 1914 the average production for the wells was about 40 barrels daily.

In the eastern part of the area—that is, the part bounded on the west by the 400-foot contour on the top of the A zone—the initial production was about the same as in the western part, but in 1914 the rate was between 50 and 60 barrels a day.

A considerable number of wells flowed originally, but all were soon reduced to pumping. In places where the sand has become flooded with water air lifts are used, and several thousand barrels of water is lifted daily. Although usually only a few barrels of oil is recovered from the wells in which the air lift is placed, the water is so reduced in the surrounding area that wells which otherwise produce only water become fairly good producers of oil.

J. M. S. sand.—The production from the lenses in the Maricopa shale in the west-central part of sec. 26 has been irregular. Some of the wells were reported to have an initial production of about 350 barrels daily. The average daily yield of the wells producing in 1914 was 40 barrels or less.

SUGGESTIONS FOR FUTURE WORK.

This area is about the most completely drilled part of the Midway field. Future drilling will be concerned chiefly in developing the A and B zones in the few remaining locations, for the whole of the productive zone in the McKittrick group has been prospected thoroughly and most of the wells would be benefited but little by being deepened. The chief trouble here is concerned with the water that has been allowed to enter the producing sand owing to faulty handling of both top and bottom water.

In sec. 26 water troubles are of three types. (1) A few wells in the northeast corner of the section have entered the water sand that lies below the A zone. So far as the whole area is concerned, however, the bottom water could doubtless be handled by plugging the few deep wells that have entered this water sand. The sand is a persistent one and is traceable toward the northwest some distance into sec. 22. (2) A few of the wells in the SE. ¼ have encountered top water. As the water sand is thin, however, and is usually separated from the productive zone by a considerable thickness of barren strata, and as the water in it is usually under low pressure, it is easily cased off. (3) The group of wells in the center of the W. ½ which derive their oil from a lens in the Maricopa shale pass before entering the productive oil lens through water sands that lie in the upper part of the Maricopa shale, and as this water has not everywhere been shut off properly it has flooded some of the wells.

In sec. 25 there are water troubles of two types—that concerned with the top water or with edge water in the top of the A zone and that concerned with bottom water. Top water or edge water are probably the more troublesome and are especially prominent in the central part of sec. 25, in the "transition belt." The top of the A zone is not very productive anywhere in this area, is occupied by water in many places, and has been cased off with the overlying barren strata in some wells and with the productive zone in neighboring wells. Were the area to be drilled now for the first time it would probably be wise to case off both above and below this part of the A zone, but as the area is now so thoroughly drilled and the normal relations of oil and water have been so greatly changed, the present handling of the wells now must be determined by an intimate study of the history of all the wells in the immediate vicinity, it being borne in mind that this top part of the A zone is occupied in places by water and that water which originally came from this sand is causing most of the trouble in this part of the hill. Bottom water, which has been encountered in one or two of the wells, is probably not very troublesome except in the northwest corner of the section. The approximate position of the bottom water is shown by the sketch contour on Plate XXXVIII.

AREA EAST OF TWENTY-FIVE HILL.

[Southeast corner of sec. 12, east edge of sec. 13, east edge of sec. 24; northeast corner of sec. 25, T. 32 S., R. 23 E.; southwest corner of sec. 17, all but northeast corner of sec. 18, secs. 19 and 20, S. ½ secs. 21 and 22, secs. 26 to 30, inclusive, N. ½ secs. 31 to 35, inclusive, T. 32 S., R. 24 E.]

LOCATION AND OPERATORS.

The area embracing the foothills east of Twenty-five Hill extends from the town of Taft southward about halfway to Maricopa along the west side of Midway Valley. The companies operating here in 1916 or controlling lands on which wells had been drilled prior to that time were the Standard, Kern Trading & Oil, Chanslor-Canfield Midway Oil, Section Twenty-five, American Oilfields, Edmunds Midway, Knickerbocker, General Petroleum, Baltimore, Petroleum Syndicate, Pyramid, Union, Lakeview No. 2, and Manitoba Crude.

GEOLOGY.

This area lies on the east end of the Spellacy anticline, which here plunges eastward at an angle of about 6°. The fold is here broad and fairly symmetric, and although it can not be traced with any great degree of precision in the beds that crop out, its position is fairly well indicated by the position of the rolling hills, for the fold does not extend much beyond their edge. The oil sands are apparently folded somewhat more sharply than the surface beds, and the structure may be interpreted readily from the logs of the wells.

Although the Spellacy anticline is broad and symmetric, the syncline that separates the anticline from the main range is very asymmetric, the dip on the south flank being very steep in contrast to the moderate dip on the north flank—that is, the dip on the south flank of the Spellacy anticline. Indeed, the bending is so sharp that the beds may possibly be fractured along the line marked by the axis of the syncline. It is difficult to correlate the oil sands here, and although no regular difference in their elevation could be made out it is possible that the irregularity is caused by faulting.

OIL SANDS.

The oil sands in this area lie entirely in the Etchegoin formation. Several of the wells have been drilled deep enough to enter the underlying Maricopa shale, but the records of these wells do not give enough information to permit an accurate determination of the position of the top of the shale. It is probable, however, that the chief producing sands—that is, those which lie about 250 feet below the top of the B zone and from which the flowing wells in sec. 30 have derived their oil—are almost if not quite at the base of the Etchegoin. It is reported, however, that near the east edge of sec. 30 fossils presumably indicative of the Etchegoin formation have been found 1,000 feet below the top of the B zone.

The oil sands in the Etchegoin formation in this area extend through a stratigraphic thickness of at least 900 feet. No one well, however, reports commercial oil sands throughout so great a thickness of beds, for the beds that form the uppermost part of the productive zone in the western part of sec. 30 do not contain oil in the eastern part of the area.

Near the west edge of sec. 30 the uppermost beds containing commercial amounts of oil lie some 400 feet above the top of the B zone.

These beds are the equivalent of the A zone, which yields the oil in the central part of sec. 25, T. 32 S., R. 23 E. In most of the area the producing sands lie below the top of the B zone and it is from sands in the upper part of that zone that the wells in sec. 28 derive their oil.

The C zone is contoured on Plate III only for the northern edge of this area. In the central and southern parts the uppermost sands containing commercial amounts of oil are clearly in the B zone, and although most of the large wells have derived their oil from beds 250 feet or so below the top of the B zone, still most of the wells depend upon the uppermost portion of the B zone for at least part of their oil. It would be possible in much of this area to contour separately the sand from which the big flowing wells derive their oil, but it is not thought desirable to do so, as the sand lies at a fairly constant distance of about 250 feet below the top of the B zone, and its position may be calculated if the position of the top of the B zone is known. Contouring the C zone throughout this area would overload the map.

WATER SANDS.

Top water.—Top water occurs fairly close to the top of the B zone in much of the area, being recorded as about 100 feet or so above the top of the B zone in many wells both on the north flank and particularly near the eastern edge of the fold in sec. 28. Many other water sands are recorded as occurring in the upper part of the section, but this lowest top-water sand is the really important one, for the water string must be set below it. In the very western edge of the area, near the axis of the anticline, beds 400 feet above the top of the B zone contain some heavy oil. This is the top of the A zone that is productive in the area to the west. The water just mentioned is properly to be considered as edge water in the A zone. The area here considered is so far down the plunge of the anticline that the A zone along the crest of Twenty-five Hill is in no danger of flooding if in the area under discussion all top water is shut off just above the top of the B zone.

Bottom water.—In the north end of the area, east of Taft, bottom water lies about 100 to 150 feet below the top of the C zone.[1]

One or two wells in the western edge of the area near the crest of the anticline report water approximately 250 to 300 feet below the top of the B zone—that is, at about the same distance below the top of the B zone as

[1] See analyses in Tables 23 and 25, Part II (Prof. Paper 117).

the sands which have yielded the big flows of oil in the central part of sec. 30. The difference in the succession of the beds penetrated by wells in the two parts of this section is striking. This difference is probably to be explained by the fact that in the center of sec. 30 the producing sands lie at the base of the Etchegoin formation, but that farther west these sands are wedged out along the unconformity and that water sands occupy either the beds of the Etchegoin or beds in the upper part of the Maricopa shale near the western edge of sec. 30.

Down the plunge of the fold water is reported about 100 feet below the top of the B zone both along the axial part of the anticline and in its north flank.[1] This water is apparently edge water in the B zone, for it lies above the horizon from which the flowing wells in the center of sec. 30 have derived their oil. It is probable that other oil sands lie below this water sand, although the single well that has been drilled in the east end of the area for any great distance below the water sand has not found commercial oil sands at greater depth.

BEDS ABOVE THE PRODUCTIVE ZONE.

The beds above the B zone contain a great number of tar and water sands. There seems to be no regularity in the occurrence of these sands other than the fact that along the crest of the anticline they constitute a zone about 200 feet thick that lies about 700 or 800 feet below the surface. This tar zone appears to have a constant relation to the surface rather than to the underlying oil sands.

BEDS BELOW THE PRODUCTIVE ZONE.

Several wells have been drilled completely through the productive zone and have penetrated the underlying Maricopa shale. No one of these wells, however, affords sufficient data to indicate the exact position of the contact between the shale and the overlying Etchegoin formation. The lower beds penetrated by these wells are usually recorded as consisting largely of sandy shale or sand, the beds resembling much those penetrated by the deep wells in the western part of sec. 24, T. 32 S., R. 23 E. None of these wells has encountered commercial amounts of oil in the shale.

[1] See analysis 49, Table 23, Part II (Prof. Paper 117).

PRODUCTION.

The production of the wells in this area varies greatly. The best wells are those of the Standard Oil Co. in the center of sec. 30, a few of which produced several thousand barrels daily when they were first brought in. Wells of the same company in the center of sec. 20 and the Edmunds Midway No. 1, in sec. 32, have likewise yielded large amounts of oil. The area is somewhat spotted, however, and many of the wells have never produced more than 50 or 60 barrels—some no more than 20 barrels—a day. The variation in production seems to be caused by three chief factors—the position of the well with relation to the anticline, the relation of the oil sands it taps to the unconformity, and the lenticular character of the beds, the large wells usually being located along the axial part of the fold and the sands that yield the oil usually lying in the lower part of the Etchegoin formation close to the underlying diatomaceous Maricopa shale.

CHARACTER OF THE OIL.

The oil obtained ranges from about 15° to 26° Baumé, but most of it runs about 20°. The deeper sands of the C zone do not appear to contain lighter oil than the sands in the upper part of the B zone, but there appears to be a variation in the gravity of the oil within a given sand according to its position in the area, for the B zone contains lighter oil in the eastern part of the area than in the western part, where it is not buried so deeply.

SUGGESTIONS FOR FUTURE WORK.

In all the area except possibly the north end, which lies near the axis of the Midway Valley syncline, and also the east end beyond the area where the B zone is contoured on Plate III, the B zone contains productive oil sands. In most of the area, however, the deeper oil sands usually contain more oil than the sands in the upper part of the B zone, and all the large flowing wells along the axial part of the anticline have derived their oil from sands 250 feet or so below the top of the B zone. West of the center of sec. 30, however, these deeper sands are wedged out along the unconformity at the base of the Etchegoin formation, and in that part of the area it is only from the upper part of the B zone that oil should be expected. It is probable that farther down the plunge and down the north flank of the anticline than the edge of the area in which the B zone is contoured on Plate III—that is, where the top of the B zone lies more than 2,500 feet below sea level—much of the upper part of the B zone, possibly all of it, is occupied by water. If producing sands occur in this part of the district they lie below the top of the C zone—that is, more than 250 feet below the top of the B zone. Wells drilled in sec. 28 have produced only from the top of the B zone, having stopped when a persistent water sand that occurs there was reached. It is probable that other producing oil sands lie below this water sand, and although one well has been drilled below it and has not encountered oil, further testing for deeper sands in this part of the area is justified. However, deep wells west of the center of sec. 30 can hope to obtain oil below the B zone only from lenses in the diatomaceous shale.

In this area many wells have been sunk into the underlying Maricopa shale, but none of them has found producing oil sands in it. The anticline here is a strong, well-marked fold and would appear to be as good a structural feature as one could hope to find for the accumulation of oil. The fact that many of the wells that have entered the shale have not found oil sands in it is a good illustration of the risk attending drilling for lenses in the shale.

SAGE-LAKEVIEW AREA.

[S. ½ secs. 31 to 34, inclusive, southwest corner of sec. 3, T. 32 S., R. 24 E.; fractional secs. 25 and 26, eastern part of sec. 27, northeast corner of sec. 34, all but southwest corner of sec. 35, sec. 36, T. 12 N., R. 24 W.; sec. 30, western part of sec. 31, T. 12 N., R. 23 W.; northwest corner of sec. 6, T. 11 N., R. 23 W.; north edge of sec. 1, T. 11 N., R. 24 W.]

LOCATION AND OPERATORS.

The Sage-Lakeview area embraces the group of hills that lies just north of Maricopa, extending from the outskirts of that town northward to the north edge of the alluvial flat at the mouth of the large gulch that trends eastward past the old August water wells, in sec. 31, T. 32 S., R. 23 E. (See geologic section, Pl. XXVII, and map, Pl. XLIII.) The companies operating here in 1916 or claiming land upon which wells had been drilled prior to that date were the Midway Oil, Canadian Crude, August, Manhattan Midway, American Oilfields, Kern Trading & Oil, Union, Lakeview No. 2, Ethel D, Maricopa National, and General Petroleum.

GEOLOGY.

This area embraces the west end of the Thirty-five anticline, extending from the axis of the Phoenix syncline on the south to the axis of the sharp syncline on the north which separates the Thirty-five and Spellacy anticlines. In this part of the area the Thirty-five anticline plunges eastward at an angle of about 6°. The axial part of the anticline—that is, the belt in which the beds have a fairly low dip—is rather more narrow than the axial part of the Spellacy anticline, for it is barely half a mile across. Both the north and south edges of the axial part of the anticline are fairly well outlined, for the dip of the beds increases rather abruptly and on the north flank of the fold the oil sands dip at angles of 20° to 30°. The Thirty-five anticline is not quite symmetric, for the Phoenix syncline is much shallower than the syncline on the north. The Thirty-five anticline does not extend westward beyond the west edge of the area here described, but as is shown on the map of the field (Pl. III), the Phoenix syncline and the Thirty-five anticline gradually approach each other and die out on the north flank of the California Fortune anticline. The steeply dipping beds in fractional sec. 27 are to be considered as forming the north flank of the California Fortune anticline rather than the north flank of the Thirty-five anticline.

OIL SANDS.

The position of the oil sands is shown rather better in this part of the field than in most other parts. They lie in the lower part of the Etchegoin formation, and the sands which have yielded great quantities of oil in such wells as Lakeview No. 1 are practically at the base of this formation. Not all the flowing wells, however, have produced oil from sands at the base of the formation, for several wells near the north line of sec. 36, T. 12 N., R. 24 W., have obtained their oil from sands at the top of the B zone, fully 400 feet above the base of the Etchegoin. On account of the unconformity between the Etchegoin and the underlying Maricopa shale these sands are wedged out and do not underlie the western part of the area along the axis of the Thirty-five anticline. The approximate position of the top of the shale is shown in the geologic section (Pl. XXVII) and on the maps (Pl. XLIII and fig. 15).

The productive sands may be divided into two groups—those in the Etchegoin and those in the underlying Maricopa shale.

The total thickness of the oil sands in the Etchegoin formation is about 1,000 feet. No single well, however, has penetrated oil-bearing beds of this thickness, for on account of the unconformity at the base of the Etchegoin the deepest sands in the Etchegoin in the eastern part of the area, in sec. 31, are not present in the western part; also the uppermost sands which are productive in the western part of the area are dry or are occupied by water in the eastern part.

The productive oil sands in the Etchegoin are here divided into two parts, which are described as the A and B zones. The A zone is productive in the western part of the area along the crest of the Thirty-five anticline, but the area in which this sand yields oil is limited rather closely to the axial part of the fold, and sands in this zone have not yielded oil in any considerable amounts outside of the area in which the top of this zone is contoured on Plate III. The top of this sand lies between 300 and 400 feet above the top of the B zone.

The B zone has its maximum thickness in the eastern part of the area. In the northeastern part of sec. 31 it is about 700 feet thick and is composed of alternating oil and water sands, like the productive zone in sec. 32, T. 12 N., R. 23 W.—in fact, the description of the zone in that section (pp. 140–142) applies equally well to the eastern part of sec. 31. The big water sand which lies 400 feet or so below the top of the B zone in sec. 32 continues westward into sec. 31, and its approximate position is shown on Plate XLIII.

In the SW. ¼ sec. 36 the chief oil sands lie in the A zone, and the B zone is not more than 100 feet thick, for the top of the diatomaceous shale is only that far below the top of the B zone. Most of the wells in this area depend on the A zone for their oil, although the big wells have derived most of their oil from the relatively thin B zone.

WATER SANDS.

Top water.—In the S. ½ sec. 36, T. 12 N., R. 24 W., in the area in which the A zone is contoured, water sands lie very close above the top of the A zone, having been encountered in many of the wells less than 100 feet and in some places less than 50 feet above the top of that zone. In many of the wells part of the A zone has been cased off with the overlying water sands, for the sands in the upper part of the A zone in most of the area contain a very heavy oil, but water is not reported to occur below the top of the A zone in any well in the area where the top of this zone is contoured on Plate III.

Edge water.—On the flanks of the Thirty-five anticline the A zone is occupied by water. The separation between the area in which the sands in this zone contain oil and that in which they contain water is fairly sharp and is marked by the line separating the axial part of the anticline, where the beds have a moderate dip, from the flank of the fold, where the beds are more steeply tilted. The logs of almost all the wells that have been drilled on the flank of the fold report water down almost to the top of the B zone, some of them recording sands that lie less than 100 feet above the top of the B zone as containing water under considerable pressure. Water from these sands is clearly edge water in the A zone, and as the oil is exhausted from that zone along the crest of the anticline water will work its way up the dip and appear in the wells near the axis of the fold. There has been no regularity in the handling of the wells on the north flank of the fold, particularly those along the line between secs. 35 and 36, some of the wells there having produced from the upper sands and some from the lower. In consequence water has been very troublesome in this part of the area.

Bottom water.—In most of the western part of the area water occupies the upper part of the Maricopa shale, and wells that have entered that shale have found water sands at different positions below the top of the B zone. The distance these water sands lie below the top of the B zone is of course dependent upon the thickness of the Etchegoin formation. In order to understand the relation of the bottom water to the producing oil sands one must thoroughly understand the significance of the unconformity, for it is impossible to correlate oil sands simply on the basis of the distance they lie below the B zone. For example, Lakeview well No. 1 derived most of its oil from sands that lie between 250 and 300 feet below the top of the B zone. Wells drilled only a few hundred feet south and west of this fold, however, have not found this producing oil sand but have encountered heavy flows of water in sands that lie at approximately the same distance below the top of the B zone as the sand from which Lakeview No. 1 derived its oil. The explanation for this discrepancy is that the producing sands of the Lakeview No. 1 well are wedged out along the unconformity, and that west of that well water sands occupy the uppermost part of the Maricopa shale or the base of the Etchegoin formation.

The water sands encountered in certain wells in the eastern part of the area—as, for example, in South Midway well No. 23, Union wells Nos. 2, 8, and 14, and a few of the Kern Trading & Oil Co.'s wells in sec. 31—are clearly in the Etchegoin formation and are comparable with the sands described in some detail in the part of this report dealing with sec. 32, T. 12 N., R. 23 W. (pp. 140–145).

PRODUCTION.

More than 20 wells in this area have had an initial production of over 1,000 barrels a day, and at least an equal number an initial production between 400 and 1,000 barrels daily. The largest well in the whole Midway-Sunset district, Lakeview No. 1 (see Pls. XL; XLI, *C*; XLII, *A*), is in the center of the area, well down on the north flank of the Thirty-five anticline. This well is said to have produced as much as 65,000 barrels a day and is credited with having produced in all more than 8,000,000 barrels of oil. It derived its oil from a sand which lies about 300 feet below the top of the B zone. Further data regarding this well are given in the part of the report dealing with the history of development (p. 65).

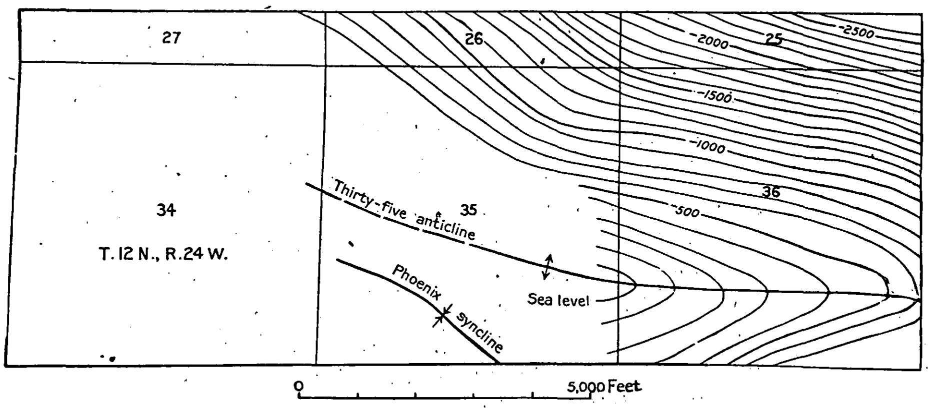


FIGURE 15.—Sketch map showing approximate position of the top of the Maricopa shale in the western part of the Sunset field.

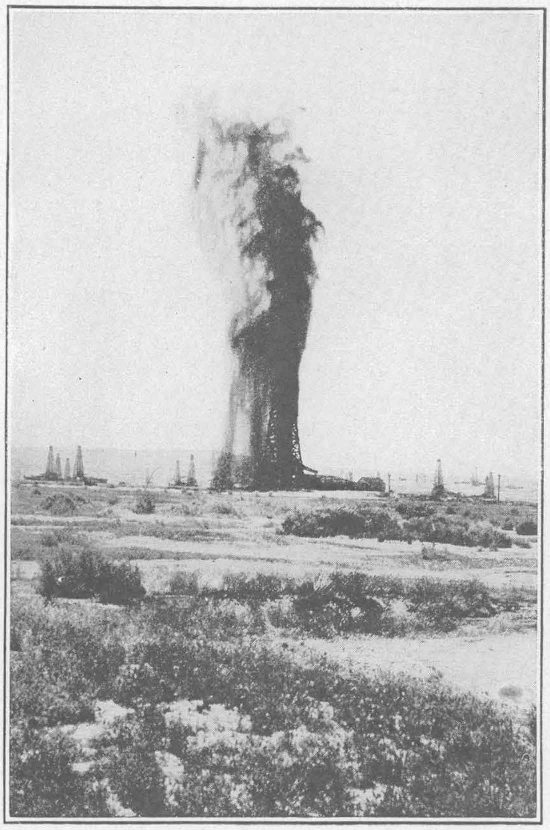
The August water wells, in the southeast corner of sec. 31, T. 32 S., R. 24 E., derive their water [1] from sands well down in the Maricopa shale. So likewise does well F of the Sunset Monarch Oil Co.,[1] in sec. 26; wells D and I of the same company; and Sage wells 11, 15, 8, 16, 17, and 19 in sec. 35.[2] The approximate position of the top of the Maricopa shale in the eastern part of T. 12 N., R. 24 W., is shown on the accompanying sketch map (fig. 15). This map is not very accurate, for the data upon which it is based are meager, but it serves to indicate roughly the base of the zone in which the producing oil sands occur in the Etchegoin formation and therefore the depth below which drilling should not be continued unless it is desired to prospect for lenses in the diatomaceous shale.

Many of the large flowing wells in this area (see Pl. XLI, *C*), particularly those near the north line of the NE. ¼ sec. 36, have derived their oil from sands which lie no deeper than 150 feet below the top of the B zone.

The location of the large flowing wells with relation to the structure is of interest, for the wells are not near the axis of the fold but well down its north flank. The factors controlling the location of the highly productive sands are clearly the folding of the beds and the relation

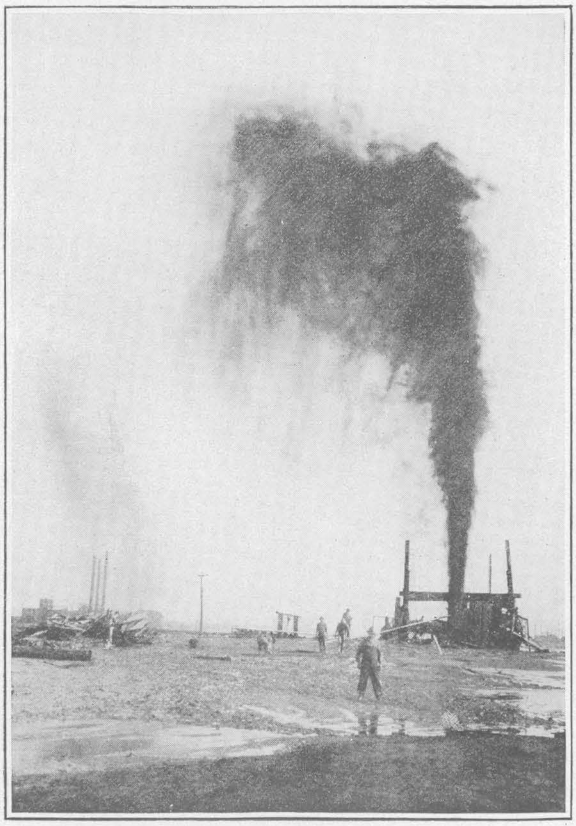
[1] For analysis see Table 16, Part II (Prof. Paper 117).

[2] See analyses 69 and 70, Table 26, and analysis 15, Table 16, Part II (Prof. Paper 117).



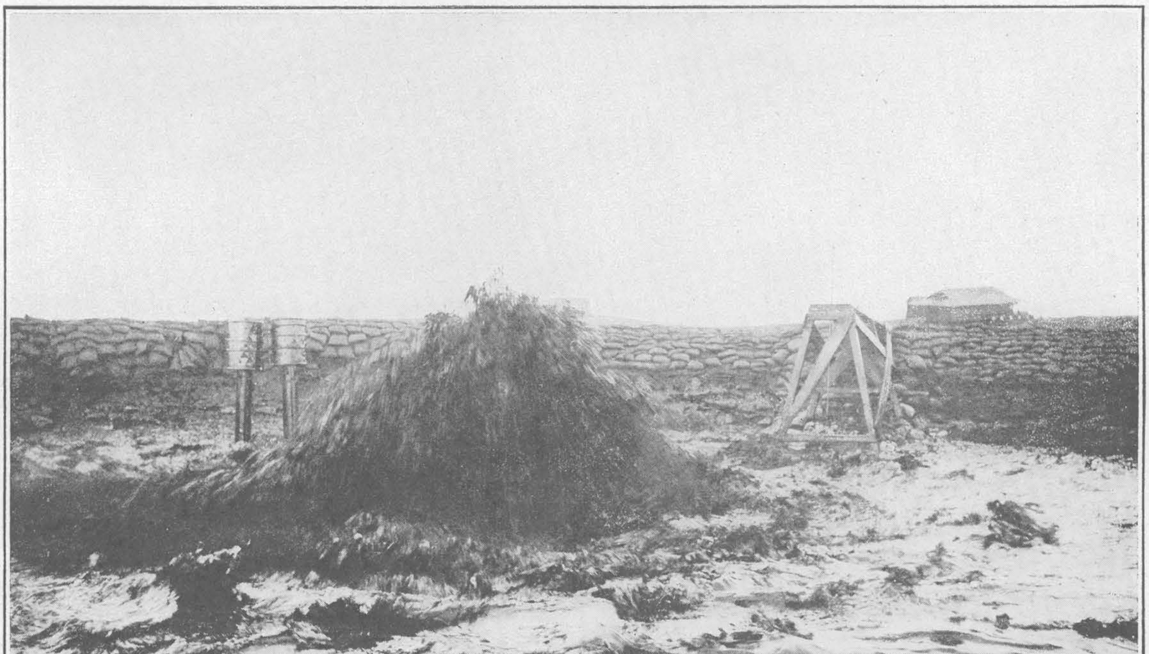
A. FLOWING WELL BEING BROUGHT IN, SUNSET OIL FIELD.

Well No. 30 of Ethel D. Oil Co. This well was soon controlled and flowed a few hundred barrels daily.



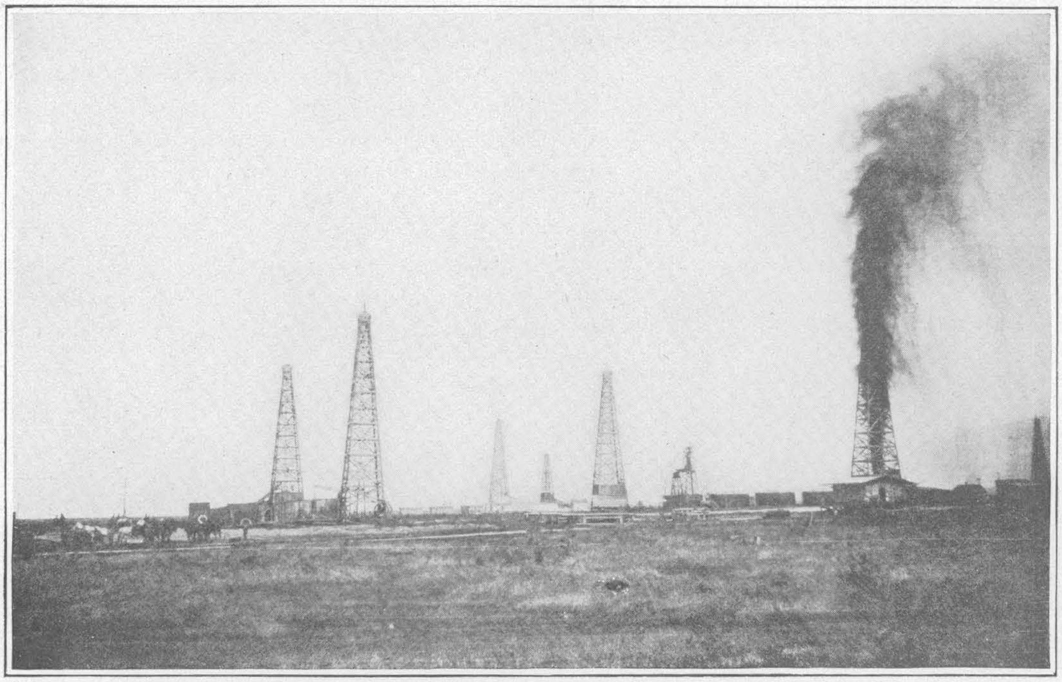
B. LAKEVIEW NO. 2 GUSHER, MAY, 1914.

This photograph was taken a few days after the well had come in. Photograph by G. S. Rogers.



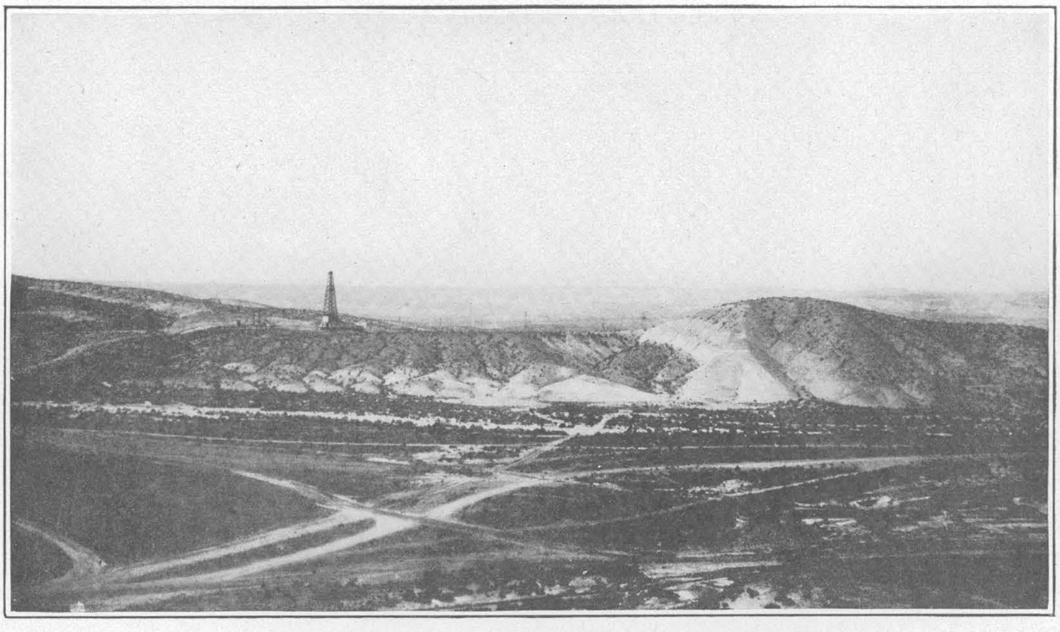
C. LAKEVIEW NO. 1 GUSHER, OCTOBER 2, 1910.

This photograph was taken after the derrick had been removed and the well surrounded by a dam of sacks filled with earth. Photograph by W. C. Mendenhall.



A. WELL NO. 1 OF LAKEVIEW OIL CO. NO. 2.

Well at right. This photograph was taken the day the well came in. Note the height of the derricks used in this part of the field.



B. SOUTHEAST END OF PLUNGING FOLD IN BUENA VISTA HILLS.

This fold is in the northeast corner of sec. 36, T. 31 S., R. 23 E. Well No. 24 of the Standard Oil Co. (McNee lease) is shown almost on the axis of this fold. The plunge of the fold is well shown by the white calcareous bed.

they bear to the unconformity. The highly productive sands near the north line of sec. 36 are wedged out along the unconformity and do not occur in the crest of the Thirty-five anticline, near the center of the W. ½ sec. 36. An inspection of the figure showing the relation of the big wells to the structure (fig. 6) will show that in the Sunset field the big wells in Maricopa Flat, sec. 35, T. 12 N., R. 23 W., near the east end of the Thirty-five anticline, are near the crest of the anticline. Toward the west the big wells are situated along a line which departs gradually from the line marking the axis of the fold, and near the west end of the fold they are some distance down the north flank. The position of the large wells is of course controlled in part by the location of the early wells, for the first wells, other things being equal, get the flush production, but it is in very large part determined by the position of the productive sand in the Etchegoin formation, which is wedged out against the unconformity farther south and west.

CHARACTER OF THE OIL.

The oil derived from the A zone ranges in gravity from 14° to about 17° Baumé. The B zone yields oil of about 22° Baumé. The lightest oil reported is 26° or 27° Baumé, but there appears to be very little indeed of oil so light as this. The average for the area is between 18° and 20° Baumé.

SUGGESTIONS FOR FUTURE WORK.

The A zone is productive along the crest of the anticline in the S. ½ sec. 36 and the north edge of sec. 1, where it has yielded moderate amounts of fairly heavy oil. This part of the area has been so thoroughly drilled that the sands in this zone are probably now pretty well drained. There is, however, enough oil remaining in it to make it worth while to produce from these sands, and in order to protect them great care should be exercised in handling wells that are drilled along the edge of the area in which the top of the A zone is contoured on Plate III, for it is from such wells that trouble is to be expected from edge water in the A zone. Unless these wells protect the A zone the oil sands in it will be flooded higher on the anticline.

The B zone yields most of the oil in this area. In the western part of the area, where the Etchegoin formation is thin, the chief producing sands in the B zone lie not more than 100 feet below the top of that zone. Inasmuch as water lies so close to the top of the Maricopa shale care must be exercised in drilling for sands in the lower part of the B zone not to enter the shale. Figure 15 indicates approximately the base of the Etchegoin formation—that is, the horizon which marks the base of the zone containing the chief productive oil sands.

A great many wells have been drilled into the underlying Maricopa shale and have found some oil in sandy lenses in it. So far these wells have not yielded any great quantity of oil, and it will be wise before prospecting for these deep sands to drain thoroughly the sands in the Etchegoin formation.

Drillers in this area have not followed any uniform practice in handling the various oil sands, and a great deal of water trouble may be ascribed to this lack of uniformity. It is very unfortunate that this part of the area should be divided into so many small holdings, for under such conditions it is almost impossible to regulate the drilling properly.

The chief geologic features which must be understood before any rational policy can be adopted are as follows: (1) The upper sands along the crest of the Thirty-five anticline in the S. ½ sec. 36 are not productive down the flanks of the fold but are there occupied by water. (2) The unconformity which separates the Etchegoin and the underlying diatomaceous Maricopa shale causes the Etchegoin formation to wedge out rather sharply toward the west, and therefore the B zone is much thinner in the western part of the area than in the eastern part. Wells may safely be drilled to depths of several hundred feet below the top of the B zone in the eastern part and should be drilled that deep in order to penetrate completely the oil-bearing measures of the Etchegoin, but in the western part of the area drilling more than 100 or 200 feet below the top of the B zone is very hazardous, for it is almost sure to penetrate water sands in the diatomaceous shale. (3) The diatomaceous shale contains lenses of oil sands that have yielded moderate amounts of oil along the crest of the anticline. The amount of oil in these lenses is, however, not very great, and their development may well await the final draining of the sands of the overlying Etchegoin formation.

MARICOPA FLAT.

[Southeastern part of sec. 31, sec. 32, southwest corner of sec. 33, T. 12 N., R. 23 W.; western part of sec. 4, northern part of sec. 5, and northeastern part of sec. 6, T. 11 N., R. 23 W.]

LOCATION AND OPERATORS.

The most productive part of Maricopa Flat is included in an area whose southwest corner lies on the southwest side of a small hill (elevation, 617 feet) about 2 miles northeast of the town of Maricopa and which extends eastward from that point for about 1½ miles. (See geologic sections, Pls. XXVIII–XXXI, and map, Pl. XLIII.) The companies operating here in 1916 were the Kern Trading & Oil, Maricopa Northern, Midway Northern, National Pacific, Maricopa Star, Spreckels, General Petroleum (Annex and Essex), Obispo, Pacific Midway, Maricopa Consolidated, Midland Oilfields, Californian Amalgamated, El Dora, Trojan, Miocene, Pacific Petroleum, Midway Fields, Lakeview No. 2, Union (Jergins, International, and Midway Fields).

GEOLOGY.

The chief structural feature is the Thirty-five anticline, which trends in a general southeasterly direction through the south-central part of the area. This fold is the southernmost of the larger folds that head in the main Temblor Range and extend southeastward into the valley, where they plunge and cease to affect the surface rocks.

Just west of the area here described the Thirty-five anticline trends almost due east and passes through the center of the S. ½ sec. 31. In this part of its course it plunges eastward at an angle of about 6°. Near the southeast corner of sec. 32 the axis of the fold swings gradually to a more southeasterly trend, and in the NW. ¼ sec. 4 its course is almost exactly southeastward. In this part of its course the fold plunges eastward a little more steeply, the average angle of plunge being about 9°. The anticline flattens markedly near the center of sec. 4 and probably does not continue much farther southeast. It is possible that the fault which trends northward down Cienaga Canyon, passing through the E. ½ sec. 17, T. 11 N., R. 23 W., continues as far northward as sec. 4 and actually truncates the east end of the Thirty-five anticline, but this hypothesis is of course not susceptible of proof, for the rocks are completely masked by the alluvium that fills San Joaquin Valley.

The Thirty-five anticline is slightly asymmetric, the dip on the south flanks being a little steeper than that on the north. Also the fold is fairly sharp, and the belt near the axis of the fold, where the beds have a low dip—that is, what may be called the crest of the fold—is fairly narrow, being as a rule not more than 1,000 or 1,500 feet across.

On the south the Thirty-five anticline is separated from the Temblor Range by the Phoenix syncline, the axis of which lies about 4,000 feet south of the axis of the anticline.

Practically all of this area is covered with alluvium, the only exposures of the older beds occurring on the northeast side of the small hill (elevation, 617 feet) in sec. 23, and the structure must be interpreted entirely from well records.

OIL SANDS.

General features.—The productive zone in this area lies in the lower part of the McKittrick group—that is, entirely within the Etchegoin formation—the Paso Robles formation here containing only water with traces of tar and gas. One or two wells have entered the Maricopa shale, but these wells got very little if any oil in that formation.

The productive zone ranges in thickness from about 350 feet to more than 1,000 feet and is thinnest at the southwestern edge of the area. This variation in thickness is due to the unconformable relation existing between the McKittrick group and the underlying Maricopa shale and to the fact that the McKittrick deposits were laid down in a transgressing sea, so that westward from the valley younger and younger beds rest upon the Maricopa shale. Thus many of the sandy beds that underlie the eastern part of the area do not extend under the western part but are truncated along the plane of unconformity. Inasmuch as the sandy beds in the basal part of the McKittrick are the beds from which the oil is obtained, the disappearance of certain of them is of considerable economic importance. This condition of affairs is shown diagrammatically in the geologic sections (Pls. XXVIII–XXX), particularly in Plate XXIX.

The stratigraphically lowest oil sand in the McKittrick group that has been developed in this area up to the present time (July, 1916) is that encountered in the Midland wells Nos. 3 and 4, in Midway Northern No. 2, and in some of the General Petroleum and Spreckles wells. These wells are situated along the northeastern edge of the area now drilled, and the lowest oil sand they encountered appears to be practically at the base of the McKittrick group. It is almost certain that farther northeast still older beds underlie this producing sand and overlie the Maricopa shale, and these older beds probably contain some oil sands. It is not very probable, however, that the zone in which productive oil sands occur increases in thickness eastward from the area in which the wells just mentioned are situated, for in that area the uppermost sand that has yielded so much oil in the western part of sec. 32 is lean, and to judge from conditions along the foothills west of Taft, farther east, this upper sand probably contains water. In the area northeast of that which has been developed the productive zone is thickened by the addition of beds at the base and thinned by the subtraction of beds at the top that are occupied by edge water. The net result is that the thickness of the productive zone is maintained fairly constant.

In sec. 32 the productive zone may be considered as composed of three main parts—an upper oil sand, a middle division occupied by water sands with lenticular oil sands, and a lower division containing numerous oil sands, the chief producing sands of the area.

Upper sand.—The uppermost of the divisions just mentioned varies slightly in thickness and has a maximum of about 150 feet. It is not a single sand but is composed of a number of more or less lenslike sands whose thicknesses vary considerably, though few of them are over 25 feet thick. More of these individual oil sands are recorded in the wells drilled near the axial part of the anticline than in those down the flank of the fold or even down the plunge to the east, but the total thickness of the zone is almost the same in both places. The top of this zone is shown by the contours on Plates III and XLIII.

This upper part of the productive zone does not, however, contain water near the crest of the anticline, whereas down the east flank a persistent water sand is recorded in the very middle of it. This water sand is shown in Plates XXVIII–XXX, and its top is contoured on Plate XLIII. A line drawn from the vicinity of Kern Trading & Oil Co. well No. 25, in sec. 31, to the vicinity of Kern Trading & Oil Co. well No. 36, in sec. 5, separates approximately the area on the northeast in which this water sand divides the upper zone into two parts and that on the southwest in which this water sand is absent.

The sands in this upper part of the productive zone become rather lean or lack oil entirely along the edge of the area contoured on Plates III and XLIII and many of the sands that contain oil closer to the crest of the fold are here filled with water.

The oil yielded by the sands in this upper part of the productive zone ranges in gravity from 17° to 24° Baumé. The sands in the lower part of this division contain oil of somewhat lighter gravity than those in the upper part, and in the eastern part of this area, where many of the wells produce only from the lower sands, the oil obtained is of about 26° Baumé. In this same part of the area the sands in the upper part of this division—those lying above the prominent edge-water sand whose position is shown on Plate XLIII—yield oil of about 19° Baumé.

Middle division.—The middle division of the productive zone extends from the bottom of the upper division just described to the bottom of the big water sand that lies a short distance above the so-called Wilhelm sand. This division varies somewhat in thickness. It is about 100 feet thick near the southwest corner of sec. 32 and is probably between 250 and 300 feet thick near the northeastern edge of the part of sec. 32 contoured on Plate XLIII. The variation in thickness is shown in the geologic sections (Pls. XXVIII–XXXI).

Most of the sands in this zone are occupied by water and not by oil, but some oil sands occur both near the top and immediately above the big water sand that marks the bottom of this zone. The chief water sand here is the one that yields a large flow of water and occurs a short distance above the so-called Wilhelm sand. This sand varies in thickness but is usually reported as being from 20 to 25 feet thick. Near the southwest corner of sec. 32 this water sand has not been recognized in several of the deeper wells, whose logs have recorded a gas sand at the horizon at which this water sand should occur. Almost all these wells which have not cased off this gas sand have later had water trouble, and it is practically certain that this sand contains water only a short distance down the dip from the place where the wells penetrated it, and that water moves up the dip when the gas is exhausted.

The top of this big water sand is contoured on Plate XLIII, but in using this map it should be remembered that water sands occur locally above this sand up to the base of the upper oil sand which has just been described, and also that in the northeastern part of the area contoured on the map other water sands occur below this big water sand and above the first underlying oil sand—that is, the sand usually called the Wilhelm sand.

The big water sand appears to be widespread and to extend to the southeast at least as far as the center of sec. 4. The water sands that occur a short distance above the big water sand are lenticular and probably not very extensive, although some of them yield flowing water. The water that occurs below the big water sand is probably edge water in the sands that, close to the crest of the anticline, yield oil—that is, the sands called the Wilhelm sand in the southeastern part of sec. 32.

A few of the wells near the southwest corner of sec. 32 record a heavy oil (about 14° Baumé) immediately above the big water sand or, more precisely, above the sand recorded as containing gas, which is really the equivalent of the water sand. Heavy oil is reported also in a similar position just above the big water sand near the center of sec. 4. Such a sand containing heavy oil probably occurs in other parts of the area, but it has not been reported in the logs of the deep wells. This sand would probably yield a fair production, but the underlying sands are so much richer that it has been disregarded. The heavy gravity of the oil it yields also makes it unattractive at present.

This middle division is really characterized by water, not by oil, and should be cased off in order to protect both the upper oil sands, already described, and the lower oil sand, described below.

Lower division.—The lower division embraces all of the productive zone lying below the base of the middle division—that is, below the big water sand and above the top of the Maricopa shale, both of which are contoured on Plate XLIII.

This division has a maximum thickness of at least 400 feet, for wells near the center of sec. 32 have penetrated it to that depth without having entered the underlying diatomaceous shale. Like the uppermost division, it is made up of a number of oil sands or lenses separated by barren strata. The individual oil sands vary in thickness, but the average is probably less than 30 feet. To these oil sands a great number of names have been applied—for instance, Wilhelm, Obispo, Spreckles, American, Kinsey, Miocene, and Lakeview No. 2. In general, particularly in sec. 32, the first oil sand below the big water sand is called the Wilhelm sand.

Near the southwest corner of sec. 32—that is, near the crest of the anticline—the uppermost productive oil sand in this lower division lies a very short distance below the base of the big water sand that occurs in the lower part of the middle division of the productive zone, in places not more than 25 feet of clay separating the two. The distance between the big water sand and the underlying oil sand, however, increases down the flank of the fold. The reason for this apparent separation of the sands is probably to be explained by the fact that the sands that are filled with oil near the axis of the anticline become barren down the dip and are in places occupied by water. Thus near the center of sec. 32 the uppermost oil sand in this lower division of the productive zone is the equivalent of the oil sands that occur a considerable distance below the uppermost productive oil sands in this division near the crest of the anticline. On account of this condition, although the name Wilhelm sand is applied by the drillers to the first productive oil sand encountered below the big flowing-water sand, this name is not always applied to the same sand. This condition is shown in the geologic sections (Pls. XXVIII–XXXI).

As yet water has not been reported in this lower division of the productive zone. The only water that has so far been reported below the big flowing-water sand that marks the base of the middle division almost certainly occurs below the base of the productive zone. This water was reported in the western part of the area, and there, on account of the unconformity at the base of the productive zone, the sands which form the lower part of the productive zone in the center of sec. 32 are absent. This lower water sand is shown in Plate XXX.

WATER SANDS.

Top water.—The records of the upper parts of the wells drilled in this area are not very good, for most of the wells were drilled with rotary tools, and many of the drillers made no special attempt to keep a careful record of anything encountered above the uppermost oil sand. However, top water occurs scattered through the sands down to a level within 50 feet or so of the top of this upper oil sand, and in order to protect the oil sands it is necessary to carry the water string down fairly close to this oil sand.

The upper water sands—that is, those furnishing water in some of the shallow water wells—clearly contain surface water,[1] but the lowest of these water sands—that is, those within 100 feet or so of the top of the upper oil sand—are the stratigraphic equivalents of those that contain oil farther to the west, namely, the A zone contoured on Plate III for the region about Maricopa. Thus the water of these lower sands is edge water in the A zone.

Bottom water.—So far only a single well has encountered what may truly be termed bottom water—that is, water that lies below the productive zone. The water sand is almost certainly in the Maricopa shale, but little more can be said definitely regarding it from this single record. Its approximate position is shown in the geologic section forming Plate XXX. From conditions in other parts of the field it is probable that in the area under discussion the upper part of the Maricopa shale contains numerous water sands which will yield flowing salt water, for the presence of such water sands has been shown by deep wells drilled in the vicinity of Maricopa.

Edge water and water in the oil zone.—The most troublesome water in this area is that encountered in what has been described above as the middle division of the productive zone. This division ranges in thickness from about 100 feet to about 200 or 300 feet. Its thickness varies with its position in the area, being least along the crest of the anticline near the southwest corner of sec. 32 and gradually increasing from that locality both northeastward down the flank and eastward along the crest and down the plunge of the fold. This middle division of the productive zone contains a number of water sands that yield flowing salt water.[2] The largest yield comes from the sand which occurs in the lower part of the division. The top of this big water sand is contoured on Plate XLIII. This water sand is very persistent and occurs beneath most if not all of the area here described. Along the crest of the anticline near the southwest corner of sec. 32 this sand was originally reported as a gas sand and in some of the wells was not cased off. With the exhaustion of the gas water has evidently worked up the dip and has appeared in these wells. The water sand itself, as nearly as can be judged from the logs, is not thick, probably averaging not more than 25 feet, but down the flanks and also down the plunge along the crest of the fold water sands, probably lenticular, appear in the upper part of this middle division—that is, above the big water sand and below the lowest oil sand of the upper division of the productive zone. (See Pl. XXIX.)

Edge water appears in the upper division of the productive zone in much of sec. 32 on the north flank of the anticline and along the crest of the fold east of the center of the north line of sec. 5. This water is very troublesome, for in much of the area it is separated from the productive oil sand by only a very thin stratum of clay, which in places is recorded as only 10 feet or so thick. This edge water separates the upper division into two parts, the upper of which yields oil of about 19° Baumé and the lower oil of 25° to 27° Baumé. Its position is shown by the contours on Plate XLIII.

CHARACTER OF THE OIL.

The oil sands that make up the productive zone contain oil of different quality. In general the heavier oil is found in the upper part of the zone, in those sands that lie close to water sands. In the western part of the area the sands that constitute what has been described as the upper division of the productive zone yield oil of 17° to about 24° Baumé, the average being about 21° Baumé. However, in the eastern part of sec. 32, where this upper division is separated into two portions by the water sand whose position is shown on Plate XLIII, the portion lying below the water sand yields oil of 25° to 27° Baumé that is of practically the same quality as that obtained from the lowest division of the productive zone.

[1] See analysis 8, Table 15, Part II (Prof. Paper 117).

[2] See analysis 9, Table 15, Part II (Prof. Paper 117).

The sands of the lowest division of the productive zone yield oil of 24° to about 27° Baumé. A sand lying a short distance above the top of the big water sand that occurs in the lower part of the middle division of the productive zone yields oil of 14° Baumé.

PRODUCTION.

The initial production of wells in this area has varied greatly, ranging from less than 100 barrels to many thousand barrels daily. The productivity of each well depends both upon its position in the area and upon the sand from which it obtains the oil, the wells along the crest of the fold and penetrating the sands of the lowest division of the productive zone yielding the most oil. The largest well in the area was well No. 1 of the Lakeview No. 2 Oil Co., which is said to have flowed for a time at the rate of 50,000 barrels daily. A summary of the history of this well is given in another part of this report (p. 66). On the whole this area has proved one of the richest in the whole field.

SUGGESTIONS FOR FUTURE WORK.

The wells so far completed have pretty thoroughly outlined the general position of the several oil and water sands, and in drilling new wells in this part of the area attention should be paid to three chief points—protecting the upper oil sand from top water; protecting the upper oil sand from water that occurs beneath it, in what has been described as the middle division of the productive zone; and protecting the oil sands that form the lowest division of the productive zone from water in the overlying sands.

The sand that forms the upper part of the productive zone appears to contain oil in commercial amounts in almost all the area along the crest of the anticline and down the north flank approximately to a depth of 2,100 feet below sea level. The area on the south flank of the anticline in which this upper sand will prove productive has not yet been outlined by drilling, but on account of the fact that the dip is somewhat steeper on this side of the fold it is probable that this sand will not prove productive to quite so great a depth as on the north flank.

Farther down both the northeast flank and the crest of the fold than where the upper sand lies approximately 2,100 feet below sea level the production must be expected from the sands that lie in what has been described as the lowest division of the productive zone, along the axial part of the fold in sec. 32, or from still lower sands which are not present in sec. 32, but which wedge in below the beds that form the lowest division of the present productive zone there and the underlying diatomaceous shale. These sands of the lowest division of the productive zone are the ones from which the big flowing wells in secs. 32 and 4 derive their oil. They unquestionably contain oil for a considerable distance both to the east and to the north of the area where they have been tapped by wells. However, the quantity of oil in these lower sands away from the axial part of the anticline can not be in any way comparable with the quantity they contain along the crest of that fold, for in this area the beds dip regularly to the northeast between the axis of the Thirty-five anticline and the axis of the Midway Valley syncline. The amount of dip of course decreases toward the syncline, but so far as is known there is here no area of reverse structure along which oil would tend to collect. The conditions are therefore comparable to those in the west side of Midway Valley northwest of Taft, in the northeastern part of secs. 10 and 14 and the southeastern part of sec. 11, T. 32 S., R. 23 E.

On the south flank of the Thirty-five anticline the sands that form the lowest division of the productive zone in sec. 32 become thin and gradually wedge out. Therefore in the western part of the area here described production must be expected chiefly from the upper division of the productive zone. In the eastern part of the area, however—that is, in sec. 4 and the eastern part of the N. ½ sec. 5—the sand forming the lowest division of the productive zone in sec. 32 occurs, and in the part of the area away from the crest of the Thirty-five anticline the production must be expected from this sand.

To the southeast, down the plunge of the Thirty-five anticline, the field has not yet been delimited by drilling. The wells in sec. 4 have shown, however, that the sands in the lower part of the upper division of the productive zone in sec. 32 contain oil in commercial amounts at least as far southeast as the point where the sand lies 2,200 feet below sea level—that is, somewhat lower than along the north flank.

It is possible that the fault which trends northeastward down Cienaga Canyon may continue out into the flat to the vicinity of secs. 10 and 4 and that it cuts off the Thirty-five anticline in this area, but definite evidence on this point is not available.

MARICOPA-PIONEER AREA.

[Southeast corner of sec. 34; southwest corner of sec. 35, T. 12 N., R. 24 W.; all but north edge of sec. 1, all but southwest corner of sec. 2, northeast corner of sec. 3, eastern part of sec. 12, northeastern part of sec. 13, T. 11 N., R. 24 W.; southwest corner of sec. 6, western part of sec. 7, sec. 18, southwestern part of sec. 17, T. 11 N., R. 23 W.]

LOCATION AND OPERATORS.

The Maricopa-Pioneer area embraces the foothills west and south of the town of Maricopa, extending from a point about a mile west of Monarch southward to a point about a mile east of the old refinery at Pioneer. The companies operating here in 1916 or claiming land upon which wells had been drilled previous to that date were the Midway Oil Co., Sunset Monarch, Ruby, Petroleum Center, McCutcheon, United Crude, Case, Midway View, Ida May, Adeline Consolidated, Hanford Sanger, Standard, Kern Trading & Oil, Lowell, Melita, Muscatine, Vancouver Midway, Sunset Mohawk, La Blanc, General Petroleum, New Center, Snook, Petrolia, Northern, Good Roads, Golden West, Consolidated Midway Chief, Topaz, Union, Yellowstone, Munzer, Johnson, and Hazelton Crude.

GEOLOGY.

This area lies on the south flank of the Phoenix syncline, extending from the axis of that fold southward to the fault that trends northeastward down Cienaga Canyon. On the west it extends almost to the outcrop of the oil sands of the McKittrick group. The structure of the beds is somewhat irregular, as is to be expected, for the area lies at the very southwest corner of San Joaquin Valley, where the San Emigdio and Temblor ranges join. As is explained on pages 57–62, the structure of the San Emigdio Mountains is very different from that of the Temblor Range, and this area in which the two ranges meet exhibits in part the features of one range and in part those of the other. Near the fault at Cienaga Canyon the beds are steeply tilted and probably fractured. At the northwest end of the area there are numerous small folds, of which the larger are the California Fortune and the Sunset Monarch anticlines. It is probable that in this part of the area there are several other small folds similar in character to these two, which are mapped.

OIL SANDS.

Divisions.—The producing sands lie in two chief divisions, one comprising sands that correspond to the productive sands in the rest of the district and lie in the basal part of the McKittrick group, and the other occurring in the upper part of the Maricopa shale. The upper of these two divisions comprises the A and B zones, whose tops are contoured on Plate III. The A zone may include near its top some beds of the Paso Robles formation. The B zone is entirely in the Etchegoin formation.

A zone.—The A zone, which is productive in the western part of the area, lies stratigraphically between 200 and 300 feet above the top of the B zone. Its thickness varies on account of the unconformity at the base of the McKittrick group, and in the northwestern part of the area it is less than 100 feet thick. Within the area where the A zone is contoured on the map (Pl. III) most of the zone is reported as oil sands, the amount of intercalated clay being notably small.

The A zone embraces the upper part of the productive sands in the vicinity of Pioneer, but on account of insufficient data the whole productive zone there is mapped with the B zone. The A zone is not productive in the axial part of the syncline east of the area where it is contoured on the map (Pl. III).

B zone.—In the northwestern part of the area the B zone is wedged out, by the unconformity at the base of the Etchegoin formation, a short distance west of the area where it is contoured on Plate III. The thickness of the B zone increases toward the east, and in the trough of the Phoenix syncline near the center of the east line of sec. 6 the top of the zone is probably 400 or 500 feet above the top of the Maricopa shale. This zone, like the overlying A zone, is, where productive, reported chiefly as oil sand with relatively little interstratified barren shale.

Oil in the Maricopa shale.—Many of the wells drilled in 1916 and even a few of the wells drilled earlier have derived considerable oil from the sandy lenses in the diatomaceous shale, and late in 1916 and early in 1917 several of the companies here were drilling for the deeper sands. These oil-bearing lenses are, however, so irregularly distributed and lenses that contain water are so abundant that it is difficult to produce oil from these sands.

WATER SANDS.

Top water.—The logs of most of the old wells in the northwestern part of the area, where the productive sands lie in the A zone, report water[1] in sands that lie about 100 feet above the top of that zone, but none of them reports water below the top of it. Top water has been successfully handled in this part of the area by setting the water string a relatively short distance above the top of the A zone.

Edge water.—The A zone is occupied by water east of Maricopa, at the south end of the area where the top of that zone is contoured on Plate III. Also east of the area where this sand is contoured practically all the A zone contains water. In this part of the area the water is considered top water and is shut off a short distance above the top of the B zone.

Bottom water.—A great many of the wells have been drilled several hundred feet below the top of the B zone, and many of them have entered the underlying Maricopa shale. Most of these wells report water[2] at a variable distance below the top of the B zone. It is difficult to make out the exact position of these water sands, but it seems probable that here, as in the area north of the town of Maricopa, water occurs chiefly in the diatomaceous shale. The distance that it is safe to drill below the top of the B zone is therefore dependent upon the thickness of the Etchegoin formation, and this distance increases toward the east. It may be that some of these water sands occur in the Etchegoin, but certainly most of them lie below it.

Many of the sandy lenses in the Maricopa shale have yielded several thousand barrels of water daily.[2] One well has been drilled 2,800 feet below the top of the B zone, the lower 2,300 feet of this in the Maricopa shale. Traces of oil have been reported deep in the shale, but no oil was found in commercial amounts.

[1] See analysis 36, Table 20, Part II (Prof. Paper 117).
[2] For analyses see Table 27, Part II (Prof. Paper 117).

CHARACTER OF THE OIL.

The oil ranges in gravity from 11° to 18° Baumé and averages about 14° Baumé. The heaviest oil comes from the upper part of the A zone in the western part of the area. Some of the wells have obtained oil of 17° or 18° Baumé in the fine-grained beds in the Maricopa shale.

PRODUCTION.

The production of the wells in this area is small compared to that of the rest of the field. Some of the wells have produced 500 barrels or so when first brought in but have maintained so great a yield for only a day or so. Most of the wells are now reduced to a daily production of much less than 100 barrels, and many of them pump less than 20 barrels.

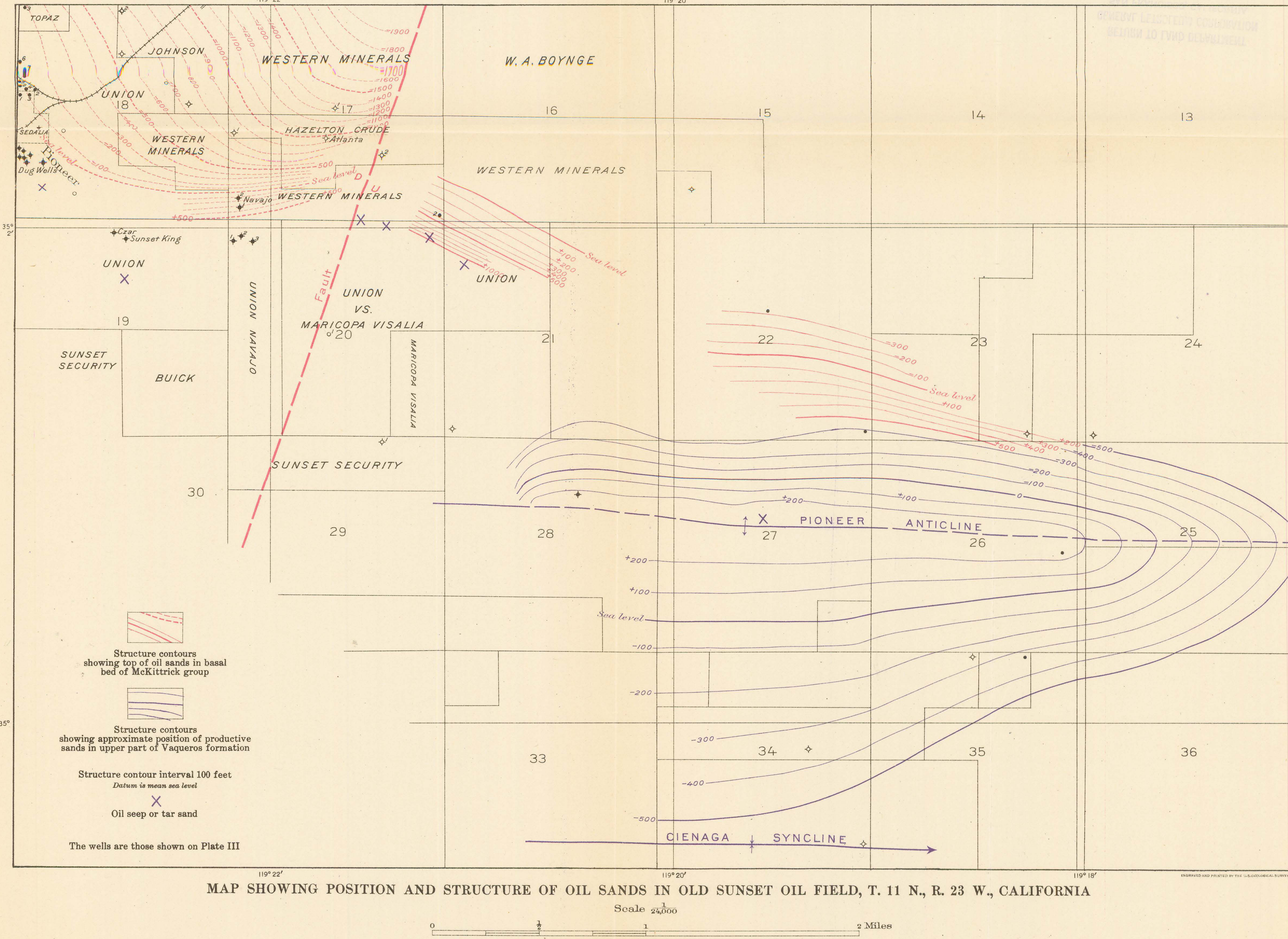
PIONEER ANTICLINE AREA.

[Southwest corner of sec. 15, southern part of sec. 16, southeast corner of sec. 17, eastern part of sec. 20, secs. 21 to 28 inclusive, all but northwest corner of sec. 29, secs. 33 to 36 inclusive, T. 11 N., R. 23 W.]

LOCATION AND OPERATORS.

The Pioneer anticline area lies in the foothills southeast of Sunset, embracing the ridge that lies east of Cienaga Canyon and a belt of San Joaquin Valley about 2 miles wide bordering this ridge. (See Pl. XLIV.) The northwest corner of the area lies about 4 miles southeast of Maricopa; the east end of the area lies about 1 mile east of Santiago Creek.

The Western Minerals Co. is the chief operator in this area and has drilled seven wells, all of which were idle in 1914. Other wells, all of them dry, have been drilled by the Vancouver Paraffine Oil Syndicate in sec. 23, the Nevada Pacific Oil Co. in sec. 24, the Test Oil Co. and Thirty-four Hill Oil Co. one each in sec. 34, and the El Cerrito Oil Co. in sec. 35. Besides these wells three holes were drilled by Jewett & Blodgett in the NE. ¼ sec. 28 in the early nineties—for this area was one of the first parts of the Sunset field to be prospected, the seeps near the north line of sec. 20 having early attracted attention. These old Jewett & Blodgett wells obtained small quantities of light oil (about 30° Baumé). They are described more fully in the section on the early history of the field (pp. 63–66).



MAP SHOWING POSITION AND STRUCTURE OF OIL SANDS IN OLD SUNSET OIL FIELD, T. 11 N., R. 23 W., CALIFORNIA

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

GEOLOGY.

This area is separated from the south end of the Sunset field by the belt of irregular structure that trends northeastward through secs. 17, 20, and 29, T. 11 N., R. 23 W., and probably by another similar belt that passes through secs. 15, 21, and 28. In these belts the beds have broken along one or more faults. The exact nature of the faulting can not be described, for the rocks affected are largely covered by alluvium. The interpretation that best fits the available evidence is that the chief break has been along a line extending down Cienaga Canyon and thence trending about N. 20° E. through secs. 20 and 17 across the flat. The rocks east of the fracture have moved upward relative to those on the west. The probable position of the fault is shown on Plates II and XLIV. It is also probable that a second but smaller parallel fault extends through the central parts of secs. 21 and 16, but here the relative movement is apparently opposite to that along the major fault to the west, and the rocks lying to the west of the fracture have been raised relative to those on the east. The evidence of the existence and position of this fault is, however, so meager that it has not been shown on the map (Pl. XLIV).

Besides these faults the chief structural features in this area are the Pioneer anticline and the Cienaga syncline. The anticline trends almost due east through the central parts of secs. 28 and 27 and may be traced in the outcropping beds as far eastward as the west line of sec. 26, where the rocks affected by it are covered with alluvium. The fold, however, continues some distance eastward, probably at least as far as the east line of the township. In the W. ½ sec. 28 the anticline abuts against the eastern one of the two fault zones just described, and, although the Pioneer anticline is evidently part of the anticline that may be traced from Cienaga Canyon westward to Bitterwater Creek, the two can not be traced across the fault zone into actual connection. (See geologic map, Pl. II.)

Near the east line of T. 11 N., R. 23 W., the Pioneer anticline and the Cienaga syncline plunge eastward. The degree of plunge can not be estimated accurately, for this part of each fold is covered by alluvium, but it is probably less than 10°.

In the west-central part of the area the upper part of the Vaqueros formation crops out in the axial part of the Pioneer anticline. The formation here is composed chiefly of dark chocolate-colored sandy shale which is probably in part diatomaceous and in places contains a considerable amount of carbonaceous matter as minute flakes. On the south limb of the anticline and in the axial part of the Cienaga syncline the Vaqueros formation is overlain by the Maricopa shale, but on the north limb of the anticline it is overlain directly by the coarse gravels and clay of the McKittrick group, the siliceous Maricopa shale having been overlapped some distance north of the axis of the anticline.

POSITION OF THE OIL SANDS.

The oil-bearing sands in this area lie in two chief zones. The upper zone includes the sandy beds in the basal part of the McKittrick group and in places some of those in the uppermost part of the formation upon which the McKittrick rests, whether that formation is the Maricopa shale or the Vaqueros formation, for in this area the McKittrick overlaps each of these formations. This zone corresponds to the chief zone that yields the oil in the main part of the Sunset and Midway fields to the north. The lower zone includes sandy beds in the Vaqueros formation and is the zone of chief importance in this area. The two zones yield oil of distinctly different character. That in the upper zone is a heavy, dark-colored or practically black tarry oil of approximately 14° or 15° Baumé. The oil in the lower zone is greenish and much lighter, usually of 25° to 28° Baumé. A few samples of oil from the lower sands are recorded as of only 19° Baumé, but the relatively heavy gravity of these samples may be the result of a mixing of oil from the sands in the Vaqueros formation with the heavier oils of the upper zone, of a loss of the light constituents in the oil through evaporation, or of contact with alkaline water. The normal oil in the sandy beds of the Vaqueros formation is evidently lighter than 25° Baumé.

OIL IN THE VAQUEROS FORMATION.

OIL SANDS.

The oil in the Vaqueros formation occurs in various lenticular sands interstratified with the sandy clay and chocolate-colored shale (probably in part diatomaceous) that compose the upper part of the formation here. Oil-bearing beds are apparently scattered through the upper shale member of the formation, but only a few of the lenses contain commercial amounts of oil, for many of them are noted only as "showing" oil when penetrated by the drill. Most of the oil has come from thin sands that lie in the lower part of the upper shale member of the formation. The wells here that have yielded oil are so few and the oil sands are clearly so lenticular that it is impossible to contour the productive zone other than in a very general manner.

On Plate XLIV an attempt has been made to show the approximate position of the horizon at which the lenses that have yielded the most oil occur. Anyone using this map should understand that this is only a first approximation of the location of the oil-bearing sands and that these contours do not have by any means the same degree of accuracy possessed by those shown on the map of the productive parts of the main fields to the north (Pl. III). In most of the wells that have obtained oil from the Vaqueros sands in this area various quantities of oil have been reported in sandy beds that lie many hundred feet above the sand that has yielded the chief production, and in one well 10 barrels of oil a day is said to have been obtained from a sandy bed that lies almost at the top of the Vaqueros—that is, stratigraphically above the lenses that have been tapped by the larger wells and above the horizon marked by the purple contours shown on Plate XLIV.

WATER SANDS.

The records of water sands encountered in the wells so far drilled along the Pioneer anticline are much too discordant to permit any very definite statement as to the location of these sands.

The logs of two of the old wells drilled by Jewett & Blodgett in the nineties reported water in practically every sandy bed penetrated, but as water was never shut off properly in these wells it is probable that much of the water came from some one or two sands pretty high up and that as drilling progressed this water leaked down into the hole. The logs of most of the wells drilled more recently report water in the upper part of the section penetrated, some of them down to levels within 300 feet or so of the productive oil sand. Much of this is clearly surface water, but in a few logs the deeper top waters are reported as sulphurous and are probably comparable with the top waters that lie close to the top of the chief oil sands in the main field.

In two, possibly in three, wells saline water is reported below the deeper oil-bearing sands—that is, those sands which lie in the lower part of the upper shale member of the Vaqueros formation. In one well this water is said to have flowed, and in another to have risen about 800 feet in the hole.

SUGGESTIONS FOR FUTURE WORK.

The drilling that has been done along the eastern half of the Pioneer anticline has shown that the shale which forms the upper division of the Vaqueros formation contains many sandy lenses saturated with oil. These lenses occur at various horizons practically from the top to the bottom of this shale, but the largest production has come from the lenses in the lower part of it. No well can therefore be considered as testing the area unless it completely penetrates this shale.

So far the successful wells here are all fairly close together along the axis of the Pioneer anticline. Most of the wells more than half a mile from the axis of the Pioneer anticline have, it is true, not been drilled deep enough to encounter the basal part of the upper shale of the Vaqueros formation, but those that have been drilled deep enough have not found oil.

It is probable that the area in which the Vaqueros formation contains commercial amounts of oil is restricted rather closely to the crest of the Pioneer anticline. On the north flank of the fold wells half a mile from the axis have obtained oil, and it may be that the productive belt extends for half a mile still farther north. On the south flank of the anticline the productive belt certainly does not extend south of the axis of the Cienaga syncline, for the beds forming the south flank of the syncline are practically on end.

The oil in the Vaqueros formation is light and very fluid and apparently does not form tarry products so readily as the heavier oil characteristic of the upper zone. Oil such as this would tend to migrate readily and would halt and concentrate only in those areas where the structure formed a fairly perfect trap—that is, such a trap as is formed by the Pioneer anticline. Oil would evidently tend to collect in the uppermost part of the fold and would not accumulate lower on the flanks, unless the porous beds near the crest of the fold were fully saturated (with oil or gas), or unless the oil in moving up the dip became trapped in a porous lens that had no outlet up the dip.

Further prospecting for oil in the beds of the Vaqueros formation should therefore be conducted first along the crest of the Pioneer anticline, and drillers of wells here should be prepared to drill completely through the upper shale member of the formation. Much of the Vaqueros formation has been removed by erosion along the crest of the anticline in secs. 27 and 28, but the diatomaceous Maricopa shale evidently swings about the nose of the fold beneath the alluvium in the vicinity of sec. 25, and there the full thickness of the upper shale member of the Vaqueros would have to be penetrated to test the area adequately. Sandy beds containing oil might and probably would be encountered above the base of this shale along the crest of the anticline in sec. 25, but no well that did not encounter oil can be said to have proved the area to be barren of oil unless it has been drilled through the shale.

In conclusion it may be said

1. That a belt half a mile to a mile in width on each side of the axis of the Pioneer anticline offers excellent promise of yielding light oil from sandy lenses in the upper shale member of the Vaqueros formation.

2. That oil occurs scattered through this shale practically from the top to the bottom, but that most of the oil so far obtained has come from sandy beds in the lower part of the shale.

3. That water sands occur scattered through the formation, but their position with relation to the oil-filled sand lenses is not known. In some of the wells water has been found both above and below the oil, and in some logs water and oil are reported in the same sand.

4. That the lenticular form of the porous beds and the lack of a pronounced unconformity along which oil might migrate readily and near which it would tend to accumulate both indicate that the area will prove spotted—that the proportion of unsuccessful wells will be much higher than in the main part of the Sunset-Midway field.

5. That the high grade of the oil and the regular nature of the folding make this area a very promising one for future prospecting.

In the area lying east of the fault that passes down Cienaga Canyon and west of a line through secs. 28 and 21 parallel to that fault and passing close to the westernmost point at which the axis of the Pioneer anticline is shown on the map (Pl. XLIV) the strata are considerably fractured and are not folded in such a way as to form a trap in which petroleum would tend to collect. This area therefore appears unpromising.

A narrow belt along the west half of the Pioneer anticline, between Cienaga Canyon and the east branch of Sunset Valley, offers some promise of yielding petroleum, but the prospect is not so good in the east end of the anticline. The beds are more steeply tilted, and the crest of the anticline, which is the area in which productive sands are to be expected, is narrower; the Vaqueros formation is less eroded, and in consequence the sands that have proved the most productive in the eastern half of the anticline are more deeply buried; and finally the Vaqueros formation here shows no surface indications of petroleum. Prospecting here should await results of further drilling east of Cienaga Canyon.

OIL IN THE McKITTRICK GROUP.

The general character and position of the McKittrick group in the east-central part of T. 11 N., R. 23 W., are much the same as along the foothills west of Taft. The beds are alternating coarse sand and fine clay; they rest unconformably upon the older formations; they lie on the flank of a small anticline that passes through the outermost foothills and plunges beneath the Great Valley; and finally they show in their outcrop the presence of oil.

Only a few general conclusions may be given as to the probable amount of oil in the basal McKittrick beds here, for the area is completely covered by alluvium, and no well that is north of a line drawn about S. 75° E. from the southwest corner of sec. 16 has been drilled deep enough to test the sands at the base of the group.

The analogy between the conditions here and those on the west side of Midway Valley appears fairly close, and it seems reasonable to expect that the basal beds of the McKittrick group will yield oil in parts of secs. 15 and 16, the northeastern part of sec. 21, and parts of secs. 23 and 24.

In certain ways, however, this area appears less promising than the belt along the foothills west of Midway Valley. From what little evidence the outcrops afford it seems probable that the dip of the oil-bearing zone is rather high, and that along the north edge of the area shown on the map (Pl. XLIV) the basal beds of the McKittrick are buried deeply, possibly too deeply to be reached by the drill. The supposition that the dip here is high is strengthened by a consideration of the structure of the outer foothills of the San Emigdio Mountains east of Santiago Creek, for all along that part of the range the beds in the outermost hills dip at a high angle to the north beneath the Great Valley. It therefore seems reasonable to suppose that in this area, which forms the west end of the San Emigdio Mountains and is thus the western extension of the belt just described, the beds likewise dip northward at a fairly high angle.

It is possible, of course, though the writer believes it highly improbable, that beneath the alluvial filling of the valley in the area north of the Pioneer anticline and south of the Thirty-five anticline the strata are folded into another anticline. The beds much more probably lie in a regular trough or syncline that separates the Pioneer and Thirty-five anticlines and is the extension of the Phoenix syncline.

No well so far drilled has really tested this area. The deep well of the El Camino Co. in sec. 10 lies on the north flank of the syncline and virtually in the extension of the Thirty-five anticline and affords no test of the strata lying between the axis of the Phoenix syncline and the southern edge of the McKittrick group.

In conclusion it may be said that the prospect is good of obtaining heavy oil from the beds in the lower part of the McKittrick group, along a belt that extends from the vicinity of the west line of sec. 16, T. 11 N., R. 23 W., to the vicinity of the east line of that township. The south line of this belt extends from the vicinity of the southwest corner of sec. 16 to the vicinity of the southeast corner of sec. 22, eastward from which its course is probably almost due east for a mile more. In sec. 21 south of this line, in the southwest corner of sec. 22, and in the northeastern part of sec. 28 the McKittrick is probably too thin to have retained commercial amounts of oil.

RUDISILL-BARNODON AREA.

[Northeastern part of sec. 1, T. 31 S., R. 22 E.; southwestern part of sec. 5, secs. 6, 7, and 8, southwestern part of sec. 9, southwest corner of sec. 10, S. ½ sec. 14, all but northeast corner of sec. 15, sec. 16, all but southwest corner of sec. 17, N. ½ sec. 18, T. 31 S., R. 23 E.]

LOCATION AND WELLS.

The Rudisill-Barnodon area lies at the extreme north end of the Buena Vista Hills, extending from the south end of the McKittrick field southward to the low divide which cuts through secs. 9 and 17 and divides the north Buena Vista Hills into two parts. There were no producing wells in this area in 1916, nor were any wells being drilled at that time. Deep wells have been drilled by the Union Oil Co. (Rudisill) in sec. 6; the Calanova, Rex Midway, and Mays Consolidated companies in sec. 8; the Standard Oil Co. (four wells) in sec. 16; and the Barnodon Oil Co. in sec. 14. None of these wells produced oil, and in 1916 most of them were definitely abandoned.

GEOLOGY.

This area lies on the two small folds, the Rudisill and Barnodon anticlines, which together form the northern of the two zones of upward folding that extend through the north half of the Buena Vista Hills. The general structure of this portion of the hills is discussed on pages 57–59. On the northeast the area is limited by the Buena Vista syncline, and on the southwest by the shallow and irregular structural depression that separates the Rudisill and Barnodon anticlines from the southerly zone of upward folding formed by the Globe and United anticlines.

The beds along the Rudisill and Barnodon folds are tilted irregularly, locally to rather high angles, 40° or 50° being not uncommon. The folds are, however, clearly secondary features, being smaller than the folds that form the southerly zone of upward folding in the Buena Vista Hills—that is, the United, Globe, and Honolulu anticlines. The Rudisill and Barnodon anticlines also evidently affect the strata to a less depth than the more southerly folds. An indication of the relative unimportance of the Barnodon fold is given by the position of the syncline that separates that fold from the United anticline, for, as shown on Plates II and III, the syncline is much closer to the Barnodon anticline than to the United anticline. The Barnodon and Rudisill folds are therefore to be regarded as surficial wrinkles in the flanks of a larger fold, much like the three small anticlines on the south flank of the Elk Hills.

The relative size of the Barnodon and Rudisill anticlines is important in a consideration of the occurrence of petroleum, for here, just as in the Elk Hills, the chief accumulations of oil seem to be along the upper parts of the larger folds, and, although the minor folds on the flanks of the larger ones, when judged from the surface, appear to be excellent traps for the collection and holding of oil, in reality they do not extend deep enough to affect the oil-bearing measures to any great extent.

OIL SANDS.

Very little can be said regarding the occurrence of oil in this area. The wells that have so far been drilled have not been commercial successes, for although oil and gas are reported to have been found in most of them, the amounts are said to have been very small. It is probable, however, that if oil occurs within this area in any considerable amount it is in beds that occupy a position equivalent to the C zone, which is productive in the southwestern part of T. 31 S., R. 23 E., just to the south.

The McKittrick group, in which the chief producing oil sands lie throughout the Midway district, thickens very greatly toward the northeast away from the main range. With the possible exception of one of the wells drilled by the Standard Oil Co. in sec. 16 no well drilled in this area has completely penetrated the McKittrick group. In this area, just as in the area to the south, the sands that show the greatest amount of oil lie several hundred feet above the lowest beds in which sea shells are reported to occur, and it is evident that the chief oil sands are not along the plane of unconformity between the diatomaceous Maricopa shale and the overlying McKittrick.

Many of the wells in this area were drilled when very large flows of oil were being obtained from wells along the axial part of the United anticline, just to the south, and in consequence a similar production was expected from wells along the Rudisill and Barnodon anticlines. Although these folds are not equal in size to the United and Honolulu anticlines and are not so isolated from the larger structural features, still they are large enough and sufficiently isolated to make them appear very promising for the accumulation of oil. Although the results already obtained indicate that large flows of oil are apparently not to be expected in this area, it seems as if careful drilling along these anticlines, with systematic testing of the various sands which have been reported as "showing" oil, will result in wells which yield a moderate amount of oil.

CALIDON-RECORD AREA.

[Southeast corner of sec. 13, east edge of sec. 24, northeast corner of sec. 25, T. 31 S., R. 22 E.; southwest corner of sec. 17, S. ½ sec. 18, secs. 19, 20, and 21, all but north edge of sec. 22, western part of sec. 27, sec. 28, all but SW. ¼ sec. 29, N. ½ sec. 30, northeastern part of sec. 33, northwest corner of sec. 34, T. 31 S., R. 23 E.]

LOCATION AND OPERATORS.

The Calidon-Record area occupies the central part of the north half of the Buena Vista Hills, extending from the highway that connects Taft and McKittrick eastward to the highest point in the north half of the hills. (See geologic section, Pl. XXIII.) The companies operating here in 1916 or controlling properties on which wells had been sunk prior to that date were the Midland Oilfields, Toronto Midway, Midway Royal, General Petroleum, Brookshire, Fairfield, Calidon, United, Kern Trading & Oil, Associated, Record, Consolidated Mutual, Caribou, and Californian Amalgamated.

GEOLOGY.

This area lies on the west end of the more southerly of the two zones of upward folding which occupy the north half of the Buena Vista Hills. (See pp. 57–59.) The chief anticline here is the United anticline, which extends across the eastern part of the area and is a broad, gently plunging fold, the beds dipping northward and southward away from the axis at very moderate angles. Close to the axis of the anticline the beds are in places tilted to angles of 15° to 20°, but the belt in which the beds are tilted as steeply as this does not extend more than a few hundred feet from the axis. Beyond the limits of this belt the beds are gently inclined, the angle of inclination being particularly low on the north flank of the anticline, where it is rarely more than 5°, and in many places the beds dip at an angle less than the slope of the surface. The inclination of the beds on the south flank of the fold is somewhat greater than on the north flank but even there is rarely more than 8° or 10°. The inclination of the beds is shown in the geologic cross section forming Plate XXIII. Near the west end of the area the United anticline plunges gently to the west, but the general zone of upward folding is continued westward beyond the limits of the area here described, by the Globe anticline. The saddle between the Globe and United anticlines is apparently pretty well marked; the United anticline plunges westward at a very low angle, and the Globe anticline eastward at a somewhat greater angle.

Just east of the east end of the area the beds are folded into a number of small anticlines and synclines—not, as in the west end, along a single gentle upfold or anticline. As is explained in the section of the report that described the structure of the Buena Vista Hills (p. 59), these folds are in the main surface features, and the beds at depths of 2,000 feet or so are not folded into regular wrinkles like the surface beds, but if bent at all are fashioned only into structural benches.

OIL SANDS.

The chief oil sands in this area lie in the lower part of the McKittrick group, well within the Etchegoin formation, for fossiliferous marine beds are reported 500 feet or more above the top of the productive oil measures. The sands that have so far yielded oil, however, are not at the base of the Etchegoin, for in the deepest wells marine fossils typical of the Etchegoin are reported 600 feet or so below the top of the uppermost productive sands (the top of the C zone). With one possible exception no well has been drilled completely through the Etchegoin. The record of the single well, which may have been drilled deep enough to enter the underlying diatomaceous Maricopa shale, does not give many data regarding the position of the top of the shale.

The oil sands extend through a zone at least 700 feet thick. The top of this zone is correlated with the C zone, which yields the oil obtained in the eastern part of T. 31 S., R. 22 E., and near the center of the Midway syncline in the vicinity of Taft. The uppermost sand (the B zone) which yields the oil in the southwest corner of T. 31 S., R. 23 E., and in the south half of the Buena Vista Hills, apparently does not contain oil in this part of the region, but heavy flows of gas are reported in some of the wells at the horizon corresponding with the top of the B zone. The wells in which gas was encountered at this horizon are chiefly along the axis of the United anticline in the eastern part of the area.

It is difficult to obtain any very definite idea of the character of the individual oil sands that make up the productive zone, for the logs report "oil sand," "sandy shale showing oil," etc., throughout a very thick zone, and the beds reported as containing oil can not be correlated exactly with beds reported as being oil bearing in a well only a few hundred feet distant. It is probable that the difference in the character of the strata as reported in the logs of the wells is more a difference in the drillers' interpretation of the character of the beds penetrated than an actual difference in the lithology of the beds. So many of the wells in this area have been drilled with rotary tools that the records are especially unreliable, and about all that it is possible to do from these records is to correlate the uppermost beds in the zone containing the productive oil sands. Plate XXIII is therefore rather less satisfactory than the other geologic sections (Pls. XVI–XXII, XXIV–XXXI), particularly those showing Maricopa Flat, and the division of the productive zone into oil sands and barren strata shown in this section is very diagrammatic.

Although the meagerness of the data given by the records of the wells in this area precludes as detailed or accurate an analysis of the character of the productive zone as can be made for other parts of the field, a few general features can be worked out, and these are discussed below.

In the east end of the area along the United anticline the uppermost 100 or 150 feet of the producing zone (the C zone) is composed of alternating sands containing oil and barren clays, possibly 40 or 50 per cent of the whole containing oil. Below this is a thin water sand, underlying which are several irregular oil sands or sands containing gas that make up a zone about 200 feet thick. A second water sand lies just below these oil sands, its top being about 300 or 350 feet below the top of the C zone. About 200 feet below this second water sand is the top of another series of producing oil sands, the lowermost producing oil sands yet encountered, which have yielded oil in several of the wells. These oil sands extend through a zone 100 or perhaps 200 feet thick. Only one well has been drilled for any great distance below these lower oil sands in the C zone, and its log records only water sands below this horizon.

BEDS ABOVE THE PRODUCTIVE ZONE.

So many of the wells here were drilled, at least in part, with rotary tools that the records of the upper parts of the holes are unreliable. Water is not recorded in any well close to the top of the C zone. Gas is reported to occur in many of the wells at various horizons throughout a zone that extends several hundred feet above the top of the C zone and is said to be particularly strong in wells along the crest of the United anticline in the eastern part of the area, at the horizon corresponding to the B zone of the area just to the east. Commercial flows of gas have been obtained in some of the wells from strata at this horizon.

BEDS BELOW THE PRODUCTIVE ZONE.

With a single possible exception no well has been drilled deep enough to enter the underlying diatomaceous Maricopa shale. The deep well was drilled more than 1,400 feet below the top of the C zone, and in the lower 700 feet only water sands and a few sands containing traces of oil and gas were encountered. These beds are apparently deeper than any in which marine fossils typical of the Etchegoin formation have been found, and they may or may not be part of the Maricopa shale. The diatomaceous shale is buried so deeply throughout this area, however, as to make it unprofitable to drill for oil in it, for experience in the parts of the field along the foothills of the main range where the shale lies at shallower depths has shown that oil sands in the shale are very lenticular and that they are usually limited to the axial parts of the anticlines.

WATER SANDS.

Top water.—Water sands are not recorded close to the top of the C zone in the log of any well in this area. Many of the wells, however, were drilled with rotary tools and their water strings were set close to the top of the C zone, so that even though the water sands are not recorded it is possible and indeed probable that they occur pretty well down in the section, for wells drilled in the manner in which most of those in this area have been drilled would not show the position of these top-water sands. The water string has been set near the top of the C zone in so many of the wells that future work in this area will probably follow the same practice.

Edge and bottom water.—Water[1] is recorded below the top of the C zone in sec. 22, on the north flank of the United anticline; in the southern and western parts of sec. 28, on the south flank of that fold; and also in sec. 20, near the west end of the United anticline. In the axial part of the fold in the northeastern part of sec. 28 many of the logs do not record water, yet water is troublesome there, being produced in considerable amount with the oil by many of the wells, and it is probable that many wells in that vicinity have penetrated the water sand, which did not show much if any water when the well first came in.

The wells whose logs record water are so scattered that it is difficult to make out just the position these water sands occupy in the section. It seems, however, that on the north flank of the fold there are two fairly well defined water sands, one lying about 100 or 150 feet below the top of the C zone and the other about 200 feet deeper. Most of the wells in this area derive their oil from the topmost beds in the C zone, and many of them do not penetrate the C zone deeply enough to enter the upper of these two water sands. These sands are shown diagrammatically in Plate XXIII. In this section neither of the two water sands is shown as extending to the crest of the Globe anticline, for although the lower one probably does extend that far its exact position may not be determined from the records of the wells so far drilled. The upper sand may not extend to the axis of the fold but may be an edge-water sand for one of the producing oil sands higher in the fold. Each of the sands, however, is a source of danger to the producing oil sands throughout this area, for even though water may not now occupy the sand along the axial part of the United anticline it certainly will work its way through when the oil is extracted.

[1] See analysis 5, Table 14, and analyses 37, 38, and 39, Table 21, Part II (Prof. Paper 117).

It is not possible to correlate exactly the two water sands described above with the water sands that lie on the south flank of the United anticline. The water sand (shown on Pl. XXIII) that lies low on the south flank of the fold is probably to be correlated with the sand that yields large flows of salt water in sec. 32, T. 31 S., R. 23 E., near the axis of the Midway Valley syncline.

PRODUCTION.

The production of wells in this area varies considerably. In general the wells in the western part of the area, near the structural depression or saddle between the Globe and United anticlines, have not had an initial production of more than a few hundred barrels Wells near the east end of the area in secs. 22, 27, and 28, near the crest of the United anticline, have yielded great quantities of oil flowing several thousand barrels of oil daily when first drilled. The gas pressure in much of this area has now been reduced very greatly, yet the wells drilled in 1916 have flowed several hundred barrels daily, and wells of like capacity can still be obtained.

CHARACTER OF THE OIL.

Near the western edge of the area the oil obtained from the C zone is all of about 20° to 23° Baumé. In the eastern part of the area, the crest of the United anticline, the oil ranges from about 22° to 30° Baumé; the average gravity is about 27° Baumé. There seems to be no regular difference in the gravity of the oil obtained from different parts of the productive zone, the deepest sands yielding oil no lighter than that obtained from the very uppermost sands of that zone. Wells that yield water produce here, as in other parts of the district, somewhat heavier oil than wells that are free from water.

SUGGESTIONS FOR FUTURE WORK.

Originally the B zone evidently contained considerable gas in much if not all of this area. Commercial amounts of gas have been obtained from it in some of the wells, and probably even now some gas might be produced if that zone were systematically prospected. Many of the wells, however, have been drilled to produce oil from only the C zone, and the upper beds—those that make up the B zone, which yields oil and gas in the area just to the southeast—have been cased off with the water string. It is therefore probable that in much of the area, particularly in sec. 28, in which the wells are fairly numerous, the B zone is now occupied by water.

Future work in exploiting this area should be concerned chiefly with the extraction of the oil from the C zone and particularly with the proper handling of the water there. So many of the wells have been drilled several hundred feet below the top of the C zone without making any attempt to ascertain the position of the probable water sands in that zone or to case off portions of the zone in which water might occur that a proper handling of the area will be very difficult. The probable position of the chief water sands is shown on Plate XXIII, and is discussed above.

Deep drilling for possible producing oil sands in the diatomaceous Maricopa shale does not appear very promising, for this shale is buried so deeply that prospecting by the drill for small lenses of oil sand such as are to be expected in it will be very expensive. The wells that have so far been drilled indicate that the producing beds in the McKittrick group (Etchegoin formation) extend 700 feet or so below the top of the C zone. Drilling to that depth below the top of the C zone as shown on Plate III is worth while.

McNEE-McLEOD AREA.

[Southern part of sec. 23, southeastern part of sec. 25, sec. 26, southeastern part of sec. 27, all of sec. 34 except northwest corner, secs. 35 and 36, T. 31 S., R. 23 E.; southwest corner of sec. 31, T. 31 S., R. 24 E.; northwestern part of sec. 1, all of sec. 2 except southwest corner, northeastern part of sec. 3, T. 32 S., R. 23 E.]

LOCATION AND OPERATORS.

The McNee-McLeod area lies in the central part of the Buena Vista Hills, extending northward from the pass that cuts through the hills near the southwest corner of T. 31 S., R. 23 E., and divides the hills into two parts to the highest point in the north half of the Buena Vista Hills. It extends from the center of Midway Valley northeastward across the Buena Vista Hills to the southwestern edge of the Buena Vista Valley. (See geologic sections, Pls. XXIV and XXV.) The companies operating here in 1916 were the Standard, Associated, Union, Kern Trading & Oil, and North American Consolidated.

GEOLOGY.

The chief structural feature in this area is the United anticline, the east end of which occupies the central part of the hills. This part of the anticline is rather different in character from the west end or from the Honolulu anticline, which occupies the southern half of the Buena Vista Hills, for instead of forming a simple arch, the beds in a belt one-half to three-fourths of a mile in width are bent into a number of sharp parallel wrinkles. The difference in the structure in this central part of the Buena Vista Hills may be appreciated readily from an examination of the geologic map (Pl. II) or, still better, from an examination of the underground contour map (Pl. III). These small anticlines and synclines all plunge sharply southeastward to the structural depression or saddle, in the southeast corner of sec. 36, that separates the United and Honolulu anticlines.

At the surface the beds are rather sharply tilted close to the axes of the small folds, dipping in many places, especially along the eastern edge of this closely folded belt, at angles of 30° to 40°. Excellent exposures of the beds in this belt are shown in the sides of the gulch that cuts through the hills near the southeast corner of sec. 36.

All the folds flatten at considerable depth, and beds that are buried 2,000 feet or so are less sharply flexed than the surface beds. However, even at that depth the beds are folded to a noticeable degree, as is shown by the contours drawn on the top of the producing oil zone (Pl. III).

A detail of the structure that is of lesser importance than the main upward folding but is still important in the consideration of the accumulation of oil is the flattening of the dip, or the formation of a structural bench, in the northeast corner of sec. 34 and the northwestern part of sec. 35. As is explained in the section dealing with the structure in the Buena Vista Hills (p. 58), this irregular flattening of the dip is really to be considered, together with a similar flattening in secs. 1 and 6, as the northwestern extension of the Sixteen anticline. The difference in the structure of the surface beds and that of the beds which contain oil is very marked in this part of the area, for the surface beds are bent into a fairly well defined though strongly plunging anticline, whereas the beds at depths of 1,800 to 2,000 feet show only irregular flattening or benching.

OIL SANDS.

As in the other parts of the Buena Vista Hills the producing oil sands in this area lie entirely within the Etchegoin formation but not at the base of that formation. It is probable that no well has yet penetrated all the Etchegoin formation, for fossiliferous beds have been found at depths of 350 feet below the top of the C zone. The stratigraphically deepest wells have penetrated beds that lie 500 or 600 feet below the top of the C zone. The lowest beds encountered in zone C are not fossiliferous, but to judge from the results obtained in the deep wells in the area just west of this one these beds are also part of the Etchegoin formation.

The uppermost producing sands in this area are correlated with the B zone of the foothill area west of Taft. This correlation is exceedingly rough, for the beds may not lie at precisely the same horizon, but they lie at approximately the same distance above the top of the C zone, which affords the only basis for correlation across the Midway Valley syncline. Below the top of the B zone oil sands have been encountered at various positions in a zone some 800 feet thick. Very few of the wells penetrate all of this zone, and most of them, particularly those that were drilled first, derive their oil from beds that lie no more than 200 or 300 feet below the top of the B zone.

It is very difficult to make any exact division of this producing zone into two parts which may be correlated with the B and C zones, for it is only along the outer edge—that is, away from the main closely folded belt near the axis of the United anticline—that the upper sands (the B zone) become dry or contain water, and the chief productive sands lie in the lower or C zone.

In sec. 36 all the folds plunge strongly toward the southeast, and in this part of the area the upper or B zone contains oil. Northwestward from sec. 36 the B zone contains less and less oil and more and more gas. A very instructive section is given by the wells drilled along the axis of the most easterly of the anticlines in the closely folded belt—that is, the fold that cuts through the center of sec. 26 and plunges beneath the Buena Vista Valley near the center of the east line of sec. 36. The sands that have yielded gas in great amounts in sec. 26 appear to be the sands that contain oil lower on the plunge of the fold in secs. 25 and 36. The same tendency for gas to occupy the sands high on the anticline is shown by the sands where they lie along the axial part of the main or United anticline, which passes almost exactly through the northwest corner of sec. 36. Even the sands which form the uppermost part of the lower or C zone appear to contain much more gas and less oil in sec. 26 than down the plunge of the fold in sec. 36.

The relation of the large producing wells in this area to the structure is very interesting, for the large flowing wells obtained by the Standard Oil Co. in sec. 36 appear to have no very definite relation to the several small folds, large wells being obtained alike in the centers of the small synclines or along the crests of the small anticlines. The relation noted in the paragraphs just preceding between the oil sands low on the plunge of the folds and the gas sands higher on the folds seems to be the chief effect of the smaller structural features on the accumulation of oil.

BEDS ABOVE THE PRODUCING OIL SANDS.

Practically no well in this area, according to the record, found water close to the top of the B zone. Many of the wells, however, were drilled with rotary tools, no record being kept of the water sands above the point at which the water string was set, and it is probable that water occurs pretty close to the top of the B zone. The practice of setting the water string close to the top of the oil sands has been followed so long that it is probable that the gas sands lying above the top of the B zone can not be handled commercially at present except perhaps in certain parts of the field where there are only a few wells. These sands were of course mudded off in most wells, but it is rather to be doubted whether the gas sands can ever be artificially so completely sealed as to retain the gas perfectly.

In many of the wells, particularly those in sec. 26, gas was noted 200 to 300 feet above the top of the B zone, and some of the wells have yielded commercial amounts of gas from beds at about this horizon. The attempt has been made to produce gas in only one or two of the wells down the plunge of the fold, for in most of the wells gas is not recorded as being especially strong there.

WATER SANDS.

Top water.—Only a single log has recorded water fairly close to the top of the B zone. In this log a small water sand is recorded about 350 feet above the top of that zone. Many of the wells have been drilled with rotary tools, and no record has been kept of the upper water sands, but it is probable that water actually occurs close above the B zone in much of the area, just as it does in other areas in the Midway district. There should, however, be no trouble in casing off the top water by setting the water string fairly close to the top of the B zone.

Bottom or edge water.—Records of the wells that have been drilled here are surprisingly free from any mention of water with the oil sands. Farther northwest along the United anticline water is noted at two or more horizons within the C zone, the B zone there not being productive of oil. Very little water, however, is recorded in the logs of the deep wells which have been drilled near the point where the United anticline plunges southward, in the central parts of secs. 26 and 36. On the west side of the Midway Valley syncline very strong flows of water are obtained from a sand that lies 100 feet or so below the top of the C zone, and this water sand has given a great deal of trouble in sec. 32, T. 31 S., R. 23 E. Its approximate position is shown on Plate XXIV, and in more detail on Plates XIX–XXI. It may be that water does not actually occupy the sand at this horizon on the east side of the Midway Valley syncline, but as soon as the oil which now occupies that sand is removed the water will move eastward across the syncline and sooner or later appear in the wells that produce oil from the C zone in that part of the area.

Too few wells have yet been drilled in the southwestern part of the area here discussed—that is, near the axis of the Midway Valley syncline—to permit any definite statements regarding the occurrence of water in the B zone.[1] From the conditions which prevail on the west side of the syncline it seems almost certain that

[1] See analysis 43, Table 22, Part II (Prof. Paper 117).

the B zone is now and was originally occupied by water near the central part of the valley, well down toward the axis of the Midway Valley syncline. The wells that now depend upon the B zone—certain wells in secs. 35, 36, and 2—will probably be troubled by edge water working eastward.

In a similar way water which lies 100 feet or so below the top of the C zone in sec. 32 will probably work eastward and appear in the wells near the southeast corner of T. 31 S., R. 23 E. The approximate position of this water sand is indicated on Plate XXIV.

The lack of water in sands interdigited with the oil sands in this part of the area is remarkable when this area is compared with other parts of the Midway Valley field, especially with Maricopa Flat. So many wells have been drilled without yielding much if any water with the oil that the original absence of such water seems to be pretty well established. The fact is evident, however, that water occurs in the producing zone both near the center of the Midway Valley syncline and on the west flank of that syncline. With the extraction of oil from the area along the United anticline this water is bound to work eastward and sooner or later to appear in the producing wells.

Only three or four logs have recorded water in the C zone in this area. The water they record lies 200 to 400 feet below the top of the B zone and thus in a measure corresponds in position to the big water sand on the west flank of the Midway Valley syncline in sec. 32, T. 31 S., R. 23 E. The wells whose logs record this sand lie on the east side of the closely folded belt near the south end of the United anticline, however, and the wells between these wells which have found water and the Midway Valley syncline did not find water at this horizon. Therefore no definite correlation can be made between the water sands in the two areas.

PRODUCTION.

Many of the wells in this area had an exceptionally high production when first brought in, the initial rating of more than twenty of them being 1,000 barrels or more a day. An indication of the richness of this part of the district is shown by the record of production from sec. 36. According to the published statement of the Standard Oil Co.[1] that section had produced prior to March 1, 1915, more than 10,000,000 barrels of oil, and at that time the daily production was about 11,500 barrels. The daily production has decreased somewhat, but up to July 1, 1917, the section had probably produced at least 7,000,000 barrels more oil.

[1] Standard Oil Bull., vol. 2, No. 11, March, 1915.

CHARACTER OF THE OIL.

The oil in this area ranges in gravity from about 24° to a little more than 30° Baumé. There seems to be a slight difference in gravity of oil obtained from the B zone and that obtained from the C zone. The difference, however, is most marked in the outer edge of the belt in which the B zone is productive, for there the B zone contains heavier oil than it does near the axial part of the anticline. The fact that the oil is heavier in that part of the area is probably due to the presence of edge water in the immediate vicinity. Although the difference in gravity of the oil is slight, it is usually a pretty fair guide, even in the axial part of the United anticline, as to the sand from which the oil is derived, for oil heavier than 25° Baumé is pretty certain to come from the B zone.

SUGGESTIONS FOR FUTURE WORK.

This area is one of the richest in the whole district, many of the wells here having had an initial production of thousands of barrels daily. Part of the area, including sec. 36 and the parts of the sections bordering it on the north, west, and south, is now so thoroughly drilled that the gas pressure is evidently greatly reduced, and, although some of the wells drilled in 1917 flowed more than 1,000 barrels a day at first, it is not to be expected that so many large wells will be obtained here in future. It is safe, however, to predict that a very great many of the wells to be drilled in this area will have an initial production of several hundred barrels daily. The producing sand is so thick here that the wells are fairly long-lived.

The chief trouble to be expected here is the working eastward of edge water in both the B and C zones. This is discussed in some detail in the section describing the water sands (p. 156). This water can be handled properly only after a careful study is made of the history of the individual wells, and a systematic record kept of the percentage of water made by each well. Sooner or later water will flood out the western part of the area and gradually work eastward up the dip to the axial part of the United anticline. Methods of retarding the movement of this water or perhaps temporarily halting it can be worked out only if such a record is available.

No well has yet reached the diatomaceous Maricopa shale, and that shale must lie buried beneath more than 3,000 feet of later Tertiary deposits. Prospecting for lenses of oil sands in the shale is therefore not a very promising commercial venture, for it means very deep drilling. The upper sands, however, are so filled with oil and the upward folding here is so pronounced that it would seem that the chances for the occurrence of oil in the underlying shale are fairly good.

In other areas along the west side of San Joaquin Valley the diatomaceous shale has yielded oil in areas where it is strongly folded and has usually proved to be barren of oil where folding is more moderate. In other words, the producing sands or lenses in the diatomaceous shale seem to be more closely limited to the axial parts of the anticline than the productive oil sands in the later Tertiary beds.

SOUTH HALF OF BUENA VISTA HILLS.

[South edges of secs. 31 to 34, T. 31 S., R. 24 E.; southeastern part of sec. 1, northeastern part of sec. 12, T. 32 S., R. 23 E.; southwestern part of sec. 1, secs. 2 to 6, all but southwest corner of sec. 7, secs. 8 to 16, all but southwest corner sec. 17, northeast corner of sec. 18, northeastern part of sec. 21, all but south edge of sec. 22, northern part of sec. 23, northwestern part of sec. 24, T. 32 S., R. 24 E.]

LOCATION AND OPERATORS.

The portion of the Buena Vista Hills lying south of the pass which cuts through the hills near the southeast corner of T. 31 S., R. 23 E., extends from the center of Midway Valley on the southwest to the edge of Buena Vista Valley on the northeast and to Buena Vista Lake on the east. (See geologic section, Pl. XXVI.) The companies operating here in 1916 were the Honolulu, St. Helens, Boston Pacific, General Petroleum, Standard, Kern Trading & Oil, Northern Exploration, Petroleum Midway (Ltd.), Maricopa Investment, Schultz, and Luxor.

GEOLOGY.

This area occupies the south half of the more southerly of the two zones of upward folding that form the Buena Vista Hills. (See p. 59.) The folding here is much more regular and simple than in the southeast corner of T. 31 S., R. 23 E., just to the north, for the beds are bent into a broad and regular elongated dome, with only a single small fold—the Sixteen anticline—to break its regularity. The main fold, the Honolulu anticline, is flat-topped and in cross section along a northeastward-trending line appears as a low arch. (See fig. 8.) The central part of the arch, where the beds dip at low angles, usually less than 5°, forms a belt a mile or two in width. Near the east end of the fold the central belt of low dip is rather sharply outlined along a line that extends from the vicinity of the center of sec. 4 to the southeast corner of sec. 2. South of this line the beds dip at very moderate angles, usually less than 5°; north of it they dip usually 10° to 15°. On the south flank of the anticline the change in dip is not so well marked except near the northwest corner of sec. 7.

The Honolulu anticline plunges very abruptly northwestward from the center of sec. 6 to the structural depression or saddle in the SE. ¼ sec. 36, T. 31 S., R. 23 E., which separates the Honolulu and United anticlines. It plunges eastward from the west line of sec. 10 at a very moderate angle, about 2° to 5°. Between these two points the crest of the fold is approximately level.

In the south flank of the Honolulu anticline there is one main structural irregularity. This is the Sixteen anticline, which is shown on Plate II as extending from the northeast corner of sec. 16, T. 32 S., R. 24 E., northwestward into sec. 2, T. 32 S., R. 23 E. This fold is not traceable throughout this distance, even in the surface beds, for the topographic depression in sec. 8 prevents the recognition of a connection between the anticline in secs. 1 and 2 and that in sec. 16, but it is probable that in the surface beds these two folds are connected. The oil sands are, however, bent into an anticline only in sec. 16, for northwestward from that locality the fold is expressed simply by a flattening of the dip and the formation of a structural bench or terrace. The difference in the structure of the beds that are exposed and the oil-bearing sands, which are buried 2,000 to 3,000 feet, may be appreciated by comparing the map showing the areal geology (Pl. II) and the map showing the structure of the oil sands (Pl. III). The structural depression or syncline that separates the Sixteen anticline from the larger Honolulu anticline on the northeast is very shallow, and for all practical purposes the beds may be considered as horizontal between the axes of the two anticlines.

OIL SANDS.

In this area, as in the north half of the Buena Vista Hills, the producing oil sands lie in the Etchegoin formation, for beds containing fossils typical of the Etchegoin are encountered 700 feet above the top of the C zone. The oil sands do not, however, lie at the base of that formation, for beds containing Etchegoin fossils have been found in the central part of the area 700 feet below the top of the B zone and at the very east end of the Buena Vista Hills more than 1,000 feet below the top of the zone, which is productive in the central part of the hills—that is, the B zone.

The maximum thickness of the zone containing productive oil sands so far developed is about 700 feet. This thickness of the producing sands has been penetrated in the central part of the hills. The uppermost producing sand that has a considerable areal extent has been considered as the top of the B zone, and its position is shown on the map (Pl. III). In certain parts of the area, particularly along the crest of the Sixteen anticline, sands or lenses containing oil are reported 100 or 150 feet above the top of the B zone, and a few wells have produced some oil from such lenses. These sands are shown diagrammatically in the geologic section (Pl. XXVI).

On the flanks of the main fold the B zone is dry or contains gas in moderate or small amounts but no oil. The part of the fold beneath which the B zone is productive is contained approximately in the area described above as the central belt of low dip along the axis of the fold.

The beds mapped as the C zone are here somewhat closer to the B zone than in other parts of the area, the distance between the top of the B zone and the top of the C zone being usually only 150 to 200 feet.

BEDS ABOVE THE PRODUCTIVE ZONE.

The beds 100 to 200 feet thick that rest upon the productive B zone in the central part of the Honolulu anticline contain much gas under pressure—reported as originally 1,000 to 1,500 pounds to the square inch in many of the wells. In places this zone contains irregular lenses of sand saturated with oil, but most of the wells which produce from this part of the section yield only dry gas. Besides the gas which occurs in this zone gas is obtained in other sands that are scattered throughout the upper part of the section. These sands are extremely lenticular, and it is difficult or impossible from the data furnished by the well logs to follow any of the gas sands over much of the area. The uppermost gas sand noted lies only about 400 to 500 feet below the surface and was encountered in several wells, notably in Standard Oil Co. well No. 1, in sec. 16, and Honolulu Consolidated well No. 3, in sec. 8. This sand is not under high pressure, however, and, although the Standard well is said to have made about 65,000,000 cubic feet of gas daily, the pressure was only 24 pounds to the square inch, and the gas was soon exhausted.

BEDS BELOW THE PRODUCTIVE ZONE.

It is doubtful whether any of the wells drilled in this area have completely penetrated the Etchegoin formation and entered the underlying Maricopa shale. The two deepest wells in the central part of the area penetrated beds only 200 feet stratigraphically lower than the lowest beds in which Etchegoin fossils have been reported. The lowest beds may or may not be part of the Maricopa shale.

WATER SANDS.

Top water.—Top water is not reported in any of the area close to the top of the B zone. The lowest top-water sand of which a reliable record is available lies about 300 feet above the top of the B zone,[1] and this is slightly above the top of the zone containing dry gas.

Bottom water.—On the north flank of the anticline a strong flow of water was encountered in some of the wells about 200 or 250 feet below the top of the C zone.[1] Water occupying a similar stratigraphic position was encountered in certain of the wells in the axial part of the Honolulu anticline, close to the point where the axis of that fold plunges eastward. Water is also reported to occur in this area last described at approximately the horizon occupied by the top of the C zone.[1] Along the axis of the Sixteen anticline water has been encountered in one well about 250 feet below the top of the C zone, but other wells along this anticline have penetrated the section much

[1] See analyses 45-48, Table 22, Part II (Prof. Paper 117).

more deeply, and their logs do not record water. It may be that this water sand is very lenticular, but its occurrence at so many points in this part of the Buena Vista Hills indicates that it is more probably fairly persistent, or at least that there are a number of lenses at this horizon and that wells which penetrate the C zone more deeply than 200 feet should use particular care in testing for water at approximately 200 to 300 feet below the top of the C zone. (See Pl. XLV, *A*, *B*.)

PRODUCTION.

The original production of many of the wells in this area has been large, for at least 24 of them have an initial daily production of more than 1,000 barrels, and a somewhat greater number have produced at first between 400 and 1,000 barrels. The two best producing wells in this area are Honolulu well No. 1, in sec. 8, T. 32 S., R. 24 E., and Kern Trading & Oil Co. well No. 25, in sec. 1, T. 32 S., R. 23 E. The Honolulu well commenced producing in October, 1911, and according to reports in the press yielded at first 5,000 barrels or more daily and during the first few months averaged about 2,000 barrels. This well is said to have produced continuously at a rate of 900 to 1,000 barrels daily up to at least January, 1916, and probably somewhat later. The Kern Trading & Oil Co. well was brought in some time in January, 1916, and is said to have produced at a rate of 5,000 or 6,000 barrels daily during the first 30 days. Its daily rating continued to be more than 2,000 barrels during the next 18 months. These two wells are, of course, exceptionally large and steady producers, but other wells that yielded a very large amount of oil daily have likewise shown a low rate of decrease.

Many of the wells in the south half of the Buena Vista Hills have been drilled only to the gas sands that overlie the B zone, and these wells produce dry gas. It is chiefly from these wells and from the wells in secs. 22 and 26, T. 31 S., R. 23 E., in the north half of the Buena Vista Hills, that the line supplying Los Angeles derived its gas in 1916.

CHARACTER OF THE OIL.

The oil obtained from the uppermost part of the productive zone—that is, the B zone—is slightly heavier than that obtained from the lower sands of the C zone. Wells producing from the B zone yield oil of 22° to 27° Baumé. Wells producing entirely from the C zone yield oil that ranges from about 25° to a little more than 31° Baumé. Most of the wells produce oil from both zones, and the mixed oil is usually of less than 30° Baumé.

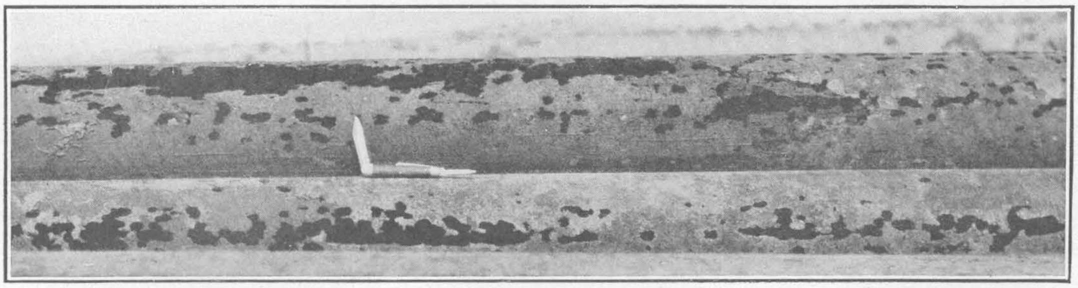
There is considerable variation in the method of handling the wells, and the gravity of the oil produced appears to vary somewhat with the method of production—for example, according to whether or not the oil has run through gas traps. Even the pressure maintained in the gas trap appears to have some effect upon the gravity of the oil.

SUGGESTIONS FOR FUTURE WORK.

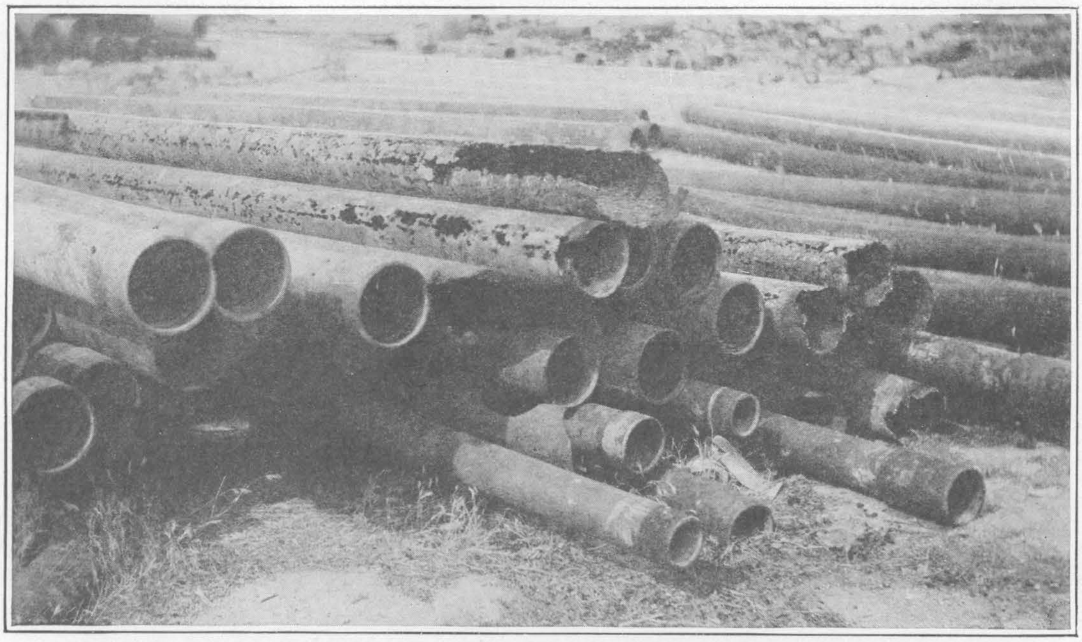
This area contains greater reserves of petroleum than any other part of the Midway district, and although wells are fairly thick in certain portions of it—for instance, in sec. 16—most of the area is still (1917) sparsely drilled. Fortunately this part of the field is now in the hands of large operating companies, and it will be possible, if the legal status of the lands is settled within a reasonable time, to formulate and follow some rational policy of development.

The drilling which has so far been done shows that a zone some 700 feet thick, the upper part of which is mapped in Plate III as the B zone, contains productive oil sands. Water has been found in this zone at one or two places—on the north flank of the Honolulu anticline, near its east end, and in at least one well along the Sixteen anticline. This water lies approximately 600 feet below the top of the B zone. Although it has not been recognized in many of the wells that have been drilled to a greater depth, any well which goes deeper than 600 feet below the top of the B zone should test the sands carefully at that horizon for water. No well has yet gone through the Etchegoin formation and entered the diatomaceous Maricopa shale, and until that shale is reached the full thickness of the upper productive zone is not penetrated. Down the plunge of the anticline the deep wells of the Pyramid Oil Co. have not passed through the entire thickness of the Etchegoin, but they have shown that the measures which contain oil higher on the fold are in this part of the area dry or contain only gas.

Future work in this area should be concerned chiefly with the efficient draining of the oil and gas sands so far recognized. Many of



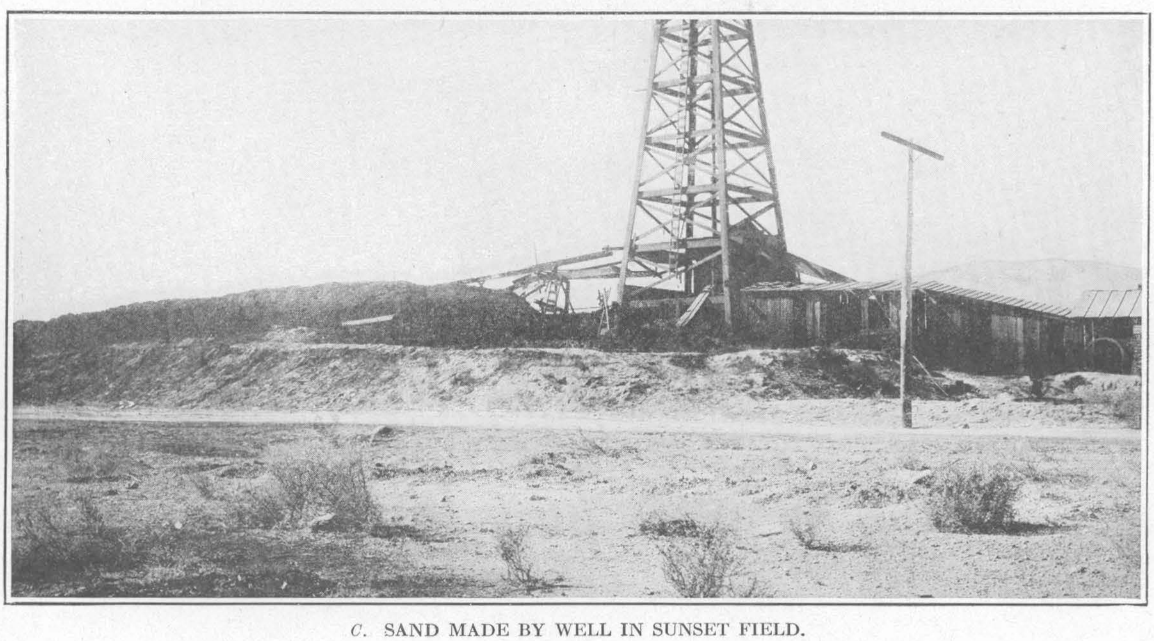
A.



B.

A, B. CASING CORRODED BY WATER IN MIDWAY OIL FIELD.

This casing was pulled from a well of the Honolulu Consolidated Oil Co. in the Buena Vista Hills. It had been in the well only about four years. Photographs by G. S. Rogers.



C. SAND MADE BY WELL IN SUNSET FIELD.

Well No. 13 of Adeline Consolidated Oil Co. View taken in October, 1908. Sand estimated to be about 110,000 cubic feet. Photograph by Ralph Arnold.

the operators disregard the gas sands that lie just above the B zone, but as those sands are capable of yielding a very considerable amount of gas they should be exploited. The Honolulu Consolidated and Kern Trading & Oil companies are doing this in parts of the area. Along the axial part of the fold the B zone is productive, but down the flank of the fold this zone probably contains water, although there is no record of it in the well logs, and away from the axial part of the fold the C zone must be regarded as the probable productive zone. It is probable that the area lying on the flat top of the dome contains most of the really productive oil land and that the area from which much oil will be obtained lies within the area shown by contours on Plate III.

In this area, where the structure is so well marked and so regular, it is probable that the underlying diatomaceous Maricopa shale is also strongly folded. It is along just such strong folds as these that in other areas, notably in the Belridge-Lost Hills district, sandy lenses in the diatomaceous shale contain commercial amounts of oil. When the sands in the Midway district that form the upper productive zone—that is, the sands in the Etchegoin formation—are drained, it will probably be found profitable to prospect the underlying diatomaceous shale along the Honolulu anticline. Such prospecting must, however, await the time when the price of oil is higher than at present and when the operators are prepared to take greater risks, for drilling for isolated lenses in the shale will always be costly, as the relative number of dry holes will be much larger than when drilling is done only for the upper and more sheetlike sand of the Etchegoin.

SOUTHEASTERN PART OF T. 32 S., R. 24 E., AND OUTSKIRTS OF MARICOPA FLAT.

Several deep wells, none of which have obtained commercial amounts of oil, have been drilled in the southeastern part of T. 32 S., R. 24 E., in the western part of T. 32 S., R. 25 E., at the edge of the Buena Vista Hills; and in Maricopa Flat east and south of the Thirty-five anticline. Some of these wells have been drilled deep enough to give the area a pretty thorough test; but others, although deep, have not been drilled deep enough to reach sands that may possibly contain oil.

The wells of chief importance here are those of the Pyramid Co. in sec. 18, T. 32 S., R. 25 E; the Lakeview Annex in sec. 26, the Lakeview No. 2 Co. in sec. 26, and the Golden Gate Co. in sec. 36, T. 32 S., R. 24 E.; the Comstock Crude in sec. 34, T. 12 N., R. 23 W.; the El Camino in sec. 10, and the Bronco, Maricopa Producers, and Sunset Extension in sec. 8, T. 11 N., R. 23 W. These wells are all situated low on the structural features that control the accumulation of oil in this part of the field—the Honolulu and Thirty-five anticlines—and on the flank of the main range southeast of Sunset.

It is impossible to predict, from a consideration of the structure alone, the location of the boundaries of the area about one of these anticlines beneath which the sands contain commercial amounts of oil, for it is only by drilling that the limits of this area may be ascertained. It is possible, however, to indicate certain general features governing the occurrence of oil in this area which may be of service in guiding test drilling. In considering the possible occurrence of oil in areas low on the flanks of these anticlines or near the axes of synclines it should always be remembered that the sands underlying such areas are deeper than those underlying areas along the axes of the anticlines, not only because the dip carries the beds that contain oil along the anticlines to greater and greater depths toward the axes of the synclines, but also because of the fact that the oil, if present in the synclines, occurs in sands that are stratigraphically lower than the sands which contain oil along the anticlines. This fact, which has been mentioned again and again in the preceding pages, is excellently shown in Maricopa Flat, in sec. 32, T. 12 N., R. 23 W. Even a cursory examination of the structural sections (Pls. XXVIII–XXX) will enable the reader to understand the general position of the oil sands in the different parts of the folds.

In the southeastern part of T. 32 S., R. 24 E., to judge from the results obtained in wells along the south edge of the Buena Vista Hills and those northeast of Kerto, the upper sand—the B zone, which is contoured on Plate III—is dry or is occupied by water, and oil, if it underlies this area, is to be expected only from sands that lie below the top of the C zone, which is shown by contours for the south end of the

Buena Vista Hills, or below the flowing-water sand that underlies Maricopa Flat.

Two of the wells in this area have been drilled about 500 or 600 feet below what appears to be the top of the C zone but have not found commercial amounts of oil. Neither have they completely penetrated the Etchegoin formation, for in the stratigraphically deeper of the two wells fossils are reported in the lowest beds penetrated. The well of the Golden Gate Co. in sec. 36 is of interest, as it lies fairly close to the highly productive part of Maricopa Flat. This well is said to have been drilled to a depth of a little more than 4,000 feet. Apparently it was not drilled deep enough to reach the sands that underlie the big flowing-water sand in sec. 32. It shows, however, that the upper sand—the B zone, contoured on Plate III—is dry in this part of the area.

The well of the El Camino Co. in sec. 10, T. 11 N., R. 23 W., is said to have been drilled to a depth of 4,800 feet. This well is directly in line with the continuation of the Thirty-five anticline and therefore should give some idea as to the extent of the productive area along that fold. If the anticline continues to plunge southeastward at the rate it plunges in sec. 4, the top of the B zone should lie at a depth of about 3,200 feet—about 1,000 feet deeper than it lies near the center of sec. 4. It is to be expected that this upper sand is dry so far down the plunge of the anticline, and that if oil occurs here it is in sands equivalent to those which underlie the sand that yields flowing water in secs. 4 and 32—that is, in sands lying more than 500 feet below the top of the B zone. This well has apparently been drilled deep enough to test the most promising sands if the structure is regular between secs. 4 and 10. It is quite possible, however, that the fault which trends northeastward along Cienaga Canyon continues this far to the northeast and, interrupting the regularity of the structure, upsets the above calculation.

The wells in sec. 8, T. 11 N., R. 23 W., have apparently been drilled deep enough to encounter the upper sand which is productive in Maricopa Flat (the B zone). The succession of beds penetrated by these wells below this sand believed to be the equivalent of the top of the B zone resembles closely the succession of beds penetrated by the wells in the vicinity of the town of Maricopa, which have entered the Maricopa shale. The log of one of the wells in sec. 8, however, reports fossil shells at a depth of about 900 feet below the oil sand believed to mark the top of the B zone. Were it not for this reported occurrence of fossils it would appear probable that these lower beds are actually part of the Maricopa shale, and that the overlying McKittrick group is wedged out rather abruptly in this direction just as it is wedged out toward the west along the axis of the Thirty-five anticline. Most of the wells in sec. 8 have encountered heavy flows of saline water below the oily beds marking the top of the B zone. The beds in the B zone here do not appear to contain oil in commercial amounts.

AREAS ADJACENT TO THE SUNSET-MIDWAY FIELD.

Certain areas lying within the region covered by the geologic map (Pl. II) but mainly outside the part of that region shown on the detailed map of the Sunset-Midway field (Pl. III) are prospective oil lands, but these areas are either still to be tested by the drill or are at present so sparsely drilled that as detailed an analysis of the character and position of the productive oil lands as is given in the preceding description of the productive fields can not be given for them. The following paragraphs discuss the prospective value of these lands as judged chiefly from a consideration of the geologic structure as interpreted from the examination of the surface exposures.

ELK HILLS.

GEOLOGY.

Broadly considered the structure of the Elk Hills is that of an anticline or dome, the highest part or axis of which trends southeastward from the vicinity of McKittrick to the north end of Buena Vista Lake, passing through the highest part of the hills. In reality the structure is not that of a single fold, for there are a number of anticlines and synclines, but most of these folds are small and probably not deep, and so far as the accumulation of oil is concerned the effect of all of them taken together is essentially the same as that of a single large upward fold. The central part of the area which this group of folds occupies—in other words, the central part of the Elk Hills—is structurally the most favorable part for the accumulation of oil. The location of this most favorable area may be described roughly by saying that it forms a belt that extends for a distance of a mile or so on each side of a line drawn from the vicinity of the southeast corner of sec. 34, T. 30 S., R. 24 E., northwestward to the vicinity of the center of the south line of sec. 21, T. 30 S., R. 23 E. The area thus described does not necessarily include all the prospective oil land, but it is structurally the most promising part of the field and should be the part first to be tested.

The producing oil sands in the Elk Hills lie in the Etchegoin formation and probably, like the oil sands in the Buena Vista Hills, are scattered through a zone several hundred feet thick. Also as in the Buena Vista Hills the zone containing these oil sands is not necessarily at the base of the Etchegoin, for it seems probable that the sands which have yielded most of the oil in the Elk Hills lie several hundred feet above the top of the diatomaceous shale that underlies the Etchegoin.

The wells in the central part of the hills start in the Paso Robles formation stratigraphically 1,000 feet below the uppermost Paso Robles beds that are exposed in the edge of the hills. Fresh-water fossils are reported to have been found in these wells at a depth of about 1,300 feet, below which lie 1,000 feet of beds from which no fossils have been obtained and which may be either part of the Etchegoin or part of the Paso Robles. At a depth of about 2,400 feet Etchegoin fossils have been obtained. From the data available it appears that no well so far drilled in the Elk Hills has completely penetrated the Etchegoin and entered the underlying Maricopa shale.

WELLS DRILLED.

The following wells have been drilled in the Elk Hills. These wells are chiefly on the south slope and along the higher parts of the hills, in the belt noted above as being structurally the most favorable for the accumulation of oil.

Wells drilled in the Elk Hills.

Location.				Company.	Well No.	Depth (feet).
Quarter.	Section.	Township.	Range.			
SE.	20	30	23	Scottish Oilfields Co.		4,005
NE.	22	30	23	Associated Oil Co.	1	1,480
SW.	22	30	23	.....do.	3	2,980
SE.	22	30	23	.....do.	4	1,185
NE.	24	30	23	.....do.	1	70
NW.	24	30	23	.....do.	2	1,291
SW.	24	30	23	.....do.	3	3,887
SE.	24	30	23	.....do.	4	1,187
SW.	26	30	23	.....do.	1	4,030
NW.	26	30	23	.....do.	2	332
NE.	26	30	23	.....do.	3	518
SE.	26	30	23	.....do.	4	460
SW.	28	30	23	Hillcrest Oil Co.	1	1,670
NE.	30	30	23	Redlands Oil Co.	1	2,850
SW.	32	30	23	Midway Pacific Oil Co.	1	2,450
SW.	30	30	24	Associated Oil Co.	1	3,836
SE.	1	31	23	F. J. Carmen.	1	745
SE.	2	31	23	Combination Midway Co.	1	1,845
NE.	10	31	23	Mercedes Oil Co.	1	1,800?
SE.	11	31	23	Hart Oil Co.	2	2,100±
NE.	13	31	23	.....do.	1	3,650±
SW.	14	31	23	Barnodon Oil Co.	1	3,208
SE.	2	31	24	East Midway Oil Co.		1,315
SE.	3	31	24	Elk Hills Midway Co.	1	1,415
SW.	4	31	24	Green & Hutchinson.	1	2,595
SE.	4	31	24	Section 4 Oil Co., or Potter, Reed & Taylor.		1,400?
NE.	5	31	24	Associated Oil Co.	1	2,128
NE.	7	31	24	Elk Hills Oil Co.	1	3,960
NE.	8	31	24	.....do.	1	2,260
SW.	9	31	24	.....do.	1	1,200?
NW.	10	31	24	General Petroleum Co.	1	3,072
SE.	11	31	24	Monsoon Oil Co.	1	1,205
NW.	12	31	24	Midway Valley Oil Co.	1	4,850
NE.	18	31	24	Kern Midway Oil Co.	2	1,860
SE.	18	31	24	.....do.	1	250

Of these wells only a few have been drilled deep enough to give the area an adequate test. The deep wells are listed below in three groups—(1) those which are along the belt most favorable structurally for the accumulation of oil and which have obtained oil (2) one which has been drilled along this same belt but did not obtain oil, and (3) those which are not in the most favorable area. None of the wells in this third group has obtained oil.

Group 1:
- SW. ¼ sec. 24, T. 30 S., R. 23 E., Associated Oil Co. well No. 3.
- SW. ¼ sec. 26, T. 30 S., R. 23 E., Associated Oil Co. well No. 1.
- SW. ¼ sec. 30, T. 30 S., R. 24 E., Associated Oil Co. well No. 1.

Group 2:
- SE. ¼ sec. 20, T. 30 S., R. 23 E., Scottish Oil Fields well.

Group 3:
- NE. ¼ sec. 7, T. 31 S., R. 24 E., Elk Hills Oil Co. well No. 1.
- NW. ¼ sec. 12, T. 31 S., R. 24 E., Midway Valley Oil Co. well No. 1.

It is possible that Hart well No. 1 in the NE. ¼ sec. 13, T. 31 S., R. 23 E., and General Petroleum well No. 1, in the NW. ¼ sec. 10, T. 31 S., R. 24 E., should be included in the third group, but it is not certain that they were drilled deep enough to reach the horizon at which the Associated Oil wells encountered oil.

The three wells listed above in group 1 have obtained considerable amounts of oil. In the testimony submitted in the suit involving the lands in the Elk Hills patented to the Southern Pacific Co., the Associated Oil Co. admitted the following production from these wells:

	Barrels.
Well No. 3, sec. 24, T. 30 S., R. 23 E.	3,602
Well No. 1, sec. 26, T. 30 S., R. 23 E.	4,074
Well No. 1, sec. 30, T. 30 S., R. 24 E.	2,265
	9,941

In the same case other testimony was submitted to show that the amount of oil produced was somewhat greater than this.

Below are the logs and history of two of the Associated wells in the Elk Hills. These records are abstracted from the testimony given by officers of the Associated Oil Co. in the suit mentioned above.

Log of Associated Oil Co.'s wells in the Elk Hills.

[From daily drilling reports.]

Well No. 1, sec. 30, T. 30 S., R. 24 E.

Feet.	
	Started July 29, 1914.
0– 130	Surface.
130– 152	Brown sandy shale.
152– 186	Blue sandy shale.
186– 230	Blue sand.
230– 300	Blue sandy shale.
300– 315	Blue clay. Small amount of gas evident.
315– 390	Blue sandy shale. 344–390, small amount of gas evident.
390– 415	Sand. Some gas.
415– 455	Blue clay. Landed 431 feet of 16-inch S. P.
455– 472	Blue clay.
472– 515	Blue sandy shale.
515– 520	Sand. Gas.
520– 565	Blue sandy shale.
565– 572	Sand.
572– 600	Blue clay.
600– 605	Hard sand rock.
605– 665	Blue clay.
665– 712	Hard rock.
712– 775	Blue clay.
775– 800	Shell.
800– 805	Blue clay.
805– 808	Shell.
808– 860	Blue clay.
860– 865	Shell.
865– 990	Blue clay.
990–1,105	Blue shale.
1,105–1,140	Blue clay. Landed 12½-inch at 1,129.
1,140–1,150	Blue clay.
1,150–1,208	Blue shale.
1,208–1,280	Blue clay.
1,280–1,285	Blue shale.
1,285–1,290	Shell.
1,290–1,310	Blue shale. Lost bailer, tried to drill up; finally shot it.
1,310–1,323	Blue shale and iron. Pulled 10 inches and rigged up for rotary at 1,323. Took from December 11, 1910, to March 25, 1911, to get ready for starting with rotary.
1,323–1,412	Blue shale.
1,412–1,417	Rock.
1,417–1,503	Blue clay.
1,503–1,509	Rock.
1,509–1,726	Blue shale.
1,726–1,730	Blue clay.
1,730–1,800	Blue shale.
1,800–1,849	Blue clay.
1,849–1,853	Shell.
1,853–1,868	Blue shale.
1,868–1,880	Blue clay.
1,880–1,989	Blue shale.
1,989–2,002	Blue clay.
2,002–2,005	Shell.
2,005–2,023	Blue clay.
2,023–2,066	Clay and boulders.
2,066–2,100	Sand rock.
2,100–2,125	Blue shale.
2,125–2,200	Shale and boulders.

Feet.	
2,200–2,275	Blue clay.
2,275–2,280	Hard shale.
2,280–2,300	Blue shale.
2,300–2,338	Hard blue shale.
2,338–2,340	Blue clay.
2,340–2,390	Hard blue shale.
2,390–2,408	Hard sand shell.
2,408–2,416	Hard blue clay.
2,416–2,423	Blue clay.
2,423–2,426	Hard brown shale and sea shells. Must be blue shale.
2,426–2,440	Hard brown shale.
2,440–2,452	Blue shale.
2,452–2,458	Sand shell.
2,458–2,465	Brown shale.
2,465–2,470	Blue shale.
2,470–2,471	Hard sandy shale showing light oil and gas.
2,471–2,508	Blue shale.
2,508–2,580	Hard blue shale. Very gritty, 2,520–2,529. At 2,580 reduced size of hole from 12½ to 8 inches to test ahead for any oil or water before setting 8-inch casing for water shut off.
2,580–2,635	Blue shale.
2,635–2,640	Hard blue shale.
2,640–2,710	Soft blue shale and ————. Good showing of oil. Eight-inch casing landed at 2,711 on what might be termed cap rock.
2,710–2,711	Sand shell.
2,711–2,713	Hard oil sand showing lots of oil, light in gravity. In starting to wash mud out of hole, the hole was found to be over one-half full of solid oil. Well made so much gas that it is not advisable to complete washing or drilling further until lines installed to take care of production. Washed and then resumed work with 4-inch drill.
2,713–2,722	Oil sand.
2,722–2,810	Blue shale.
2,810–2,819	Soft sandy shale.
2,819–3,058	Shale, showing some oil.
3,058–3,147	Blue shale.
3,147–3,151	Shell.
3,151–3,234	Blue shale.
3,234–3,244	Shell.
3,244–3,384	Sandy shale.
3,384–3,386	Shell.
3,386–3,572	Blue shale.
3,572–3,583	Sandy shale.
3,583–3,705	Blue shale. 8¼-inch at 2,711.
3,705–3,720	Rock.
3,720–3,836	Blue shale. 6¼-inch at 3,836. Water bailed to 2,100 from surface; after test of 24 hours no water enters hole. Flowing 20 barrels per day between 6-inch and 8-inch casings. Well perforated, 3,470 to 2,730, three holes per foot; 2,730 to 2,690, four holes per foot.

HISTORY OF WELL.

Jan. 22, 1912. Well on pump at 236. Pumped water for three hours; then turned to oil. Showed production at rate of 350 barrels for 18 hours; no water, 9 per cent B. S.

Jan. 23. Production at rate of 350 barrels. Gravity, 26.4; 4/10 water, 2.2 B. S.

Date.	Oil (barrels).	Gravity.	B. S. (per cent).	Water (per cent).	Remarks.
1912.					
Jan. 24	400 gage	24.5	6	2.1	
25					Rods parted.
26					On pump at 11 p. m.
27	400	25			
28					Pulled tubing, on pump at midnight.
29	212 rate	25			
30	90	25			
31	100	25			
Feb. 1					Rods parted.
2	300 rate	25			On pump 5 p. m.
3	72	25			
4	72	25			
5	53	25			
6	53	25			
7	50	22.6			
8	50	22.6			
9	50	22.6			
10–15					Swabbing and sand pumping.
16–28					Perforation 2,800–2,650. Swabbed, etc.
29	120				To get oil to flood well.
Mar. 1	75				
2	50				
3	50				
4	50				
5					Flooded well with 250 barrels of oil. Pressure ran up to 180 pounds.

HISTORY OF WELL—continued.

Date.	Oil (barrels).	Gravity.	B. S. (per cent).	Water (per cent).	Remarks.
1912.					
Mar. 6	200				Well no better than before flooding.
7					Put in new pump.
8					Do.
9					Do.
10	100 rate				
11	60				
12					
13	50				
14					Pulling rods, etc.
15–17					Do.
18	150 rate for 12 hours				
19	60				Showed 10 per cent water.
20					Rods parted.
21					Do.
22	50				
23	45				
24	45				
25	45				
26	45				
27	45				
28	35				
29	45				
30	40				
31	40				
Apr. 1	40				
2	40				
3	40	25	$4\frac{1}{10}$	$\frac{1}{10}$	
4	40				
5	40				
6	35				
7					Rods parted.
8–18					Idle.
19					On pump at 3 p. m.
20	40				
21	30				
22	30				
23	35				
24	25				
25	25				
Apr. 26–May 3	25 barrels oil per day pumped				
May 4	25 barrels oil and water				
5	do				
6	20 barrels oil and water				
7	16 barrels oil and water				
8	15 barrels oil and water				
9	20 barrels oil and water				
10	do				
11	25			10	
12	20			10	
13–26					Rods parted, idle.
27	30				
28	30				
29	20				
30	30			Some.	
31	20			do	
June 1	10				Rods parted.
2					Do.
3	30				
4	30				
5–8					Idle.
9	20				
10					Put on pump.
11	30				
12	30				
13	20				
14	20				
15	20				
June 16–July 12					Rods parted.
July 13					Put on pump; pumping water.
14	30			50	
15	20			50	

HISTORY OF WELL—continued.

Date.	Oil (barrels).	Gravity.	B. S. (per cent).	Water (per cent).	Remarks.
1912.					
July 16	30			50	
17	35			90	
18	40			50	
19					Placed on pump.
20	35			25	
21-25					Rods parted.
26	50			50	
27	20			a 20	
28	30			a 10	
29	20			a 10	
30	27			a 9	
31	34			a 31	
Aug. 1	14			a 12	
2	15			a 10	
3	14			a 12	
4					Rods parted. Off production and shut down on Aug. 23, 1912.

a Barrels.

Well No. 1, sec. 26, T. 30 S., R. 23 E. (rotary).

Feet.	
0–1,086	Surface, shale, rock, boulders, etc.
1,086–1,095	Shale; some gas.
1,095–1,657	Shale, gumbo, rock, etc., 10-inch, at 1,657.
1,657–1,673	Rock.
1,673–2,090	Shale and gumbo.
2,090–2,094	Rock.
2,094–2,162	Gumbo.
2,162–2,210	Shale, with sea shells.
2,210–2,235	Rock.
2,235–2,285	Gumbo.
2,285–2,432	Blue shale and sea shells.
2,432–2,548	Brown shale and sea shells.
2,548–2,562	Gumbo.
2,562–2,590	Hard shale and rock.
2,590–2,800	Shale and gumbo.
2,800–2,802	Rock.
2,802–2,811	Gumbo. 6⅝-inch casing, at 2,811.
2,811–2,813	Gumbo.
2,813–2,875	Sandy shale.
2,875–3,050	Shale and gumbo.
3,050–3,052	Rock.
3,052–3,138	Shale and gumbo.
3,138–3,143	Shale.
3,143–3,145	Rock.
3,145–3,175	Shale and gumbo. Rigging up for Standard tools. 4½-inch casing set at 3,168. 220 feet of 4½-inch perforated. Put rotary back.
3,177–3,226	Blue shale and gumbo.
3,226–3,241	Hard shale.
3,241–3,243	Shell.
3,243–3,259	Soft blue shale.
3,259–3,263	Hard rock.
3,263–3,268	Blue shale and gumbo.
3,268–3,280	Hard blue shale.
3,280–3,342	Soft blue shale and gumbo.
3,342–3,360	Shale and shell.
3,360–3,361	Rock.
3,361–3,387	Hard blue shale.
3,387–3,407	Sandy shale.
3,407–3,408	Hard rock.
3,408–3,414	Hard blue shale.
3,414–3,548	Shale and gumbo.
	After washing mud out of hole and washing oil formation at 3,342–3,485 with drill pipe, pulled drill pipe out of hole. As last of pipe came out of hole gas blew nearly all water out, standing at 30 fee above derrick. Hole bridged at 2,640.
	White bridge in well. Flowed twice of its own accord and once from agitation with bailer, probably 2 or 3 barrels each time. Set 3-inch line pipe, 3,104–3,548. Perforated it up to 3,303.

HISTORY OF WELL.

March 25, 1911. Well pumped some water, also flowed. Produced about 75 barrels oil.

March 29. Tried to put on air. Production 10 a. m. March 29 to 7 a. m. March 31 was 90 barrels oil, 9 barrels water.

March 31. Well on air at 3,051 feet. Production, 20 barrels day of oil, no water.

Cut 4½-inch pipe at 2,880. Left casing in hole: 4½-inch, 2,837–3,168; 3-inch, 3,104–3,548.

REDRILLING AND DEEPENING.

On redrill a show of oil is noted at 3,140. [Record of redrill to 3,548 feet not copied.]

3,550–3,571	Blue shale and shells.
3,571–3,575	Shale and gumbo. 4½-inch casing, at 3,571.
3,575–3,580	Blue shale.
3,580–3,593	Blue shale showing heavy oil.
3,593–3,596	Compact sand.
3,596–3,609	Hard shale and gumbo.
3,609–3,615	Soft blue shale.
3,615–3,619	Hard blue shale.
3,619–3,622	Gumbo.
3,622–3,637	Hard blue shale.
3,637–3,642	Soft blue shale.
3,642–3,651	Hard blue shale.
3,651–3,657	Soft blue shale.
3,657–3,664	Hard blue shale.

Feet.	
3,664–3,666	Hard sand. Very light trace of oil all through 3,657–3,686.
3,666–3,686	Hard blue shale. Also in soft shale 3,609–3657.
3,686–3,708	Hard blue shale.
3,708–3,724	Shale and hard sand.
3,724–3,725	Shale and hard sand, showing oil. Shell.
3,746	Hard blue shale.
3,746–3,806	Firm blue shale, showing all light oil.
3,806–3,848	Hard blue shale; shows oil.
3,848–3,850	Sand rock.
3,850–3,857	Blue shale.
3,857–3,858	Blue shale, showing oil and more gas than it has ever shown.
3,858–3,859	Hard shale, showing gas.
3,859–3,860	Hard sand shell, showing gas and oil.
3,860–3,865	Oil sand; shows up good light oil.
3,865–3,918	Oil sand; shows good.
3,918–3,919	Hard shale.
3,919–3,971	Oil sand.
3,971–3,974	Sand shell.
3,974–3,996	Oil sand.
3,996–4,000	Hard blue shale; showed oil sand and could only be distinguished by drilling.
4,000–4,030	Oil sand. At 4,030 encountered hard formation which could not be recognized on account of large quantity of sand running in from above.

4½-inch casing at 3,572. 3-inch perforated liner at 4,000 feet. Top of liner at 3,498.

HISTORY OF WELL.

July 31, 1911. Put on air at 2,500 feet; first 830 pounds, then dropped to 350 pounds.
Produced 50 barrels of emulsion between 5 p. m. and 4 a. m.

Aug. 1. Made 70 barrels in 36 hours. Appears to be no salt water.
Aug. 2. In last 55 hours well made 100 barrels, 50 per cent oil, 50 per cent water.
Aug. 3. In last 79 hours, 56 barrels oil, 53 barrels water. Air at 3,410 feet.
Aug. 4. In last 24 hours, 10 barrels oil, 9 barrels water.
Aug. 8. Salt water appears.
Aug. 24. Perforated, 4½-inch casing, 3,475–3,330.
Aug. 27. Well flowed 30 barrels.
Aug. 28. Well on pump.

[Telegrams to Bell & Henderson.]

1911.
July 16. Pumped 30 barrels; 50 per cent water.
17. Pumped 35 barrels; 90 per cent water.
18. Pumped 40 barrels; 50 per cent water.
19. No report.
20. Pumped 30 barrels; 40 per cent water.
21. Pumped 30 barrels; 10 per cent water.
22. Pumped 23 barrels; 20 per cent water.
23. Pumped 30 barrels; 10 per cent water.
24. Pumped 20 barrels; 5 per cent water.
25. Pumped 23 barrels; 10 per cent water.
26. Pumped 30 barrels; 5 per cent water.
27. Pumped 23 barrels; 7 barrels water.
28. Pumped 28 barrels; 4 barrels water.
29. Pumped 26 barrels; 4 barrels water.

1911.
July 30. Pumped 24 barrels; 9 barrels water.
31. Pumped 21 barrels; 3 barrels water.
Aug. 1. Pumped 27 barrels; 3 barrels water.
2. Pumped 23 barrels; 4 barrels water.
3. Pumped 18 barrels; 5 barrels water.
4. Pumped 24 barrels; 5 barrels water.
5. Pumped 21 barrels; 4 barrels water.
6. Pumped 20 barrels; 4 barrels water.
7. Pumped 20 barrels; 4 barrels water.
8. Pumped 25 barrels; 4 barrels water.
9. Pumped 20 barrels; 4 barrels water.
10. Pumped 22 barrels; 4 barrels water.
11. Pumped 20 barrels; 3 barrels water. 36° Baumé.
12. Pumped 22 barrels; 4 barrels water.
13. Pumped 22 barrels; 4 barrels water.
14. Pumped 22 barrels; 4 barrels water.
15. Pumped 20 barrels; 4 barrels water.
16. Pumped 20 barrels; 4 barrels water.
17. Pumped 20 barrels; 1 barrel water.
18. Pumped 20 barrels; 3 barrels water.
19. Pumped 20 barrels; 3 barrels water.
20. Pumped 20 barrels; 4 barrels water.
Shut down.

Well No. 3, sec. 24, T. 30 S., R. 23 E.

[Telegrams.]

1912.
Mar. 28. Rigging up to perforate.
29–Apr. 12. Perforated 3,700–2,500.
Apr. 13–18. Pumping water and a little oil.
19. Pumped dry to 2,000. Produced 30 barrels oil in first 36 hours.
20–28. Bailing, etc.
29. Started on pump 4 p. m. Pumped 30 barrels oil and water.
30. After pumping 30 hours well pumped dry to depth of 2,500 feet, during which time pumped 15 barrels oil, 45 barrels water.
May 1. Pumped dry to 2,500 feet.
2. Pumped head off in four hours. Made 25 barrels (5 oil, 20 water).
3. Pumped 25 barrels, 3 oil, rest water.
4. Pumped 25 barrels, 3 oil, 37 water.
5. Pumped 25 barrels, 3 oil, 27 water.
6. Pumped 16 barrels oil and water.
7. Pumped 15 barrels oil and water.
8. Pumped 12 barrels, practically all water.
9. Pumped 12 barrels, principally water.
10. Pumped 12 barrels, principally water.
11–23. Perforated 3,100–2,500.
24. Put on pump at 2,500.
25. 25 barrels oil, 100 barrels water.
26, 27. Rods parted, etc.
28. Pumped 25 barrels oil, 100 barrels water.
29. Pumped 50 barrels oil.
30. Pumped 60 barrels oil, some water.
31. Pumped 40 barrels oil, 50 barrels water.
June 1. Pumped 40 barrels oil, 20 barrels water and shale.
2. Pumped 45 barrels oil, 25 barrels mud, 10 water.
3. Pumped 50 barrels oil, water, and mud.
4. Pumped 90 barrels oil, 10 M. and B. S. in nine hours. Shows great improvement.
5. Pumped 190 barrels oil, 10 M. and B. S. in 24 hours.
6. Pumped 125 barrels net, no trace of water.

1912.

June 7. Pumped 105 barrels oil, some water.

8. Pumped 115 barrels, practically pure oil. Gravity 21.8°, 9/10 water, 2/10 B. S.

9. Pumped 175 barrels pure oil; shows quantity gas.

10. Pumped 120 barrels; lots of gas.

11. Pulled to put on tight gas head.

12. Well flowed almost continuously while pulling tubing to put on tight gas head between 8 inches and 6 inches. Started flowing between casings. At present is making 800 or 900 barrels; may not keep up at this rate.

13. Stopped flowing. Putting on pump. Gravity 19.7°; 0.3 per cent water, 13 per cent B. S.

14. Flowed 250 barrels through 6¼-inch casing. Reduced to 2-inch outlet.

15. Flowed 300 barrels through 6-inch casing.

16. Flowing through 6-inch casing spasmodically. Produced at lowest figures 750 barrels oil.

17. Flowed 325 steadily.

18. Flowed steadily 225; agitated by bailer.

19. Flowed 200. Hole bridged at 2,940.

20. Flowed 200.

21. Flowed 175 }
22. Flowed 150 }
23. Flowed 150 }
24. Flowed 150 } Cleaning out bridge.
25. Flowed 150 }
26. Flowed 125 }

27. Flowed 100.

28. Flowed 100.

29–July 11. Washing, etc.

July 12. Placed on pump. Flowing about 350 barrels per day through tubing. As yet has not made all oil that was put into wash hole out.

13. Stopped flowing.

14. Started flowing; made about 350 barrels.

15. Sand at 2,500. Flowed 75 barrels.

16. Flowed 75 barrels.

17. Flowed 75 barrels.

18. Flowed 75 barrels. Hole filled to 2,500. In same condition as before washing.

19. Flowed 100 barrels.

20. Flowed 75 barrels. Filled with sand.

21. Filled with oil to clean out.

22. Flowed 75 barrels.

July 23–Aug. 7. Cleaning out.

Aug. 8. Lost string small tools.

11. Well flowed 100 barrels per 24 hours.

12. Flowing 100 barrels oil, 3,000,000 cubic feet gas.

13. Flowing 100 barrels oil, 3,000,000 cubic feet gas.

14. Flowing 100 barrels oil, 3,000,000 cubic feet gas.

15–20. Flowing about same as above. All this time fishing for lost tools.

21–23. Shutting down.

The well of the Scottish Oilfields Co., which is in the west end of the belt described above as structurally the most favorable for the accumulation of oil, did not obtain oil, although it was drilled 4,005 feet and should therefore have penetrated beds lying at the same horizon from which the oil was derived in the Associated Oil Co's. wells. It is worthy of note, however, that this well was drilled with rotary tools below 2,200 feet.

The well of the Midway Valley Oil Co. in sec. 12, T. 31 S., R. 24 E., was drilled deep enough to penetrate beds at the same horizon as those from which the wells of the Associated Oil Co. obtained oil. This well, however, is not in the belt of most favorable structure.

WHEELER RIDGE.

The anticline that forms Wheeler Ridge is the easternmost of the folds that occur in the foothills along the southwest side of San Joaquin Valley. This fold is limited on the west by the fault or zone of fracture that is believed to be the northeast end of the fault along Tejon Pass. East of Coaloil Canyon the Wheeler Ridge anticline plunges eastward, and it probably does not affect the Tertiary beds much beyond the east end of the ridge.

The structure of Wheeler Ridge and the possible occurrence of oil in the rocks there have been described by Robert Anderson,[1] and it is necessary here to do no more than to offer a slight correction to his interpretation of the structure, and to record the results of the drilling done since his visit. Those interested in the area and desiring a more detailed description of it are referred to his report.

Anderson interpreted the structure as a "domelike anticline that rises in the foothills and sinks abruptly again at the edge of the valley a few miles distant." The writer's interpretation of the structure is that the west end of the anticline does not plunge normally, but that west of Coaloil Canyon it is broken and finally ended by faults. This difference in interpretation is of some practical importance, for if the fault hypothesis is accepted it is more easy to understand the occurrence of the oil seep in Coaloil Canyon. That seep, unlike most of those along the border of San Joaquin Valley, is not at the contact between the diatomaceous shale and the overlying formation, for the oil issues from beds that are well above the base of the late Tertiary gravel, sand, and clay which rest upon that shale. The writer believes that the oil has worked its way up along fractures which cut through these late Tertiary beds, and that, although the oil sand that crops out in Coaloil Canyon may underlie a considerable area in the west end of the fold, it does

[1] U. S. Geol. Survey Bull. 471, pp. 125-132, 1912.

not necessarily underlie the east end, where the fold is unbroken.

It is therefore necessary to look not to this sand but to a sand that lies deeper, perhaps very much deeper, as the possible productive oil sand in this part of the ridge. Unfortunately the structure is so complicated south of Wheeler Ridge that it is impossible to estimate the thickness of these late Tertiary beds which overlie the diatomaceous shale and thus to give a rough measure of the depth at which oil sands might be expected to underlie Wheeler Ridge.

A number of wells have been drilled in this area, but only one of them was so located as to give the structure an adequate test. This well, which is usually known as the G. R. well, was in the center of sec. 26, T. 11. N., R. 20 W., in the low wind gap that cuts through the ridge. According to reports in the press, it was drilled to a depth of 2,925 feet, at which the 4½-inch casing became stuck and the well was abandoned, commercial amounts of oil not having been found.

The writer has no information as to the character of the beds through which this well passed, but he believes that the late Tertiary rocks which form the surface here were not completely penetrated. The well does not prove the absence of commercial amounts of oil in Wheeler Ridge, but it does show that the belt beneath which oil may occur in considerable amounts and not too deeply buried to be reached by the drill is narrow—much narrower even than Anderson suggested.

The ridge is, however, worthy of another and more thorough test before it is definitely abandoned, but the test well should be located close to the axis of the anticline in the central part of the ridge, and the operators should be prepared for deep drilling.

FOOTHILLS OF THE SAN EMIGDIO MOUNTAINS.

For the most part the structure of the foothills of the San Emigdio Mountains is too broken by faults to favor the accumulation and retention of petroleum in considerable amounts. In one area, however, it seems possible that oil may occur. This area lies along the small anticline which extends from a point on the east side of San Emigdio Creek about 3 miles above its mouth eastward to Pleito Creek. The beds forming the surface along the axis of this fold are in the lower part of the Vaqueros formation as mapped in this report. Along San Emigdio Creek near the Devils Kitchen these beds rest upon a dark clay shale which is mapped as the top of the Tejon formation. This shale contains considerable carbonaceous matter and in a measure resembles the impure facies of the diatomaceous shale that occurs in the younger Tertiary formations in this and in other parts of California, and it seems to the writer to be not altogether unreasonable to regard this shale as a possible source of oil. Should oil have been formed in this shale the small anticlinal fold mentioned above would offer a structural trap in which the oil would probably tend to collect, the beds that would probably serve as reservoirs being those which lie at the base of the Vaqueros formation. The general structure of this area is shown in geologic section G–G′, Plate II.

It must be stated, however, that the prospect for obtaining oil in commercial amounts in a well drilled along this fold does not appear to be very bright, for in the first place there is no field evidence that the shale in the upper part of the Tejon has actually given rise to oil; and in the next place even if oil had been formed in the shale the area from which oil might drain out of the shale and collect in the Vaqueros formation along the anticline is small, for the beds are cut by faults of considerable size both north and south of the fold. This area therefore does not appear to be one in which drilling is now advisable, nor should drilling even be considered until the value of oil has so increased that the operator can afford to take a very much greater risk than at present.

HIGHER PARTS OF THE TEMBLOR RANGE.

The higher parts of the Temblor Range west of the Sunset-Midway district are formed chiefly of the diatomaceous Marioopa shale, which is much folded. As this shale is believed to be the original source of the petroleum obtained in the main field, and as in places the shale now contains oil in considerable amount in certain sandy lenses that are bedded with the finer-grained material, the higher parts of the range where the shale is not too closely folded and fractured must be considered as possible oil land. Moreover, the shaly beds that compose the upper part of the Vaqueros formation west of Santiago Creek are very similar to those composing the Maricopa shale, and this formation contains commercial amounts of oil in at least one part of the area—that is, along the Pioneer anticline.

The general conclusions regarding the possible occurrence of oil in this part of the area expressed by Arnold and Johnson in the preliminary report[1] may be repeated here:

In a region of complex structure like that of the Temblor Range the conditions affecting the accumulation of oil differ widely within short distances, so that a detailed study of each particular locality is necessary before a proper conclusion can be drawn as to the depth of the oil-bearing zone below the surface. It may be said in general, however, that the most favorable localities are near the axes of the anticlines, especially those with relatively low dipping flanks. Another favorable locality is along any line which marks a change from a low to a steep dip, both dips being in the same direction. This is simply a special form of the anticline in which the plane of the axis is oblique instead of vertical, as in a symmetrical anticline. An anticline which appears to fulfill these favorable conditions at one place or another along its course is the one lying one-half to 1 mile northeast of the crest of the [Temblor] range in the region southwest of the developed part of the Midway district. Other anticlines in the territory under discussion also appear favorable at one place or another, these particularly favorable localities usually being indicated on the map by anticlines with low dips.

[1] U. S. Geol. Survey Bull. 406, pp. 211-212, 1910.

ELEVATIONS OF WELLS IN NORTHERN PART OF MIDWAY FIELD.

The following table gives the elevations above sea level of the collars of several wells in the northern part of the Midway field—the part for which surface contours are not shown on Plates I and III. These elevations have been compiled from the records of the oil companies.

The elevations marked A were determined instrumentally; those not so marked may have been determined accurately, but information regarding the method of determining them was not available. They should therefore be regarded as subject to an error of perhaps 20 feet.

Elevations of wells in northern part of Midway oil field.

Company.	Old name or lease name.	No. of well.	Location.				Elevation (feet).
			Quarter.	Section.	Township S.	Range E.	
Armstrong & Jergins		1	SW	26	31	22	1,500 A
Do		2	SW	26	31	22	1,500
Do		3	SW	26	31	22	1,500
Do		4	SW	26	31	22	1,499 A
Do		5	SW	26	31	22	1,501 A
Associated Oil Co		1	NE	35	31	22	1,365 A
Do		1	NE	35	31	22	1,364 A
Do		2	NE	35	31	22	1,374 A
Do		3	NE	35	31	22	1,392 A
Do		4	NE	35	31	22	1,414 A
Do		5	NE	35	31	22	1,449 A
Do		6	NE	35	31	22	1,438 A
Do		21	NE	35	31	22	1,381 A
Do		24	NE	35	31	22	1,390 ±
Do		25	NE	35	31	22	1,432
Do		26	NE	35	31	22	1,456 A
Do		33	NE	35	31	22	1,409
Do		34	NE	35	31	22	1,424
Do		35	NE	35	31	22	1,439
Do		41	NE	35	31	22	1,429
Do		42	NE	35	31	22	1,424
Do		43	NE	35	31	22	1,436
Do		51	NE	35	31	22	1,444 A
Do		52	NE	35	31	22	1,443
Do		61	NE	35	31	22	1,457 A
Do		62	NE	35	31	22	1,455 A
Do		54	NE	20	31	23	1,027 A
Do		72	SE	20	31	23	1,135
Do		83	SE	20	31	23	1,163
Do		1	SW	22	31	23	1,207
Do		4	NW	22	31	23	998
Do		23	SW	22	31	23	1,150
Do		32	SW	22	31	23	1,133
Do		33	SW	22	31	23	1,102
Do		43	SW	22	31	23	1,102
Do		52	SW	22	31	23	1,141

Elevations of wells in northern part of Midway oil field—Continued.

Company.	Old name or lease name.	No. of well.	Location. Quarter.	Section.	Township S.	Range E.	Elevation (feet).
Associated Oil Co		63	SE	22	31	23	1,210
Do		3	SW	26	31	23	992
Do		24	NW	26	31	23	1,105
Do		33	SW	26	31	23	1,049
Do		42	SW	26	31	23	1,140
Do		53	SE	26	31	23	1,031
Do		72	SE	26	31	23	952
Do		91	SE	26	31	23	948
Do		93	SE	26	31	23	1,150
Do		44	NW	34	31	23	935
Do		74	NE	34	31	23	939
Do		96	NE	34	31	23	1,020
Calidon Petroleum Syndicate		1	SW	19	31	23	1,106
California Star Oil Co		1	SW	26	31	22	1,486 A
Do		2	SW	26	31	22	1,481 A
Do		3	SW	26	31	22	1,465 A
Do		4	SW	26	31	22	1,457
Do		5	SW	26	31	22	1,455
Chanslor-Canfield Midway Oil Co.		1	NW	27	31	22	1,555 A
Do		1	SE	35	31	22	1,522 A
Do		2	SE	35	31	22	1,454 A
Do		3	SE	35	31	22	1,473 A
Do		4	NW	35	31	22	1,458 A
Do		5	SE	35	31	22	1,514 A
Do		7	NW	35	31	22	1,468 A
Do		8	NW	35	31	22	1,484 A
Do		9	SE	35	31	22	1,490 A
Do		10	SE	35	31	22	1,471 A
Do		11	NW	35	31	22	1,488 A
Do		12	NW	35	31	22	1,473 A
Do		13	SE	35	31	22	1,498 A
Consolidated Mutual Oil Co	Mays	1	SW	28	31	23	1,162
Do	do	2	NE	28	31	23	1,192
Do	do	3	NW	28	31	23	1,183
Do	do	4	NE	28	31	23	1,138
Do	do	5	NE	28	31	23	1,215
Do	do	6	NE	28	31	23	1,204
Do	do	7	NE	28	31	23	1,133
Do	do	8	NE	28	31	23	1,167
Do	do	9	NE	28	31	23	1,236
Do	do	10	NE	28	31	23	1,173
Do	do	11	NE	28	31	23	1,198
Do	do	12	NE	28	31	23	1,215
Do	do	13	NE	28	31	23	1,194
Dabney Oil Co		1	SW	26	31	22	1,495 A
Do		2	SW	26	31	22	1,478 A
Do		3	SW	26	31	22	1,480 A
Do		4	SW	26	31	22	1,484 A
Do		5	SW	26	31	22	1,491 A
Doheny Pacific Petroleum Co.	Fairfield	1	SW	19	31	23	1,152
El Camino Oil & Development Co.		1	SW	26	31	22	1,420 A
Do		2	SW	26	31	22	1,447 A
General Petroleum Co	Carnegie	1w.	NE	9	31	22	1,530
Kern Trading & Oil Co		21	SE	21	31	23	1,200 A
Do		2	NW	27	31	23	1,225 A
Do		6	SW	27	31	23	1,158
McKittrick Oil Land Co	Starlight	1	NW	21	31	22	1,734
Maxwell Oil Co		1	NE	27	31	22	1,540
Midland Oil Fields Co. (Ltd.)		1	SW	12	31	22	1,266 A
Do		2	NW	12	31	22	1,201 A
Do		3	NE	12	31	22	1,178 A
Midway Royal Petroleum Co.		1	NW	19	31	23	1,157
Miley & Buley	Kimball & Crellin	1	NE	21	31	22	1,634 A
Record Oil Co		1	NE	28	31	23	1,195
Do		2	NE	28	31	23	1,206

Elevations of wells in northern part of Midway oil field—Continued.

Company.	Old name or lease name.	No. of well.	Location.				Elevation (feet).
			Quarter.	Section.	Township S.	Range E.	
Record Oil Co		3	NE	28	31	23	1,232
Do		4	NE	28	31	23	1,261
Soudan Oil Co		1	SW	26	31	22	1,486
Do		2	SW	26	31	22	1,480
Do		3	SW	26	31	22	1,487 A
Do		4	SW	26	31	22	1,466 A
Do		5	SW	26	31	22	1,475
Do		6	SW	26	31	22	1,460
Do		7	SW	26	31	22	....
Do		8	SW	26	31	22	1,065
Do		9	SW	26	31	22	1,453
Standard Oil Co		1	SE	16	31	23	905 A
Do		2	SE	16	31	23	907 A
Do		3	SE	16	31	23	956 A
Do		4	SE	16	31	23	1,071 A
Do	Burr	1	SW	17	31	23	1,150
Do		1	SW	22	31	23	1,106
Do		2	NW	22	31	23	1,064
Do		3	NE	22	31	23	1,076 A
Do		4	SE	22	31	23	1,127 A
Do		5	SW	22	31	23	1,131 A
Do		6	SE	22	31	23	1,055 A
Do		7	SW	22	31	23	1,096 A
Do		10	SW	22	31	23	1,073
Do		1	SW	26	31	23	1,153 A
Do		2	NW	26	31	23	1,179 A
Do		3	NE	26	31	23	1,100 A
Do		4	SE	26	31	23	1,133 A
Do		5	SW	26	31	23	1,118 A
Do		6	SW	26	31	23	1,144 A
Do		7	SE	26	31	23	1,066 A
Do		8	SW	26	31	23	1,088
Do		9	NW	26	31	23	1,174
Do		1	NW	28	31	23	1,193
Do		2	NW	28	31	23	1,193
Do		4	NW	28	31	23	1,175
State Consolidated Oil Co		1	SW	26	31	22	1,449 A
Do		2	SW	26	31	22	1,491 A
Do		3	SW	26	31	22	1,465 A
Do		4	SW	26	31	22	1,455 A
Do		5	SW	26	31	22	1,472 A
Do		6	SW	26	31	22	1,482 A
Do		7	SW	26	31	22	1,446 A
Do		8	SW	26	31	22	1,486 A
Do		9	SW	26	31	22	1,469 A
Do		10	SW	26	31	22	1,456 A
Do		11	SW	26	31	22	1,458 A
Do		12	SW	26	31	22	1,419 A
Do		13	SW	26	31	22	1,456 A
Do		14	SW	26	31	22	1,460 A
Do		15	SW	26	31	22	1,456 A
Toronto Midway Oil Co		1	SW	18	31	23	1,151
Do	Sheridan	1	NE	10	31	22	1,416
United Oil Co		22	SE	20	31	23	1,055
Do		23	NE	20	31	23	1,091
Do		25	SE	20	31	23	1,155
Do		26	SW	28	31	23	1,096
Wilkes		1	SE	28	31	23	1,096
Do		2	SE	28	31	23	1,156

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