PRELIMINARY REPORT ON THE GEOLOGY AND POSSIBLE OIL RESOURCES OF THE SOUTH END OF THE SAN JOAQUIN VALLEY, CAL.

By Robert Anderson.

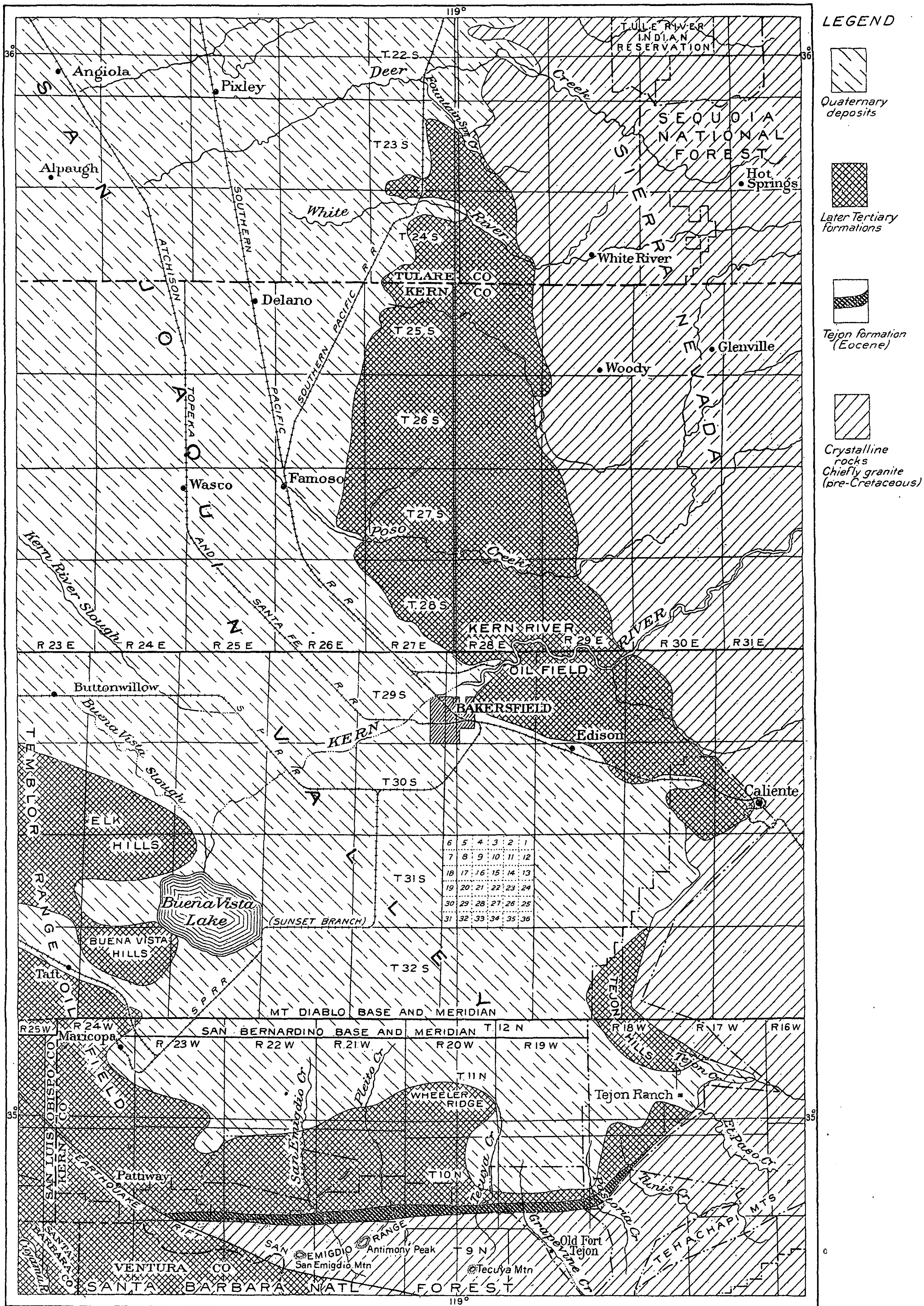
INTRODUCTION.

PURPOSE OF THE WORK.

The purpose of this paper is to give a brief description of the geologic features of the south end of the San Joaquin Valley, Cal., and to consider their bearing on the question of the presence or absence of oil in that region. The vast stores of petroleum discovered in the rocks along the foothills of the Temblor Range on the southwest side of the valley and in the foothills of the Sierra Nevada near Bakersfield on the northeast side at once suggest the possibility of oil occurring in the continuation of this foothill belt, around the south end of the valley between these two productive districts. Very little attention has been given to the geology of this intermediate region and no tests of its oil possibilities have been made. With a view to obtaining a general idea of the geologic features and the possible oil resources the writer made a reconnaissance around the south end of the valley during the early part of October, 1910. The conclusions here expressed are necessarily of a general and preliminary nature.

CONCLUSIONS.

The main conclusion derived from the brief field examination is that a continuous productive area joining the present developed fields on the two sides of the valley is by no means to be expected, but that two or more areas situated near the border of the foothills at the south end of the valley offer favorable conditions for the accumulation of oil. Across the level San Joaquin Valley from Bakersfield to Buena Vista Lake, to the San Emigdio region, and to the Tejon region, even though it is likely that the oil-bearing rocks underlie the valley, every indication is that they are too deep to be accessible by present methods of drilling. Around the foothill belt that fringes the valley the possible oil-bearing formations are not continuous and the structural conditions are not uniform, so that if oil is to be found at all it must be sought in areas where the presence of



RECONNAISSANCE MAP OF THE SOUTHERN END OF THE SAN JOAQUIN VALLEY, CALIFORNIA

THE NORRIS PETERS CO., WASHINGTON, D. C.

oil-bearing strata and the occurrence of favorable geologic structure make the accumulation of oil possible. One such area containing peculiarly favorable conditions is to be found in Wheeler Ridge, which extends into the valley east of Pleito Creek. Another promising area lies farther west, along the edge of the valley north of the mouths of Muddy and Santiago creeks and northwest of the mouth of San Emigdio Creek. The latter area bids fair to form an eastward extension of the Sunset field, but it does not appear likely to be continuous with the prospective Wheeler Ridge field mentioned above. There is still another area to the east in which some of the geologic conditions suggest the possibility that oil may be present, although others lead to the conclusion that the chance is slight. This area lies along the edge of the hills near the mouth of Tejon Creek, northeast of the Tejon ranch house. The crescent-shaped group of hills of Tertiary rocks occurring there will be referred to for convenience as the Tejon Hills.

These areas as well as other parts of the region will be described more fully in the body of this paper. It is possible that, when studied in detail, areas other than those just mentioned may prove to have stratigraphic and structural conditions favorable for the accumulation of oil.

ACKNOWLEDGMENTS.

Particular acknowledgment is due to Dr. Ralph Arnold, formerly of the United States Geological Survey, for the assistance derived from his geologic work in the Temblor Range oil field, discussed in Bulletin 406 of the Survey, and from his report to the Midway Union Oil Co. on the prospective oil territory of Wheeler Ridge. Special thanks are likewise due to Mr. H. R. Johnson, also a former member of the Geological Survey and collaborator in the bulletin above mentioned, who supplied valuable information obtained some years ago by him while engaged in a reconnaissance study of the underground water resources of the south end of the San Joaquin Valley. Many of the data embodied in the reconnaissance map (Pl. X) accompanying this report were kindly furnished by Mr. Johnson.

The writer also wishes to acknowledge his indebtedness for assistance and information received from Mr. R. W. Pack, of the Geological Survey, who made a reconnaissance examination of the San Emigdio region in 1908; from Mr. A. T. Parsons, of Bakersfield, Mr. Frank M. Anderson and Mr. G. C. Gester, of San Francisco, Mr. V. R. Garfias, and Mr. A. T. Preston, of Los Angeles. The writer is greatly indebted to Mr. Donald C. C. Grant and Mr. S. Ed Baily, of the Tejon ranch, and to Mr. H. A. Jastro and Mr. J. S. Douglas, of the San Emigdio ranch, for courtesies shown to him.

LAND WITHDRAWALS.

In pursuance of the policy of the Federal Government and on the recommendation of the Geological Survey, the public lands in the areas listed below have been withdrawn from all forms of entry. Attention should be called to the fact that the areas listed as withdrawn lands include large tracts that are privately owned and that are in no way affected by the order. The withdrawals are recorded by the General Land Office in terms of the whole area, as the most convenient and certain way of including all the public land. It should also be clearly understood that the second and third withdrawals here listed were made temporarily, pending field examination, and were intended to include all lands in this vicinity which might possibly contain petroleum or natural gas. When a detailed examination is made, areas without promise will be restored to agricultural entry and land believed to contain oil will be held by the Government subject to the laws controlling such resources.

LANDS CLASSIFIED AS OIL LANDS AND WITHDRAWN.

The public lands in the areas listed below have been classified by the United States Geological Survey as oil lands and withdrawn from entry by the General Land Office. In addition to these areas large parts of the townships adjoining on the west and northwest in the Temblor Range oil field have been classified as oil land and withdrawn.

San Bernardino base and meridian, Cal.

T. 12 N., R. 23 W.:
- Sec. 28: W. $\frac{1}{2}$, W. $\frac{1}{2}$ of E. $\frac{1}{2}$.
- Secs. 29 to 32.
- Sec. 33: W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of NE. $\frac{1}{4}$, NW. $\frac{1}{4}$, S. $\frac{1}{2}$.
- Sec. 34: W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of SW. $\frac{1}{4}$.

T. 12 N., R. 22 W.:
- Sec. 31: S. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
- Sec. 32: S. $\frac{1}{2}$ of NE. $\frac{1}{4}$, S. $\frac{1}{2}$.
- Sec. 33: NE. $\frac{1}{4}$, S. $\frac{1}{2}$ of NW. $\frac{1}{4}$, S. $\frac{1}{2}$.
- Sec. 34.

T. 11 N., R. 23 W.:
- Sec. 1: SE. $\frac{1}{4}$ of NE. $\frac{1}{4}$, S. $\frac{1}{2}$ of SW. $\frac{1}{4}$, SE. $\frac{1}{4}$.
- Sec. 2: SE. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
- Sec. 3: W. $\frac{1}{2}$ of NE. $\frac{1}{4}$, W. $\frac{1}{2}$, NW. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
- Secs. 4 to 9.
- Sec. 10: SW. $\frac{1}{4}$ of NE. $\frac{1}{4}$, NW. $\frac{1}{4}$ of NW. $\frac{1}{4}$, SW. $\frac{1}{4}$ and E. $\frac{1}{2}$ of SW. $\frac{1}{4}$, SE. $\frac{1}{4}$.
- Sec. 11: E. $\frac{1}{2}$, E. $\frac{1}{2}$ and SW. $\frac{1}{4}$ of NW. $\frac{1}{4}$, S. $\frac{1}{2}$.
- Secs. 12 to 36.

T. 11 N., R. 22 W.:
- Secs. 3, 4, and 5.
- Sec. 6: E. $\frac{1}{2}$, E. $\frac{1}{2}$ and SW. $\frac{1}{4}$ of NW. $\frac{1}{4}$, S. $\frac{1}{2}$.
- Secs. 7 to 10, 15 to 22, 27 to 34.

The public lands in the following areas at the south end of the San Joaquin Valley have been withdrawn from entry pending geologic examination and classification.

Temporary petroleum withdrawal September 27, 1909.

Tps. 11 and 12 N., R. 22 W.: East third of both townships.

Temporary petroleum withdrawal No. 11, January 18, 1910.

San Bernardino base and meridian, Cal.

T. 10 N., R. 19 W.:
- Sec. 1: W. ½.
- Secs. 2 to 11.
- Sec. 12: W. ½.
- Sec. 30: Lots 1, 2, 3, 4, 5, 6.
- Sec. 31: Lots 1, 2, 3, 4, 5, E. ½ of W. ½, W. ½ of E. ½, SE. ¼ of NE. ¼, E. ½ of SE. ¼.
- Sec. 32: Lots 1, 2, 3, 4, W. ½ of SW. ¼.

T. 10 N., R. 20 W.:
- Secs. 1 to 12.
- Sec. 13: W. ½.
- Secs. 14 to 23.
- Sec. 24: W. ½, lots 1, 2, 3, 4, 5.
- Secs. 25 to 36.

T. 10 N., R. 21 W.:
- Secs. 1 to 6.
- Sec. 7: Lots 1, 2, 3, 4, 5, 6, N. ½ of NE. ¼, NE. ¼ of NW. ¼.
- Sec. 8: N. ½, lots 1, 2, 3, 4.
- Sec. 9: N. ½, lots 1, 2, SE. ¼.
- Secs. 10 to 15.
- Sec. 16: SE. ¼, lots 1, 2, 3, 4, 5, 6, 7, 8, SE. ¼ of SW. ¼.
- Sec. 20: Lots 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11.
- Sec. 19: Lot 1.
- Secs. 21 to 29.
- Sec. 30: SE. ¼, S. ½ of NE. ¼, E. ½ of SW. ¼, lots 1, 2, 3, 4, 5, 6.
- Secs. 31 to 36.

T. 10 N., R. 22 W.:
- Sec. 1: S. ½ of NE. ¼, SE. ¼, SE. ¼ of NW. ¼, lots 1, 2, 3, 4, 5, 6, 7.
- Sec. 3: N. ½.
- Sec. 4: N. ½.
- Sec. 5: N. ½.
- Sec. 6: N. ½.
- Sec. 19: E. ½ of SW. ¼, W. ½ of SE. ¼, SE. ¼ of SE. ¼, lots 1, 2, 3, 4, 5, 6.
- Sec. 20: S. ½ of SW. ¼, SW. ¼ of SE. ¼, lots 1, 2, 3, 4.
- Sec. 21: Lots 1, 2, 3, 4.
- Sec. 22: Lot 1.
- Sec. 25: Lots 1, 2, 3, 4, W. ½ of SW. ¼, SE. ¼ of SW. ¼, S. ½ of SE. ¼, NE. ¼ of SE. ¼.
- Sec. 26: S. ½, lots 1, 2, 3, 4.
- Sec. 27: S. ½ of N. ½, S. ½, lots 1, 2, 3, 4.
- Secs. 28 to 36.

T. 10 N., R. 23 W.:
- Secs. 1 to 11.
- Sec. 12: NW. ¼ of NE. ¼, NW. ¼, N. ½ of SW. ¼, SW. ¼ of SW. ¼, lots 1, 2, 3, 4.
- Sec. 13: NW. ¼ outside of private land grants.
- Sec. 14: NE. ¼ of NE. ¼, W. ½ of NE. ¼, NW. ¼, SW. ¼, NW. ¼ of SE. ¼, lots 1, 2, 3.
- Secs. 15 to 22.

T. 10 N., R. 23 W.—Continued.
  Sec. 23: W. ½, S. ½ of SE. ¼, lots 1, 2, 3, 4.
  Sec. 24: S. ½ of S. ½, lots 1, 2, 3, 4, 5.
  Secs. 25 to 36.
T. 10 N., R. 24 W.:
  Secs. 1 to 18.
  Sec. 19: E. ½, lots 1, 2.
  Secs. 20 to 36.
T. 11 N., R. 20 W.:
  Secs. 19 to 36.
T. 11 N., R. 21 W.:
  Secs. 1 to 36.
T. 12 N., R. 21 W.:
  Secs. 1 to 36.

The public lands in the following areas on the east side of the San Joaquin Valley, north and south of the Kern River field, have been withdrawn temporarily pending geologic examination and classification:

Petroleum reserve No. 18, California No. 8, January 26, 1911.—Mount Diablo base and meridian.

T. 25 S., R. 26 E.:
  Secs. 1, 2, 11 to 14, 23 to 26, 35, 36.
T. 26 S., R. 26 E.:
  Secs. 1, 2, 11 to 14, 23 to 26, 35, 36.
T. 27 S., R. 26 E.:
  Secs. 1, 2, 11 to 14, 23 to 26.
Tps. 25 to 27 S., R. 27 E.:
  All.
T. 28 S., R. 27 E.:
  Secs. 1 to 6, 8 to 17, 20 to 29, 32 to 36.
T. 29 S., R. 27 E.:
  Secs. 1, 2, 12.
T. 25 S., R. 28 E.:
  Secs. 6 to 8, 16 to 22, 26 to 35.
T. 26 S., R. 28 E.:
  Secs. 2 to 36.
Tps. 27 and 28 S., R. 28 E.:
  All.
T. 29 S., R. 28 E.:
  Secs. 1 to 17, 22 to 24.
  Sec. 26, NE. ¼.
T. 27 S., R. 29 E.:
  Secs. 18, 19, 30, 31.
T. 28 S., R. 29 E.:
  Secs. 6, 7, 18 to 20, 29 to 32.
T. 29 S., R. 29 E.:
  Secs. 4 to 10, 14 to 28.
  Sec. 30, NE. ¼.
  Secs. 34 to 36.
T. 29 S., R. 30 E.:
  Secs. 19, 20, 28 to 34.
T. 30 S., R. 30 E.:
  Secs. 2 to 9.
  Sec. 10, N. ½.

GEOGRAPHY AND TOPOGRAPHY.

As yet there is no satisfactory map showing the south end of the San Joaquin Valley and its surrounding hills. The area represented by the Mount Pinos and Tejon topographic sheets of the United States Geological Survey does not extend northward quite to the edge of the valley. Topographers of the Survey are now engaged in extending their work over this region, so that before long maps of the Caliente, Bakersfield, and McKittrick quadrangles will be available, giving a complete map of the south end of the valley as far north as latitude 35° 30′, which is a line about 8 miles north of Bakersfield. The area thus covered will include the two great oil fields that border the south end of the valley—the Kern River field on the east and the Temblor Range field on the west. Under the latter designation is included the whole productive region usually referred to under the names of its indefinitely separated parts—the McKittrick, Midway, Sunset or Maricopa, Elk Hills, and Buena Vista Hills districts. This region is both geographically and geologically a unit that needs frequently to be referred to as a whole and therefore deserves a comprehensive name.

The south end of the San Joaquin Valley is an almost level plain that is terminated rather abruptly by the surrounding hills. It is open toward the northwest, but is bordered on the northeast and east by the Sierra Nevada; on the southeast by the Tehachapi Range, which trends northeast and southwest and forms a connecting link between the Sierra Nevada on the northeast and the Coast Ranges on the southwest; on the south by the San Emigdio Mountains, into which the Tehachapi Range merges at Tejon Pass; and on the southwest by the Temblor Range. Along the sides of the valley the plain is separated from the mountains by a rolling foothill belt several miles wide, but at the south end the foothills are less continuous and where present form a narrower belt, the valley being hemmed in for the most part by steep slopes. The abruptness of the change from the level floor of the valley to the steep face of the mountain is everywhere modified by the presence of alluvial fans, which slope upward several hundred feet to the edge of the hills. These fans are especially numerous at the south end of the valley, where they are built up against the base of the mountains. The elevation of the main portion of the floor of the valley is, roughly, between 300 and 400 feet above sea level. Along the sides of the valley the alluvial slopes rise at most places to elevations between 500 and 1,000 feet within a distance of a few miles, and at the south end some of the fans reach an altitude of 1,800 feet.

At some places around the south end of the valley the foothill belt is slightly wider than at others, owing to structural conditions, as, for instance, in the crescent-shaped group of hills around the mouth of Tejon Creek, above referred to as the Tejon Hills, and in Wheeler Ridge, east of Pleito Creek. Such areas as these are noteworthy in connection with a study of the possible oil resources of the region and will receive mention below.

GEOLOGY.

GENERAL FEATURES.

The geologic features of the region here discussed are closely related to the topography already outlined. Broadly classified they are comprised in three main groups corresponding to the topographic districts—(1) inclosing mountain ranges formed of crystalline rocks, chiefly granite; (2) a foothill belt of upturned Tertiary strata that rest upon the older crystalline rocks and dip under the valley; and (3) the valley basin covered by flat-lying alluvial deposits. The above statement of the character of the mountains does not apply, however, to the Temblor Range on the west, in which the basement of crystalline rocks is brought to the surface only within a very small area, and the main mass of the range in its southern part is formed of highly disturbed middle Tertiary strata, with later Tertiary beds along the foothills.

The San Joaquin Valley is a great syncline that is terminated abruptly at its south end by the axis of uplift represented by the San Emigdio Mountains and Tehachapi Range, which lie in general at right angles to the trend of the valley and separate it from the structural basin occupied by the Mohave Desert. The strata on the Sierra flank dip much more gently into the San Joaquin Valley syncline than those on the Coast Range flank. Consequently the syncline is supposed to be unsymmetrical, the axis lying west of the center of the valley. Another though hypothetical argument in favor of this being an unsymmetrical syncline may be based on the fact that the lowest part of the valley lies much nearer to the Coast Range than to the Sierra Nevada. This is shown by the concentration of the surface water along a line considerably to the west of the central line of the valley and by the perceptible difference between the very gentle slope of the floor to the foothills of the Sierra and the steeper rise to the edge of the Coast Ranges.[1] Heretofore this difference of slope has been ascribed to the widespread distribution of silt brought down by the Sierra Nevada rivers, on the one hand, and the restricted zone of deposition of alluvial-fan material by the intermittent and smaller streams of the Coast Ranges, on the other. In the opinion of the writer the possibility is worthy of consideration that this topographic feature may be in part a reflection of the

[1] The topographic and general features of the valley are well described by W. C. Mendenhall in Ground waters of the San Joaquin Valley, Cal.: Water-Supply Paper U. S. Geol. Survey No. 222, 1908.

structural character of the valley—in other words, that the steeper slope of the floor on the west side may be due in part to a recent slight tilting on the Coast Range side as a continuation of the movements that gave rise to the original unsymmetrical structure. A consideration of the structure of the valley and the movements that it has undergone is important in connection with the problem of the minor anticlines that project into the valley at several places, and also is important in considering the possibility that folds of a similar type oblique to the main trend of the depression may continue beneath the valley filling. Such folds, if they exist, might be of economic importance as places for the accumulation of oil. Unfortunately the Quaternary material that forms the valley floor conceals the structure of the underlying rocks, and therefore statements regarding the structure in the bottom of the valley are largely in the realm of conjecture. Certain points in this connection will be mentioned in a later portion of this paper.

The oblique folds just mentioned include a number of anticlinal offshoots from the mountainous belt bordering the valley. These folds are generally marked by ridges of tilted beds which project into the valley, where they gradually disappear beneath the alluvium of the valley floor. After leaving the main range the anticlines are separated from it by synclinal troughs forming reentrants in the margin of the valley. The following are prominent examples of such anticlinal folds: The Coalinga anticline, which forms the long, locally interrupted range including Anticline Ridge and the Guijarral, Kettleman, and Lost hills; the supposed anticline of the Antelope Hills; the group of anticlines in the Elk Hills; the similar group of anticlines of the Buena Vista Hills; and the two well-developed anticlines already referred to in the immediate region under discussion, namely, Wheeler Ridge and the Tejon Hills. It is believed that the smaller spurs projecting from the Temblor Range southeastward toward the valley between Midway Valley and Maricopa, on which the Lakeview and other very productive oil wells are situated, and the spur just west of the mouth of Santiago Creek, several miles to the southeast of Maricopa, are due to similar structures. The group of foothills along Kern River on which the great Kern River oil field is situated probably represents the same kind of structure. Several of these anticlines have already proved to be places of accumulation for petroleum, and it is important that all the others be carefully studied to determine whether or not the character of the beds involved and the structure are favorable for such accumulations.

CRYSTALLINE ROCKS.

OCCURRENCE AND CHARACTER.

The granite of the Sierra Nevada is continuous around the south end of the San Joaquin Valley, constituting the main mass of the Tehachapi and San Emigdio ranges. It appears in most places only a few miles back from the edge of the level valley floor, forming an escarpment that rises above the less pronounced slopes of the Tertiary rocks. Between El Paso and Tejon creeks and southwest of Caliente, where the Tertiary rocks are absent or buried beneath the valley floor, it forms an abrupt mountain front at the very edge of the valley. In the vicinity of Kern River the granite escarpment of the mountain front is thought to mark a normal fault along which the granite on the east has been raised and the Miocene beds on the west depressed. Along the southern border of the valley, however, the abrupt slope of the granite probably corresponds with the original plane of deposition of the overlying Tertiary beds, which, owing to their lesser resistance to agents of erosion, have been worn down nearly to the level of the valley. In the Temblor Range, which is much lower than the other ranges mentioned, crystalline rocks doubtless form a basement beneath the highly disturbed Tertiary rocks that form the surface. An indication of the existence of the older rocks beneath is afforded at two small areas on the east side of the Carrizo Plain some 10 miles southwest of McKittrick, where blocks of granite, schist, and other metamorphic rocks have been brought to the surface by faulting. A large part of the coarse material of the Tertiary formations was derived from the granite of the neighboring mountains, and even the formations of finer-grained material contain locally bowlders and blocks of the granite and lenses of sand derived from it. This granite is presumably of the same age as that of the Sierra Nevada, which is thought to be Jurassic.

The granite in the mountains at the south end of the valley, as well as in the Temblor Range, was intruded into metamorphic rocks, probably of Paleozoic age. These rocks consist chiefly of mica and hornblende schists and crystalline limestone. They are similar to and probably of the same age as the supposedly Paleozoic metamorphic rocks that are associated with granite in the Coast Ranges farther northwest, including the terrane in the Santa Lucia Range referred to by Willis [1] as the Coast complex.

RELATION TO PETROLEUM.

The areas of crystalline rocks may be stated with practical certainty not to contain petroleum in commercial quantities. The

[1] Willis, Bailey, Bull. Geol. Soc. America, vol. 11, 1900, p. 419.

origin and character of these rocks, as well as the lack of oil indications in them, bear out this statement. As the oil of the California fields is with little doubt of organic origin and occurs in sedimentary strata in all the productive fields, with the exception of one area to be mentioned presently, it is not to be expected that accumulations of oil will be found in the crystalline rocks unless it has migrated from its original source in the sedimentary beds. A remarkable example of such migration, which constitutes the single exception above noted, is known in Placerita Canyon, near Newhall, about 50 miles southeast of the end of the San Joaquin Valley, where oil is found in small quantities in crystalline rocks like those here described.[1] The occurrence of the oil there is probably due to its migration from Tertiary beds, in which it is believed to have originated. The accumulation of an appreciable quantity of petroleum in rocks of this type is so unusual that a recurrence of the peculiar conditions that gave rise to it is hardly to be expected.

TERTIARY ROCKS.

The belt of Tertiary strata which intervenes between the crystalline rocks of the mountains and the unconsolidated material in the bottom of the valley is a continuation of the belt of similar rocks in the Temblor Range oil field described by Arnold and Johnson.[2] The description given in that report applies in a general way to the eastward continuation of the belt, but stratigraphic changes take place that render difficult a precise correlation of the formations.

AREAL DISTRIBUTION AND STRUCTURE.

Commencing in the Sunset field, the belt of Tertiary strata bordering the south end of the valley extends southeastward for a few miles to a group of hills west of the mouth of Santiago Creek, in the southeastern part of T. 11 N., R. 23 W., San Bernardino base and meridian. Thence it trends eastward across three townships to Wheeler Ridge, in the northern part of T. 10 N. and the southern part of T. 11 N., R. 20 W. Throughout this portion of its extent the belt has a fairly uniform width of 7 or 8 miles. Its great width in this region is due to the presence of several folds which cause a reduplication of outcrops of the same strata. At the east edge of R. 20 W. a large reentrant of the San Joaquin Valley extends toward the base of the Tehachapi Range, between the mouths of Tecuya and Tejon creeks. This reentrant is less than 10 miles across at its opening to the San Joaquin Valley between the points of Wheeler

[1] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley oil district, southern California: Bull. U. S. Geol. Survey No. 309, 1907, pp. 100–101.

[2] Preliminary report on the McKittrick-Sunset oil region, California: Bull. U. S. Geol. Survey No. 406, 1910.

Ridge and the Tejon Hills, but widens to as much as 18 miles farther in. It is about 10 miles deep and forms the southernmost tip of the San Joaquin Valley. Along the south and southeast borders of this reentrant valley the foothill belt and the strip of Tertiary strata which is coincident with it are much narrower, being on the average only about a mile wide. In general the rocks in this strip dip steeply toward the valley. The trend of the belt curves gradually from southeastward south of Wheeler Ridge to eastward in the region of Cañada de las Uvas and northeastward between Pastoria Creek and the Tejon ranch. In the vicinity of the Tejon ranch house, at the mouth of El Paso Creek, the Tertiary strata are concealed, and there is a subsidiary reentrant valley between that place and Tejon Creek, around the borders of which the granite appears at the edge of the plain. This smaller reentrant is due to the removal by erosion of the Tertiary beds along a synclinal axis, the strata in the strip south of the Tejon ranch house dipping northwestward and those a few miles to the north, in the Tejon Hills, next to be described, dipping southward.

The Tejon Hills are formed of a crescent-shaped area of Tertiary rocks some 10 miles long and 2 to 3 miles wide that curves to the northwest, north, and northeast around an outstanding spur of the granite range. They thus form the northeastern border of the large reentrant of the San Joaquin Valley mentioned above. The dip of the strata in the hills is toward the valley on all sides, and the strike, which is reflected by the crescentic shape of the hills, curves around gradually from an east-west trend on the south side to a northeast-southwest trend on the north side; thus a structure is produced which may be considered as a broad anticline plunging westward or southwestward toward the valley. This anticline was probably produced by the upward doming of the granite mass forming the spur around the nose of which the Tertiary beds curve.

On taking into consideration the opposite dips of the strata in Wheeler Ridge, which forms the corresponding spur inclosing the reentrant valley on the southwest side, and also the general valleyward dip of the formations around the inner edge of this valley, it is evident that the reentrant at the south end of the San Joaquin Valley is due to a broad syncline that forms the termination of the syncline of the valley as a whole.

North of the Tejon Hills, which extend to about the north line of T. 32 S., R. 30 E., Mount Diablo base and meridian, the Tertiary belt is again interrupted and the granite mountains border the plain for a distance of about 7 miles.

Beginning west of Caliente, in the southeast corner of T. 30 S., R. 30 E., about 3 miles south of the railroad, and continuing thence northward as far as Fountain Spring Creek, 8 miles south of Porterville, in southern Tulare County; the Tertiary formations cover a strip of foothills along the eastern border of the San Joaquin Valley 4 to 15 miles wide and over 50 miles long. Throughout this strip the strata dip gently toward the valley, and consequently the belt occupied by these rocks is broad. The Kern River oil field is situated on the border of this belt, at the point where it is crossed by Kern River.

The V-shaped portion of the valley between the Tejon Hills and the Kern River region is in a way a synclinal reentrant similar to that south of the Tejon Hills just described, the strata on the south dipping northwestward and those on the north southwestward. These synclinal embayments and the corresponding anticlines that bound them, like those on the west side of the San Joaquin Valley already mentioned, indicate that the valley is not a simple syncline, but that it is warped, at least on its flanks, by important cross folds. It is possible that these transverse folds extend entirely across the valley, but if so their position and extent can not be determined because they are concealed by a covering of recent sediments. The writer is of the opinion that the cross folds are more persistent than has been supposed, but does not believe that there is actual connection between the folds on the two sides of the valley.

TEJON FORMATION (EOCENE).

OCCURRENCE AND CHARACTER.

On the north flank of the San Emigdio Mountains, in the region of San Emigdio Creek, and thence eastward past Cañada de las Uvas to a place a short distance beyond Pastoria Creek, on the north flank of the Tehachapi Range, the granite is overlain by the Tejon formation, comprising marine sedimentary beds of Eocene age. These beds consist of sandstone, shale, and conglomerate, locally indurated, but in places almost incoherent, and highly fossiliferous at some horizons. The fossils have been the subject of much study and even controversy among paleontologists since their discovery in the fifties by the Pacific Railroad survey party. They were originally examined by Conrad, who thought that they were of Eocene age, but this determination was considered incorrect by Gabb and Whitney, of the Geological Survey of California, who referred them to the Upper Cretaceous. Subsequent studies, however, have confirmed Conrad's determination. The name Tejon was applied to these beds by Whitney,[1] from their occurrence near old Fort Tejon, in the region here under discussion. The formation has been identified at many places along the Pacific slope.

[1] Geol. Survey California, Paleontology, vol. 2, 1869, p. xiii.

The Tejon formation does not occur in the southern part of the Temblor Range nor along the eastern border of the south end of the valley, but is limited to the strip 20 or 25 miles long mentioned above. The estimated thickness of the formation varies from 600 to 2,000 feet or over, and the strip that it occupies varies in width from less than a quarter of a mile to about a mile. The narrowness of this strip is due to the steep northward dips, nowhere observed to be less than 30°, and to the lack of repetition by folding. The formation was evidently laid down in the sea upon a basement of granite and along a granite shore that supplied much of its material. The even slope that forms the face of the mountains above the contact of the granite and the sedimentary beds looks like a remnant of the plane of deposition, from which the sediments have been worn away by erosion down to the level at which they now appear. Locally the lower part of the formation is made up largely of granitic sand interspersed with irregularly aggregated bowlders and blocks of granite and other crystalline rocks up to many feet in diameter. A good example of this zone may be seen along Cañada de las Uvas, where there are 100 to 200 feet of beds of this type containing marine fossils. On Tecuya Creek the lower zone contains huge blocks of granite. One of these that is believed to be in place in the formation, though it can not be stated with absolute confidence to be so, is over 50 feet in length and 30 feet in breadth.

Above the lower zone the formation consists chiefly of soft yellowish and grayish brown fine sand and sandy clay, indurated along fossiliferous layers and in irregular patches and nodules. In places true shale beds, intercalated with sand, constitute a considerable part of the formation. The beds throughout possess a marked similarity and give every appearance of representing a period of continuous deposition in one basin. They are therefore to be regarded as making up a formation, and not a larger division of the geologic column. The line of demarcation between this formation and the later Tertiary is a line of great stratigraphic importance and doubtless of unconformity, as it is known on paleontologic grounds to represent a long time interval. This line is not traceable everywhere with ease, and in places it is difficult to determine whether or not certain beds of considerable thickness belong to the earlier or later Tertiary divisions.

RELATION TO PETROLEUM.

No oil has been found in association with the Tejon formation in this region and the beds through the greater part of their extent are not of a character to suggest that petroleum has originated in them. In the vicinity of San Emigdio Creek a body of shale with interbedded layers of sandstone and some conglomerate, making up a formation over 700 feet thick, constitutes the base of the Tertiary, below the known Miocene and in what is believed to be the Tejon formation (Eocene), although definite evidence of its stratigraphic relations was not obtained. This shale bears some resemblance to the more impure facies of the organic shale found in the producing California oil fields and very likely contains a small proportion of material of organic origin. This feature suggests the possibility of petroleum occurring in association with these beds, as it does with the Eocene in the region of Santa Clara River to the south and the Coalinga region to the north, but there is no evidence of the presence of petroleum in this formation at the south end of the San Joaquin Valley. Moreover, the structure throughout the belt of Eocene strata in the latter region is such as to make a valuable accumulation of oil unlikely.

LATER TERTIARY (MIOCENE AND PLIOCENE) FORMATIONS.

OCCURRENCE AND CHARACTER.

A threefold division may be made of the later Tertiary strata of the Temblor Range and Kern River oil fields on the basis of lithologic features and age—a lower division consisting of sandstone, a middle one of beds in which the most prominent and characteristic element is white diatomaceous and foraminiferal shale, and an upper division in which coarse unconsolidated sand, gravel, and bowlders are predominant. These divisions represent a considerable part of later Tertiary time, the first one being lower Miocene in age and the last one comprising the upper Miocene and possibly reaching through the Pliocene into the early Quaternary. In the Temblor Range field the lower division corresponds to the Vaqueros sandstone (lower Miocene), the middle one to the Monterey shale and the similar shale of the Santa Margarita (?) formation (middle Miocene), and the upper one to the sandy and gravelly beds of the Santa Margarita (?) formation and to the McKittrick formation (upper Miocene, Pliocene, and Pleistocene), described in Bulletin 406 of the United States Geological Survey. In the Kern River field and along the east border of the valley north and south of that field the three divisions represent approximately the same portions of the Tertiary column and correspond roughly with at least parts of the formations mentioned. Although great differences in thickness and details of lithologic character occur, the similarity is sufficient to show that the major features of Tertiary geologic history were alike on the two sides of the valley. The presence in both these extremely productive oil regions of great masses of diatomaceous shale is especially notable. There is every reason to believe that in the Kern River field as well as in the Temblor Range field the diatomaceous and foraminiferal shale, which has an aggregate thickness of several hundred feet in the middle division, was the original source of the petroleum.

At the south end of the valley the formations of the Temblor Range continue into the San Emigdio region, with changes, however, that alter the section considerably, especially in the lower and middle divisions. These divisions have not been differentiated in the present study. A significant change is the decrease in the exposed thickness of the organic shale from several thousand feet in the Temblor Range to about 1,000 feet in the San Emigdio region, and its gradation into a less diatomaceous and more clayey and sandy type of shale. Whether this is due to the fact that a smaller volume of the organic sediment was deposited here, or to its having been partly eroded in this region, owing to its nearness to the zone of uplift represented by the granite mountains, or to its being hidden in part by unconformably overlapping formations has not been determined. The character of the material composing the Miocene section gives some weight to the belief that the greater proximity of this area to the mountain belt caused a nearer approach to shore-line conditions and the deposition here of coarser sediments in place of part of the purely organic deposits of the Temblor Range. It is believed that all the conditions stated above have combined to bring about the reduction in thickness mentioned, but in any event the probability is that the shale has a greater thickness out toward the valley, beneath the later sediments, than appears along its outcrop. This question is an important one in connection with the occurrence of oil, because it is believed that this organic shale is the source of any petroleum occurring in the region, and that the volume of shale of this type is one of the principal factors affecting the amount of oil present in a field. Eastward from Wheeler Ridge around the remainder of the south end of the valley the organic shale is not present at the surface. Instead, Miocene and probably also Pliocene sand and gravel overlap directly upon the Tejon formation (Eocene) already described, or upon the granite. The fact that the shale occurs in the Temblor Range field, in the San Emigdio region, and in the belt north and south of Kern River is an argument in favor of its presence in the intermediate regions. It therefore probably underlies the valley and approaches within a few miles of the extreme southeastern border.

The Miocene and Pliocene formations are the only ones traceable at all continuously around the end of the valley, and though their outcrops are interrupted locally, as before described, it is highly probable that they are actually continuous beneath the alluvium at the valley's edge. They consist, like the McKittrick formation and the sandy portions of the Santa Margarita (?) in the Temblor Range field, of soft, lenticular masses of bowlders, gravel, coarse sand, clayey sand, and clay. Many of the strata are indurated and form prominent outcrops. The sand and gravel are composed largely of grains of quartz and feldspar of granitic origin, and in consequence have the usual gray to white color. The coarse material in places weathers down to irregular slopes which are without outcrops but are covered with large angular blocks and bowlders of granite that remain after the finer material is removed. Such surface coverings are apt to create a doubt as to whether the underlying strata belong to the later Miocene or are Quaternary terrace deposits or alluvial fans, for little difference exists between the types of material characterizing these two epochs.

Marine fossils discovered in the Tertiary sand, gravel, and clay of the Tejon Hills suggest that the beds are contemporaneous with the Santa Margarita (?) formation (upper middle Miocene) of the Temblor Range. The fauna, however, is of a type occurring also in the lower Miocene, and a definite correlation can not yet be made. The fact that these beds lie directly upon the crystalline rocks favors the supposition that they are a continuation of the lower Miocene beds occupying a similar position on Kern River. These fossils were found at the western edge of the Tejon Hills, on top of the outer ridge of the hills north of the mouth of Tejon Creek, at a point where there are prominent outcrops of white granitic sand. The shells occur locally in great abundance and are well preserved in the white sand and in hardened nodules. According to field determinations the more abundant species found are the following:

Ostrea titan.
Pecten crassicardo.
Venus pertenuis.
Phacoides cf. nuttalli.
Hinnites gigantea.
Dosinia ponderosa.
Shark teeth.
Sea-urchin spines.

The thickness of the later Tertiary section in the San Emigdio region is at least 7,000 feet. Of this at least 3,000 feet correspond to the upper one of the three lithologic divisions above outlined. In the Tejon Hills the beds have an estimated thickness between 2,000 and 3,000 feet, although they may prove to be thicker when the details of structure are worked out.

Intrusions and flows of basalt appear in the Miocene beds at several points along the border of the San Joaquin Valley, notably between Tecuya and Tunis creeks along the south side of the reentrant valley before described. In this region there are several hundred feet of stratified basalt and basaltic agglomerate. These igneous rocks are late Miocene or post-Miocene in age.

RELATION TO PETROLEUM.

The later Tertiary formations are of prime importance in connection with the occurrence of petroleum, as they are the source of the oil and contain the reservoirs for its accumulation in the adjacent fields, and they may be expected to serve the same purpose in the region under discussion wherever oil occurs. The lower of the three divisions is of the least importance in this region, the middle division is regarded as the source of the oil, and the upper division is the main zone of its accumulation. It is believed that where the shale of the middle division is absent there is little or no chance of finding oil. Where the shale is present, however, and gives evidence of being petroliferous, there is apt to be a saturation of the overlying sandy beds of the upper division, and if the folds of the beds are of such a character as to allow the accumulation and retention of the oil, the conditions become favorable for obtaining it by drilling.

QUATERNARY FORMATIONS.

OCCURRENCE AND CHARACTER.

Brief mention has already been made of the alluvial fans around the base of the mountains and foothills and of the materials that form the floor of the San Joaquin Valley. These fans and the valley filling, which partake of the usual character of fluviatile deposits, are the representatives of the Quaternary period and are still being formed. The deposits on the floor of the valley lie approximately horizontal, as they were originally laid down, and are distinguished from the older formations principally by their undisturbed position. It is quite probable that the uppermost strata of the tilted formations reach beyond the Tertiary into the Quaternary, and that in fact movements have continued to affect the later deposits, though without having been sufficiently intense or long continued to make the deformation evident. Probably no sharp line of demarcation, either structural or lithologic, exists between the Tertiary and Quaternary formations. For this reason definite evidence as to the depth of the Quaternary filling of the San Joaquin Valley is difficult to obtain. Some of the deep wells in the wider portion of the valley farther north than the region here under discussion penetrate to depths of 1,500 to 3,000 feet in unconsolidated materials, usually supposed to be Quaternary. It is not certain, however, whether any change would be detected in passing from the Quaternary into the equally unconsolidated strata of the later Tertiary. General considerations lead to the belief that the Quaternary filling in the wider parts of the valley is from one to several thousand feet in depth, yet it is quite within the range of possibility that in parts of the valley, especially near the margins, the Quaternary material forms only a veneer where anticlinal ridges, now submerged beneath the recent sediments, projected out into the valley when the material forming the floor had not been built up to its present thickness.

RELATION TO PETROLEUM.

The only effect of the presence of Quaternary beds is to render more difficult and uncertain the solution of problems connected with the occurrence of oil. They mask the older formations and conceal the structure in the interior of the valley and around the edge of the hills. They thus prevent the determination of the presence or absence of oil and the depth and the structure of the oil-bearing rocks.

POSSIBLE OCCURRENCES OF OIL.

AREAS CONSIDERED.

In the following paragraphs a number of different areas into which this region may be divided will be taken up for the purpose of describing some of the local geologic features that have a bearing on the question of the presence or absence of oil. Only those areas underlain by Miocene and Pliocene strata will receive consideration here. As before explained, there is little or no chance for the accumulation of oil in the areas of crystalline and older Tertiary (Eocene) rocks, which will therefore not be mentioned further.

The areas to be considered are the following:

1. The foothills and valley margin from the Sunset district to San Emigdio Creek.
2. The foothills and valley margin between San Emigdio Creek and Wheeler Ridge.
3. Wheeler Ridge, east of Pleito Creek.
4. The reentrant valley and its bordering foothills between Tecuya and Tejon creeks.
5. The Tejon Hills.
6. The region from the Tejon Hills north to Tulare County.
7. The floor of the San Joaquin Valley.

THE FOOTHILLS AND VALLEY MARGIN FROM THE SUNSET DISTRICT TO SAN EMIGDIO CREEK.

The geology of the Temblor Range oil field, including the Sunset district, and the occurrence of oil there has been discussed by Arnold and Johnson.[1] Developments made since the publication of their report have proved the field to be productive almost as far southeast as the southern edge of the region shown on their geologic map—that is, as far as the southeastern part of T. 11 N., R. 23 W., San Bernardino base and meridian. There, on the slopes of an alluvial fan near the edge of the foothills, the Western Minerals Co. has wells that produce light oil in moderate quantities from depths between 1,000 and 1,500 feet.

The hills just back of these wells are formed of the oil-bearing McKittrick formation, which dips northeastward under the valley at an angle of about 10°. The dip probably continues at a slight angle out under the valley to the northeast, so that the beds may be

[1] Op. cit.

accessible in that direction for several miles. This territory bids fair to be productive in the western part of T. 11 N., R. 22 W.

In the hills just back of the wells of the Western Minerals Co. there is a short anticline running northwest and southeast through secs. 28, 27, and 35, T. 11 N., R. 23 W. This anticline is marked by a little spur of the hills west of Santiago Creek in sec. 35. It is comparable on a very small scale with the oblique anticlines mentioned earlier in this paper as favorable places for the accumulation of oil. The anticline may continue to the southern line of T. 11 N. and produce favorable conditions for the accumulation of oil in the area northwest of the mouth of Muddy Creek.

The hills west of Santiago Creek and south of the area mapped in Bulletin 406 have not been studied and therefore nothing definite can be said concerning them. The reader is referred to the statements made by Arnold and Johnson[1] regarding the region south and southwest of the developed territory of the Sunset district. The area described by them adjoins on the north the one here referred to, and the geology is of a somewhat similar type.

The foothills between Santiago Creek and San Emigdio Creek are composed of Tertiary strata dipping for the most part steeply toward the north. Cursory examination leads to the belief that a search for oil in these hills, except possibly in a strip along their northern border adjacent to the valley, would not be repaid. The organic shale outcrops in the central part of this foothill belt in an east-west direction and is overlain by sandstones and unconsolidated sandy and gravelly materials that are believed to represent the Santa Margarita (?) and the McKittrick formations of the Temblor Range field. Near the mouth of Muddy Creek oil appears at the surface in coarse material, which dips gently and overlies the more steeply dipping sandstone beds. This oil-bearing bed dips northward beneath the valley at a low angle and would be accessible over a considerable area if the dip continues at a uniform rate. It is likely, therefore, that oil could be obtained along the border of the valley in wells penetrating the late Tertiary formations, and that the edge of the plain may be productive continuously from this locality northwestward. Several factors, however, combine to make it seem improbable that this will be as richly productive as territory in the heart of the Temblor Range field, because in this area there is a smaller volume of the organic shale from which the original supply of oil was supposedly derived and because there is a comparative uniformity of structure which does not favor unusual concentration of oil. The significance of the first-mentioned factor is somewhat reduced by the probability that the organic shale increases in thickness out under the valley to the northward.

[1] Op. cit., pp. 213-214.

THE FOOTHILLS AND VALLEY MARGIN BETWEEN SAN EMIGDIO CREEK AND WHEELER RIDGE.

Of the foothill and valley border between San Emigdio Creek and Wheeler Ridge very little can be said definitely on the basis of the observations made. The general impression obtained concerning this area is that it does not offer conditions favorable for the occurrence of oil. However, there are folds of the strata in this area that must be examined further before any reliable conclusion can be formed. Eastward from San Emigdio Creek the dip of the beds of sand and gravel at the northern edge of the hills is much steeper than in the region farther west, being for the most part greater than 40°, and for this reason it appears that the probable productive territory along the border of the valley mentioned in the preceding paragraph ends in the vicinity of San Emigdio Creek. The steepness of the dip renders the valley border unfavorable for the accumulation of oil, because of the regularity of the structure and the great depth at which the possible oil-bearing stratum may be below the surface. The margin of the valley, however, deserves further study in view of the possibility, especially at some places, of a marked decrease in the dip of the late Tertiary formation outward beneath the valley floor. At the mouth of Pleito Creek beds of coarse granitic gravel, supposedly representative of the McKittrick formation, dip at an angle of 20° toward the plain. Along San Emigdio Creek above its mouth similar beds lie almost horizontal and with evident unconformity upon more highly deformed middle or upper Miocene strata, and at the mouth of the canyon these overlying beds dip abruptly toward the valley at an angle of about 20°. The possibility of these beds flattening out beneath the valley and serving as a reservoir for oil is worthy of consideration.

WHEELER RIDGE.

Wheeler Ridge has been mentioned in an earlier part of this paper as one of the anticlines that characterize the periphery of the San Joaquin Valley. It is formed of an elongated dome in the later Miocene strata at the outer edge of the Tertiary belt and projects eastward as one of the spurs that inclose the reentrant at the southernmost tip of the San Joaquin Valley. Owing to its interesting features and economic possibilities it will be discussed in more detail than the surrounding areas.

In 1910 Ralph Arnold made a geologic examination of Wheeler Ridge and wrote a brief report for the Midway Union Oil Co. in which he reaches the conclusion that the possibility of finding oil on certain properties situated along this ridge is good. This report was published by the company and has been of considerable service to the writer.

Topography.—The foothills east of Pleito Creek, and those in the district between San Emigdio and Pleito creeks just mentioned, rise abruptly from the edge of the valley and have a rather rugged outline. Their steep front facing the plain corresponds to the dip of the sandstone and conglomerate beds of the later Miocene, which occur here at the top of the exposed Tertiary section. In places the slope is formed by the face of a hard stratum dipping 40° to 60° toward the plain. In the hills the gulches are sharply incised in the usually soft, upturned Miocene beds, and many of the side slopes of the ridges show the effects of rapid erosion. The elevation of the belt of Tertiary rocks referred to as the foothills reaches over 3,000 feet above the valley floor, the constituent ridges rising continuously from the valley into the mountain slopes.

A few miles east of Pleito Creek, however, the outer foothills continue into a partly detached ridge that runs eastward across T. 11 N., R. 20 W., and projects into the reentrant of the San Joaquin Valley before mentioned. This ridge is sometimes spoken of as Wheeler Ridge and is so designated in this paper. Its summit is about 1,300 feet above the edge of the valley and only about a mile distant from it at the nearest point. The ridge is of especial interest because it is the topographic expression of a well-developed elongated dome, the axis of which follows the central part of the ridge. At its east end the ridge declines in height and width until it merges with the valley floor, its contour in this portion being almost identical with that of the strata which arch over the nose of the plunging anticline.

Stratigraphy.—So far as known Wheeler Ridge embraces only one formation, which is thought to be the equivalent of the Santa Margarita (?) and McKittrick formations described in Bulletin 406. As exposed in Wheeler Ridge this formation comprises at least 3,000 feet of varied marine sediments. The gravel and sand of which it is largely composed indicate that the prevailing rock of the parent land mass was of granitic type and that this area of deposition was not far removed from the original source of supply. Pebbles of typical white siliceous diatomaceous shale known in this region only in the middle Miocene strata occur in some of the gravel layers of this formation, showing that shale of this type had been uplifted to form part of the land area prior to the deposition of these beds. This evidence points to an unconformity between the formation of Wheeler Ridge and the earlier Miocene diatomaceous shale and makes plausible the theory advanced in a previous part of this paper that the thickness of this shale is greater underneath the valley than it is where the shale is exposed in the foothill belt.

The formation of Wheeler Ridge consists of material of all gradations of texture from fine tough clay to bowlder beds and angular rock fragments. Beds and bands of different material and texture alternate throughout the section, the bedding planes being fairly sharp but the individual strata not being constant in character for any considerable distance along the strike. Lenses of sand and gravel are present at many places and there are few zones without scattered pebbles. Among the finer-grained strata a common type is straw-colored, mouse-colored, or greenish-gray tough clayey granitic sand with thin clay partings. The predominant materials, however, are only slightly consolidated gypsiferous sand and gravel. Similar materials locally consolidated form hard, prominent beds of sandstone and conglomerate scattered through the formation. The base of the formation is not exposed on Wheeler Ridge, but the beds on the axis of the anticline in the central part of the ridge are believed to be not far above the base.

Structure.—Wheeler Ridge is formed by a domelike anticline that rises in the foothills and sinks abruptly again at the edge of the valley a few miles distant. In the western part of T. 11 N., R. 20 W., the anticline plunges steeply westward (at an angle of about 15°) and appears to come to an end. Whether or not it is continued in one of the folds farther west was undetermined. At the east end of Wheeler Ridge, in the southeastern part of the same township, the anticline plunges southeastward a little less abruptly, at an average angle of about 10°, and is lost beneath the plain. The dips on the north flank of the fold steepen rapidly from those of a low arching structure over the axis to 40° or so within one-third or one-half mile to the north and to 50° or 60° farther away from the axis of the fold. At the east end of the ridge the steepening of the dip does not take place so rapidly on the flank and it is believed that the belt of moderate dip is wider there. On the southern flank the dips are slightly less than those on the north flank.

The axis of the anticline runs eastward from the center of sec. 30 to the center of sec. 29, T. 11 N., R. 20 W., and thence east-northeastward to the center of the NE. ¼ sec. 28; thence it curves southeastward and follows down the nose of the ridge into the east-central part of sec. 36. The curve that it makes from northeast to southeast in the northern part of sec. 28 is a notable feature involving a change in strike of 30° or more. This curve is plainly evident in the trend of the strata on the north flank and in that of the border of the hills, both of which change near the line separating secs. 20 and 21 from about 15° north of east to 30° south of east, or through an arc of about 45°. This curve is the result of an upward warping of the Wheeler Ridge anticline and might be considered in effect a broad and short anticlinal structure crossing the main anticline and plunging steeply to the northwest on the north flank of the ridge. Such a curve is the natural result of the doming of an anticline like that of

Wheeler Ridge, where the strata on one flank are steeper than on the other. The highest part of the anticlinal dome is in the northern part of sec. 28, where the curve of the axis takes place, and therefore the lowest strata are exposed in that vicinity.

Oil seepage.—A good seepage of petroleum occurs in a gulch sometimes called Coal Oil Canyon, toward the west end of Wheeler Ridge, on the north flank of the anticline. Its location is about a mile up the canyon from its mouth, near the center of the south line of sec. 20, T. 11 N., R. 20 W., about half a mile from the anticlinal axis. The oil impregnates beds of gravelly sand that dip 40° NNW. This seep age is about 400 or 500 feet stratigraphically above the beds exposed at the axis of the anticline in this part of its course and considerably more above the lowest beds exposed farther east. It is estimated that the seep is at least 1,000 feet above the base of the formation.

Along the creek bed the strata through a thickness of some 30 feet are stained brown by the oil residue in them and give off a strong odor of petroleum. At one point a hole has been dug a few feet below the surface and the sand appears black with oil, which exudes slowly as a heavy brownish-black liquid. Along the strike of the beds toward the east the impregnated zone is traceable a long distance, and it increases in thickness to at least 100 feet within a few hundred feet from the seepage, as is indicated by an almost solid mass of brown-stained sand of that thickness which is plainly visible on the bluff east of the gulch. This is a good indication of the thickness of the oil sand that might be expected in places at this horizon.

The strata at the seepage along the bottom of Coal Oil Canyon afford a good index of the character of the oil sand and its confining medium. The beds forming the reservoir for the oil are composed of friable granitic sand full of scattered pebbles and angular fragments up to a foot in diameter. The sand grains vary in size, ranging from the finest grit upward, and consist largely of little-worn crystals of quartz and feldspar. At the base of the oil zone there is about 15 feet of coarse petroleum-stained sand of the type described. Above this are alternating beds, averaging about a foot in thickness, of oil sand of the same type and of olive-gray sand having no stain or odor of oil. The latter sand resembles the former closely, being gritty and pebbly, but the critical difference which causes it to be free from oil seems to be that it has a matrix of moist clayey material that renders it tough and less porous. On fresh exposures it is of a steel-blue color and very moist. In places such sand occurs as lenses or stringers free from oil in the midst of the oil sand. A thick band of this blue sand occurs at the top of the oil zone and seems to be the cause of the failure of the oil to impregnate higher beds. Outcrops of this character confirm the belief hitherto held that in formations such as this, in which beds and lenses of porous sand and gravel usually occur interspersed with beds of tough gritty clay or clayey sand, the moist clayey material acts as an impermeable barrier and where occurring in beds or lenses of sufficient extent confines the oil to the more porous zones.

About a quarter of a mile up the canyon from the locality just described and between 200 and 400 feet stratigraphically below the horizon of the first seepage there occur other zones of brown sand that are probably petroliferous. The brown sand looks like the oil sand described, alternates with unstained layers, and has a strong odor of sulphur.

Economic possibilities.—Wheeler Ridge satisfies the four main geologic conditions of a prospective oil field, namely, that there shall be good indications of the presence of oil in the rocks, that the lithologic character of the rocks shall be such as to allow accumulations to take place in porous zones confined by impermeable or less permeable ones, that the structural position of the rocks shall be such as to favor concentration rather than diffusion and escape of the oil, and that the probable oil-bearing sand shall be at a depth accessible to the drill. These conditions are unusually well satisfied along the anticline of Wheeler Ridge, and for this reason the writer feels justified in believing that here a promising though comparatively small oil field awaits development.

The first of the four main conditions is fulfilled by the seepage in Coal Oil Canyon already discussed. This proves the existence of oil in the formation and makes probable its presence in beds underlying the greater part of the ridge. This probability is strengthened by the occurrence of extensive oil-bearing zones in the same general portion of the Tertiary series along the two sides of the San Joaquin Valley and by the supposed existence of the middle Miocene oil-forming shale beneath Wheeler Ridge. That the second condition is fulfilled is indicated by the texture of the rocks as previously described and by the seepage in Coal Oil Canyon. The porous sands and gravels of this formation should provide excellent thick reservoirs for the accumulation of oil, and the clayey zones should afford confining media. In this respect the conditions are similar to those of the Temblor Range and Kern River fields. The third condition is satisfied by the perfect anticlinal structure, which has proved to be a favorable condition in almost every one of the important California fields. The fourth condition is satisfied along a comparatively small belt which will be discussed below.

Of course there exist important uncertain factors which must await actual test. In the present case there seem to be two principal doubtful factors. One of these is whether the oil that probably underlies this ridge occurs in large quantity; the other is whether the thickness of the sandy and gravelly zones through which the oil might be disseminated is not too great for it to be concentrated in large quantity at any particular place. As to the first of these doubtful factors, it may be said that the seepage in Coal Oil Canyon is active and is of a character to lead to the belief that oil in much larger quantities could be found below the surface. The fact that a rich oil sand appears at the surface in the midst of a great thickness of beds most of which would be suitable for the absorption of oil and many of which are doubtless oily beneath the surface argues that there is an abundance of oil present. The same argument might be used as opposed to the second doubt stated above. Moreover, the occurrence of numerous clayey zones, their apparent impermeability as exposed at the seepage, and the analogy afforded by the Temblor Range and Kern River fields, where large concentrations of oil occur in formations of similar character, tend to minimize this second doubt.

Another favorable consideration not yet brought out is that oil very likely occurs at the base of the formation, below the lowest beds exposed, and that a productive zone may occur there in addition to the one supposed to exist higher in the formation and represented by the oily beds of Coal Oil Canyon. This likelihood is borne out by the conditions in other fields, where the line of unconformity at the base of the sandy formation and the top of the organic shale has proved to be an especially favorable position for the accumulation of petroleum.

A number of wells have been or are being drilled for oil in the vicinity of Wheeler Ridge, but none has gone deep enough to test the area effectually or afford a clue as to its possibilities. Most of the wells in this region are unfavorably located and can not be expected to give an adequate test.

With regard to the depth of the oil sand and the extent of the area that may prove to be productive, only estimates can be given at the present time. When a detailed examination of this region is undertaken it will be feasible to make careful measurements of the inclination and thickness of the strata and to calculate with a fair degree of accuracy the depth of the oil sand at any particular locality. In the opinion of the writer the most promising territory is along the crest of the anticline from the western edge of sec. 27 southeastward to sec. 36, T. 11 N., R. 20 W. Throughout this distance the oil sand that outcrops in Coal Oil Canyon underlies the beds on the summit of the fold and dips uniformly southeast, so that it becomes deeper and deeper in that direction. It would be found to sink gradually from a shallow depth in sec. 27 to one between 2,000 and 3,000 feet in the eastern part of sec. 36. From this section southeastward the fold is concealed, but it may be present in the Tertiary strata beneath the covering of flat-lying alluvium. If the same rate of plunge persists, say about 10°, the oil sand would lie at a depth of less than 5,000 feet for 2 miles farther. If the fold flattens out it is possible that productive beds might be found within reach of the drill even farther east, but any statement regarding the structure beneath the valley floor is based almost wholly on conjecture and consequently has little value.

Throughout the greater part of secs. 28 and 29 the oil sand of Coal Oil Canyon has been eroded, being higher in the section than the beds exposed. In this part of the anticline, therefore, a lower sand must be depended on to furnish oil if any is present. It is probable that a lower oil-bearing sand exists, as before stated, and if such a sand is present the structural conditions make it likely to be productive.

Still farther west the known oil-bearing sand of Coal Oil Canyon would be accessible on the crest of the fold and may be productive as far as the anticline remains well defined and does not plunge too steeply.

The steep dips on the flanks of the anticline restrict the productive area to the belt of hills and make the possibility of finding oil outward from the axis of the anticline decreasingly favorable. In a general way it may be said that a strip about a mile wide, with the axis of the anticline as a median line, will cover the best territory. Wells put down at the border of the valley, except near the east end of Wheeler Ridge, would have to go extremely deep, with only small chances of getting a good production even if they reached an oil sand.

The strip of prospective oil land above outlined is 6 to 10 miles long. Its length being considered as 8 miles and its average width as 1 mile, there is here an area of 5,000 acres offering a good chance for the discovery of oil. It is believed that a test should be made in that part of the area which from the evidence obtained seems to be the most favorable, namely, along the axis of the anticline in the eastern half of Wheeler Ridge.

THE REENTRANT VALLEY AND ITS BORDERING FOOTHILLS BETWEEN TECUYA AND TEJON CREEKS.

Along the southern border of the reentrant valley between Tecuya and Tejon creeks the Tertiary belt narrows to a mere fringe at the base of steep granite slopes. In this region the late Tertiary formations are for the most part steeply inclined and lie directly upon the earlier Tertiary or the granite. The strata likewise are intruded by volcanic rocks. For these reasons the hills bordering the plain show no promise for the occurrence of oil and do not encourage a belief that the adjacent area of the valley floor offers favorable conditions. There is no surface indication of the geologic structure of the Tertiary rocks underlying the floor of the reentrant valley a few miles out from the hills, but the possible existence of an eastward continuation of the Wheeler Ridge anticline should be borne in mind. In this connection a careful study should be made of the foothills in the vicinity of the mouth of Tunis Creek, where the Tertiary belt widens somewhat in consequence of a low dip of the late Tertiary gravel, sand, and clay toward the valley. It is possible that the structure of these beds may throw some light on the conditions beneath the valley. If the middle Miocene organic shale were present beneath this reentrant valley it would not be surprising if oil had risen from it and had collected in the lightly dipping late Tertiary strata at points sufficiently near the edge of the hills to be at an accessible depth beneath the surface.

THE TEJON HILLS.

The structure of the Tejon Hills has been described in a previous part of this paper, and the general character of the strata has been mentioned also. The beds are of Miocene age and are similar in character to those of the same age in other parts of the region under consideration, especially to those of Wheeler Ridge. The formation rests directly on the eroded surface of the granite and has a thick basal conglomerate containing large bowlders and fragments of granite. The slope of the mountain above the contact appears to be the original surface upon which these beds were deposited.

The broad anticline of the Tejon Hills is somewhat similar to the folds that have been referred to before as projecting into the San Joaquin Valley at several places from the surrounding mountains and hills. This structure suggests the possibility that oil has accumulated here as in analogous folds elsewhere. The lithology of the strata and the anticlinal structure lend support to the belief that were petroleum present, it would probably be in large quantity. However, no direct indications of oil are known, and there are no definite data to indicate either the presence or absence of the middle Miocene organic shale from which oil might be expected to have come. In the absence, therefore, of any evidence of the existence of oil or of the presence of the formation which is regarded as the source of oil, the possibilities of accumulation in these hills must be considered very doubtful. As explained before, the middle Miocene shale may be present in the easternmost part of San Joaquin Valley and be hidden by overlapping Miocene and later formations. If it were present beneath upper Miocene beds within the area of the Tejon Hills and carried oil in large amount, indications of oil would be likely to occur in the overlying sandy strata at their outcrop. If the shale does not underlie the hills but is in close proximity to them beneath the edge of the valley there would be some chance of the occurrence of oil beneath the valley border in this region, without any evidence of it at the surface. In order to test this marginal area, wells would have to go to great depths through Quaternary and late Tertiary formations to reach the hypothetical productive sand. In the opinion of the writer the chance of obtaining any oil here is too slight to warrant the great expenditure necessary for such a test.

The position of the Tejon Hills anticline, only a few miles away from the anticline of Wheeler Ridge, which plunges in the opposite direction, suggests structural connection between them. If such a connection exists the mouth of the reentrant valley would be crossed by a fold along which the possible oil-bearing formations might lie at a lesser depth than in other portions of the valley. It is believed, however, that these two folds are independent of each other, that of Wheeler Ridge plunging toward the southeast and that of the Tejon Hills plunging toward the west. It is probable that the possible oil-bearing strata lie too deep to be accessible in the central portion and at the mouth of the reentrant valley.

REGION FROM THE TEJON HILLS NORTHWARD TO TULARE COUNTY.

The reconnaissance examination on which the present paper is based covered only scattering areas of the region north of the Tejon Hills, and therefore no attempt will be made to offer suggestions regarding that region. For a distance of about 7 miles north of the Tejon Hills the granite comes directly to the edge of the plain and the Tertiary formations are not exposed. Thence northward along the east side of the San Joaquin Valley a broad Tertiary belt extends to a point beyond White River in Tulare County. This belt of outcrop deserves careful geologic examination, but time did not permit such an examination during the season of 1910.

FLOOR OF THE SAN JOAQUIN VALLEY.

The occurrence of petroleum in large quantities on the two sides of the San Joaquin Valley in formations of similar character and age naturally suggests the possibility of a continuity of the productive strata across the intermediate valley region; therefore the character, structure, and depth of the formations underlying the alluvial plain are worthy of consideration, but it is a question that allows only a speculative treatment. Little definite can be said beyond a statement that the depth below the floor of the valley to the Tertiary beds which are oil bearing in the lateral fields is probably too great for them to be reached by present methods of drilling; and even though they were reached it is by no means certain that oil would be found in large quantities in them.

The Miocene beds are believed to be present under the valley because there is a similar succession of formations along the ranges on both sides and a continuity of at least parts of the formations around the south end of the valley, because of the narrowness of the valley in this portion as compared to the extent to which these broader lithologic divisions of the Miocene continue both along the strike of their belts of outcrop and across the Coast Ranges, and because of the strong likelihood that the structural depression of the San Joaquin Valley existed during Tertiary time and formed a central portion of the basin of deposition of the Miocene series exposed along its present border.

If it be granted that this is the case, and that the formations beneath the plain have been the source and are the receptacles of large quantities of petroleum, like the exposed portions of the same formations, which is highly probable, then the next question is whether or not they are still oil-bearing. The answer to this question depends largely on the solution of the problem of the structure of the rocks underlying the valley floor. If the structure of the beds is uniformly synclinal, with gradual dips from either side toward an axial line somewhere under the valley, it is probable that most of the oil has been disseminated through a great extent of strata, and that much of it has migrated, during the long periods of time that have elapsed since its formation, to the more favorable collecting grounds presented by the folded structures along the valley sides, where such large supplies are now found. Its place after such migration would probably be taken by water. On the other hand, if subsidiary folds cross the syncline of the valley or warp its flanks it is more probable that oil has collected and is being held in such folds.

There are certain features that lend support to the supposition that the structure of the formations underlying the valley is not entirely uniform. Among these the most important are the many folds along the sides of the valley whose axes diverge from the main trend of the ranges and project long distances into the alluvial plain. These folds have received mention earlier in this paper. Two-thirds of the great Coalinga anticline, which is at least 60 or 70 miles long, is in the plain, and for 15 miles in its southeastern part between the Kettleman Hills and the end of the Lost Hills it is almost entirely hidden beneath the valley floor, being recognizable only by the slight topographic relief presented by the Lost Hills. This anticline, as well as the anticlinal spur of the Elk Hills, projects a third of the distance across the valley from the edge of the plain on one side to its edge on the other. The distance that these anticlines project is in each case almost the distance to the present line of lowest depression of the floor, which has been mentioned as being much nearer the Coast Range than the Sierra side of the valley. To judge by the greater deformation of the strata along the Coast Ranges than along the border of the Sierra, it seems probable that the syncline of the underlying rocks is also unsymmetrical, with its axis nearer the Coast Range side. If this is the case it is evident that some of the folds which are actually traceable at the surface extend almost to the synclinal axis. Some of the other folds, which can not be traced, owing to the alluvial cover, may project to an equal or even greater distance. On the Sierra side the folds are of a broader and lower type and may readily be conceived of as merging into a uniform slope toward the center of the valley, although they may affect the Tertiary strata as far as or farther than the center.

It is a characteristic feature of the Coast Ranges that they are crossed by structural axes oblique to the trend of the mountain system as a whole. The general direction of such cross axes is slightly more to the west of north and to the east of south than the main trend. The folds that project into the San Joaquin Valley are of this type. The occurrence of such cross folds on the east side of the valley, as already mentioned, is an indication that at least the margin of the Sierra and therefore the valley region between the Sierra and the Coast Ranges form a portion of the province affected by structure of this type, which is another reason for believing that the Tertiary basement of the valley may be transversely warped.

As regards the depth of the Tertiary formations beneath the floor, some idea may be gained by estimating the dip of the strata from both sides. The south end of the valley from the latitude of Kern River southward is about 30 to 35 miles across in its wide portions. Between the outstanding spurs it is only 20 to 25 miles. Assuming the average distance from the Coast Range side to the axis of the syncline to be 15 miles, which is believed to be liberal, and assuming an average dip of 2° in the uppermost Tertiary beds exposed at the edge of the hills to the axis we find the depth to these beds at the axis to be about 2,500 feet (subtracting about 300 feet for difference in altitude of the center and the margin of the valley). With a dip of 3° the depth would be approximately 4,000 feet; with 1° hardly more than 1,000 feet. If an estimate were made from the end of the Elk Hills and the axis assumed as being one-third of the way across the valley, where it is only 21 miles wide, the strata forming the edge of the hills would be about 2,000 feet below the floor at the deepest point if the average dip were only 3°. At 2° their depth would be 1,300 feet. The writer believes it is safe to say that the strata that are oil bearing in the adjacent fields underlie the southern part of the valley at a depth nowhere greater than 10,000 feet. If cross folds occur beneath the plain it is not improbable that these strata lie in places at depths not greatly in excess of 5,000 or 6,000 feet. The time may come when drilling to such depths will be practicable and then the oil fields bordering the valley may encroach upon the plain, but for the present the greater part of the valley surface, beyond a strip a few miles wide along the border, is to be regarded as of extremely hypothetical value for oil.