GEOLOGY AND OIL RESOURCES ALONG THE SOUTHERN BORDER OF SAN JOAQUIN VALLEY, CALIFORNIA

By H. W. Hoots

ABSTRACT

The region described in this report includes a foothill belt of the San Emigdio and Tehachapi Mountains along the southern border of San Joaquin Valley. The belt displays portions of the rugged granitic cores of the mountains and also rocks of Eocene, Oligocene, Miocene, Pliocene, and Pleistocene age. Although there is thus a complete representation of the geologic series from the Eocene to the Pleistocene, some portions of the different series are wanting because of major faults and overlaps. The thickness of the Tertiary rocks (Eocene to Pliocene) varies considerably but has a maximum of about 29,000 feet. Miocene and Pliocene rocks cover most of the area investigated.

The San Emigdio and Tehachapi Mountains form a structural and physiographic link that connects the Coast Range on the west with the Sierra Nevada on the east. In these mountains there is a gradual eastward transition from the complex folds and faults of the Coast Range to the comparatively simple, gently dipping monocline of the west flank of the Sierra Nevada. The complex structural features in the San Emigdio foothills west of Grapevine Canyon and north of the San Andreas fault provide evidence that this portion of the area has been deformed by stresses with major lateral components from the south—stresses which have been responsible for thrust faulting and the development of asymmetrical and overturned folds.

Much of the present height of the foothill belt of the San Emigdio and Tehachapi Mountains has been produced by uplift since the beginning of Pleistocene time.

Wheeler Ridge is at present the only oil-producing area along the southern border of San Joaquin Valley. Three other areas, however, appear worthy of consideration for the drilling of test wells—namely, (1) a partly buried structural feature, possibly an anticline, 1 mile northwest of the mouth of San Emigdio Canyon; (2) the structural terrace that forms the eastern extension of the San Emigdio anticline, near Pleitito Creek; (3) the Tejon Hills.

INTRODUCTION

LOCATION AND EXTENT OF AREA

The belt of Tertiary rocks described in this report is exposed along the southern border of the Great Valley of California between the Temblor Range on the west and the Sierra Nevada on the east. These rocks form the northern foothills of the San Emigdio and Tehachapi Mountains and extend northward to form the Tejon Hills, which flank the south end of the Sierra Nevada. The Tejon Hills are geologically similar to the indistinct foothill belt farther north that borders the eastern edge of the San Joaquin Valley. Their geologic structure is radically different from that of the Coast Ranges and the San Emigdio foothills, but they may be considered an integral part of the structural system that extends eastward

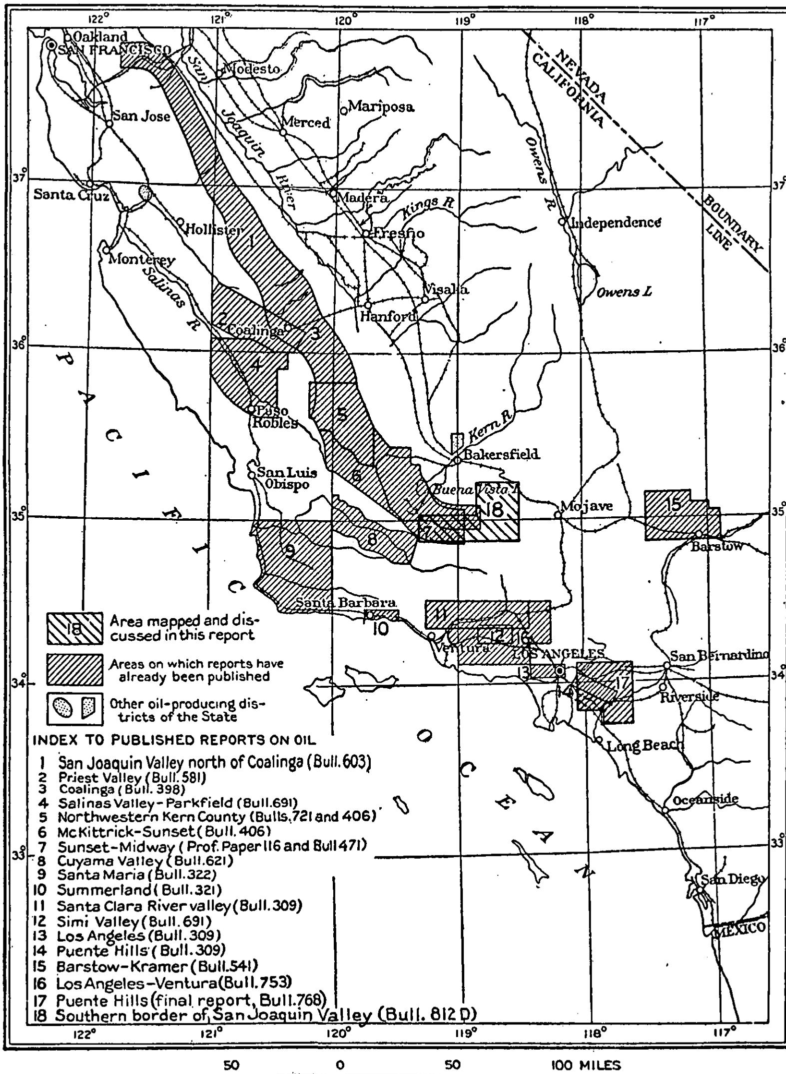

FIGURE 7.—Index map of southern California, showing oil fields considered in reports published by the United States Geological Survey

from the Temblor Range around the south end of the Great Valley to the Sierra Nevada. In brief, it may be said that this belt of Tertiary rocks around the south end of San Joaquin Valley forms a connecting link between two major geologic provinces of California, provinces whose geologic characteristics are profoundly different.

The area covered by this investigation, which is shown in Figure 7, lies east of Santiago Creek, a stream that enters San Joaquin Valley just east of its southwest corner. Although the western part of this belt—the San Emigdio foothills between Santiago and Grapevine Creeks—was previously mapped by R. W. Pack and discussed in Professional Paper 116, the hopefulness for future oil production from this district has led to a resurvey of the northern or outermost portion of the San Emigdio foothills. The entire belt is 1 to 6 miles in width and extends eastward to the Sierra Nevada, a distance of over 30 miles, and thence northward along the east edge of San Joaquin Valley for about 10 miles.

This belt of Tertiary rocks, in addition to having one small oil field on Wheeler Ridge, whose daily output was about 1,000 barrels a day in April, 1927, forms a partial physiographic connection between two of the major oil districts of California—the Sunset-Midway field, west of the area here described, and the Kern River-Poso Creek fields, north of the area.

EARLIER PUBLISHED INVESTIGATIONS

It appears that W. P. Blake, geologist for the Pacific Railroad Survey, was the first to record geological observations at the south end of San Joaquin Valley. In 1854 the survey party with which Blake was connected camped near Old Fort Tejon, in Grapevine Canyon, which was then known as the Cañada de las Uvas. Fossils collected by Blake in this vicinity were submitted to T. A. Conrad, who pronounced them to be Eocene. Blake's account of his investigation,[1] together with Conrad's report on the fossils,[2] was published in 1857.

In 1865 J. D. Whitney,[3] in charge of the first Geological Survey of California, published a brief account of observations by him and his assistants in the foothill belt along the southern border of San Joaquin Valley. Fossils similar to those found by Blake were collected in the Cañada de los Alisos (now known as Live Oak Canyon) and were determined by W. M. Gabb to be Cretaceous and not Eocene, as previously reported by Conrad, a conclusion which has since proved to be erroneous.

The first published account of the systematic geology and possible oil resources of the south end of San Joaquin Valley was that by

[1] Blake, W. P., Geological report: U. S. Pacific R. R. Expl., vol. 5, pt. 2, pp. 41–50, 163–164, 197–211, 1857.

[2] Conrad, T. A., Description of the fossil shells: Idem, pp. 317–318.

[3] Whitney, J. D., California Geol. Survey, vol. 1, pp. 186–197, 1865.

Robert Anderson,[4] although unpublished investigations of parts of the region had previously been made by Ralph Arnold, H. R. Johnson,[5] R. W. Pack, and others. Anderson, whose investigation was of a strictly reconnaissance nature, subdivided the Tertiary formations into two units—the Tejon formation and later Tertiary (Miocene and Pliocene) formations—and discussed the general structure and the possible presence of oil in the region.

In 1911 and 1912 R. W. Pack, with the assistance of A. T. Schwennesen and R. G. Davies, mapped the foothill belt along the north flank of the San Emigdio Mountains. Pack's description of the geology and oil prospects of this district was included in his report on the Sunset-Midway oil field.[6] In this investigation Pack recognized all the major stratigraphic units except the Meganos (middle Eocene), but, for convenience in mapping, grouped Oligocene strata with the lower Miocene Vaqueros formation.

B. L. Clark[7] has since studied the Eocene sediments of the San Emigdio region and has subdivided them into the Meganos (middle Eocene) and the Tejon (upper Eocene). Wagner and Schilling[8] have separated the Oligocene deposits from the overlying Vaqueros formation (lower Miocene) and have made stratigraphic and faunal studies of them. In the following pages further reference will be made to the preceding publications and to those concerning other faunal studies that have been made in the Tertiary beds of this district.

ACKNOWLEDGMENTS

In 1911 R. W. Pack, of the United States Geological Survey, assisted by A. T. Schwennesen and J. D. Northrop, mapped the Tejon Hills and the strip of beds between the Tejon ranch and the San Emigdio foothills. Their maps and field notes have been at hand during the present investigation and have been of material assistance in completing this project, but unless otherwise noted in the text the present writer assumes full responsibility for the conclusions presented herewith. In 1918 W. A. English, of the United States Geological Survey, compiled a geologic map from the field data accumulated by Pack and his assistants, a map which has facilitated the use of observations made by these earlier workers.

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[4] 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, 1912.

[5] An abstract of Johnson's observations is included in U. S. Geol. Survey Water-Supply Papers 222 and 398.

[6] Pack, R. W., The Sunset-Midway oil field, Calif.: U. S. Geol. Survey Prof. Paper 116, 1920.

[7] Clark, B. L., The stratigraphic and faunal relationships of the Meganos group, middle Eocene of California: Jour. Geology, vol. 29, pp. 145–154, 1921.

[8] Wagner, C. M., and Schilling, K. H., The San Lorenzo group of the San Emigdio region, Calif.: California Univ. Dept. Geology Bull., vol. 14, pp. 235–276, 1923.

Dr. B. L. Clark has examined and identified much of the invertebrate fossil material collected from this district.

The geologic departments of oil companies that have information concerning the surface and subsurface geology of this district have tendered valuable cooperation. Mr. G. C. Gester, of the Standard Oil Co. of California, and Messrs. E. D. Nolan and C. H. Wagner, of the General Petroleum Corporation, have furnished logs and production records of their wells in the Wheeler Ridge oil field. Mr. J. A. Taff, of the Associated Oil Co., Mr. G. H. Doane, of the Milham Exploration Co., and officials of the Midland Oilfields Co. (Ltd.) and the Tejon-Kern Petroleum Co. have also furnished logs and other information from wells drilled within the district. Officials of the Tejon ranches have likewise furnished logs of wells which have been drilled on their property. Dr. E. F. Davis and other geologists of the Shell Oil Co. of California have kindly cooperated and tendered many courtesies during this investigation.

Appreciation is expressed for the hospitality of employees of the General Petroleum Corporation's Rose pumping station, and to Mr. Fred Rush and officials of the Kern County Land Co. for providing living quarters during a part of the time occupied in field work.

The writer wishes to acknowledge his indebtedness to numerous geologists who have offered suggestions and have discussed observed phenomena and theoretical questions concerning this complicated district. Especially is he indebted to Dr. R. D. Reed, Dr. J. P. Smith, Mr. B. F. Hake, Dr. B. L. Clark, Dr. Gerhard Henny, Mr. L. M. Clark, Mr. W. A. English, Mr. W. D. Kleinpell, Dr. W. S. W. Kew, and Mr. P. C. McConnell.

FIELD WORK

Field work was begun in July, 1924. During that season Wheeler Ridge and adjoining areas were mapped by plane-table triangulation on a scale of 2 inches to the mile and mapping on a topographic base enlarged to 2 inches to the mile was extended westward to San Emigdio Creek and southward to include the Pleito Hills. In April and May, 1926, mapping on an enlarged topographic base was continued westward from San Emigdio Creek to Santiago Creek and eastward from Salt Creek to and beyond Comanche Point.

STRATIGRAPHY

Except for the pre-Tertiary batholith of granodiorite and other closely associated rocks of igneous and metamorphic origin, the rocks of the section along the southern border of San Joaquin Valley are entirely of Tertiary age. (See pl. 31.) All parts of the Tertiary system beginning with middle Eocene are represented, and the total maximum exposed thickness of these deposits aggregates approximately 24,000 feet. Most of the section is composed of clastic sediments of marine origin, but continental deposits occur in the lower Miocene and in the Pliocene and Pleistocene, and basaltic and andesitic lava and pyroclastic deposits occur in the lower Miocene. In addition, a bed of bentonite that represents a decomposed layer of volcanic ash appears to lie within the upper Eocene.

BASEMENT COMPLEX

The San Emigdio and Tehachapi Mountains connect the Coast Ranges with the Sierra Nevada and adjoin the broad San Joaquin Valley to the north. Their central granitic core is continuous with that of the Sierra Nevada and in this region represents one or more batholithic intrusions of pre-Tertiary age. In the northern Sierra, where Mesozoic sediments are associated with the granodiorite, there is evidence that the intrusion occurred during or at the end of late Jurassic time. It is uncertain, however, that the San Emigdio-Tehachapi mass was developed at the same time. It is conceivable that this enormous linear intrusion was a progressive action and that, instead of producing a single unit, it actually gave rise to a series of intrusive bodies of slightly different age. The southern or San Emigdio-Tehachapi portion may thus be either older or younger than the granodiorite of the northern Sierra and may well be of pre-Jurassic or Cretaceous age. From its relation to associated rocks exposed along its flanks this southern intrusive mass is regarded merely as pre-Tertiary.

Although granodiorite is by far the most common rock type in the San Emigdio and Tehachapi Mountains, the mass is far from uniform in petrographic details and grades from gray and pink granite with a comparatively small amount of ferromagnesian minerals to black diorite. This granitic mass is gneissic in part and is associated with a metamorphic series that consists largely of gneiss and schist but includes a relatively small amount of coarsely crystalline limestone.

EOCENE ROCKS

MEGANOS FORMATION (MIDDLE EOCENE)

The presence of rocks in the San Emigdio foothills containing what was believed to be a Meganos (middle Eocene) fauna was first recognized by B. L. Clark.[9] These rocks, which had previously been included with the overlying Tejon formation, were traced by Clark from a point just west of San Emigdio Creek eastward to

[9] Clark, B. L., The stratigraphic and faunal relationships of the Meganos group, middle Eocene of California: Jour. Geology, vol. 29, pp. 145–154, 1921.

Grapevine Canyon. Clark [10] has more recently concluded that these fossiliferous beds east of San Emigdio Canyon should be referred to the horizon that he has named Domengine. These rocks east of San Emigdio Canyon have not been studied in detail by the present writer, but according to Clark they are best exposed between Pleito and San Emigdio Canyons, where "the basal beds consist of several hundred feet of fairly indurated coarse reddish-gray arkosic sandstone. The upper part of the section is composed principally of sandy shales and platy shaly sandstone.[11]

Large angular boulders of granite also occur at the base of the Eocene section in San Emigdio Canyon.

The Meganos formation is described by Clark as resting directly upon the granite and is reported by the same writer to be overlain unconformably by the Tejon formation (upper Eocene). He says: [12]

One of the localities where the unconformable contact between the Meganos and the Tejon may be seen distinctly is about one-eighth of a mile back of the old Douglas ranch house, in the main canyon of San Emigdio Creek (near the south edge of the NW. ¼ sec. 5, T. 9 N., R. 21 W.). Here the contact is beautifully exposed on the side of the canyon. There is a difference in dip between the two series of as much as 10°. A basal conglomerate containing fossiliferous boulders derived from the beds below was found along the contact.[13] * * *

At the locality just mentioned the Meganos beds have a thickness of less than 15 feet, and not more than 300 feet to the west the basal conglomerate of the Tejon rests on the granite. Just back of the ranch house, a little farther west, a remnant of the basal Meganos sandstone outcrops below the basal conglomerate. Here the unconformity is evident. Traced east of this locality, the Meganos beds are found to thicken rapidly, reaching their maximum thickness near the head of Pleito Canyon about 3 miles to the east, where the Meganos beds have an estimated thickness of more than 1,000 feet. These beds thin out rapidly farther east, and in the canyon of Salt Creek, only a little more than 4 miles distant, their thickness probably is not more than 100 feet. The conglomerate of the basal Tejon was traced to Tecuya Creek in the next large canyon east of Salt Creek. In Grapevine Canyon the basal conglomerate of the Tejon was found to be separated from the granite by about 25 feet of unfossiliferous coarse arkosic sandstone, together with a few feet of dark shales.

Thus the beveled Meganos is transgressed by the Tejon from west to east in the vicinity of Grapevine Canyon, only a very small part of the Meganos being left, and in the next canyon to the east of Live Oak Canyon the Meganos beds fail to appear.

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[10] Clark, B. L., The Domengine horizon, middle Eocene of California: California Univ. Dept. Geol. Sci. Bull., vol. 16, p. 107, 1926.

[11] Clark, B. L., op. cit. (Jour. Geology), p. 152.

[12] Idem, pp. 149–152.

[13] The present writer has examined the exposure in the east wall of San Emigdio Canyon illustrated by Clark and is not certain that the apparent structural discordance in this exposure indicates a period of uplift between Meganos and Tejon times. The beds are very lenticular, and it seems at least possible that the observed phenomenon is the result of normal deposition by currents in shallow water—conditions under which these basal Eocene sediments may well have accumulated.

As a result of more recent fossil collections from this district Clark has concluded that his Meganos formation as described above includes beds which are actually equivalent to his Domengine formation north of Coalinga. His statement is as follows: [14]

Later work on the Eocene fauna from San Emigdio Canyon, listed by the writer in the 1921 paper as coming from the Meganos, shows that it probably should be referred to the Domengine horizon. However, to the west of San Emigdio Canyon in the eastern branch of San Diego [Santiago] Canyon what appears to be a good Meganos fauna was found near the base of the Eocene and only a little distance above the granite contact. Here *Turritella merriami* and several other distinctive Meganos species were collected. No stratigraphic work has been done in differentiating these two horizons in this region.

Clark now considers that the Meganos formation extends eastward to the vicinity of Salt Creek and that only his Domengine formation and the Tejon are present farther east in Grapevine Canyon.[15] It should be noted that all fossils thus far reported from the structurally complicated Eocene east of Salt Creek have been referred to the Tejon by different workers.

On the east bank of Los Lobos Creek, just below the road crossing near the granite contact, Eocene beds of probable Meganos age crop out in a small but prominent hill and consist of well-bedded brown and greenish-gray sandstone and sandy shale that are conglomeratic in part and contain angular boulders of dark gneiss and schist 1 to 5 feet in diameter. (See pl. 32, *A*.) These beds are fossiliferous, but the forms collected were too poorly preserved for identification. Similar well-bedded brown sandstone and shale appear farther west, near the granite contact, where they dip either northward at an angle of about 75° or southward toward the granite.

TEJON FORMATION (UPPER EOCENE)

PALEONTOLOGIC STUDIES

The richly fossiliferous Eocene beds of the Tejon formation between Live Oak Canyon and San Emigdio Creek have furnished material for study by many investigators since they were first discovered in 1854 by Blake.[16] The first Eocene fossils reported from California came from Grapevine Canyon, and, as determined by subsequent investigations, this and adjoining localities contain an unusually rich marine invertebrate fauna that makes up a distinct faunal unit of the California Eocene. The linear outcrop of these rocks in the vicinity of Live Oak, Grapevine, and Tecuya Creeks is thus the type locality of the Tejon formation, the name Tejon having been

[14] Clark, B. L., The Domengine horizon, middle Eocene of California: California Univ. Dept. Geology Bull., vol. 16, p. 107, 1926.
[15] Personal communication, October, 1926.
[16] Blake, W. P., U. S. Pacific R. R. Expl., vol. 5, pp. 41–50, 163–164, 197–211, 1857.

first applied to these sediments by Gabb [17] from their occurrence near old Fort Tejon. Much recent work has been done on the paleontology of the Tejon, and the last and most comprehensive study of the fauna of this formation is that by Anderson and Hanna.[18]

SAN EMIGDIO CANYON

In the vicinity of San Emigdio Canyon only the upper 800 feet of the Tejon formation was examined. This part of the formation on the north limb of the Devils Kitchen syncline supports an unusually sparse vegetation and consists of numerous thin slabby brown and gray sandstones of fine texture that are intercalated with purplish-gray and brown shale and sandy shale and very hard thin yellowish-brown nodular beds of iron carbonate. Some of the slabby sandstones have ripple-marked surfaces, but others are finely conglomeratic, with well-rounded pebbles. The sandstone of the upper 300 feet of the Tejon formation at this locality is more massive and occurs in beds from 1 to 4 feet thick, in contrast to the thin slabby sandstone of the underlying portion. Poorly preserved invertebrate fossils and abundant plant fragments were found near the top of the formation.

The lithology of the upper part of the Tejon formation in San Emigdio Canyon differs from that of the overlying San Lorenzo formation (Oligocene) in that it is comparatively thin-bedded throughout, with no unusually massive beds of sandstone, and that shale is the preponderant type of rock. No conglomerate or suggestion of unconformity could be found at the top of the Tejon formation in this vicinity.

EAST OF SALT CREEK

In some localities east of Salt Creek the Tejon formation rests upon the granite or upon a slight thickness of beds belonging to the Domengine formation of B. L. Clark that are believed by him to crop out below the Tejon formation east of Salt Creek. At other localities these Eocene rocks are faulted against the granite. The Tejon is overlain unconformably by the Vaqueros formation (lower Miocene). The Tejon-Vaqueros contact is well exposed at several localities, and east of Salt Creek, although there is no noticeable angular discordance, marine Oligocene strata are missing, and a coarse conglomerate of the Vaqueros rests directly upon the Tejon formation.

The outcrop of the Tejon formation between San Emigdio and Salt Creeks was not examined during this investigation but is well

[17] Gabb, W. M., Cretaceous and Tertiary fossils: California Geol. Survey, Paleontology, vol. 2, p. 13 of preface, and footnote on p. 129, 1869.

[18] Anderson, F. M., and Hanna, G. D., Fauna and stratigraphic relations of the Tejon Eocene at the type locality in Kern County, Calif.: California Acad. Sci. Occasional Paper 11, 1925.

described by Pack,[19] who states that its greatest thickness, approximately 4,300 feet, occurs near Pleito Creek, where it consists of shale, sandstone, and some conglomerate. This thickness, however, includes the Meganos formation, which, according to Clark,[20] is more than 1,000 feet thick. The Tejon formation thins markedly both to the west and to the east of this locality; near Live Oak Creek, 13 miles east of Pleito Creek, it has a thickness of about 1,200 to 1,500 feet, but it decreases eastward until, at a point 5 miles distant, it is completely overlapped by the overlying Miocene deposits. Between Salt and Live Oak Creeks the Eocene sediments are so greatly deformed and duplicated by faulting and folding that their thickness can not be accurately determined. West of Grapevine Creek Eocene sediments within 100 to 200 feet of the granite consist entirely of brown shale and fine sandy shale and, at several well-exposed places, dip southward toward the granite at angles commonly less than 50°. It seems certain that Eocene sediments in this vicinity are in fault contact with the granite, a condition that may exist throughout parts of the district farther west.

In the vicinity of Tecuya Creek and Grapevine Canyon the Tejon formation (with possibly a slight thickness of the upper Meganos), consists in greater part of soft dark-brown, dark-gray, lavender, and greenish-gray shale and sandy shale. Associated with the shale is considerable poorly cemented soft gray and brown sandstone, and much of the section contains numerous hard brown sandstone concretions that resemble cannonballs, many of which are fossiliferous. More abundant well-preserved fossils commonly occur in thin lenticular beds of hard brown sandstone. A concretionary bed of gray limestone 1 foot thick was noted in Grapevine Canyon, and round limestone concretions are fairly common.

Brown sandstone conglomerate occurs 500 feet or more above the base of the Eocene series on the east side of Grapevine Canyon and also just west of Tecuya Creek; the cobbles in this conglomerate are subangular, are 8 inches or less in diameter, and consist of gray granite, diorite, gray and pink quartzite, felsite porphyry, dark-gray flint, fine and coarse gray sandstone, and light-gray limestone. Near the base of the Eocene in the west wall of Grapevine Canyon cobbles and boulders of similar petrographic character range from rounded to subangular and are as much as 12 inches in diameter.

In Live Oak Canyon the upper 100 feet of the Tejon formation consists of soft brown sandstone, with only a small amount of shale

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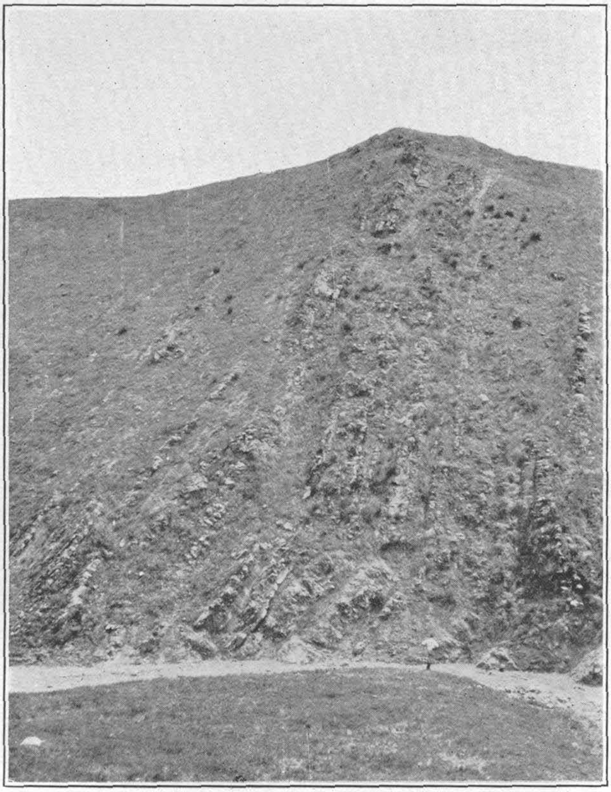
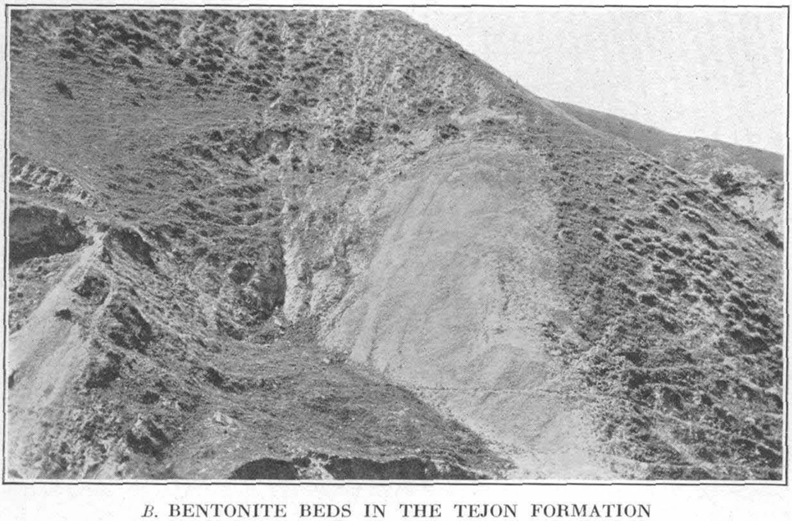
[19] Pack, R. W., The Sunset-Midway oil field, Calif.: U. S. Geol. Survey Prof. Paper 116, pp. 23–25, 1920.

[20] Clark, B. L., The stratigraphic and faunal relationships of the Meganos group, middle Eocene of California: Jour. Geology, vol. 29, p. 152, 1921.



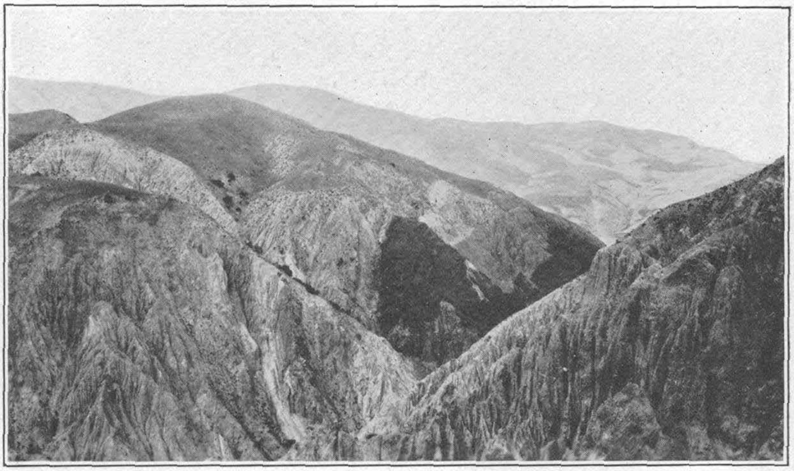
A. EOCENE SANDSTONE AND CONGLOMERATE OF PROBABLE MEGANOS AGE, KERN COUNTY, CALIF.

This exposure is north of the granite, on the east bank of Los Lobos Creek.



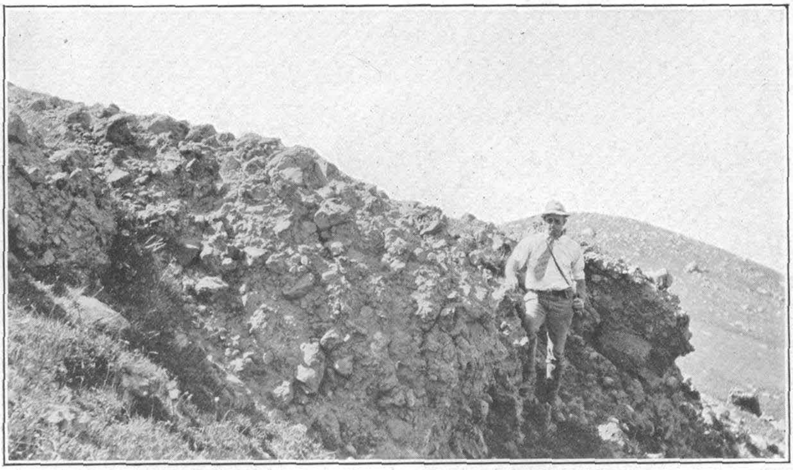
B. BENTONITE BEDS IN THE TEJON FORMATION

These white-weathering beds are vertical and crop out 1½ miles west of the mouth of Grapevine Canyon.



A. COARSE VAQUEROS SEDIMENTS AND BASALT AGGLOMERATE BETWEEN SALT AND TECUYA CREEKS

The sediments are of many colors, and the dark body of basalt is strikingly irregular. Note the badland topography.



B. BASALT AGGLOMERATE OR FLOW BRECCIA IN VAQUEROS JUST WEST OF PASTORIA CREEK

The coarse white boulders on the distant hill have weathered from overlying Vaqueros beds.

but with numerous intercalated hard beds of brown and gray sandstone less than a foot thick, many of which are very fossiliferous. Stratigraphically lower the formation is composed largely of soft brown-weathering shale and sandy shale that contains many brown and gray sandstone beds 8 feet or less in thickness. Marine invertebrate fossils occur in the sandstone throughout most of the section.

A notable feature of the Tejon formation between Tecuya and Grapevine Creeks is the presence of a bed that contains considerable bentonite. Two beds of this white fluffy-weathering material crop out in the first large gulch west of Grapevine Canyon. (See pl. 32, *B*.) The thicker bed appears to be 15 or 20 feet thick and is associated with considerable bentonitic clay. Bentonite from this bed appears to be comparatively free from coarse detrital grains or other impurities and to be a fairly pure substance. A chemical analysis of this bentonite, together with an analysis of a gypsiferous bentonite of probable Vaqueros age from Muddy Creek, appears below.

Chemical analyses of bentonite from the San Emigdio foothills, Calif.

	1	2		1	2
SiO_2	65.44	63.76	H_2O-	5.68	7.16
Al_2O_3	14.16	12.28	H_2O+	3.58	4.38
Fe_2O_3	[a] 2.89	[a] 2.52	TiO_2	.40	.36
MgO	2.05	2.35	SO_3	Undet.	2.34
CaO	1.42	2.16			
Na_2O	2.30	1.33		100.27	100.04
K_2O	1.35	1.40			

[a] Calculated from total Fe.

1. Sample from 15 to 20-foot bed in Tejon formation, San Emigdio foothills, sec. 19, T. 10 N., R. 19 W. Weight 100 grams.
2. Sample from Muddy Creek, San Emigdio grant, NW. ¼ sec. 18, T. 10 N., R. 22 W. Selenite present. Weight 400 grams.

OLIGOCENE ROCKS

SAN LORENZO FORMATION

PREVIOUS STUDIES

Pack,[21] who mapped the region in 1911, recognized the presence in the San Emigdio foothills of a considerable thickness of fossiliferous Oligocene marine sediments, although for convenience in mapping he grouped these deposits with the overlying Vaqueros formation (lower Miocene). Gester[22] and Dickerson[23] briefly refer to marine

[21] Op. cit., p. 26.

[22] Gester, G. C., Geology of a portion of the McKittrick district, a typical example of the west side San Joaquin Valley oil fields, and a correlation of the oil sands of the west side fields: California Acad. Sci. Proc., 4th ser., vol. 7, opposite p. 220, 1917.

[23] Dickerson, R. E., Climate and its influence upon the Oligocene faunas of the Pacific Coast, with descriptions of some new species from the *Molopophorus lincolnensis* zone: California Acad. Sci. Proc., 4th ser., vol. 7, p. 161, 1917.

deposits of Oligocene age in the San Emigdio region, but Wagner and Schilling[24] were the first to discuss the stratigraphic relations of these fossiliferous beds and to map their areal distribution. From a study of the marine invertebrate fossils they concluded that the Oligocene deposits in this district contain two fairly distinct faunas, and on this basis they divided the rocks into two formations, the "San Emigdio" (lower) and "Pleito" (upper), correlating the upper one with the typical San Lorenzo formation of the Santa Cruz Mountains and the lower one with the nonfossiliferous Butano sandstone of that area. The Oligocene deposits were believed to have an unconformity at their base and at their top and to contain a "disconformity" between the "San Emigdio" and "Pleito" formations.

According to B. L. Clark,[25] more recent fossil collections have shown that many of the fossil species that were found only in the lower or "San Emigdio formation" by Wagner and Schilling also occur in the overlying "Pleito formation." Clark therefore believes that the faunal break between these two divisions is a minor one but is certain that an important faunal break occurs higher in the Oligocene section, within the "Pleito formation," although no unconformity appears to occur at this horizon.

The writer, in the time at his disposal, was unable to divide on a satisfactory faunal basis the Oligocene deposits of this area, all of which he has, for convenience, called the San Lorenzo formation but with the admission that the assemblage may include some beds younger and some Oligocene beds older than the typical San Lorenzo formation of the Santa Cruz Mountains.

SAN EMIGDIO CANYON

Most of the outcrop of Oligocene rocks lies outside the area considered in this report, but a complete section of the San Lorenzo formation was examined in the east wall of San Emigdio Canyon, where it is well exposed along the axis and in the north limb of the Devils Kitchen syncline. This section, much of which is illustrated in Plate 42, *A*, appears below. Thicknesses are approximate and are computed from barometric altitudes and structural observations.

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[24] Wagner, C. M., and Schilling, K. H., The San Lorenzo group of the San Emigdio region, California: California Univ. Dept. Geology Bull., vol. 14, No. 6, 1923.

[25] Correspondence dated Apr. 19, 1927.

Section measured near Devils Kitchen, San Emigdio Canyon

[Top of ridge (altitude 5,000–5,100 feet), 1 mile east of San Emigdio Creek]

	Feet
Massive light-gray and brownish-gray sandstone and conglomerate; weathers to darker color in upper part. Texture is fine in greater part, but coarse, pebbly, and conglomeratic beds are very abundant, although generally thin and lenticular. Pebbles and cobbles are well rounded, the largest 6 inches in diameter, and consist of a variety of rock types, including quartz, quartzite, basalt, felsite, granite schist, and gneiss. Large shells of *Ostrea* sp. occur near top and base. Wagner and Schilling included the upper portion of this unit in the Vaqueros formation	1,000
Massive light-gray to white sandstone; texture ranges from fine to finely conglomeratic	200
A distinctly brown and brownish gray weathering series of shale, sandy shale, and sandstone in beds from a few inches to a few feet thick. Weathered surface has corded appearance, with shale poorly exposed. Sandstone is all fine-grained and, like the underlying more massive beds, is gray and greenish gray when freshly broken. Bones of fossil whales and casts of small pelecypods were found about 350 feet above the base of this unit in a dark-gray concretionary calcareous sandstone. Poorly preserved invertebrate fossils were also noted about 150 feet above the base of the unit	1,500
Massive beds of fine gray and greenish-gray sandstone in greater part, with thin lenticular sandstones that weather to a spotted brown and gray color; some brown-weathering slabby and more thinly bedded sandstones are also present. These beds are cut by two sets of joints that are practically normal to the bedding, one of which strikes N. 45° W., and the other N. 35° E. The base of this unit is near the base of the canyon wall at the synclinal axis, and the lower part contains thin lenses that are rich in well-preserved invertebrate fossils. Fragments of plant leaves and stems were noted at several horizons	160
Massive gray and greenish-gray sandstone of fine texture that contains several beds of conglomerate 2 feet or less thick. One bed of fine gray sandstone 10 feet thick is cross-bedded. Pebbles and cobbles are rounded to subangular, the largest of them 4 inches in diameter, and consist of basalt, pink trachyte, white quartz, dark-gray quartzite, gray granite, and gray limestone. The base of this unit, according to B. L. Clark, is the base of Wagner and Schilling's "Pleito formation	80
Massive tan to brown and gray fine-grained sandstone. No conglomerate noted. Basal 10 feet is massive sandstone and is overlain by 75 feet of softer sandstone and sandy shale that weathers to poorly exposed slope. A bed of dark-green glauconitic sandstone 1 foot thick occurs at	

	Feet
base. Basal 150 feet is very fossiliferous; upper 100 feet contains thin dark-gray sandstone lenses rich in invertebrate fossils, which are intercalated with soft shaly sandstone	450
Tan, bluish-gray, and purplish sandy shale with dark-gray carbonate concretions and some thin layers of tan and greenish concretionary sandstone of fine texture. A massive 50-foot bed of greenish-gray sandstone occurs in the lower 100 feet. A few fossils were noted in the dark concretions	525
Massive brownish-gray and tan sandstone of medium to coarse texture, coarser than overlying beds; contains brown imprints of plant fragments near base, but no other fossils were found. A 6-inch bed of conglomerate occurs locally near the top, but none was noted at the base	50
Tejon formation (for description, see p. 251).	
Approximate total thickness of this section	3,965
Approximate thickness at top of section arbitrarily assigned to the Vaqueros formation (an attempt to follow Wagner and Schilling in the absence of more original detailed stratigraphic data)	165
Approximate thickness of San Lorenzo formation	3,800

The whale bones mentioned, which were found considerably below the middle of the San Lorenzo formation (in the lower part of Wagner and Schilling's "Pleito formation"), were examined by Remington Kellogg. According to him, they consist of

two lumbar vertebrae with rather wide transverse processes, centra more or less pentagonal in cross section, and high neural spines. They correspond in most features with vertebrae of shark-toothed dolphins (Squalodontidae).

These forms appear to be the first remains of fossil whales reported from pre-Miocene deposits of the Pacific coast.

East of Salt Creek, 8 miles east of San Emigdio Creek, no marine Oligocene rocks are present, and the coarse conglomerate at the base of the Miocene Vaqueros formation rests directly upon the Tejon formation. The 3,800 feet of San Lorenzo deposits described above are therefore lost entirely in a distance of 8 miles and, as mapped and discussed by Wagner and Schilling,[26] this condition appears to be due largely, if not entirely, to progressive overlap by the overlying lower Miocene Vaqueros formation.

EAST OF SAN EMIGDIO CREEK

A fossiliferous series of sandstone and sandy shale belonging to the San Lorenzo formation is exposed in the east wall of San Emigdio Canyon along the western extension of the Pleito syncline.

[26] Wagner, C. M., and Schilling, K. H., op. cit., pl. 43, pp. 250–251.

These sediments are bluish gray and brownish gray, comparatively soft in greater part, and fine in texture. Owing to much jointing, they weather to nodular surfaces. Harder beds of fine sandstone from 1 to 6 feet thick are abundant and commonly very fossiliferous, and hard dark-brown carbonate concretions and lenses as large as 2 feet in diameter occur throughout these exposures. The lithology at this locality is much like that of the middle and upper parts of the "Pleito formation" exposed 2 miles to the south in the Devils Kitchen syncline, but definite correlation on lithology can not be made, for the intervening structure is complex and these detrital deposits appear to differ greatly in character within short distances. From a study of the fossils, Wagner and Schilling came to the same conclusion concerning the age of these deposits and mapped them as belonging to the "Pleito formation."[27]

The northern edge of this isolated mass of San Lorenzo rocks is in fault contact with the Pliocene, Etchegoin, and Tulare formations.

WEST OF SAN EMIGDIO CREEK

West of San Emigdio Creek, but particularly between Los Lobos Creek and Santiago Canyon, is a belt of sandstone and shale that is sharply folded into a series of eastward-trending overturned folds. A massive soft white and brown sandstone with abundant brown sandstone concretions is here closely associated with and apparently overlain by a series of dark-gray shale and more thinly bedded fossiliferous sandstone. The shale contains several 1-foot beds of limestone that weathers yellowish brown and is bentonitic; one bed of bentonite is 1 to 2 feet thick and weathers to a fluffy light-gray surface. These lithologic characteristics strongly suggest that these rocks belong to the Vaqueros formation and that they are equivalent to Nos. 3 and 4 in the section given on pages 259–260, exposed on Pleitito Creek near the axis of the Pleito syncline. However, fossils collected from a fossiliferous sandstone in the area west of Los Lobos Creek are considered by Clark to be of San Lorenzo age.

In view of the striking lithologic similarity of these rocks to those that occur in the middle part of the Vaqueros formation near Pleitito and Pleito Creeks, and the presence of fossils believed to be of San Lorenzo age, this belt of rocks is mapped as San Lorenzo, probably including some Vaqueros. As the list of fossils thus far collected and reported from the Vaqueros formation of this region is probably far from a complete record of the forms that actually exist, the writer wonders if some of the fossils that are believed to be restricted to the Oligocene do not actually exist in the Vaqueros formation. As shown on the geologic map and in section A–A′ (pl. 31),

[27] Idem, pl. 43.

these deposits west of San Emigdio Creek are faulted against the Meganos (middle Eocene), formation parallel to the granite, and the writer has some doubt if Oligocene rocks actually exist north of this fault.

MIOCENE ROCKS

GENERAL FEATURES

Deposits of Miocene age attain a considerable thickness in the San Emigdio foothills and consist of sandstone and conglomerate, soft shale, hard white siliceous shale, and volcanic rocks of "basic" and intermediate composition. Massive sandstone and conglomerate and soft shale are by far the most abundant rock types in this part of the section.

In the San Emigdio foothills these Miocene rocks include representatives of the Vaqueros and Maricopa formations. Rocks of Santa Margarita (upper Miocene) age crop out at the north end of the Tejon Hills and are probably present farther south near the Tejon ranch house and in the subsurface strata of the Wheeler Ridge oil field, but there appears to be no paleontologic evidence that this formation is exposed along the southern edge of San Joaquin Valley between Santiago Creek and the Tejon ranch. Pack[28] considered that the Santa Margarita formation is present between Santiago and San Emigdio Creeks, a belief which apparently was based on lithologic character and the presence of a fossil considered to be *Pecten estrellanus*. As found by the writer, this form is fairly abundant, and, although in a poor state of preservation, several of them were collected from a locality just west of Los Lobos Creek that is mentioned by Pack. According to B. L. Clark, this fossil appears to be *Pecten terminus* Arnold, a form which was originally described as a variety of *P. estrellanus* but which is a very distinct species characteristic of the Jacalitos formation.

It seems probable that in the San Emigdio foothills the Santa Margarita formation is overlapped and entirely concealed by the younger Jacalitos and Etchegoin formations (Pliocene), which, as shown in Plate 35, *A*, overlap much more steeply tilted Maricopa shale, of middle Miocene age, and upon rocks near Los Lobos Creek that carry Oligocene fossils. (See section A–A′, pl. 31.)

VAQUEROS FORMATION (LOWER MIOCENE)

BETWEEN SANTIAGO AND SALT CREEKS

The Vaqueros formation of the San Emigdio foothills consists largely of massive coarse-grained and conglomeratic arkosic sandstone, soft clay shale, and sandy clay shale, and a series of volcanic

[28] Pack, R. W., op. cit., pp. 42–43 and pl. 2.

flows, agglomerates, and minor intrusive rocks that vary in character from basalt to andesite. In the most southern exposures of this formation, from the south limb of the Devils Kitchen syncline eastward across Tecuya Creek, there are tentatively included with it at the base several hundred feet of shale, sandstone, and conglomerate which has a red and variegated color and which may be the equivalent of part of the Sespe formation of Ventura County.[29] At the top there is also mapped with it a considerable thickness of soft brown clay shale and fine sandstone that directly underlies the Maricopa shale (middle Miocene) and is probably the equivalent of a part of the "Temblor formation" (*Turritella ocoyana* zone), as originally described by F. M. Anderson in the Mount Diablo Range[30] and in the vicinity of the Kern River.[31]

The following section describes the lithologic character of the Vaqueros formation and overlying beds, probably corresponding to the *Turritella ocoyana* zone, as they are exposed along the Pleito syncline, between San Emigdio and Salt Creeks:

Section of the Vaqueros formation as exposed along the Pleito syncline from the Pleito Hills westward nearly to San Emigdio Creek

	Feet
1. Basal conglomerate of Maricopa shale; consists of pebbles, cobbles, and boulders as much as 2 feet in diameter embedded in a matrix of soft granitic sandstone and soft brown and bluish-gray clay shale. Pebbles and boulders are of light-gray granite, diorite, schist, and gneiss, all angular to subangular; gray and dark bluish-gray coarsely crystalline limestone, subangular; and hard white trachyte, very well rounded. The pebbles and cobbles of trachyte are very abundant	150±
2. A series of soft brown shale, sandy shale, and sandstone, which locally contains round hard brown sandstone concretions from 1 to 4 feet in diameter. Except for these concretions and local thin beds of hard gray and brown sandstone, this member of shale and fine sandstone is very soft	3,500±
3. Soft shale and sandstone with some thin limestone layers. Lower part contains considerable massive but soft light-brown and white coarse sandstone, together with gray and brown shale. This soft light-brown sandstone contains abundant hard brown sandstone concretions on the ridge west of Pleito Creek,	

[29] Kew, W. S. W., Geology and oil resources of a part of Los Angeles and Ventura Counties, Calif.: U. S. Geol. Survey Bull. 753, pp. 31–32, 1924.

[30] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, pp. 168–173, 1905; A further study in the Mount Diablo Range of California: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 17–20, 1908.

[31] Anderson, F. M., The Neocene deposits of Kern River, Calif., and the Temblor Basin: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 90–95, 97–109, 1911.

	Feet
about a mile north of the axis of the Pleito syncline. The upper part consists largely of soft brown, cream-colored, and gray shale which contains numerous limestone layers from 2 to 12 inches thick that weather light brown. Approximate thickness	1,000±
A lenticular and irregularly distributed series of basalt and andesite agglomerates, flows, and tuffs appears at about this horizon south of the Pleito syncline; small outcrops of dense basalt also appear farther north, near Pleito and Pleitito Creeks.	
4. Very massive gray and buff sandstone, fine grained in lower part but contains 50 to 100 feet of conglomerate about 200 feet above its base and is coarse and pebbly in upper part. Conglomerate contains well-rounded cobbles as much as 6 inches in diameter, composed of granite, gneiss, schist, quartz, rhyolite, gray sandstone, limestone, and other rocks. Dark-brown coarse-grained calcareous sandstone concretions are abundant, and some of them are very fossiliferous, containing massive shells and bones. This member weathers to gray and red along the synclinal axis just west of Pleitito Creek	700
5. Shale that weathers black and tan and is everywhere poorly exposed. Fragments of gray and pink calcareous concretions occur over weathered surface. A few casts of pelecypods were found	150
6. Gray and buff sandstone and shale with gray calcareous concretions, harder and considerably more massive than the underlying member. Sandstones are coarse grained in lower part, but in upper part they are fine grained, hard, and weather to angular blocks. Hard brown concretionary sandstone masses are common in the upper half of this member	300
7. Fine-grained, soft, and less massive buff and greenish-gray sandstone and sandy shale. Fossil bones, representing posterior caudal fin of cetacean were found on surface	600
8. Very massive, coarse, and conglomeratic sandstone, exposed in low hills and dips 30° E. This member corresponds to the uppermost member of the section measured in the Devils Kitchen syncline (see p. 255) and may belong, in part at least, to the San Lorenzo formation, but it is herein considered the basal member of the Vaqueros formation	500
Total thickness of Vaqueros formation and overlying beds that probably represent the *Turritella ocoyana* zone (approximate)	6,750±

As shown on pages 253–255, a considerable thickness of sandstone and shale between San Emigdio Canyon and Santiago Creek may belong to the Vaqueros formation. In this area, however, it has not been possible to separate these sediments accurately from associated beds that contain Oligocene fossils, and the entire belt is therefore shown on the geologic map as San Lorenzo.

Fossils from the Vaqueros formation and overlying beds, probably corresponding to Turritella ocoyana zone, of the San Emigdio foothills

	6	11	12	13	15	16	18
Pelecypods:							
Chione sp			X	X			
Dosinia sp		X		X			
Glycimeris branneri Arnold				X			
Macoma sp	X		X				
Mytilus matthewsonii Gabb			X				
Mytilus sp	X						
Ostrea sp				X			
Panope generosa Gould	X						
Pecten sespeensis Arnold						X	?
Pecten perrini Arnold						X	
Pecten sp	X						
Phacoides sp					X		
Phacoides richthofenii Gabb					X		
Pinna (Atrina) sp	X						
Saxidomus sp					X		
Solen gravidus Clark			X				
Solen sp	X						
Spisula albaria Conrad			X				
Gastropods:							
Agasoma barkerianum Cooper	X	X	X	X			
Polinices (Neverita) ocoyana Conrad	X						
Polinices sp				X			

6. In massive sandstone near top of eastward-trending ridge just north of the Pleito syncline and 2,000 feet west of Pleitito Creek; altitude, 3,000 feet.
11. Just west of Pleitito Creek, at east end of ridge just north of the Pleito syncline.
12. In massive sandstone half a mile east of Pleitito Creek and half a mile north of the Pleito syncline, in the southwest corner of sec. 10, T. 10 N., R. 21 W.; same horizon as 6.
13. In massive sandstone near top of ridge east of Pleitito Creek and three-quarters of a mile north of the Pleito syncline; near the center of the W. ½ sec. 10, T. 10 N., R. 21 W.; same horizon as 6 and 12.
15. In shaly sandstone in east wall of Pleitito Canyon; south-central part of sec. 21, T. 10 N., R. 21 W.
16. In sandstone at top of ridge near center of the west side of sec. 3, T. 10 N., R. 21 W.
18. In gray sandstone on low ridge east of Pleito Creek, in E. ½ SW. ¼ NW. ¼ sec. 2, T. 10 N., R. 21 W.; altitude, about 1,900 feet.

SALT AND TECUYA CREEKS

Near the mouth of Salt Creek beds that appear to be the upper part of the Vaqueros formation are exposed along the axis of a sharp northwestward-trending anticline that probably continues northwestward along the lower part of the Pleito Hills as an overturned fold. The exposed Vaqueros on lower Salt Creek contains some basalt but consists chiefly of soft light-gray and brown sandstone and shale which contain in the upper part hard round dark-brown sandstone concretions and in the lower part thin layers that are filled with lignitic fragments of plants.

South of the axis of the Pleito syncline and east of Salt Creek the lower part of the Vaqueros formation is coarsely conglomeratic and contains irregular masses of coarse volcanic agglomerate (see pl. 33, *A*), and sediments of variegated and brilliant colors. A " sliver " of granite has apparently been thrust northward in this vicinity and, having concealed the Tejon formation entirely, is in contact with the variegated conglomerates of the lower part of the Vaqueros. North of this granite "sliver" these lower conglomerates and fragmental volcanic rocks are overturned and dip southward at an average angle of 50° to 60°.

The approximate stratigraphic succession exposed north of the granite is as follows:

Section south of the axis of the Pleito syncline and east of Salt Creek

	Feet
Maricopa shale: White siliceous shale associated with fine conglomerate that contains well-rounded pebbles of white trachyte	50
Vaqueros formation:	
Soft brown and gray fine-grained sandstone and sandy shale with some massive beds of hard brown sandstone. Approximate thickness	1,500
Coarse granitic sandstone and conglomerate that weathers light gray and carries streaks of red clay. Subangular cobbles and boulders of granite, schist, gneiss, limestone, basalt, andesite, and sandstone 10 inches or less in diameter	200–500
Basalt agglomerate and dense and scoriaceous basalt in lenticular beds intercalated with soft light-gray sandstone, gravel, and red clay; some greenish-gray bentonitic clay is also present. The agglomerate weathers dark brown, red, and maroon and contains angular volcanic fragments as large as 12 inches across that are embedded in a dark-brown matrix of much smaller volcanic fragments	50–150
Andesite agglomerate; similar in texture to basalt agglomerate and intercalated with soft light-gray sandstone and conglomerate. Volcanic fragments are pink and light-blue porphyry, and the mass weathers to light bluish gray	50–100
Coarse conglomerate that weathers light gray and bluish gray, soft granitic sandstone, and red and blue clay	1,500–2,000
Granite fault block.	

In Tecuya Creek the brilliant colors of the lower part of the Vaqueros formation are particularly striking. These beds are commonly overturned and are probably in fault contact with the Eocene in much of this area. In the first arroyo east of Tecuya Creek, however, the contact is well exposed and the relation appears to be normal, with no evidence of faulting or angular discordance. Both the Vaqueros and the Tejon are in a vertical position at this locality, and the coarse conglomeratic sandstone member at the base of the Vaqueros red beds is in contact with soft brown and gray shale and concretionary sandstone of the Tejon.

The coarse ill-sorted character and brilliant colors of these lower Vaqueros beds near Tecuya Creek suggest that they are continental deposits. Some of the volcanic flows and agglomerates west of Salt

Creek may have been deposited on the bottom of the sea floor, for they are intercalated with sandstones that carry marine fossils. No marine fossils have been found in the lower Vaqueros east of Salt Creek, but these coarse deposits have yielded fragmentary remains of land mammals that have been described by Chester Stock. According to him, "The collection consists of relatively numerous individuals of the genus *Hypertragulus*—a form related to the early camels or deer—a rhinoceros, and a squirrel-like rodent."[32] Concerning the age of these lower Vaqueros deposits, which he called the "Tecuja [Tecuya] beds," Stock says:[33]

> The evidence derived from a study of the geology and invertebrate paleontology of the area between San Emigdio Creek and Tecuya Creek suggests the possibility that the strata containing the vertebrate remains represents the initiation of a period transitional in time between Oligocene and Miocene. Such a view is perhaps in closest agreement with the known relationship of lower Miocene and upper Oligocene vertebrate faunas found elsewhere in North America.

In the San Emigdio foothills the red beds and associated ill-sorted conglomerates in the lower part of the Vaqueros formation grade upward into and are conformable with the overlying marine Vaqueros strata, a stratigraphic relation which is common to the Vaqueros and Sespe formations in the Santa Clara Valley and the Santa Monica Mountains.[34] The red beds on Tecuya and Salt Creeks continue westward along the strike to the head of Pleitito Creek, where they overlie the San Lorenzo formation and are overlain by volcanic deposits and marine sandstone containing *Pecten branneri* Arnold, *Pecten perrini* Arnold, and *Pecten sespeensis* Arnold.

BETWEEN GRAPEVINE CREEK AND THE TEJON RANCH

No diagnostic fossils have been found in the rocks east of Grapevine Creek that are here included within the Vaqueros formation, but in this vicinity a similar series of volcanic rocks and coarse conglomerate has the same stratigraphic relation to the underlying Tejon formation. It seems fairly certain that these deposits east of Grapevine Creek are equivalent to the lower part of the Vaqueros formation near Tecuya and Salt Creeks, which is characterized by volcanic flows, sills, agglomerate, and coarse conglomerate. In this more eastern area the Vaqueros formation crops out 1 mile east of Grapevine Creek, where approximately 100 feet of volcanic rock, consisting of reddish-brown vesicular and amygdaloidal basalt (with calcite amygdules), coarse basaltic agglomerate, gray ashy sand, and dark-green bentonitic clay is underlain by coarse sediments that con-

[32] Stock, Chester, An early Tertiary vertebrate fauna from the southern Coast Ranges of California: California Univ. Dept. Geology Bull., vol. 12, p. 269, 1920.

[33] Idem, p. 274.

[34] Kew, W. S. W., op. cit., pp. 32, 34, 37.

tain red and gray clay. Part of the Tejon formation at this locality, especially that exposed north of the Vaqueros, probably lies in a landslide. From this locality eastward to a point midway between Live Oak and Pastoria Creeks the Vaqueros and the underlying Tejon formation are broken by several faults, and are everywhere steeply dipping or overturned toward the north. (See structure section G–G′, pl. 31.) At Live Oak Canyon the only volcanic rock is a vesicular basalt that shows flow structure and has an average thickness of a little more than 50 feet. This basalt is overlain by about 1,500 feet of coarse sandstone, conglomerate, and boulder beds, and beneath the basalt lies about 700 feet of soft coarse granitic sandstone, gray shale, and conglomerate, with a 25-foot bed of conglomerate at the base in contact with the Tejon formation. Cobbles and boulders in these conglomerates range from subangular to well rounded, and are as much as 2 feet in diameter. They consist of quartzite, granite, schist, limestone, and other materials. Near Pastoria Creek the upper conglomerates contain angular boulders of similar character, the largest of which are 8 feet in diameter.

This same series continues eastward to Pastoria Creek with little noticeable change in character. Just west of Pastoria Creek a thin series of rhyolite and andesite flows and agglomerate that weathers pink and purple underlies the black basalt and basaltic agglomerate. The andesitic portion of this volcanic series is much thinner than on Tecuya Creek and is barely noticeable except in good exposures; at such places these deposits are intercalated with light-gray coarse well-bedded sandstone that contains considerable volcanic ash and numerous small fragments of scoriaceous basalt and trachyte.

From Pastoria Creek the Vaqueros formation continues northeastward to Tunis Creek with the same general character and thickness, although for a short distance the conglomerate above the basalt is concealed beneath Recent alluvium, and moreover, toward Tunis Creek, the basalt and associated volcanic rock thicken considerably at the expense of the conglomerate. (See structure section H–H′, pl. 31.) A mile west of Tunis Creek the Vaqueros formation completely overlaps the Tejon and, from the granite contact, dips northwestward in a gentle monocline at an average angle of about 20°. The total thickness of the Vaqueros formation at this locality is approximately 1,800 feet, of which 1,000 to 1,200 feet is basalt and basalt agglomerate. This unusually thick basalt lenses out completely to the east in a distance of little more than a mile and, except for a single small outcrop, is not exposed east of Tunis Creek. The associated Vaqueros conglomerate also rapidly thins northeastward, until south of the Tejon ranch house it is completely overlapped by the overlying Santa Margarita (?) formation.

West of Pastoria Creek the basalt interbedded in the Vaqueros is largely coarse agglomerate with angular blocks of dense basalt (see pl. 33, *B*), many of which show distinct flow lines. Apparently these blocks have resulted from the shattering of cooled or partly cooled basalt flows. Northeast of Pastoria Creek the basalt is more dense, although scoriaceous at the base, and appears to consist of a series of flows. Midway between Pastoria and Tunis Creeks the upper and major basalt is underlain by a 50-foot bed of cream-colored rhyolite agglomerate that is broken by a series of northwestward-trending faults. Just west of these faults, near the head of a prominent gulch, a good exposure shows an angular discordance of about 15° between the inclination of the basal basalt flows and the dip of the underlying soft coarse granitic sandstone. This relation is illustrated in Figure 8.

Although no further data could be found in regard to the extent of this angular unconformity, it may quite possibly extend into adjoining districts, especially farther west, into the area of more intense deformation.

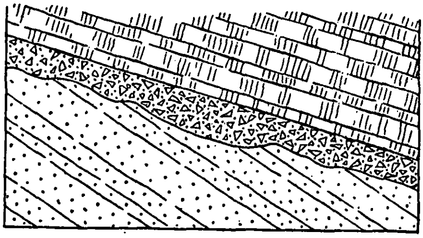

FIGURE 8.—Unconformity between sandstone of the lower part of the Vaqueros and overlying breccia and basalt flows, 2 miles northeast of mouth of Pastoria Creek, Kern County, Calif.

MIDDLE MIOCENE ROCKS OF THE TEJON HILLS

LITHOLOGY

Tertiary rocks are absent in the Tejon Valley east and northeast of the Tejon ranch; this broad, flat alluvium-covered valley is bordered on the south and east by rugged granite slopes, and at several places granitic rock crops out from beneath the alluvium of the valley floor. Farther north and northwest, however, late Tertiary sediments have been tilted and folded to form a group of low hills—the Tejon Hills—which border the granite on the Sierra Nevada on the west and which rise 500 to 1,000 feet above the adjacent floor of San Joaquin Valley.

In the northern part of the Tejon Hills Miocene sediments rest with normal depositional contact upon the basement complex and dip at an average angle of about 12° W. They crop out east of Comanche Creek and reappear farther west at Comanche Point, where they are folded into a prominent anticline. These Miocene sediments, which are herein mapped with the Vaqueros formation (lower Miocene), are chiefly of middle Miocene age, for they contain in their lower part a marine invertebrate fauna that is similar to that from the " Temblor formation," or *Turritella ocoyana* zone, in the Mount Diablo Range[35] and in the vicinity of the Kern River.[36] They may actually represent a near-shore phase of the Maricopa shale. They are overlain unconformably by the Santa Margarita formation, which locally overlaps all the underlying strata and rests directly upon the granite.

There are some foraminiferal data which suggest a tentative correlation of the lower part of the Miocene beds encountered in the W. W. Stabler well, at Comanche Point, with the Miocene sediments exposed 25 miles farther north in the Poso Creek district and with the lower part of the Maricopa shale on the west side of San Joaquin Valley. According to W. D. Rankin,[37] *Valvulinaria* were encountered in the Miocene of the Stabler well at a depth of 2,100 feet. W. D. Kleinpell[37] has informed the writer that a distinct and similar *Valvulinaria* zone occurs near the top of the exposed middle Miocene sediments in the Poso Creek district, 25 to 30 miles north of the Tejon Hills, and also on the west side of San Joaquin Valley, 4 miles southwest of Taft, in the lower part of the Maricopa shale. If this fossil zone in the Maricopa near Taft may be assumed to be equivalent to the *Valvulinaria* zone in the Stabler well, then all of the overlying 2,000 feet, more or less, of pre-Santa Margarita Miocene of the Tejon Hills is the near-shore equivalent of the Maricopa shale.

East of Comanche Creek these middle Miocene beds have a maximum exposed thickness of 600 to 700 feet and consist, with a few exceptions, of clean light-gray sandstone and conglomerate that in greater part is massive and exhibits little or no bedding. (See pl. 34, *A*.) Although well-bedded light-gray shale and fine sandy shale containing leaves occur locally in the lower 100 feet, the lower 25 to 100 feet is commonly a basal conglomerate and contains many angular or rounded boulders of granitic and metamorphic rocks 10 feet or more in diameter; the overlying 200 to 300 feet consists largely of soft fine gray and brown sandstone in which concretions and thin beds of locally fossiliferous brown sandstone are common. Approximately the upper half of these middle Miocene beds is generally of coarser texture and contains well-rounded pebbles and cobbles 6 inches or less in diameter that consist of quartz, granite, quartzite, dark schist and gneiss, and black chert. Large angular chunks, 8 inches or less in diameter, of soft green sandy shale occur at places in the upper and lower parts of this formation. It is evident from this that middle Miocene or earlier sediments of a character corresponding to these green chunks have been de-

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[35] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., Geology, vol. 2, pp. 156–250, 1905; A further study in the Mount Diablo Range of California: Idem, 4th ser., vol. 3, pp. 1–40, 1908.

[36] Anderson, F. M., The Neocene deposits of Kern River, Calif., and the Temblor Basin: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 99–101, 1911.

[37] Oral communication.

posited, indurated, broken up, and redeposited in angular blocks without being much waterworn. Sediments of this type were not found exposed in this or near-by areas, and it is possible that after being deposited this green sandy shale was entirely removed by erosion along or near the middle Miocene shore line. The character of the detrital masses is strikingly different from that of the clean coarse sand in which they were deposited; this occurrence and the size of the blocks strongly suggest that they resulted from subaerial erosion. In this connection it should be remembered that an angular unconformity occurs within the Vaqueros formation south of this district, although apparently at a lower stratigraphic horizon.

The thickness and character of this middle Miocene formation change rapidly as it dips westward from the old granite shore line beneath San Joaquin Valley and toward an area that in middle Miocene time was probably occupied by an open sea. To judge from the log of the Comanche Point Oil Co.'s well and exposures of middle Miocene rocks on Comanche Point, west of lower Comanche Creek and 2½ miles west of the granite contact, this formation has thickened to at least 1,750 feet and consists of a middle member of light-brown shale and upper and lower members of coarse sandstone and conglomerate.

The middle brown-shale member is exposed along the axis of the anticline on Comanche Point, where it contains some brown sandstone and a single 2-foot ledge of hard, dense yellowish-brown limestone; in the limestone Foraminifera of the genus *Bulimina* (large form), are abundant and plainly visible to the naked eye. These minute fossils have been examined by D. D. Hughes, who reports them to be of Miocene age but to be a different species from any of the other recognized Miocene Foraminifera of San Joaquin Valley. The brown shale is fairly soft but compact and somewhat brittle, and when struck with a hammer it breaks along indistinct bedding planes. Minute white specks that resemble diatoms are abundant along these bedding planes, and in thin sections of some of this shale diatoms were common although not abundant. In the log of the Comanche Point Oil Co.'s well this middle member of brown shale is recorded as about 600 feet thick.

Only the upper of the two sandstone members of this middle Miocene formation is exposed on Comanche Point. These beds are cut by many joints and probably also by faults, and they contain considerable selenite as vein material. This member is coarse and conglomeratic in large part, and its finer portions are composed of poorly rounded and only fairly well sorted grains of quartz, feldspar, and ferromagnesian minerals; biotite and hornblende are commonly noted constituents. The maximum size of the cobbles is at least 6 inches, and they consist of granite, rhyolite porphyry, gneiss, schist, and quartzite. As shown in Plate 34, *B*, these cobbles are invariably well rounded, in contrast to the poorly rounded fragments of rock in the overlying Santa Margarita (see pl. 34, *C*), and the buff Chanac formation. It is also noteworthy that in the conglomerates of the Chanac formation pink rhyolite porphyry is by far the most common detrital rock type, whereas granite and dark metamorphic rock are preponderant in the middle Miocene formation.

RELATIONS TO THE SANTA MARGARITA FORMATION

The actual contact of the middle Miocene beds with the overlying Santa Margarita (upper Miocene) formation is nowhere well exposed around Comanche Point, but it is apparent from the areal distribution of these two formations (see pl. 31) that they are unconformable. It appears that the middle Miocene formation at Comanche Point was folded into an anticline before Santa Margarita time and that the Santa Margarita formation, here much thinner than elsewhere, was deposited over the eroded surface of an anticlinal hill of Vaqueros sediments. East of Comanche Creek the two formations are gently inclined and their relations are in most places not entirely clear; the Santa Margarita formation, however, completely overlaps the Vaqueros in the southern part of the Tejon Hills, and farther north, where both formations are exposed, it appears to transgress the eroded upper surface of the middle Miocene beds.

FOSSILS

In 1915 J. P. Buwalda, B. L. Clark,[38] and associates studied the geology of the Tejon Hills and collected a number of marine fossils from the middle Miocene beds. These forms were identified by Clark as follows:

Scutella andersoni Twitchell.
Scutella merriami Anderson.
Pecten andersoni Arnold.
Leda ochsneri Anderson and Martin.
Oliva californica Anderson.
Trophon kernensis Anderson.
Conus oweniana Anderson.
Terebra cooperi Anderson.
Turritella ocoyana Conrad.

Of this list *Pecten andersoni*, *Trophon kernensis*, *Terebra cooperi*, and *Turritella ocoyana* have also been found in the *Turritella ocoyana* zone ("Temblor formation"), of the Kern River district and, as far as known, are restricted to this general horizon of the Miocene.[39]

Except for barnacles no additional marine forms were found in the middle Miocene beds during this investigation. At one locality east

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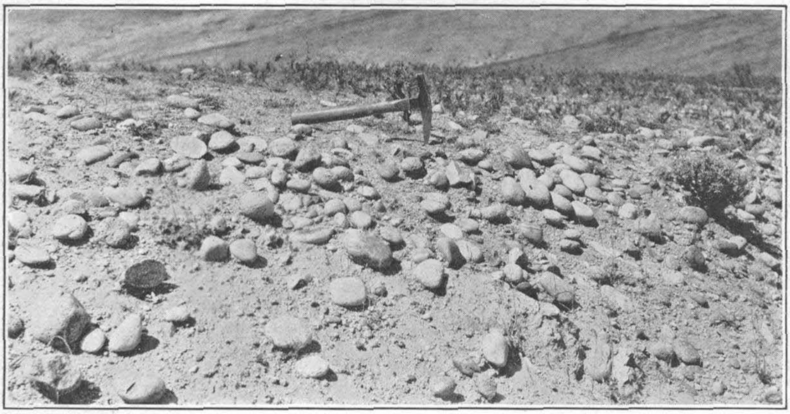
[38] Merriam, J. C., Mammalian remains from the Chanac formation of the Tejon Hills, Calif.: California Univ. Dept. Geology Bull., vol. 10, pp. 113–115, 1916.

[39] Anderson, F. M., The Neocene deposits of Kern River, Calif., and the Temblor Basin: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 99–101, 1911.

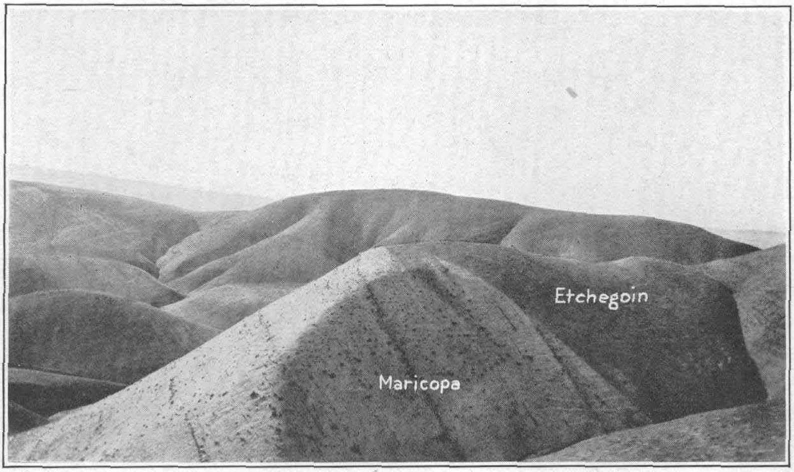
A. CONGLOMERATIC SANDSTONE OF TURRITELLA OCOYANA ZONE IN THE TEJON HILLS

Note lack of bedding and characteristic well-rounded pebbles and irregular concretionary masses.



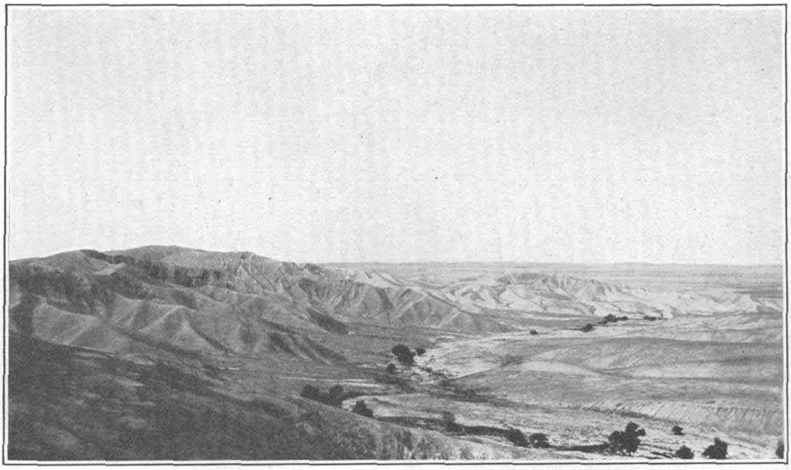
B. WELL-ROUNDED COBBLES OF THE SANDSTONE SHOWN IN *A*

C. ANGULAR AND SUBANGULAR ROCK FRAGMENTS, TYPICAL OF THE SANTA MARGARITA AND CHANAC FORMATIONS IN THE TEJON HILLS



A. UNCONFORMITY BETWEEN WHITE-WEATHERING MARICOPA SHALE AND OVERLYING ETCHEGOIN NEAR MUDDY CREEK

The contact is traceable for at least half a mile.



B. SANTA MARGARITA AND CHANAC FORMATIONS IN THE TEJON HILLS

Looking northwest down Comanche Creek. Light-gray beds of the Santa Margarita appear in the right distance; the dark formation at the left is the Chanac.

of Comanche Creek, near the sharp jog in the El Tejon grant line, the basal part of the formation consists of well-bedded light-gray sandy shale with imprints of leaves. All fossils found in these beds came from the lower 50 to 100 feet and, in some places, from the basal bed, in contact with the granite.

MARICOPA SHALE (UPPER AND MIDDLE MIOCENE)

GENERAL FEATURES

The Maricopa shale is exposed in three small areas in the San Emigdio foothills—in lower Muddy Creek, in middle Pleitito Creek, and in the Pleito Hills south of Wheeler Ridge. In each of these areas only a part of the total thickness of this formation crops out, so that no accurate information is available concerning the total thickness east of Santiago Creek. The type section of the Maricopa shale, as described by Pack,[40] occurs just south of Pioneer, 6 miles west of the area considered in this report, where the exposed thickness is 4,800 feet. The entire formation in the San Emigdio foothills east of Santiago Creek may or may not have a comparable thickness. Its total area of outcrop in this district is only about 5 square miles, and at no place is the complete formation exposed. In the area here considered the Maricopa shale includes only that part of the Miocene section that consists largely of siliceous shale, an assignment that is in accord with the earlier definition of Pack.[41] There appears to be no good evidence that rocks of Santa Margarita age are included in the Maricopa shale of this area.

LOWER MUDDY CREEK

Along the lower course of Muddy Creek the Maricopa shale is exposed to a thickness of about 800 feet and is composed largely of white and light-brown thinly bedded siliceous shale and intercalated beds of dense limestone that weathers brown. The siliceous shale is generally fissile and brittle; it is only of intermediate hardness and commonly is somewhat punky. The lower exposed portion carries some soft dark brownish-gray sandy clay shale that contains abundant dark-green grains resembling glauconite. Calcareous Foraminifera are abundant at some horizons in the Maricopa shale on Muddy Creek, and brown fish scales are common, but diatoms are generally scarce or absent.

The Maricopa shale in this vicinity is exposed along what appears to be a sharp anticlinal fold that is broken near its crest by a longitudinal fault. The formation is faulted against Etchegoin

[40] Pack, R. W., The Sunset-Midway oil field, Calif.: U. S. Geol. Survey Prof. Paper 116, p. 38, 1920.

[41] Idem, p. 35.

(Pliocene) greenish-gray clay on the south, and as it dips it underlies the Etchegoin formation with pronounced unconformity, the angular discordance between the dip of the two formations in actual contact being 30° to 35°. (See pl. 35, *A*.) This striking unconformity is well exposed for a considerable distance along the strike of these rocks and provides ample proof that the Maricopa shale and older rocks were sharply folded and deeply eroded along this foothill belt in pre-Etchegoin time. That considerable erosion of the Maricopa shale of the Muddy Creek area occurred in pre-Etchegoin time is supported by foraminiferal evidence, for, according to P. P. Goudkoff and S. G. Wissler,[42] who have studied the Foraminifera of this shale, the Muddy Creek section contains no equivalent of the upper part of the type section of the Maricopa south of Pioneer. In fact, according to Wissler, the Foraminifera in the Maricopa of Muddy Creek more clearly resemble the microfauna of the shale in the Sunset Valley area which Pack included in the Vaqueros than that of the overlying siliceous shale of that area. In this district there appears to be no evidence that permits a more definite statement as to the exact time of this notable epoch of deformation—that is, whether it occurred before or after the Santa Margarita formation (upper Eocene) was deposited. At Comanche Point, however, 25 miles to the east, lower and middle Miocene rocks were folded and eroded before Santa Margarita time. (See p. 273.) As there appears to have been only one epoch of pronounced folding in each of these areas in late Miocene time, it is reasonable to conclude, tentatively at least, that both areas were uplifted and deformed at about the same time and that much, if not all, of the present foothill belt along the south end of San Joaquin Valley was folded and exposed to subaerial erosion at about the end of the middle Miocene.

PLEITITO CREEK

A small outcrop of Maricopa shale occurs on middle Pleitito Creek about 2 miles from the northern edge of the foothills. The formation at this locality is of the same general character as that on Muddy Creek and has similar structural relations with the Etchegoin formation (Pliocene). A sharp anticinal fold at this locality has been faulted along its axis so that about 300 feet of light-brown and cream-colored siliceous shale is exposed in fault contact with green clay shale of the Etchegoin. As on Muddy Creek the siliceous shale on Pleitito Creek is also overlain unconformably by the Etchegoin, but the angular discordance is slight, being only about 5°. One of the noteworthy features is the presence of a 6 to 8 foot bed of

[42] Oral communication.

coarse conglomerate at the base of the Etchegoin that transgresses the beveled strata of Maricopa shale.

PLEITO HILLS

The only locality in the foothill belt east of Santiago Creek that affords an opportunity to observe the stratigraphic relations between the Maricopa shale and the underlying Miocene deposits is south of Wheeler Ridge, along the axis of the Pleito syncline in sec. 13, T. 10 N., R. 21 W. At this locality the soft brown sandy shale, which probably belongs to the middle Miocene *Turritella ocoyana* zone, is overlain with apparent structural conformity by a coarse basal conglomerate of the Maricopa shale. The conglomerate is about 150 feet thick and grades upward into beds that consist largely of white siliceous shale and coarse gray sandstone; the conglomerate contains pebbles, cobbles, and boulders as much as 3 feet in diameter that are embedded in a matrix of soft granitic sandstone and soft brown and bluish-gray clay shale. Partly disintegrated granite, diorite, schist, gneiss, and gray coarsely crystalline limestone occur in angular and subangular boulders of the largest size, but one of the most striking features of this conglomerate is the abundance of well-rounded pebbles and cobbles of white trachyte.

The Maricopa shale overlying the conglomerate probably attains a thickness of about 1,500 feet. Much of this shale is similar in character to that exposed on Muddy and Pleitito Creeks, but some of the beds are soft clay shale, and others are more highly indurated and consist of opal shale. Beds of coarse gray arkose sandstone and brown-weathering limestone are also common. Foraminifera and fish scales are very abundant in much of the fissile white shale, but diatoms are either absent or relatively scarce in the hand specimens and thin sections examined. Diatoms may, however, constitute a large part of much of this shale. D. D. Hughes has examined one of these thin sections in which Foraminifera are particularly abundant and has identified the following genera: *Bolivina* (abundant), *Globigerina* (rather common), *Bulimina* (rather common), *Cristellaria* (rare), *Pullenia* (rare), and several genera of the family Rotaliidae. Silicified wood and bones of marine mammals are also fairly common in this part of the Maricopa shale. According to Remington Kellogg, who examined some of these bones, they represent "a worn lumbar vertebra of a cetothere and fragments of vertebrae from a smaller cetacean." Poorly preserved specimens of a small pecten, believed by B. L. Clark to be *Pecten andersoni*, a typical middle Miocene form, were found in one of the beds of gray sandstone of the Maricopa near the top of the Pleito Hills.

Along the axis of the Pleito syncline and near the top of the Pleito Hills the Maricopa shale is overlain unconformably by a Pleistocene deposit of coarse stream gravel and boulders.

The northern slope of the Pleito Hills, just south of Wheeler Ridge, is an area of complex structure, a condition that is due, no doubt, to the fact that these hills occupy the foremost wedge of a major thrust fault block. As illustrated in structure section E–E′ (pl. 31), the writer believes that an overturned anticline lies north of and parallel to the Pleito syncline and that much of the northern slope of the Pleito Hills has been formed by a multitude of large and small landslides. Masses of Maricopa shale have certainly slid from place in the steep bluffs at the top of this slope and now have a distribution that is entirely out of harmony with any conceivable underground structure.

White siliceous Maricopa shale is exposed in place at intervals along the northern edge of the Pleito Hills fault block, south and west of Wheeler Ridge. In addition, large masses of this material rest along the edge of San Joaquin Valley at the northern foot of the Pleito Hills south of Wheeler Ridge and are believed to represent landslides from the prominent slope to the south.

TEJON HILLS

There is no white siliceous shale exposed along the southern and southeastern border of San Joaquin Valley east of Tecuya Creek, but in the Tejon Hills the exposed middle Miocene *Turritella ocoyana* zone, with its characteristic fauna and brown shale and limestone containing diatoms and foraminifers, may well represent a near-shore facies equivalent in age to much of the Maricopa shale.

SANTA MARGARITA FORMATION (UPPER MIOCENE)

TEJON HILLS

The age of sediments in the San Emigdio foothills previously mapped as Santa Margarita by R. W. Pack [43] is discussed on page 258. Deposits of undoubted Santa Margarita age occur in only one area along the south and southeast border of San Joaquin Valley. This area is at Comanche Point, in the northern part of the Tejon Hills, where coarse marine sediments contain a typical Santa Margarita fauna and consist in greater part of soft white to light-gray and greenish-gray granitic sandstone, clay shale, and conglomerate. (See pl. 35, *B*.) The sandstone is commonly loose and friable and is composed largely of ill-sorted angular grains of quartz, feldspar, and granite; the clay shale resembles that of the Etchegoin formation (Pliocene), in Wheeler Ridge and west of Pleitito Creek and contains locally small round concretions and white nodules and irreg-

[43] Op. cit., pl. 2.

ular beds of white or light-gray limestone and marl; and the conglomerate, although it has a fairly uniform composition, varies considerably in texture and shape of component rock fragments. White and light-colored felsites, quartz, granite, and quartzite are the most abundant types of coarse detrital rock; these fragments commonly attain an average diameter of 3 to 5 inches and range in shape from very angular to well rounded.

The thickness of the Santa Margarita formation in the Tejon Hills is far from uniform; around the flanks of the sharp anticline at Comanche Point the formation is unusually thin, and on the southwest flank of this fold there is not more than 100 feet of these upper Miocene sediments; east of Comanche Creek, along the northern edge of the hills, the maximum thickness appears to be about 1,000 feet.

In the southeastern part of the Tejon Hills the Santa Margarita formation rests directly upon the granite, and in Hill 2660 it contains angular boulders of felsite, granite, black schist, and quartzite as much as 4 feet in diameter.

As stated on page 270 the Santa Margarita formation at Comanche Point rests unconformably on the more steeply dipping middle Miocene beds herein mapped with the Vaqueros formation and is believed to overlap, with probably slight angular discordance, similar beds east of Comanche Creek. These upper Miocene marine sediments are overlain with apparent conformity by buff continental beds of the Chanac formation (Pliocene)—in fact, there appears to be no clean-cut stratigraphic boundary between these two formations, for the light-gray Santa Margarita beds grade upward into the overlying buff strata through a transition zone 50 to 100 feet thick that is composed of beds of alternating gray and buff color.

Marine invertebrate fossils, shark teeth, and indeterminate fragmentary bones are abundant in the upper part of the Santa Margarita formation at several localities around Comanche Point, west of Comanche Creek. In 1916 B. L. Clark [44] reported the following fossils from this vicinity:

Dosinia arnoldi Clark.	Piteria stalderi Clark.
Metis alta (Conrad).	Saxidomus nuttalli Conrad.
Ostrea titan Conrad.	Siliqua cf. S. lucida (Conrad).
Ostrea cf. O. vespertina Conrad.	Venus pertenuis Gabb.
Pecten crassicardo Conrad.	Bulla sp.
Pecten crassicardo n. var.	Calyptraea sp.
Pecten hastatus Sowerby.	Conus sp.
Pecten raymondi Clark.	Fusinus n. sp.
Phacoides richthofeni (Gabb).	Nassa pabloensis Clark.
Phacoides sanctaecrucis Arnold.	Natica sp.
Pinna alamedensis Yates.	Shark teeth.

[44] Merriam, J. C., Mammalian remains from the Chanac formation of the Tejon Hills, Calif.: California Univ. Dept. Geology Bull., vol. 10, p. 115, 1916.

Additional fossils collected during this investigation and identified by Doctor Clark are as follows:

Pecten estrellanus Conrad.
Chione sp.
Cardium sp.
Dosinia sp.
Tortoise bones and other indeterminate fragments of bones.

SOUTH OF THE TEJON HILLS

Along the south border of Tejon Valley there is a small area of gray shale which extends southwestward from a point near the Tejon ranch house for a distance of about 5 miles and which is probably of Santa Margarita age. This shale near the ranch house rests directly upon the granite and at points farther southwest upon the lower Miocene series of basalt and coarse conglomerate. Above the gray shale lies a slight thickness of unconsolidated buff conglomerate that probably belongs, in part at least, to the Chanac formation. The stratigraphic relation of this gray shale is thus similar to that of the Santa Margarita formation in the Tejon Hills. It is unfossiliferous, but, like the Santa Margarita near Comanche Point, it contains round concretions of aragonite, nodules of marl, and thin lenses of impure limestone. The exposed thickness of this shale increases southwestward to a point west of Tunis Creek, where it is probably about 500 feet.

WHEELER RIDGE

Wells drilled on Wheeler Ridge, in and near the oil-producing area, have penetrated in the upper part of the brown-shale zone about 750 feet of beds that are somewhat more arenaceous than the underlying Maricopa shale. According to P. P. Goudkoff,[45] the Maricopa shale that has been examined in core samples taken from the wells contains a calcareous foraminiferal fauna typical of this part of the California Miocene, but the overlying subsurface beds of sandy brown shale yield arenaceous Foraminifera that closely resemble those which occur in the Santa Margarita (?) formation as mapped by Arnold and Anderson[46] in the Pyramid Hills and in Big Tar Canyon of the Coalinga district. As yet it seems uncertain whether these arenaceous Foraminifera were restricted to Santa Margarita time or had a longer geologic range and a distribution dependent largely upon ecologic conditions. For the present the upper 700 to 800 feet of the "brown shale" in the Wheeler Ridge subsurface beds is tentatively referred to the Santa Margarita.

In Wheeler Ridge this formation and the upper part of the underlying Maricopa contain considerable oil shale that is similar to the oil shale of the Rocky Mountain region in that it contains no free

[45] Correspondence dated Dec. 22, 1926.

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

oil but yields oil when heated. The character and occurrence of this oil shale are described elsewhere [47] in more detail. The most significant facts in this connection are that the oil-shale member, which is composed of marine sediments, yields good shows of oil and gas and holds a stratigraphic position identical with that of most of the horizons marked by producing beds in the Wheeler Ridge oil field.

PLIOCENE ROCKS

GENERAL FEATURES

Pliocene rocks crop out over a considerable area along the southern border of San Joaquin Valley and are confined almost entirely to the northern or outer belt of the foothills between Santiago and Salt Creeks and to the Tejon Hills. Along the intervening strip of the valley border, between Salt Creek and Tejon Valley, the Recent alluvium overlaps these Pliocene deposits except in a comparatively small area southwest of the Tejon ranch house.

AREA BETWEEN SANTIAGO AND SALT CREEKS

Pliocene deposits are sharply deformed along the foothill belt east of Santiago Creek, where they occupy prominent folds and dip northward beneath San Joaquin Valley at widely varying angles, although in most of the area the angle of dip probably averages about 45°. Near San Emigdio Creek these northernmost Pliocene beds are considerably overturned and dip to the south. South of the valley border they either are faulted against older formations or unconformably overlie them. They consist of soft clay and poorly cemented sandstone and coarse fanglomerate and as a general rule are divisible into two distinct map units—the lower, which consists chiefly of the Etchegoin formation but locally includes at the base beds that represent the Jacalitos formation, and the upper, which consists of the Tulare formation.

JACALITOS AND ETCHEGOIN FORMATIONS (LOWER, MIDDLE, AND UPPER(?) PLIOCENE)

GENERAL FEATURES

The name Etchegoin beds was first used by F. M. Anderson [48] to apply to a thick series of soft sandstone, conglomerate, and clay that is characteristically developed near the Etchegoin ranch, about 20 miles northeast of Coalinga, along the west border of San Joaquin Valley. Later workers recognized the presence of these beds in the

[47] Hoot, H. W., Oil shale in a producing oil field in California: U. S. Geol. Survey Prof. Paper 154, pp. 171–173, 1928.

[48] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, p. 178, 1905.

Temblor Range south of Coalinga, but because of the difficulty in separating them from the conformably overlying Tulare formation, these two formations were commonly grouped together under the name McKittrick formation,[49] although where practicable Pack[50] later mapped the Etchegoin and Tulare separately as component parts of the McKittrick group. The Etchegoin formation of the area described in this report includes a series of marly clay, sandstone, and conglomerate, which weather gray and greenish gray and locally contain marine fossils. It rests unconformably upon the Maricopa shale and older formations and grades upward into buff continental strata of the Tulare formation. In Wheeler Ridge the characteristic gray and greenish-gray beds of the Etchegoin grade westward along the strike into buff deposits that resemble the overlying Tulare formation; for this reason the Etchegoin-Tulare boundary in Wheeler Ridge, west of Coaloil Canyon, is not based upon any distinct lithologic change but is drawn to conform to observed structure. Locally mapped with the Etchegoin are older Pliocene fossiliferous sediments that represent the Jacalitos formation of the Coalinga district.[51] The Etchegoin formation crops out in three isolated areas—in the vicinity of Muddy and Los Lobos Creeks, in the vicinity of Pleitito Creek, and in the central part of Wheeler Ridge.

MUDDY AND LOS LOBOS CREEKS

Distribution and character.—The outcrop of the Etchegoin formation crosses lower Muddy and Los Lobos Creeks near the northern edge of the foothills. As shown by the geologic map (pl. 31), the formation is exposed along a sharp anticlinal fold, which is faulted along its crest and which plunges eastward toward San Emigdio Canyon.

The exposed thickness of the formation appears to range from 600 feet to about 1,000 feet and to increase from west to east. On Little Muddy Creek the formation is well exposed and is about 700 feet thick. At the base of the formation in this locality is a fossil ledge from 1 to 2 feet thick in which *Mulinia densata* Conrad is very abundant. Above the fossil bed lies about 75 feet of dark-gray shale, the lower part of which is bentonitic, and the upper 600 feet

[49] Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Calif.: U. S. Geol. Survey Bull, 406, pp. 74–90, 1910.

[50] Pack, R. W., The Sunset-Midway oil field, Calif.; U. S. Survey Prof. Paper 116, pl. 2, 1920.

[51] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district. Calif.: U. S. Geol. Survey Bull. 398, pp. 96–113, 1910. See also Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ. Dept. Geology Bull., vol. 10, pp. 192–216, 1917. After making more extensive fossil collections from the Jacalitos and Etchegoin formations of the Coalinga district Nomland concluded that the two faunas are very much alike and that the name Jacalitos should be discarded.

of the formation is characterized by beds of shale that weather greenish gray and thin beds of hard gray nodular limestone, gray and brown granitic sandstone, and conglomerate. The sandstone is poorly cemented, except for local thin beds, and it is composed of angular grains of quartz and feldspar that are poorly sorted as to size; the conglomerate, as compared to the overlying Tulare and Pleistocene deposits, is not coarse, although subangular rock fragments are commonly 3 or 4 inches in diameter; these fragments consist of granite, black chert, quartzite, gneiss, and diorite, but the most abundant are fragments of white siliceous shale from the underlying Maricopa. It is noteworthy that these fragments of Maricopa shale appear to be confined to the upper 600 feet or more of the Etchegoin and were not found in the lower 75 feet of gray shale.

According to Goudkoff,[52] the lower shale member of the Etchegoin formation near Muddy Creek contains definite Pliocene Foraminifera in contrast to the upper part of the formation, which, according to him, is characterized by Foraminifera of Miocene aspect that are commonly incased in fragments of white Maricopa shale. After making further studies of the microscopic characteristics of the Etchegoin in and near the Sunset-Midway oil field, Goudkoff tentatively concluded that an unconformity separates his lower Etchegoin, which is represented by the lower shale member on Little Muddy Creek, from the upper part of the Etchegoin. No angular discordance or surface of erosion was noted in this vicinity, however, and it is considered doubtful whether an unconformity actually exists within exposed Etchegoin strata of the San Emigdio foothills, although one may exist in other areas of San Joaquin Valley.

If the deformation responsible for the unconformity shown in Plate 35, *A*, occurred at the end of Maricopa time it is difficult to account for complete absence of Maricopa shale fragments in the lower part of the Etchegoin where these beds rest unconformably upon the Maricopa, unless the Maricopa was completely concealed beneath the Etchegoin sea. A gentle uplift in early Etchegoin time might have caused the southern edge of the sea to recede and thus result in the exposure of Maricopa shale to subaerial erosion. Another alternative is that the deformation represented by the unconformity in Plate 35, *A*, did not occur until after Santa Margarita time; in that case the Maricopa may not have been uncovered by erosion until the lower Etchegoin beds had been deposited.

Although the abrupt appearance of Maricopa shale fragments and the apparently coincident disappearance of marine Pliocene microfossils are significant features, the former may be explained for the

[52] Goudkoff, P. P., oral communication; also, Correlative value of the microlithology and micropaleontology of the oil-bearing formations in the Sunset-Midway and Kern River oil fields: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 485–490, 1926.

area in question in some such manner as that suggested above, and the latter may be taken to indicate the beginning of fresh-water conditions, which may have continued throughout the remainder of Etchegoin time and gradually given place to the conditions that produced the alluvial plains of Tulare time.

South of the San Emigdio syncline, near Los Lobos Creek and just west of San Emigdio Canyon, strata herein mapped as belonging to the Etchegoin and Jacalitos formations consist in greater part of coarse, poorly sorted, light-gray sandstone and conglomerate which contain in the lower part abundant poorly preserved fossil forms that B. L. Clark has identified as *Astrodapsis arnoldi* var. *crassis* Kew and a shell that appears to be *Pecten terminus* Arnold. On the ridge just west of Los Lobos Creek the sandstone and conglomerate are underlain by a small amount of white siliceous shale that contains numerous casts of Arcas. All these lower fossiliferous beds were mapped as Santa Margarita by Pack, but, according to Clark, they should, on the basis of the contained fossils, be considered as equivalent to the Jacalitos formation of the Coalinga region.

Stratigraphic relations.—As already discussed on page 277 and illustrated in Plate 35, *A*, the Etchegoin on lower Muddy Creek rests unconformably upon the Maricopa shale with unquestionable angular discordance of 15° to 30°. This unconformity, it is believed, marks the first notable epoch of folding in the San Emigdio foothills during the Tertiary period. South of the San Emigdio syncline the coarse sandstone and conglomerate and siliceous shale herein included within the Etchegoin formation dip north at an average angle of about 60° and overlap nearly vertical or even overturned beds that belong to either the Vaqueros (lower Miocene) or the San Lorenzo (Oligocene).

The Etchegoin near Little Muddy Creek is overlain by a few hundred feet of buff poorly sorted fanglomeratic sediments of probable Pleistocene age that have at their base about 30 feet of buff clay. At the contact of this buff clay with the underlying gray clay and sandstone of the Etchegoin there is a strong suggestion of an angular unconformity; the buff clay dips 30° to 35° N., whereas the uppermost Etchegoin strata are tilted at angles of 50° to 52°—a difference of about 15°. At a place 2 miles farther east coarse Pleistocene fanglomerate rests upon overturned Tulare (upper Pliocene) sediments with an angular discordance of more than 90°. (See pl. 36, *B*.)

Fossils.—The following fossils were collected from the basal bed of the Etchegoin formation at the tar seep in Little Muddy Creek:

Cryptomya cf. C. californica Conrad.
Mulinia densata Conrad.
Paphia staminea Conrad.
Polynices sp.
Schizothaerus nuttalli Conrad.
Tellina sp.
Astyris sp.
Nassa (Alectrion), n. sp., usually referred to N. californica Conrad.

According to B. L. Clark, who identified these fossils, this fauna is to be correlated with the lower Etchegoin of the Coalinga district. As this fossiliferous bed at the base of the Etchegoin rests directly and unconformably upon Maricopa shale, the Jacalitos is absent at this locality.

Fossils collected from beds near Los Lobos Creek are discussed above.

PLEITITO CREEK AREA

In the vicinity of lower Pleitito Creek, north of the faults that cross this creek in sec. 4, T. 10 N., R. 21 W., the Etchegoin formation is sharply folded along the east end of the San Emigdio anticline. Owing to the complicated structure and the poor exposures that result from the uniformly soft character of the Etchegoin from this area westward toward San Emigdio Canyon, no accurate detailed description of the lithologic character can be given, but much the greater part of the formation consists of green marly clay shale and sandy shale intercalated with a subordinate amount of soft gray arkosic sandstone and conglomerate. Although an exposed thickness of only about 2,700 feet can be measured in this vicinity, the records of wells recently drilled by the Union Oil Co. have made it possible to state that the total thickness is about 5,700 feet unless unexposed faulting has produced a duplication of part of the section, a possibility that seems improbable. The lithology is much like that of the Etchegoin near Muddy Creek, except that a larger proportion of the formation consists of clay shale and fine sand. Some thin beds of brown marly clay shale are intercalated with the green and gray beds, and some of the shale contains lenticular beds of white nodular limestone less than a foot thick. Much of the exposed Etchegoin contains abundant angular but water-worn chips of white siliceous Maricopa shale, and as a result the weathered grassy surface of this formation is locally difficult to distinguish from that of the Maricopa. There appears to be no indication that beds of Jacalitos age are present in this area.

The weathered outcrop of a bed of greenish-gray bentonitic clay shale appears in the lower part of the Etchegoin on Pleitito Creek, just north of the faulted Maricopa shale. This bed, which probably consists of material too impure for commercial use, is 15 to 20 feet thick and may be the same as that exposed just above the base of the Etchegoin on Little Muddy Creek.

South of the northernmost fault in Pleitito Canyon a coarse conglomerate about 8 feet thick lies at the base of the Etchegoin and contains rounded and subangular cobbles of granite, gneiss, black schist, and quartzite, the largest of which are 8 inches in diameter.

The total thickness of the overlying Etchegoin beds is unusual in that it is only about 300 feet, a condition that may be due to original thinness of beds deposited over a hill of Maricopa shale, or to decided squeezing and thinning of these soft incompetent Etchegoin strata during deformation. Also, in view of the striking contrast in this thickness and the 5,700 feet of this formation directly north of the fault (see structure section D–D′, pl. 31), it seems necessary to assume that this area was near the southern border of the Etchegoin sea and that much of the upper part of the 5,700 feet of Etchegoin is represented south of the fault by buff continental conglomerate, which has been mapped as a part of the Tulare formation.

The major and northernmost mass of the Etchegoin formation in the Pleitito Creek area is in fault contact with Maricopa shale. South of the fault, however, the basal conglomerate of the Etchegoin rests with slight angular discordance upon the Maricopa and dips to the south.

The Etchegoin is overlain conformably by the Tulare formation. In this area there is a gradual change from the typical green and gray clay shale and gravelly sand of the Etchegoin to the coarser buff angular fanglomeratic material of the overlying Tulare. The transition zone is from 100 to 200 feet thick and is composed of alternating greenish-gray and buff beds. The boundary between these two formations is therefore not distinct, and the stratigraphic relation is remarkably similar to that of the transition zone between the Santa Margarita and the overlying Chanac formation in the Tejon Hills.

Sedimentation during the later part of the Tertiary period underwent a radical change in the San Emigdio and Tejon Hills district, a change which in both areas was from marine to alluvial-plain conditions but which occurred at somewhat different times in the two areas. Exposures of these late Tertiary formations in the San Emigdio foothills and in the Tejon Hills are near the old shore line of the last sea that covered this region, and it is to be expected that the boundary between marine and continental deposits in this gradually filling basin would transgress the stratigraphic column and be of different ages in different parts of the region. Not only are there marked regional variations in the age of the last marine deposits of the south end of San Joaquin Valley but, as will be pointed out in the following discussion of the Etchegoin of Wheeler Ridge, there appear to be notable local differences that probably resulted from minor shiftings of the last marine waters in response to local deformation.

WHEELER RIDGE

General character.—The Pliocene deposits in Wheeler Ridge are similar to those farther west in the vicinity of the San Emigdio ranch in that they consist of two formations which, in much of this area, are distinguishable by their contrast in color and difference in texture. In the major part of Wheeler Ridge, east of Coaloil Canyon, the Etchegoin has the distinct gray and greenish-gray color that characterizes this formation elsewhere, whereas the overlying Tulare is typically buff.

Although distinctly finer in texture than the Tulare formation, the Etchegoin of Wheeler Ridge is notably coarser than the Etchegoin farther west, in the vicinity of Pleitito and Muddy Creeks. This coarseness is particularly striking in the upper part of the formation in the central part of the ridge and in the lower half of the exposed portion in Coaloil Canyon, where light-gray coarse pebbly soft sandstone and conglomerate with subangular rock fragments 10 inches or less in diameter are common. Green and gray clay and sandy clay are, however, abundant constituents of the formation in Wheeler Ridge and locally contain small nodules, thin discontinuous bands, and prominent beds of impure light-buff to cream-colored limestone. As indicated in the following section of exposed Etchegoin strata in Coaloil Canyon, finer sediments of green marly clay and soft sandstone constitute most of the upper half of the formation, whereas coarse sandstone and conglomerate are characteristic features of the lower portion.

Section of exposed Etchegoin strata on north flank of Wheeler Ridge, in east wall of Coaloil Canyon

	Feet
Tulare formation (buff sediments; for description see p. 290).	
Etchegoin formation:	
Coarse sand and gravel with some clay, light gray and greenish gray. Clay occurs in lenticular layers about 12 inches thick. Pebbles and rock fragments as much as 8 inches in diameter are present, but those from 1 to 3 inches are most common. Subangular fragments of white siliceous shale are locally abundant	165
Sand, sandstone, and clay. Arenaceous beds are gray and buff and range in texture from fine to conglomeratic; some beds are partly indurated by carbonate cement. Clay is gray and greenish gray and contains sandy layers with abundant angular fragments of white siliceous shale. This number is probably 50 per cent clay and fine sand	240

	Feet
Clay and clayey sand, mostly light gray and green but in part light brown and buff. Many white and buff nodules of marl 1 inch or less in diameter and others of fine gray sand cemented by carbonate are present. Considerable selenite and some coarse granitic sand and angular pebbles of quartz, feldspar, granite, and dark-gray schist occur over weathered surface	370
Sand and sandy clay, ranging from light and dark gray to greenish gray and alternating in lenticular beds from 2 to 8 feet thick. Some beds contain much yellow iron stain	100
Green sandy clay, containing abundant angular fragments of white feldspar one-eighth inch or less in diameter, together with a small amount of intercalated coarse brown sand	10
Sand and gravel, containing thin lenses and beds of green clay and fine clayey sand. Sand and gravel are coarse and granitic, with some layers hardened by carbonate cement. This member is overlain by the south end of a Pleistocene terrace deposit	130
Green sandy clay, with abundant subangular specks of white feldspar	8
Sand and gravel. Sand is coarse, arkosic, and light brown and gray; contains lenses a few inches thick of green sandy clay. Pebbles average 2 inches in diameter and occur sparsely distributed and in lenses and pockets from a few inches to several feet thick. Streaks of yellowish-brown iron stain occur throughout. Basal and upper parts have oily odor, but only upper part is stained	150
Sand, green and greenish brown, ranging from coarse to fine and clayey	10
Sand, coarse and conglomeratic, intercalated with thin lenticular beds of fine green clayey sand. Sand is arkosic and is stained light chocolate-brown by impregnated oil	28
Gravel, sand, and clay. Pebbles and rock fragments vary greatly in size and are as much as 10 inches in diameter; they occur both in thick massive beds and irregularly distributed throughout the greenish-gray clayey sand. Much of upper 15 feet is stained brown by oil from seep	110
Sand, gravel, and clay in alternating beds. Sand is brownish gray, with some beds slightly indurated; clay is green and reddish brown	65
Sand, soft; weathers light gray; uncemented except for irregular lenses, nodules, and concretions of fine gray and brown sandstone 1 foot or less in diameter. Texture ranges from fine to coarse and coarsely conglomeratic. Pebbles are of pink granite, granodiorite, and crystalline limestone	92

	Feet
Sand. Coarse light-brown and gray granitic beds alternate with finer, more argillaceous bluish-gray and brown beds. What appears to be an erosional surface with uneven contact and boulders as much as 8 inches in diameter occurs near middle	52
Sand, very coarse and conglomeratic, light gray and greenish gray; soft, massive and uncemented except for small irregular nodules and lenses; contains angular pebbles 1 inch or less in diameter, many of which are white feldspar and black basalt	30
Axis of Wheeler Ridge anticline.	
	1,560

In addition to the small marl nodules and thin calcareous bands in the green clay of the Etchegoin, a 4-foot bed of impure limestone occurs in the upper part of the formation just east of Coaloil Canyon. Owing to poor exposures this bed could not be traced laterally, but at about this stratigraphic horizon, 1 mile west-southwest, the greenish-gray clay of the Etchegoin is very calcareous and contains two closely associated beds of nodular limestone, each of which is approximately 1 foot thick. Careful examination of these beds and of thin sections prepared from the nodules failed to reveal the presence of any organisms. The fine-grained calcite that composes this impure limestone contains abundant angular fragments of quartz, fresh feldspar, chlorite, and hornblende from 0.01 to 1 millimeter in size, in addition to a few small fragments of basaltic and trachytic glass.

The beds of sand, gravelly sand, and coarse conglomerate are soft and, except for local fairly hard concretions and thin lenticular beds of gray sandstone and conglomerate, lack cementing material. All the sands and sandstones are either granitic or arkosic, with abundant angular grains of undecomposed granite or feldspar, and many of the beds contain considerable fresh biotite. The most common of the larger rock fragments consist of coarse-textured gray and pink granite, granodiorite, basalt, dark mica schist, gneiss, and white and dark-gray coarsely crystalline limestone. Angular fragments of white siliceous shale occur in thin lenses irregularly distributed throughout the upper 400 to 500 feet of the formation.

On microscopic examination individual grains of the finer sediments were found to be practically free from rounding; all of them are very angular. Quartz and feldspar are present in proportions that range from 5:1 to 1:1, and heavy minerals commonly make up about 2 per cent of the finer sandstones. Extremely turbid grains, mostly feldspar, are commonly not abundant, although they form as much as 25 per cent of some samples. As has been pointed out in an earlier paper,[53] the kind and percentage of heavy nonopaque

[53] Hoots, H. W., Heavy mineral data at the southern end of San Joaquin Valley: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 369–372, 1927.

minerals present in the sandstones of the Etchegoin differ considerably from bed to bed, but in the whole formation these minerals occur in the following approximate order of abundance: Biotite, garnet, titanite, andalusite, zircon, hornblende, epidote, tourmaline, and rutile. Only those minerals are present that might be expected in sediments derived from the erosion of a granitic and metamorphic mass of rocks such as that of the present San Emigdio Mountains.

Lateral variation in color and texture.—The upper 700 to 800 feet of the Etchegoin formation becomes somewhat coarser east of Coaloil Canyon, along the north flank of Wheeler Ridge, where this part of the formation contains a larger proportion of light-gray pebbly sand. Green clay and sandy clay are still abundant constituents, however, and this part of the Etchegoin, which is the only part continuously exposed, undergoes relatively little change in lithologic character eastward in the northern part of the ridge. But similarity in lithologic character does not appear to be so persistent when the upper part of these same beds is traced southward, through the oil-producing area, to the south flank of the anticline. The upper 200 to 300 feet of the Etchegoin east of Coaloil Canyon and south of the axis contains a larger percentage of coarse, sandy gravel than its stratigraphic equivalent farther north, and this general southward increase in coarseness is accompanied by a marked change in color. When viewed from the west, the color of these beds east of Coaloil Canyon grades from greenish gray north of the axis to buff and brown on the south flank. This lateral change in color also extends westward across Coaloil Canyon, for in the western part of Wheeler Ridge the upper 300 feet or more of the Etchegoin consists almost entirely of buff sediments with a large proportion of fine marly clay. The overlying coarse Tulare sediments are also predominantly buff, a condition that caused considerable difficulty in mapping the contact of these two formations.

Fossils, probable origin, and stratigraphic relations.—During an early survey of the Wheeler Ridge area, Ralph Arnold and Wayne Loel obtained several species of marine fossils from beds near the base of the exposed stratigraphic section in Coaloil Canyon. No complete record of the collection is available, but Mr. Loel has kindly furnished the following list of fossils from memory:

Pecten crassicardo? Conrad.
Panopea generosa Gould.
Several clams, identification uncertain.
Dosinia jacalitosana Arnold.
Schizodesma abscissa Gabb.

At the time of collection Arnold tentatively correlated these lower fossiliferous beds of Wheeler Ridge with the Jacalitos or the Santa

Margarita formation.[54] No evidence of an unconformity was found in the exposed section of rocks in Wheeler Ridge, and it is fairly certain that these oldest exposed rocks of probable Jacalitos or of Santa Margarita age are conformable and grade into the overlying Etchegoin.

It seems probable from the presence of marine fossils in a part of the Etchegoin and the fairly uniform color of all the sediments in the Coaloil Canyon section, that most if not all of the formation in this locality is of marine origin. The small amount of sorting and stratification in these deposits and the angularity of mineral and rock fragments are features that are characteristic of many of the marine fossil-bearing Miocene and Pliocene beds of this region. There is little doubt that these sediments accumulated along the southern border of a sea that stood north of a prominent land mass in the region of the San Emigdio and Tehachapi Mountains during most of the Tertiary period. The abundance of marl nodules and the presence of limestone beds in the upper part of the formation indicate the existence, during late Etchegoin time, of bodies of quiet water that had poor connections with the open sea and were undergoing active evaporation. Such bodies of quiet water may have been brackish-water lagoons near the shore or large fresh-water lakes, such as old Tulare Lake, on the alluvial plain some distance from the sea. The presence of such lakes and alluvial plains adjoining the coast may have provided the conditions that produced the marked lateral change in color of the upper Etchegoin sediments.

The green and gray Etchegoin strata grade upward into coarse buff poorly sorted sediments of the Tulare formation that were deposited to form alluvial fans and alluvial plains during late Pliocene time. The contact of the two formations along the north flank of Wheeler Ridge, east of Coaloil Canyon, is marked by an abrupt change in color and by a definite but somewhat more gradual upward increase in coarseness of sediments. South of the axis of the Wheeler Ridge anticline, near the producing area, the transition zone is several hundred feet thick, and the contact between the formations is more difficult to draw because of the increased coarseness and buff color of the uppermost Etchegoin strata. West of Coaloil Canyon a similar relation exists, and coarse granitic sand and gravel occur irregularly throughout the upper 100 feet of strata that have been arbitrarily included within the Etchegoin.

[54] Arnold, Ralph, oral communication and correspondence dated Apr. 28, 1927

TULARE FORMATION (UPPER PLIOCENE)

GENERAL CHARACTER AND DISTRIBUTION

A series of lenticular beds that consists of poorly cemented and ill-sorted sand, sandy clay, gravel, and boulders crops out on the flanks of Wheeler Ridge and in the northern part of the foothills farther west. These beds grade downward into somewhat finer sediments of the Etchegoin formation and are overlain by similar deposits which, during Pleistocene and Recent times, have accumulated to form alluvial fans along the edge of the foothills. The buff color, coarse texture, and lack of sorting of these deposits, together with the angularity of the included rock fragments, are features that are common to the overlying alluvial-fan deposits as well and support the conclusion that all these sediments were deposited by short torrential streams, such as now drain mountainous areas and dump their load along the border of San Joaquin Valley. Irregular boulders of granitic and metamorphic rock as much as 6 feet across occur throughout the lower part of this formation, but in Wheeler Ridge the upper half is composed of finer and better-sorted sand, clay, and fine gravel, much of which occurs in clean-cut strata.

This series of coarse sediments, above the Etchegoin formation and below the alluvial-fan deposits of Pleistocene age, is considered equivalent, in part at least, to the Tulare formation, which is exposed in the flanks of the Kettleman Hills and in the intervening areas of the Lost Hills, Elk Hills, and Buena Vista Hills. The Tulare is unfossiliferous throughout its exposures along the southern border of San Joaquin Valley.

HISTORY OF NOMENCLATURE

F. M. Anderson [55] applied the name Tulare formation to fresh-water deposits fully 1,000 feet thick that conformably overlie the marine Etchegoin formation in the Kettleman Hills. In a later paper [56] he expressed the opinion that these fresh-water deposits were probably equivalent to similar deposits in the Salinas Valley that had already been described under the name Paso Robles formation by Fairbanks [57] and by Hamlin.[58] An earlier description of

[55] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, p. 181, 1905.

[56] Anderson, F. M., A further stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 4th ser., vol. 3, p. 32, 1908.

[57] Fairbanks, H. W., Geology of a portion of the southern Coast Ranges: Jour. Geology, vol. 6, pp. 465–466, 1898; see also U. S. Geol. Survey Geol. Atlas, San Luis folio (No. 101), 1904.

[58] Hamlin, Homer, Water resources of the Salinas Valley, Calif.; U. S. Geol. Survey Water-Supply Paper 89, pp. 15–16, 1904.

these beds in the Kettleman Hills and farther south in the McKittrick district was made by Watts,[59] and in the same paper J. G. Cooper described fossils collected by Watts from these deposits. Both Anderson and Watts considered similar fresh-water deposits farther south in the vicinity of McKittrick to be equivalent to the Tulare of the Kettleman Hills.

The first detailed description of this formation was that by Arnold and Anderson,[60] who called it the Paso Robles formation (Pliocene—lower Pleistocene), because of its supposed equivalence to that formation of the Salinas Valley, which was considered of Pliocene age by Fairbanks and by Hamlin. In their final report on the Coalinga district Arnold and Anderson [61] restored the name Tulare formation (upper Pliocene—lower Pleistocene) for these sediments, the thickness of which is over 3,000 feet. This restoration was based largely on the fact that marine fossils collected by Robert Anderson from the lower portion of the Paso Robles formation of the Salinas Valley proved this lower part to be older than the Tulare and equivalent to the Jacalitos and Etchegoin of the Coalinga district east of the Coast Ranges. Arnold and Anderson considered it uncertain that even the unfossiliferous upper few hundred feet of the Paso Robles formation farther west is equivalent to any part of the Tulare near Coalinga.

In 1910 Arnold and Johnson [62] grouped beds considered to be in large part equivalent to the Tulare, Etchegoin, and Jacalitos formation (upper Miocene). A few years later Gester [63] subdivided this group in the McKittrick district and named and described its components as the Etchegoin (lower Pliocene) and Tulare (Pliocene) formations.

English [64] said that the Paso Robles formation in the Salinas Valley-Parkfield area occupies the same stratigraphic position and corresponds to the fresh-water deposits mapped and described as Tulare formation in the report on the adjoining Coalinga district. As the name Paso Robles had precedence he abandoned the name Tulare formation and referred to these sediments as the Paso Robles

[59] Watts, W. L., The gas and petroleum-yielding formations of the central valley of California: California State Min. Bur. Bull. 3, pp. 65–67, 1894.

[60] Arnold, Ralph, and Anderson, Robert, Preliminary report on the Coalinga oil district, Fresno and Kings Counties, Calif.: U. S. Geol. Survey Bull. 357, pp. 56–61, 1908.

[61] U. S. Geol. Survey Bull. 398, pp. 140–143, 1910.

[62] 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. 74–90, 1910.

[63] Gester, G. C., Geology of a portion of the McKittrick district: California Acad. Sci. Proc., 4th ser., vol. 7, pp. 207–227, 1917.

[64] English, W. A., Geology and oil prospects of the Salinas Valley-Parkfield area, Calif.: U. S. Geol. Survey Bull. 691, p. 231, 1919.

("Tulare") formation (Pliocene). Pack,[65] following Arnold and Johnson, grouped equivalents of the Jacalitos, Etchegoin, and Tulare formations under the name McKittrick group (upper Miocene, Pliocene, and Pleistocene?) in his report on the Sunset-Midway and adjoining San Emigdio region but where practicable mapped the components of this group separately and followed English's usage in referring to the beds. The youngest tilted sediments of Wheeler Ridge and the foothills farther west were therefore described and mapped by Pack as the Paso Robles ("Tulare") formation. Although he says that beds exposed in the central part of Wheeler Ridge probably belong to the Etchegoin formation, he mapped them, for convenience, as a part of the Paso Robles ("Tulare").

It is evident, from the fossils collected by Robert Anderson, that the Tulare formation of the Coalinga and McKittrick region can not be correlated with all those beds of the Salinas Valley originally described as Paso Robles. Proper usage demands that the name Tulare be retained, as originally proposed, for the beds, mainly of fresh-water origin, that overlie marine Etchegoin strata in the Coalinga region.

In this report the geographic distribution of the Tulare formation is extended considerably, so that the formation is made to include coarse continental deposits in the San Emigdio foothills, 150 miles from the type locality, which overlie fossiliferous marine Etchegoin strata and which, except for minor overlying deposits of probable Pleistocene age, are the youngest tilted sediments along the southern border of San Joaquin Valley. The base of the Tulare formation—that is, the base of the upper Pliocene continental beds—along the southern and western borders of San Joaquin Valley probably transgresses the geologic column and varies considerably in age from place to place. This part of the Great Valley, through uplift of the Coast Ranges to the west and the San Emigdio Mountains to the south, began to assume its present outline within or directly after Etchegoin time. As a result, the Tulare formation of the Coalinga region and synchronous fresh-water deposits farther south accumulated in lakes and in alluvial fans as the result of the work of short streams which, like those of to-day, drained from the bordering mountains and spread their sediments over the valley floor. In the San Emigdio foothills these deposits, as indicated by their coarse boulders and other lithologic characteristics, are thought to have accumulated as alluvial fans near the base of the San Emigdio Mountains.

In the present report the name Tulare is applied in a more restricted sense than was originally intended by F. M. Anderson.

[65] Pack, R. W., The Sunset-Midway oil region: U. S. Geol. Survey Prof. Paper 116, pp. 43–51, 1920.

Although most of the uppermost tilted series of continental deposits are included in the Tulare formation, the youngest of these beds, on the basis of marked angular discordance in dip with the underlying major part of this series, are considered a unit distinct from the Tulare and equivalent in age to terrace and related Pleistocene stream deposits of the San Emigdio foothills.

LOCAL FEATURES AND THICKNESS

The lower one-half or two-thirds of the Tulare formation in Wheeler Ridge and along the foothills farther west is composed of a varied assortment of coarse subangular pebbles and boulders in a soft matrix of buff and gray calcareous sand and clayey sand. Individual beds are very poorly sorted, the included rock fragments ranging from fine sand to boulders 6 feet in diameter. The beds of this portion of the formation are extremely lenticular, one of them having been observed to decrease in thickness from 40 to 10 feet in a horizontal east-west distance of 100 feet, and many other beds show comparable lenticularity. This lower series of coarse gravel and boulder beds is best exposed on the north flank of Wheeler Ridge (see pl. 36, *A*) and, together with overlying strata, is described in a section measured near Coaloil Canyon that is given below.

In Wheeler Ridge a finer texture is common to the upper one-third to one-half of the Tulare formation, and, although coarse gravel is locally present in thin lenses, boulders are rare, and much of the greater part of this division consists of fine-grained buff arkosic sand, gravelly sand, and clay. Bedding is fairly distinct, and individual strata have an average thickness of 2 or 3 inches and are continuous without change throughout exposures 10 or 15 feet across, though more intricate banding, produced by thin clay partings one-eighth of an inch thick, intercalated with fine sand, may be traced through somewhat smaller exposures. This upper division is best exposed in the NW. ¼ sec. 34, along the main road up the south side of Wheeler Ridge, and similarly near the west side of sec. 22, along the road leading up the north flank to the old camp of the Midlands Oilfields Co. (Ltd.). The section given below records a thickness of about 450 feet for this division and a small amount of overlying Pleistocene on the north flank of Wheeler Ridge, half a mile east of the mouth of Coaloil Canyon. At this locality the contact between the Tulare and the overlying tilted Pleistocene is not distinct.

Section of the Tulare formation and overlying Pleistocene sediments exposed on the north flank of Wheeler Ridge, half a mile east of the mouth of Coaloil Canyon

	Feet
A series of fine gravel and buff clayey sand and sandy clay, which becomes progressively finer toward its top and the outer edge of Wheeler Ridge. Fine gravel, the most common pebbles of which are 2 or 3 inches in diameter, occurs in lenticular beds from a few inches to 3 feet thick and comprises 60 per cent of the lower half. Gravel beds are thinner and less abundant in the upper half, although pebbles as much as 8 inches in diameter are scattered throughout this member	450
Coarse gravel, boulders, fine sand, and clayey sand. Finer beds are buff. Boulders are of granodiorite and as large as 18 inches in diameter	70
Sand, clayey sand, and fine gravel. Subangular pebbles from 2 to 3 inches in diameter are most common and occur as thin discontinuous beds throughout this member. The upper half, 200 feet farther west, contains much more gravel	160
Gravel, sand, and sandy clay. Gravel composes 75 per cent of this member and occurs in beds from 1 to 40 feet thick, intercalated with buff sand and sandy clay beds from 1 to 6 feet thick. All beds are extremely lenticular. Pebbles are 60 to 75 per cent granodiorite	340
Gravel, sand, and sandy clay, interbedded in lenticular layers from a few inches to 6 feet thick. Sand is granitic and clayey and ranges in texture from coarse to fine. All beds are gray or buff, are poorly sorted, and change lithology within short distances	120
Sand, sandy clay, and gravel of light-brown color. Coarser sand is granitic and largely light gray in fresh exposures. Finer sand and sandy clay are brown and contain considerable feldspar; pebbles from 1 to 2 inches in diameter are most common	100
Etchegoin formation.	
	1,240

This section is continued on page 281.

Farther west, in the vicinity of the San Emigdio ranch, the Tulare formation has more thin beds of buff clay intercalated with poorly sorted sand and gravel, and, as it is fairly uniform throughout, it is not so easily divisible into two distinct divisions.

The poorly rounded rock fragments contained in the Tulare formation have been eroded from the pre-Tertiary granitic and metamorphic mass of the San Emigdio Mountains and from the accompanying belt of uplifted pre-Tulare sediments and volcanic deposits. Large and small fragments of granodiorite are by far the most abundant detrital rock type and fragments of the old metamorphic rocks are very common, whereas fragments of the Tertiary rocks are present in subordinate amounts.

Estimated composition of gravel and boulder beds in the Tulare formation of Wheeler Ridge

	Per cent
Granodiorite, with some diorite	65
Black mica schist, hornblende schist, and dark-gray gneiss	15
Pink and gray granite	5
Gray and blue coarsely crystalline limestone	5
Basalt, andesitic agglomerate, brown sandstone, quartzite, white siliceous shale, etc	10

The thickness of the Tulare formation exposed on the north flank of Wheeler Ridge ranges from 1,000 feet near the center of the ridge to about 1,500 feet 3½ miles farther west, near its west end. This westward thickening appears to be gradual but constant wherever the entire formation is exposed. From Telegraph Canyon, near the west end of Wheeler Ridge, to Pleitito Creek, a distance of 3½ miles, the coarse sand, gravel, and clay included in the Tulare increase in thickness from 1,500 to about 5,000 feet. These figures include from 50 to 250 feet of younger Pleistocene sediments. Just west of San Emigdio Canyon, on the south limb of the San Emigdio anticline, the Tulare formation has an exposed thickness of 3,000 feet, and neither the base nor the top of the formation is exposed.

STRATIGRAPHIC RELATIONS

The stratigraphic relations between the Tulare and the conformably underlying Etchegoin formation are discussed on page 285. At several points along the northern edge of the San Emigdio foothills the main mass of coarse buff gravel and boulder beds, here designated the Tulare formation, is overlain with marked angular discordance by a slight thickness of coarse fanglomeratic deposits, similar in character to the Tulare, which were laid down as alluvial fans along the southern edge of the Great Valley during Pleistocene time. Plate 37, *A*, illustrates the stratigraphic relation between the Tulare and these overlying beds along the north side of Wheeler Ridge, and Plate 36, *B*, shows a much more striking unconformity between these two formations near the San Emigdio ranch.

TEJON HILLS

Pliocene strata of the Tejon Hills, near the base of the Sierra Nevada, are fairly uniform in lithologic character and, unlike the Pliocene of the San Emigdio foothills, compose only one formation. This formation, the Chanac, is of continental origin and conformably overlies the marine Santa Margarita formation. These sediments commonly dip away from the granite at angles between 5° and 20°, though locally tilted more steeply. Owing to their gentle inclination and soft, poorly cemented character, the Chanac beds in much of this district present a subdued topography of low-lying round-topped hills that are gashed by many steep-walled arroyos.

CHANAC FORMATION (PLIOCENE)

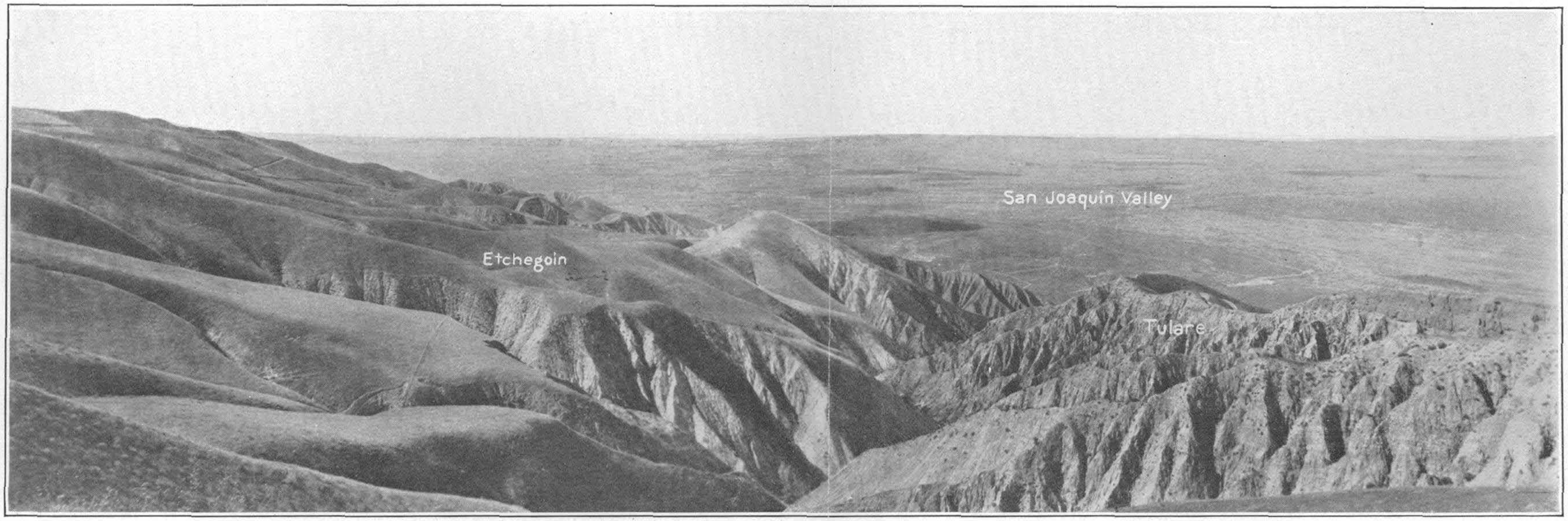
Lithology, surface features, and thickness.—The Chanac formation, so named by Buwalda [66] from the proximity of its occurrence to Chanac Creek, is easily distinguished from other sedimentary rocks of the Tejon Hills by its buff color and the angular, ill-sorted character of the large rock fragments that are common to the formation. These coarse detrital accumulations were deposited during the Pliocene to form extensive alluvial fans along the base of the Sierra Nevada and should be termed fanglomerate.[67] They are intercalated with lenticular beds of coarse gray arkosic grit and buff clay that commonly weather to a fluffy surface. (See pl. 37, *B*.) The stratification is indistinct and discontinuous, and many of the beds of coarse grit are very much cross-bedded. The rock fragments show little effect of water wear (see pl. 34, *C*) and are generally 6 inches or less across, but large boulders are not uncommon, and the largest are 9 feet or more across. Angular fragments of white, gray, and pink rhyolite are the most common type, and white quartz, trachyte, granodiorite, quartzite, granite, acidic agglomerate, schist, and gneiss, mentioned in the approximate order of abundance, are notable constituents of the fanglomerate.

The coarse gray arkosic grit appears to be more common in the upper part of the Chanac, whereas thin beds of buff clay are more common in the lower part, a relation which suggests that the formation is of somewhat finer texture in its lower portion, although fanglomerate is abundant throughout. In addition to the abundant buff clay there are local thin beds of green clay in both the upper and lower parts of the formation.

As shown in Plate 37, *B*, the Chanac formation is eroded locally to a typical badland topography, especially where Comanche Creek has carved prominent bluffs along the up-dip side of prominent ridges. This topography is in striking contrast, however, to the rounded, subdued hill slopes common to this formation throughout most of the Tejon Hills. Bedding is indistinct in the soft sediments of these low-lying hills, but locally it is plainly visible as a result

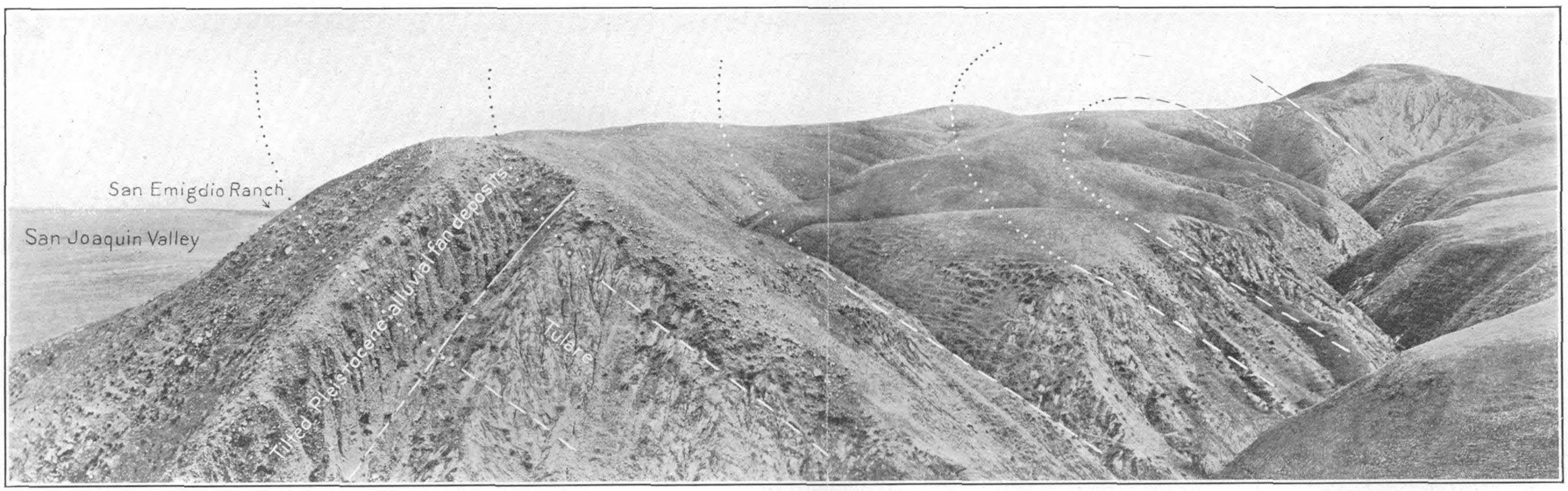
[66] Buwalda, J. P., in Merriam, J. C., Mammalian remains from the Chanac formation of the Tejon Hills, Calif.: California Univ. Dept. Geology Bull., vol. 10, p. 114, 1916.

[67] Lawson, A. C., The petrographic designation of alluvial-fan formations: California Univ. Dept. Geology Bull., vol. 7, pp. 325–334, 1913.



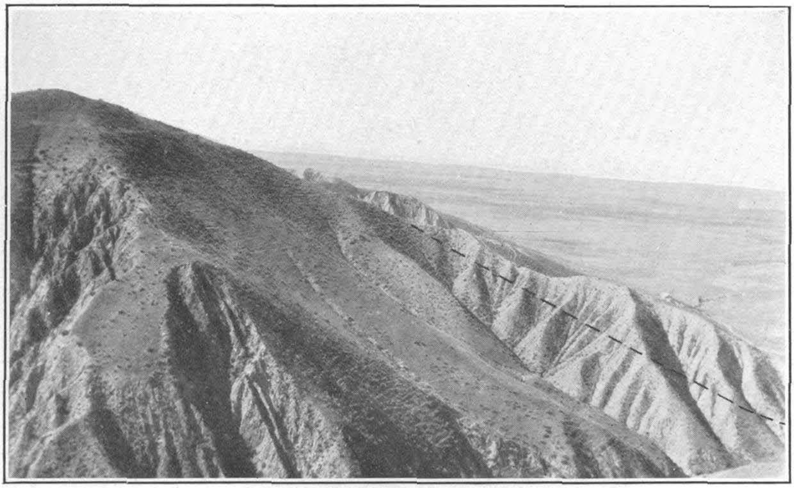
A. TULARE AND ETCHEGOIN SEDIMENTS ON THE NORTH FLANK OF WHEELER RIDGE

Looking northwest. The coarse buff Tulare exhibits badland topography at the right; the finer greenish-gray Etchegoin appears in the left foreground.

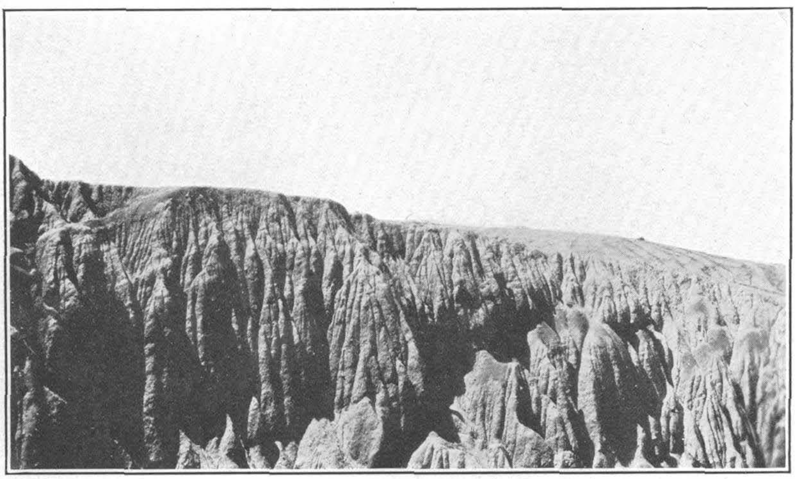


B. UNCONFORMITY BETWEEN OVERTURNED TULARE STRATA AND OVERLYING TILTED PLEISTOCENE ALLUVIAL-FAN DEPOSITS, 1 MILE WEST OF SAN EMIGDIO RANCH

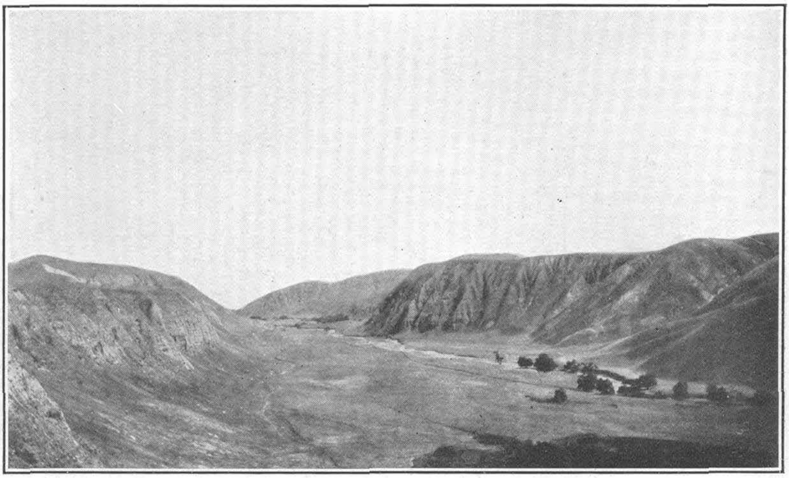
Looking east along north edge of foothills. Dashed lines show overturned San Emigdio anticline.



A. UNCONFORMITY ON WHEELER RIDGE BETWEEN TULARE AND OVERLYING TILTED PLEISTOCENE ALLUVIAL-FAN DEPOSITS

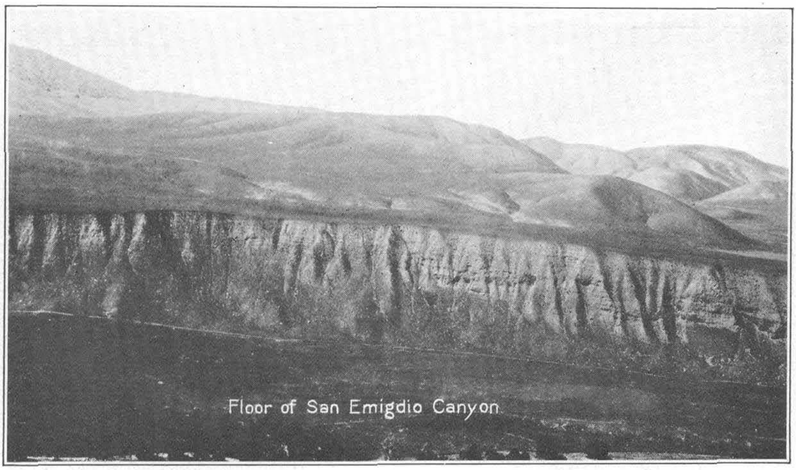


B. COARSE INDISTINCTLY BEDDED CHANAC SEDIMENTS IN THE TEJON HILLS



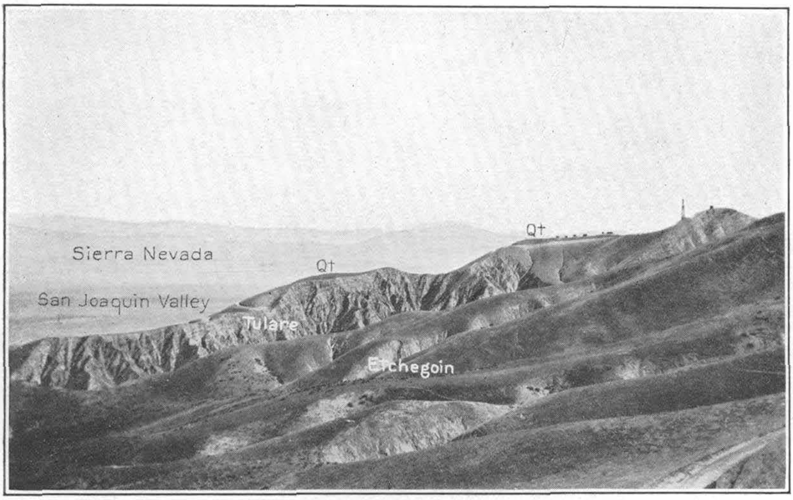
A. STREAM TERRACES ALONG SAN EMIGDIO CANYON

Looking north. Terraces are 400 feet above present stream.



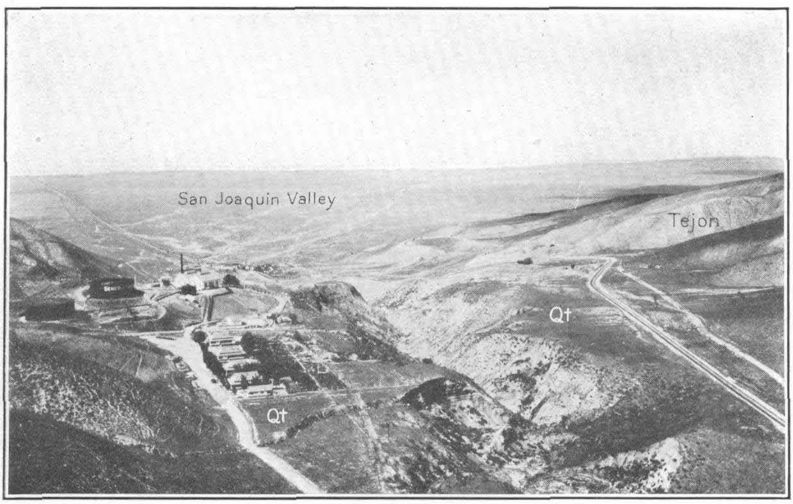
B. STREAM TERRACE ALONG SAN EMIGDIO CANYON AND ITS RELATION TO MATURE PHYSIOGRAPHIC SURFACE OF THE UPLAND

Note gentle arching of terrace deposits, presumably caused by post-Pleistocene stresses along Pleito fault.



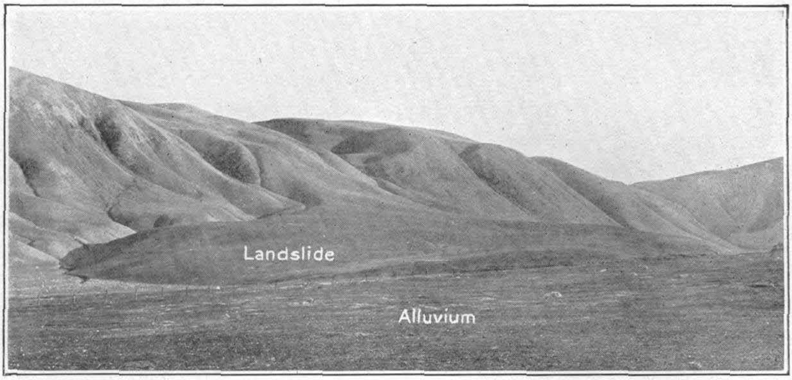
A. TERRACE REMNANTS OF PLEISTOCENE ALLUVIUM (Qt) HIGH ON NORTH FLANK OF WHEELER RIDGE

These deposits rest upon Tulare and Etchegoin beds dipping 45°–50° N. Looking east.

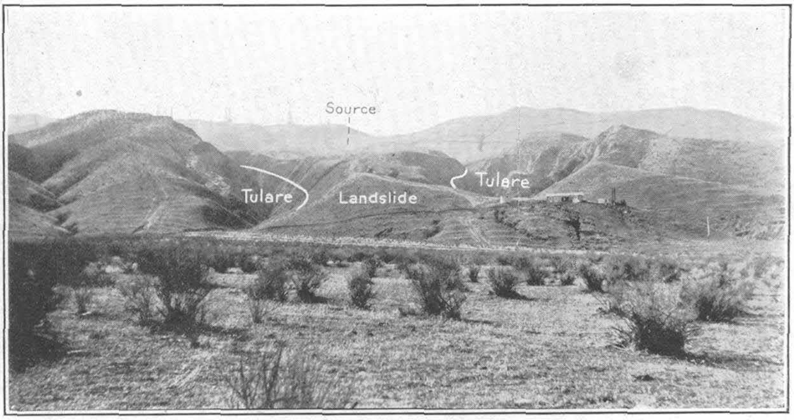


B. HIGH PLEISTOCENE STREAM TERRACE DEPOSITS (Qt) IN LOWER GRAPEVINE CANYON

Looking north.

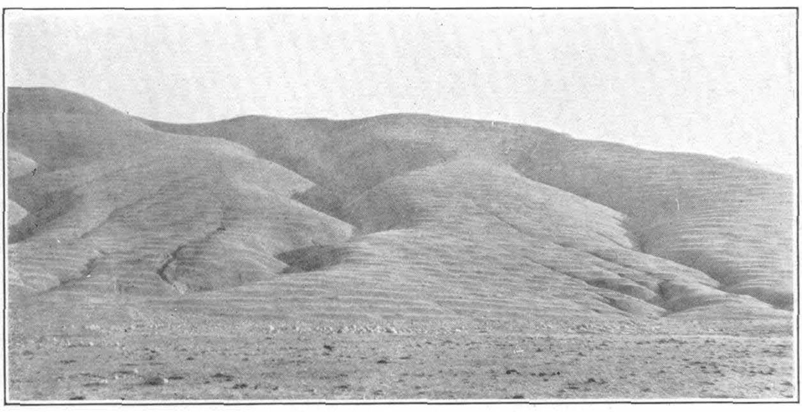


A. SMALL LANDSLIDE OF ETCHEGOIN CLAY ON THE FLOOR OF SAN JOAQUIN VALLEY JUST EAST OF SAN EMIGDIO CANYON



B. ONE OF THE LANDSLIDES ON THE NORTH FLANK OF WHEELER RIDGE

Slide rests upon steeply dipping Tulare gravel.



C. MAMMILLARY SOLIFLUXION FEATURES ALONG NORTH EDGE OF SAN EMIGDIO FOOTHILLS, NEAR PLEITO CREEK of color banding produced by alternating beds of buff clay and gray sand.

The thickness of the Chanac appears to range from 300 to 1,000 feet or more and to be greatest west of Comanche Creek and south of the anticline at Comanche Point. The stratigraphic relation between this formation and the underlying Santa Margarita is considered on page 273.

Fossils and age.—In surveying Tejon Hills in 1911 R. W. Pack and assistants, of the United States Geological Survey, collected mammalian bones from the Chanac and underlying Miocene strata near Comanche Point. Additional material was collected later by R. C. Stoner and J. P. Buwalda and in 1915 by Buwalda and others, who again visited this district. These bones have been described by Merriam,[68] who in his second paper concerning this material states that the representation of mammalian forms obtained in the land-laid beds of the Chanac formation is very scanty; he identified the following forms from the material available:[69]

Rhinocerotid, indet.
Protohippus tehonensis Merriam.
Neohipparion gratum tehonense Merriam.
Neohipparion near N. molle Merriam.
Prosthennops sp.
Camelid indet., large.
Merycodus near M. necatus Leidy.
Proboscidean (Tetrabelodon?), indet.

Concerning the relationships of this fauna Merriam presented the following conclusion:[70]

> The available evidence furnished by the Chanac mammalian fauna indicates that it represents a stage older than the *Pliohippus proversus* zone of the upper Etchegoin in the North Coalinga region, and later than the Barstow, the youngest recognized upper Miocene of the Pacific coast and the Great Basin provinces. The Chanac is evidently of an early Pliocene or latest Miocene phase. It is presumably nearest to the faunas of the lower portion of the Jacalitos-Etchegoin of the North Coalinga region and to the Ricardo stage of the Mohave area.

Although many fragmentary bones were found during the present investigation, no additional fossil material of value is as yet available from the Chanac formation. All the mammalian bones from this formation have come from layers within 50 feet or so of the base, resting directly upon marine Santa Margarita (upper Miocene) deposits. The Chanac formation is believed to represent alluvial-plain deposits that accumulated throughout the Pliocene until, near the end of this epoch, these deposits were uplifted and folded and thereafter dissected by a system of streams much like that of

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[68] Merriam, J. C., Remains of land mammals from marine Tertiary beds in the Tejon Hills, Calif.: California Univ. Dept. Geology Bull., vol. 8, pp. 283–288, 1915; Mammalian remains from the Chanac formation of the Tejon Hills, Calif.: Idem, vol. 10, pp. 111–127, 1916.

[69] Op. cit., (1916), p. 116.

[70] Idem, p. 117.

the present. Deposits of similar character occur along the east side of San Joaquin Valley farther north and have been described as the Kern River "group." [71] These more northern sediments have also yielded bones of land mammals, but this fossil material has not yet been studied and classified,[72] and it seems that the Kern River formation can not, on the basis of available information, be correlated with the Chanac formation.[73] Much of the Kern River formation was probably deposited under similar conditions and at about the same time as the Chanac, but as the Kern River rests upon middle Miocene strata containing a *Turritella ocoyana* fauna, with no intervening recognized marine strata of upper Miocene age, it seems at least possible that the Kern River may include upper Miocene deposits of Santa Margarita age and therefore can not at this time be considered the equivalent of the Chanac formation of the Tejon Hills.

PLEISTOCENE DEPOSITS

Deposits of Pleistocene age are taken, in this report, to include the youngest group of beds that has undergone marked deformation. They represent coarse detrital accumulations which, during Pleistocene time, were deposited in valleys and as alluvial fans by overloaded streams. At the end of the Pleistocene epoch the entire foothill belt was uplifted several hundred feet, and the present stream valleys were cut below the old Pleistocene erosion surface. The results of these events are particularly striking in the vicinity of San Emigdio Canyon and farther west, but it is evident that all of the foothill belt along the southern border of the Great Valley was subjected to similar uplift at about this time. Post-Pleistocene uplift not only elevated the foothills themselves and provided the final geologic setting for the development of high stream terraces, but it produced a remarkable northward tilting of the Pleistocene alluvial-fan deposits along the borders of these foothills.

STREAM TERRACE DEPOSITS

SAN EMIGDIO FOOTHILLS

Stream terrace deposits in the vicinity of San Emigdio Canyon, Los Lobos Creek, and Santiago Canyon compose one of the most striking formations of this foothill belt. Those in San Emigdio Canyon have a total areal distribution of several square miles and

[71] Anderson, F. M., The Neocene deposits of Kern River, Calif., and the Temblor Basin: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 95–96, 1911.

[72] Stock, Chester, oral communication.

[73] Chester Stock has recently made extensive collections from both the Chanac and the Kern River beds. Although his studies are not complete, he has informed the writer that vertebrate-fossil evidence warrants the conclusion that the Chanac formation is definitely older than the fossil-bearing beds of the Kern River "group."

a maximum thickness of at least 300 feet. Their upper surface is a broad flat which stands from 300 to 500 feet above the present stream (see pl. 38) and which, as it extends away from the canyon walls, merges with the subdued land forms of a physiographically old or mature Pleistocene surface. These deposits occupy similar high terraces in the upper parts of Los Lobos and Santiago Canyons and broad flats in high intervening areas (pl. 31) which as yet are untouched by the present system of intrenched streams. Lower and less prominent terraces occur at three different levels along the lower part of Los Lobos Creek, the highest about 150 feet and the lowest about 30 feet above the stream bed.

These alluvial-terrace deposits are indistinctly bedded and are characterized by an abundance of large angular unassorted fragments of dark granitic and metamorphic rock that have been derived from the mountain mass to the south. The color of the assembled fragments, owing to the prevalence of black schist and diorite, is commonly dark gray, in contrast to the buff and light gray of the more argillaceous Tulare formation.

WHEELER RIDGE

Stream deposits of Pleistocene age occur as small terrace remnants in Coaloil and Telegraph Canyons, in the western part of Wheeler Ridge, where they lie from 30 to 150 feet or more above the stream beds. Farther east there are no large streams that cut across the central part of Wheeler Ridge, but there are wind gaps which were carved by such streams during Pleistocene time and which are closely related genetically to high alluvial terraces on the north flank of the ridge, 800 feet above the floor of San Joaquin Valley. (See pl. 39, *A*.) Still farther east there are several less prominent wind gaps across the lower part of Wheeler Ridge, some of which contain fine black loam as the sediment deposited by streams which crossed this anticlinal ridge during the Pleistocene epoch.

GRAPEVINE CANYON TO THE TEJON HILLS

In lower Grapevine Canyon there is a remarkable alluvial terrace, (see pl. 39, *B*), which, in its lowest part near the mouth of the canyon, is 300 feet above the alluvial floor of San Joaquin Valley, less than a mile to the north. The material composing this terrace deposit consists of fairly well bedded buff and gray sand, clay, and gravel, and it is apparent that the Pleistocene stream that produced this deposit had a comparatively gentle gradient, very different from that of Grapevine Creek to-day.

Prominent but narrow and relatively low stream terraces occur also along Live Oak and Pastoria Creeks. Still farther east, in the lower part of Tejon Canyon, there is a prominent alluvial bench level about 75 to 100 feet above Tejon Creek, and along the northeast wall of this same canyon there are small remnants of an earlier terrace approximately 200 feet higher. Most of the material that composes these terraces consists of poorly stratified coarse angular rock fragments and sand.

In the Tejon Hills alluvial terraces are low and indistinct and, as a result, are not very prominent features of the landscape. They are present along lower Tejon Creek, Comanche Creek, and the short westward-draining tributaries that empty into Comanche Creek from the east. Along lower Tejon Creek there are locally small remnants of two terrace levels about 40 and 80 feet above the creek bed. East of Comanche Creek and near the Tertiary granite contact there are at least three prominent levels of terrace deposits, approximately 40, 75, and 100 feet above the present drainage level. The upper terrace is continuous with an old surface which caps most of these hills and which is strewn with angular blocks of black schist, gneiss, and granodiorite.

TILTED ALLUVIAL-FAN DEPOSITS

GENERAL FEATURES

During the Pleistocene epoch poorly sorted sediments of coarse texture were deposited in alluvial fans along the southern border of San Joaquin Valley by streams that flowed from the mountainous country to the south. This material accumulated near the present edge of the foothills, and at about the end of Pleistocene time underwent a marked northward tilting as a result of the same broad movement that uplifted the entire foothill belt and paved the way for the development of the prominent stream terraces described in the preceding paragraphs. These tilted alluvial-fan and terrace deposits are considered to be of approximately the same age; they both unconformably overlie the Tulare formation (upper Pliocene), which is also an old alluvial-fan or alluvial-plain deposit; they are practically continuous with each other at some localities, as near the mouth of San Emigdio and Grapevine Canyons; and they were both laid down prior to the last extensive uplift.

Lithologically the tilted alluvial-fan material is very much like the terrace deposits and consists largely of coarse granitic sand and angular rock fragments of granitic and metamorphic rock, all of which are indistinctly bedded and poorly assorted. Because of the abundance of large fragments of rock of dark color and, in most localities, the relatively small amount of clay, these Pleistocene deposits can usually be readily distinguished from the older buff Tulare formation. In the vicinity of Little Muddy Creek, however, the two formations are so similar that there is some doubt as to where the contact should be drawn.

SAN EMIGDIO FOOTHILLS

The lithologic character and structural and stratigraphic relations of this tilted Pleistocene alluvial-fan material are well exposed at the mouth of the first large gulch west of San Emigdio Canyon. (See pl. 36, *B*.) Here the coarse Pleistocene sediments dip 45° N. and unconformably overlie the light-buff sandy and gravelly clay of the Tulare formation, which is overturned and dips about 25° S. The northward tilting of this Pleistocene material apparently has resulted from the renewed growth, at the end of Pleistocene time, of an already overturned anticline.

Farther west along the north flank of this fold all of the Tulare formation appears to be overlapped by these tilted Pleistocene sediments, which in Little Muddy Creek seem to contain more buff clay and to rest with an angular discordance of 10° to 15° upon the Etchegoin formation (lower, middle, and upper (?) Pliocene). (See p. 278.)

East of the mouth of San Emigdio Canyon the significance and relations of these Pleistocene sediments are obscured for a distance of 2 miles by prominent earth flows of Etchegoin clay, beyond which they can not be readily separated from the underlying Tulare formation. However, in the west wall of the large arroyo east of Hill 1764 (sec. 25, T. 11 N., R. 21 W.), there is a good exposure in which steeply dipping Tulare fanglomerates are overlain by similar Pleistocene sediments with an angular discordance of at least 20°. A similar relation exists along the north flank of Wheeler Ridge (see pl. 37, *A*), where the Tulare is overlapped by several hundred feet of Pleistocene fanglomerate with a difference in northward dip of approximately 30°.

Just west of the mouth of Grapevine Canyon there is, at the edge of the foothills, a large exposure of coarse gray angular ill-sorted material of probable Pleistocene age that is considered to be the age equivalent of the high terrace deposits in the lower part of Grapevine Canyon. This Pleistocene material at the edge of the foothills is tilted northward 65° to 70° and rests directly upon the Tejon formation (Eocene), which is here overturned and dips to the south.

NEAR THE TEJON RANCH

Structural deformation throughout late geologic time has been far less intense in the southeastern part of San Joaquin Valley than in the San Emigdio foothills, to the west. Uplift at the end of the Pleistocene epoch was comparatively gentle in the foothills near the

Tejon ranch, and as a result Pleistocene alluvial fans have been tilted but little toward San Joaquin Valley. The best record of this last extensive though gentle uplift appears along the lower part of Tunis Creek, where a long, gently sloping aggraded surface now lies 100 to 150 feet above the level of the minor stream drainage that has carved away its western border. The present channel of Tunis Creek, where this stream leaves the resistant basement complex, lies 40 to 50 feet below the upper surface of this old alluvial fan.

Along lower Tejon Creek, 7 miles northwest of the Tejon ranch house, the surface of the hills grades westward into a gently sloping plain which lies 20 to 50 feet above the creek bed and which, prior to the last uplift, belonged to the alluvial fan of Tejon Creek. The surface of this alluvial plain, now lifted above the present stream channel, is practically continuous with the stream terraces along Tejon Creek and grades imperceptibly into the broad alluvial floor of San Joaquin Valley.

LANDSLIDES

Landslides form striking physiographic features within and along the northern border of the San Emigdio foothills. They occur in practically all types of rock, from the hard massive pre-Tertiary granite and metamorphic complex to the soft Pliocene clay of the Etchegoin formation. Only the largest and most obvious landslides are shown on the geologic map (pl. 31), and it will be noted that they are particularly abundant long the northern part of the foothills, where comparatively soft Tertiary rocks underlie unusually steep slopes. The features that have been recognized as landslides are probably all of Quaternary age. Some of them are definitely post-Pliocene, and it seems probable that conditions favorable to the widespread development of landslides in Tertiary rocks of this region have existed only since the post-Tulare (post-upper Pliocene) uplift. Some of them appear to be younger than the Pleistocene terrace and tilted alluvial-fan material and probably resulted, directly or indirectly, from the last great uplift of this region. However, as they all have undergone noticeable erosion and dissection by minor streams, it is improbable that any of them are very recent.

SLIDES OF ETCHEGOIN CLAY

The soft clay of the Etchegoin formation is the stratigraphic unit most susceptible to landsliding. Near the northern edge of the San Emigdio foothills this formation is exposed along the crests of sharply folded anticlines and, prior to landsliding, stood unsupported at the top of steep slopes overlooking San Joaquin Valley. In addition to the soft character of the rock and the structure and resulting steep slope, the conditions favorable to the development of landslides in this region include the prevalence of gentle rains during the wet season, the scarcity of vegetation, and the probable occurrence of earthquakes.

Two landslides just east of the mouth of San Emigdio Canyon are particularly striking in that they rest upon the flat floor of San Joaquin Valley and have assumed clean-cut rounded forms in sharp contrast to the adjoining topography. The smaller one is shown in Plate 40, *A*. The greenish-gray masses of Etchegoin clay that compose them have slid from the crest of the sharply overturned San Emigdio anticline (see pl. 31) and, on striking the valley floor, have flowed like a viscous fluid and come to rest in lobe-shaped forms with steep terminal slopes. Their points of exit from the high foothills to their rear appear as fairly distinct windows in this wall of nearly vertical rocks.

Two prominent landslides occur on Wheeler Ridge. These features are of somewhat different character from those farther west near San Emigdio Canyon. Instead of originating at the crest of an overturned anticline at the very edge of the foothills and sliding down a steep face to the valley floor, they have come from points near the axis of a comparatively broad anticline and have moved along a relatively gentle slope (approximately 11°). (See pl. 40, *B*.) Although their forward ends have reached the edge of the valley, they rest upon this gentle slope of buff Tulare fanglomerate in tonguelike masses of greenish-gray clay derived from the Etchegoin formation. The base of the eastern landslide shows remarkable slickensiding, but it seems probable, from the gentle slope and the character of the material involved, that in general the movement of these two masses was characterized by slow flowing rather than by rapid sliding. In fact, it is believed that these two features on Wheeler Ridge may properly be designated earth flows, rather than typical landslides; in character of movement they are probably very much like the Gros Ventre slide described by Blackwelder.[74] In point of origin they are also closely related to the multitude of small mammillary solifluxion features that occur along the northern edge of the foothills west of Wheeler Ridge. (See pl. 40, *C*.)

SLIDES OF MARICOPA SHALE

In the upper part of the Pleito Hills, south of Wheeler Ridge and just north of the Pleito syncline, there are numerous fairly large slides of Maricopa shale that have resulted in part from the more rapid erosion of soft Vaqueros shale directly to the north; these fea-

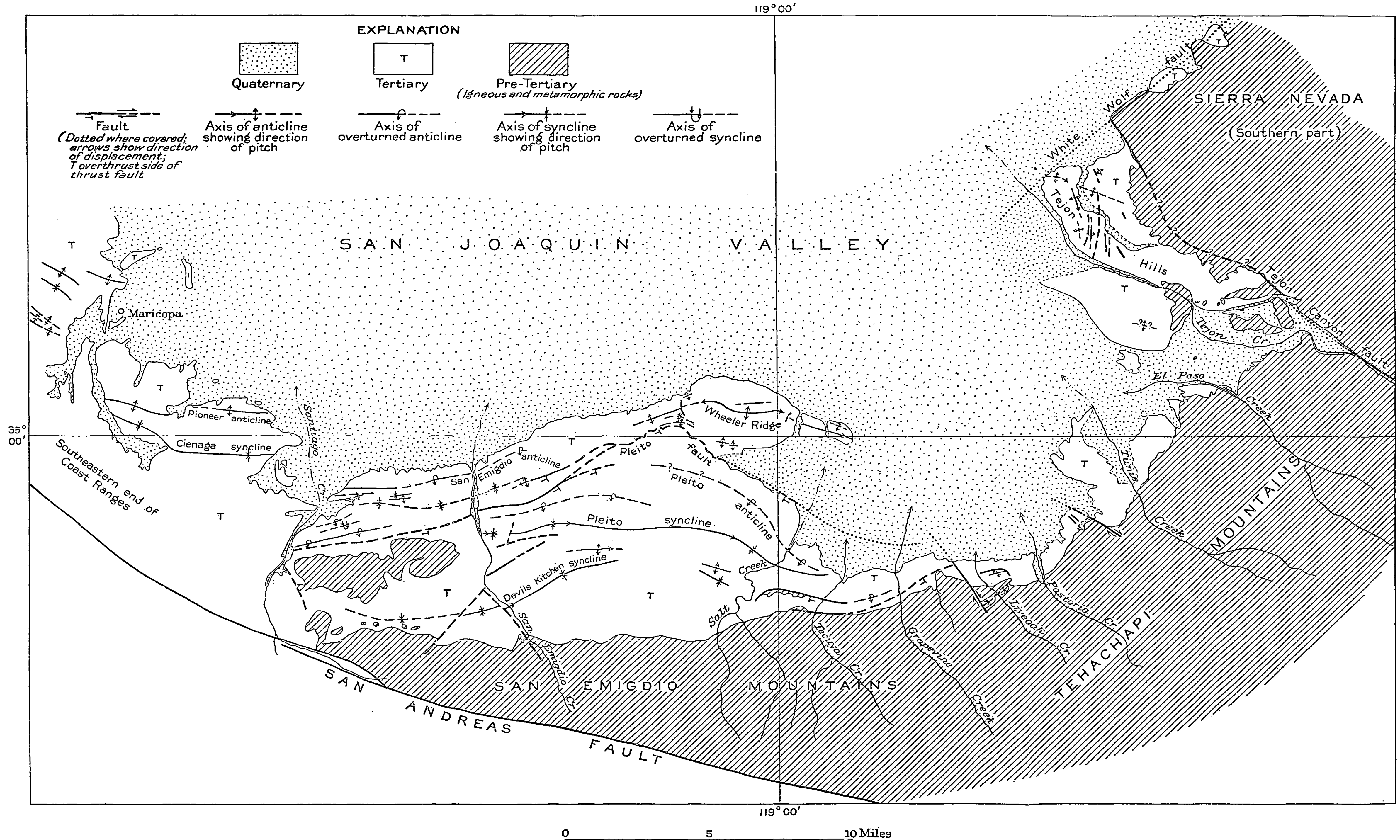
[74] Blackwelder, Eliot, The Gros Ventre slide, an active earth flow: Geol. Soc. America Bull., vol. 23, pp. 487–492, 1912.

tures do not appear on the geologic map. Landslides from the steep north face of Maricopa shale near the top of the Pleito Hills, and also from the softer Vaqueros shale farther north, are so abundant that structural conditions in the Pleito Hills can not be satisfactorily determined. It seems probable that gravity sliding and slumping of soft rocks have been instrumental in emphasizing the subdued topographic aspect of the extensive north slope of the Pleito Hills, a slope that appears to be an old peneplain now tilted northward and incised by sharp youthful arroyos.

Extending onto the flat floor of El Rincon, at the north foot of the Pleito Hills and just south of Wheeler Ridge, are two unusually large flat-topped lobes of Maricopa shale that are believed to represent landslides from the edge of the hills at their rear. Not only are their form and their location at the foot of a prominent slope suggestive of landslides, but the geology and contour of the northern edge of this slope lend support to this tentative conclusion. (See pl. 31.) Objection may be raised that there are, in the eastern lobe, exposures 100 feet or more across that show fairly uniform rock structure, a condition not common to many landslides. It seems probable that this mass of hard siliceous shale moved upon a lubricated base of soft wet Vaqueros clay shale and acquired its present position by a single rapid movement. It also seems easily possible that the involved Maricopa shale, which is highly indurated and well bedded, remained essentially unshattered throughout areas 100 feet or more across, especially when it is considered that the entire lobe covers an area of three-fourths of a square mile. That the structure in much of the lobe is far from uniform is indicated by dip observations shown on the geologic map.

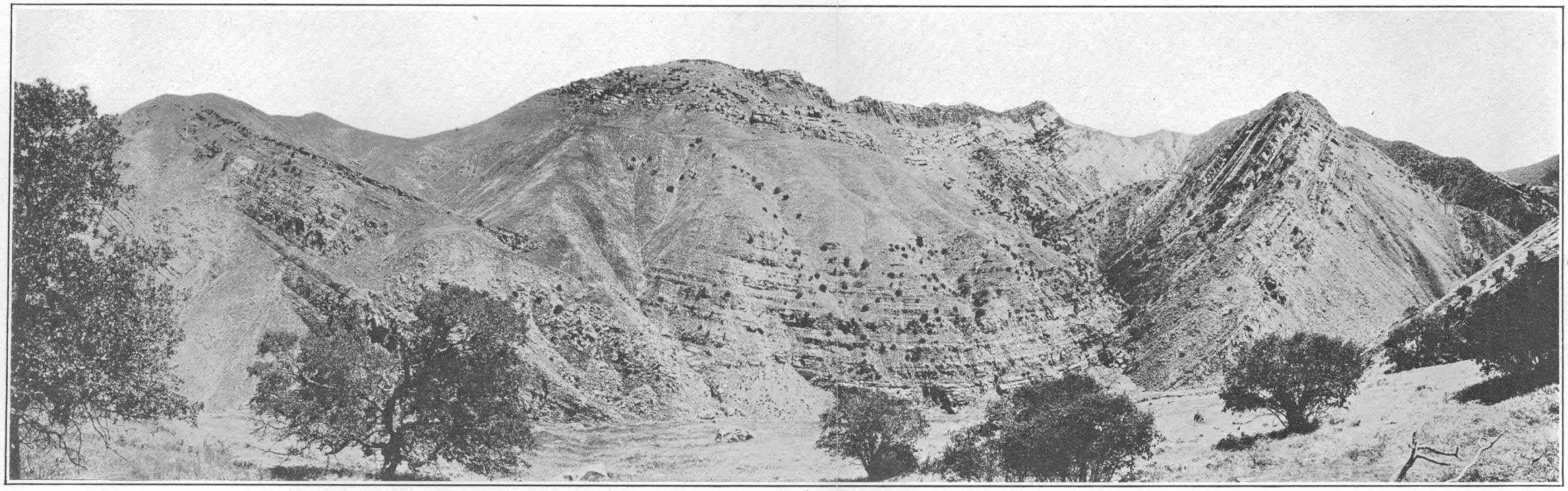
RECENT DEPOSITS

The extensive alluvial mantle of San Joaquin Valley approaches this southern mountainous region with gradually increasing northward slope and at the base of the foothills laps upon the steeply folded Tertiary rocks as a broad apron composed of innumerable alluvial fans. The conditions that caused the development of this remarkable alluvial plain have existed along the base of this foothill region since middle Pliocene time and have resulted in a great thickness of poorly sorted fanglomeratic material of much the same lithologic character. This material includes the Tulare formation (upper Pliocene) and the Pleistocene and Recent deposits, and it is apparent from the relative distribution of these three formations that the San Emigdio foothills, since middle Pliocene time, have been extended more and more to the north and now include a considerable area that was once a part of San Joaquin Valley.



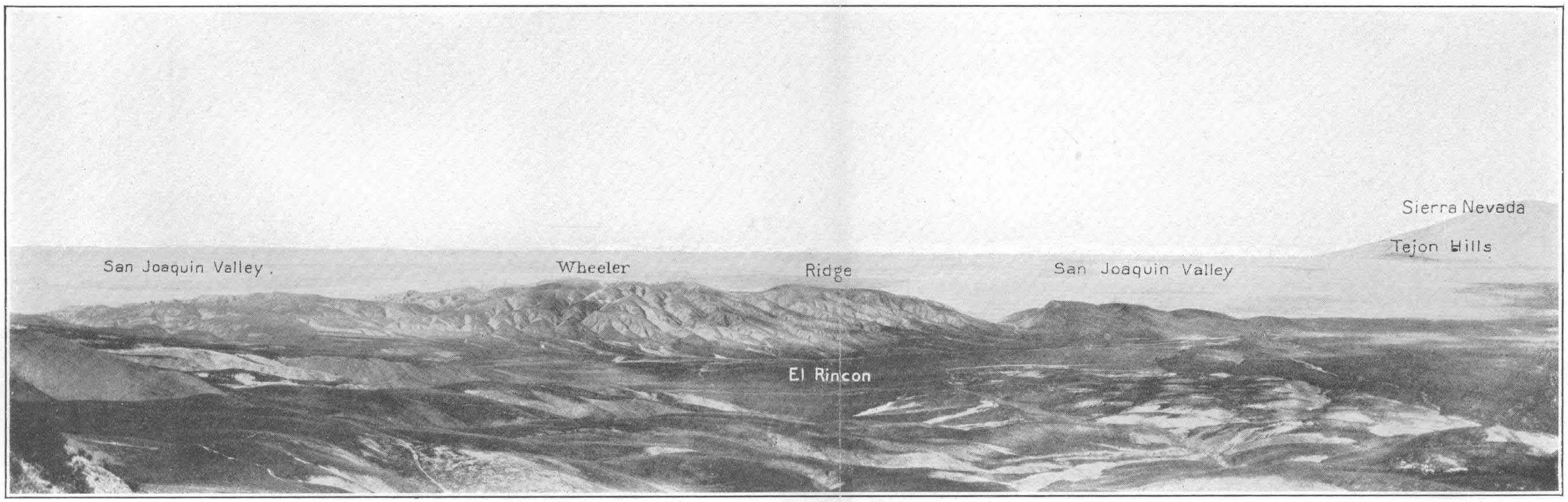
SKETCH MAP SHOWING STRUCTURAL FEATURES IN TERTIARY ROCKS ALONG SOUTHERN AND SOUTHEASTERN BORDER OF SAN JOAQUIN VALLEY AND THE RELATION WHICH THIS BELT HAS TO ADJOINING MAJOR STRUCTURAL PROVINCES

The mapping of some of the features south of the Pleito syncline and west of Santiago Creek is adapted from Professional Paper 116, by R. W. Pack.



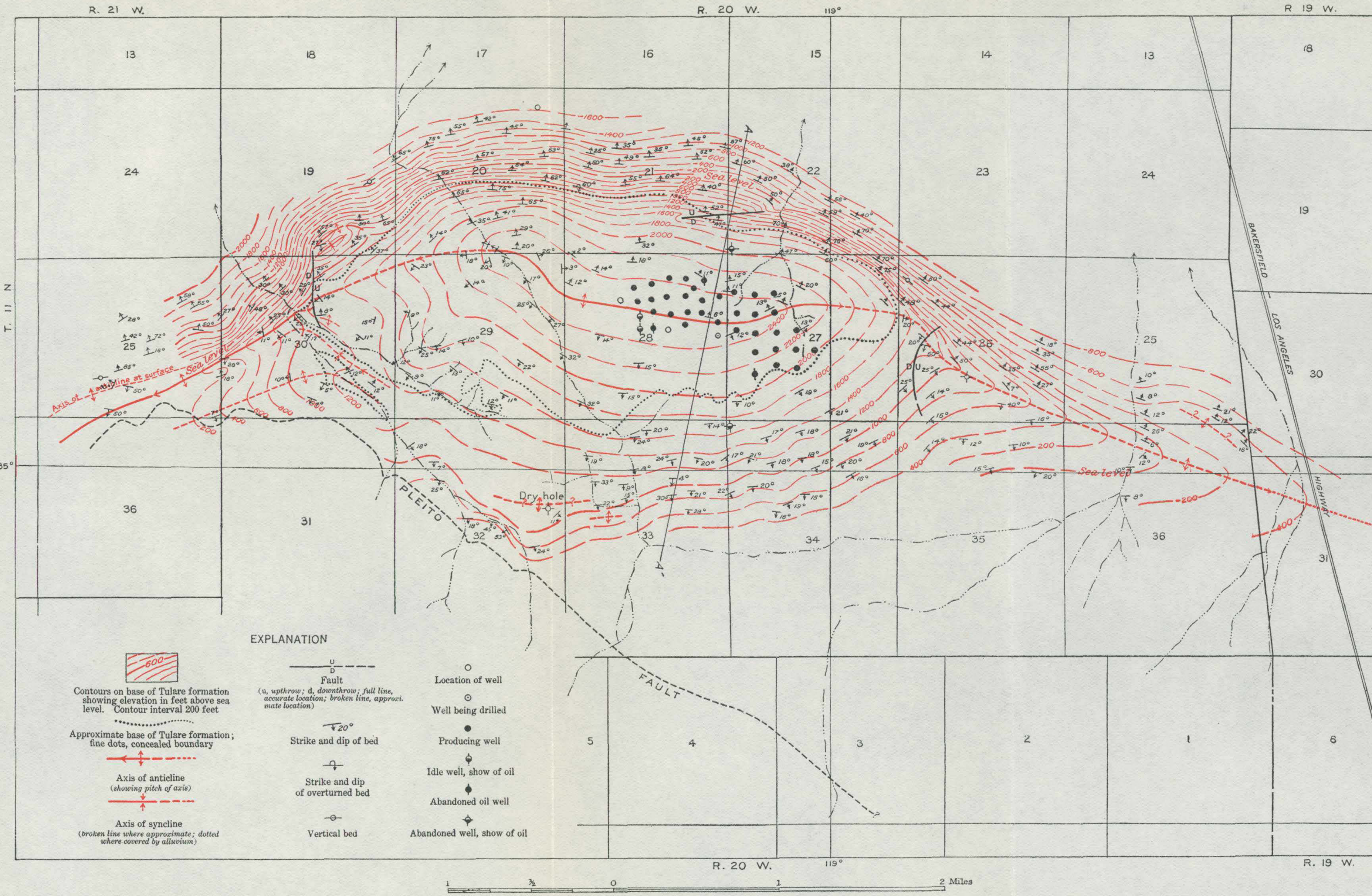
A. DEVILS KITCHEN SYNCLINE, IN SAN EMIGDIO CANYON, AS SEEN FROM THE WEST

The massive dark-appearing ledge at the top of the ridge, in the middle, is probably Vaqueros (lower Miocene); the shale at the extreme right is Tejon (upper Eocene); the remaining and major part of this exposure is Oligocene. Exposure is about 3,000 feet high.



B. WHEELER RIDGE AS SEEN LOOKING NORTH FROM THE TOP OF THE PLEITO HILLS

Note the remarkable physiographic form of this post-Pliocene anticlinal ridge. Numerous wind gaps occur along its crest, especially in the eastern part, and were carved by streams in Pleistocene time.



STRUCTURE CONTOUR MAP OF WHEELER RIDGE

STRUCTURE

GENERAL CHARACTER

The foothills along the southern border of San Joaquin Valley form a connecting link between the Coast Ranges on the west and the Sierra Nevada on the east. (See pl. 41.) As these two mountainous regions on opposite sides of the Great Valley of California are known to be of highly different structural character, it has been suspected that the San Emigdio-Tehachapi foothills contain structural characteristics similar to both the Coast Ranges and the Sierra Nevada, and that there may exist a gradual transition from the type structure of one to the type structure of the other. This transition actually exists, and for this reason the study of the broader structural relations of this foothill belt proves to be unusually interesting.

The Coast Ranges west of the southern part of San Joaquin Valley trend in a northwesterly direction and are composed essentially of Tertiary sediments that are sharply deformed into many folds and are broken by numerous faults. The most notable structural feature of this region is the San Andreas fault, which cuts diagonally from San Francisco through the Coast Ranges in a southeasterly direction and near the southwest corner of San Joaquin Valley curves to the east and strikes approximately parallel to the curving trend of the foothills and in conformity with the general shape of the southwestern and southern borders of the Great Valley. A prominent belt of highly deformed sediments of the Coast Range northeast of the San Andreas fault forms the southwest corner of the valley and extends to the east as the northern foothills of the San Emigdio Mountains.

The Sierra Nevada is characterized by a major mass of pre-Tertiary granitic and metamorphic rock, along the western border of which is a relatively narrow strip of late Tertiary beds that dip gently to the west. This granitic mass and the accompanying sediments curve to form the southeast corner of the Great Valley, and the granitic rock extends westward to the San Andreas fault as the central part of the Tehachapi and San Emigdio Mountains. The deformation of the accompanying narrow strip of Tertiary deposits becomes progressively more intense westward as the San Emigdio foothills are approached, and midway between the Sierra and the Coast Ranges this increasingly intense deformation has been at least in part the cause of an abrupt increase from 1½ to 9 miles in the width of the foothill belt of Tertiary beds.

The mountainous belt along the southern border of San Joaquin Valley thus contains a composite of the features that characterize the Coast Ranges and the Sierra Nevada. The structure in the Tertiary rocks of the San Emigdio and Tehachapi foothills grades eastward from a typical complex Coast Range type to the simple gentle monocline characteristic of much of the western flank of the Sierra, and the granitic mass of the Sierra extends westward with decreasing prominence until it is terminated by the San Andreas fault and concealed by the younger Tertiary deposits of the Coast Ranges.

STRUCTURAL FEATURES

SAN EMIGDIO AND TEHACHAPI FOOTHILLS

STRUCTURE NEAR THE GRANITE CONTACT

The San Emigdio foothills of this report contain the topographically prominent belt of Tertiary rocks between Santiago Creek and Grapevine Canyon. The Tehachapi foothills are here considered as including the narrow strip of Tertiary deposits between Grapevine Canyon and the Tejon Valley. Throughout most of the San Emigdio-Tehachapi district the Tertiary sediments rest with normal depositional contact upon the pre-Tertiary basement complex of granitic and metamorphic rock and dip northward at an average angle of 45° or more. Between Tecuya Creek and Grapevine Canyon, however, and probably at some other points farther west the Tejon formation (Eocene) dips steeply toward the basement complex and, from all indications is in fault contact with the massive crystalline rocks of the San Emigdio Mountains and has been overthrust by them. (See pl. 31.) This fault may not extend west of Tecuya Creek, but for purposes of illustration it has been projected into structure section F–F′, Plate 31.

A sharp overturned anticline lies in the Tejon formation north of the granite between Tecuya and Grapevine Creeks. The anticline seems to pass westward into an overthrust fault, but because of terrace deposits and landslides it can not be traced east of Grapevine Canyon. Steeply dipping and overturned beds, however, continue eastward along the strike, parallel to the granite contact, to a point midway between Live Oak and Pastoria Creeks. Just east of Live Oak Canyon the Tejon formation appears to be thrust over the Vaqueros, which throughout this belt is itself vertical or even overturned. These features, like those of the San Emigdio foothills, appear to be the result of thrusting from the south and are associated with cross faults along which considerable horizontal displacement has occurred. (See pp. 303, 312–313.)

Eastward from Pastoria Creek the structure is comparatively simple and the Tertiary deposits dip north-northwest at an angle that becomes progressively smaller until, near the Tejon ranch, they dip only about 10° to 15°.

MAJOR FOLDS

The San Emigdio foothills have been developed as a direct result of bodily uplift and complex folding and faulting of a belt of Tertiary beds from 6 to 9 miles wide. All the major folds strike in a general easterly direction, parallel to the trend of the San Emigdio Mountains, and several of them extend throughout the greater part of the foothills. One of the most striking facts concerning the major folds of this district is that they all are either overturned toward the north, or tend to be so overturned, so that the northward-dipping limb of any one fold is invariably much steeper than the southward-dipping limb. The Devils Kitchen syncline (pl. 42, *A*), the Pleito syncline, the San Emigdio anticline (structure section C–C′, pl. 31), and the Wheeler Ridge anticline (pl. 42, *B*) are notable examples of such folds, but the preceding statement is equally true for every other major fold of the San Emigdio foothills.

The tendency toward the northward overturning of all folds of this district is in agreement with other facts presented in this report, all of which, the writer believes, furnish ample proof that rocks of the San Emigdio foothills have been deformed during late Tertiary and Quaternary time by forces that had a strong horizontal component from the south.

SAN EMIGDIO ANTICLINE

The axis of the San Emigdio anticline crosses San Emigdio Canyon about half a mile south of the mouth of the canyon and extends eastward for about 1 mile and westward to Los Lobos Creek, beyond which the fold is broken along its crest by a strike fault. This anticline, which borders the northern edge of the foothills, is overturned throughout most of its length and is one of the most if not the most sharply deformed major folds of the San Emigdio district. The axial part of the anticline may be studied to best advantage about half a mile west of San Emigdio Canyon, where steeply dipping Tulare strata on the south flank of the fold become almost horizontal near the axis. The geologic map (pl. 31) shows dip observations at this locality, and Plate 36, *B*, illustrates the remarkable degree to which this anticline is overturned. The relations of this fold to other structural features of this district are presented diagrammatically in structure sections B–B′, C–C′, and D–D′, Plate 31.

Vertical uplift along the San Emigdio anticline has been greater east and west of San Emigdio Canyon. As a result the fold plunges toward San Emigdio Canyon from both directions, and the east and west parts of this major fold have the Etchegoin formation (lower middle, and upper? Pliocene) exposed along the axis. Near Muddy

Creek, in fact, Maricopa shale is at the surface, but its exposure at this locality is due largely to a strike fault along the crest of the anticline. About 1 mile east of San Emigdio Canyon this fold loses its anticlinal character and passes eastward into a terrace which, near Pleitito Creek, is abruptly cut off by a branch of the Pleito fault.

PLEITO ANTICLINE

It seems that an anticlinal feature of some sort crosses the Pleito Hills between and approximately parallel to the Pleito syncline and the Wheeler Ridge anticline. Certainly such a fold crosses Salt Creek near its mouth and extends westward, but in the Pleito Hills landslides are so abundant and exposures so poor that little reliable information can be obtained regarding the character and accurate location of the fold. Its presence in the Pleito Hills is suggested by the areal distribution of the Maricopa shale and the underlying brown shale of probable middle Miocene age, which is herein mapped with the Vaqueros formation. In Salt Creek the north limb of the anticline is very steep, and farther east and west there are strong suggestions that the anticline is even overturned. In brief, it seems reasonable to assume that a sharp fold, herein called the Pleito anticline, probably crosses the Pleito Hills and occupies the northern part of the Pleito Hills fault block, a block which from all indications has been thrust from the south toward Wheeler Ridge. (See structure section E–E′, pl. 31.)

WHEELER RIDGE ANTICLINE

Major folding.—Wheeler Ridge is the topographic expression of an unusually prominent anticline in the south half of T. 11 N., R. 20 W. (See pls. 42, *B*, 43, 47, 48.) The trend of the anticlinal axis is roughly eastward, but with minor exceptions it describes a broad arc concave toward the south and ranges from N. 75° E. near the west end to S. 70° E., in the eastern part. This anticlinal ridge is formed by asymmetric folding of Pliocene and Pleistocene beds and stands at a maximum height of 1,500 feet above the adjoining border of San Joaquin Valley.

The north limb of this fold emerges abruptly from the floor of the valley with dips of 30° to 50°. In the steepest portion of the north limb, some distance from the edge, dips range from 50° to 90°, and in some places the beds are slightly overturned, whereas the average dip over the south limb is between 15° and 20°. Although at some distance from the axis steep dips are the rule on the north limb, the anticline is symmetrical at the surface in its central portion, with dips of about 15° on both north and south limbs.

The anticline, although only about 7 miles long and 2 miles wide, has a closure of over 2,000 feet. It is somewhat dome-shaped in its central portion and plunges in both directions at the rate of about 20°, beginning some distance east and west from the center. The axis extends westward to the western part of sec. 25, T. 11 N., R. 21 W., and possibly into sec. 26. A mile farther west-southwest, on Pleito Creek, horizontal gravel beds of the Tulare formation, which a few hundred feet farther north dip 25° N., indicate a westward continuation of the Wheeler Ridge folding. Toward the east the anticline plunges beneath the alluvium of San Joaquin Valley and has no recognized topographic expression east of sec. 32, T. 11 N., R. 19 W.

In addition to being offset by faults east and west of the central part of the anticline, the axis throughout much of the bulging dome-like portion between the faults is sinuous and makes several abrupt changes in trend. Just east of Coaloil Canyon the axis makes two nearly right-angle turns; other changes in trend farther east occur mainly in areas in poor exposures but apparently are not so abrupt.

Near the mouth of Coaloil Canyon the entire thickness of Tulare beds is concealed by a landslide for a strike distance of 1,000 to 1,700 feet. The structural conditions concealed by this slide are problematic; that a fault is responsible for the abrupt change in strike of the basal Tulare beds at this locality is possible but is supported by little evidence.

The structure contour map (pl. 43) shows the altitude of the approximate base of the Tulare formation throughout Wheeler Ridge. The contouring is based on the altitude of this contact where it is exposed and on the attitude of the beds throughout the ridge. On this map are shown only those observations on dips that have been used in contouring the anticline. Others were taken, most of which support the present contouring, but some of them apparently represent the result of earth creep or local irregularities in structure, the character of which could not be determined. It is evident from the 200-foot contour interval of the structure map that the character of minor structural features is not shown in detail, but the contours are close enough to illustrate the features that could be determined with certainty. The poor and lenticular nature of stratification in these Pliocene beds and the difficulty experienced in recognizing the Etchegoin-Tulare contact on the south flank of the fold and west of Coaloil Canyon have made it inadvisable to attempt to show the structure of Wheeler Ridge in more detail.

Minor folding.—Several small folds are distributed over Wheeler Ridge near its west and east ends. They are for the most part low down on the flanks of the main anticline, and each is distinct from the larger fold.

What appears to be a subsidiary anticlinal fold or pair of folds occurs on the southwest flank of the ridge in secs. 32 and 33. In this locality there is a distinct topographic bulging in the south slope, and the principal drainage line of this area follows a course that must be controlled by structural features in surface rocks. As shown by surface dips where exposures are good, these flexures pass into structural terraces and finally die out completely farther east. Their relations to the west are obscure, but the larger one may parallel Telegraph Canyon and be continuous with the minor anticline shown in the SE. ¼ sec. 25. The latter fold, which is separated by a distinct syncline from the main axis of the Wheeler Ridge anticline, is a gentle flexure and appears to make a change in trend of 60°, parallel to the curvature of the apparent Vaqueros-Tulare fault contact.

Directly east of a north-south fault that lies about 800 feet east of Telegraph Canyon is a very small anticlinal fold on the south limb of the major anticline. Another subsidiary anticline farther north, low down on the north flank of the ridge, holds a similar position with relation to this fault and is by far the most sharply flexed anticline of the Wheeler Ridge area. This fold parallels the main anticlinal axis and is probably related genetically to overturned beds 700 to 800 feet farther east.

A broad anticlinal nose occurs on the southwest flank of Wheeler Ridge, northeast of Telegraph Canyon. It plunges southwestward, and its relation to other subsidiary folds is obscure.

A minor structural feature, presumably a small fold, occurs on the north flank near the east end of the ridge. It has the appearance of a small but prominent anticlinal bulge with a topographic closure of about 10 feet. Pleistocene alluvium, deposited in old stream channels across this part of Wheeler Ridge, conceals actual structural conditions. Another minor feature of the eastern part of the ridge appears as a structural terrace on the south limb of the anticline and is exposed in the east wall of the large gap in sec. 26.

Faulting.—The rocks of Wheeler Ridge are broken by numerous small faults and by three faults of mappable magnitude. Two of these larger fractures are cross faults that strike approximately normal to the anticlinal axis, and the third is an oblique fault on the north limb of the major fold. All the faults appear to be of the high-angle class, although in none of them is the fault plane actually exposed.

Of the two larger cross faults one is in the eastern part of the ridge and is exposed in the west wall of the large gap that occupies part of sec. 26. Westward tilting of the gravel beds near the axis on the west side of the fault is evidence of the character of the displacement. The east block, which contains the large wind gap, apparently has moved upward relative to the west block, and possibly this movement has occurred as a result of the erosion of an unusually large amount of surface material from the gap. The movement has permitted steeply dipping beds north of the axis on the east block to rest against beds of the west block that are only slightly inclined toward the north and has resulted in what appears to be a displacement of the anticlinal axis; the axis of the east block seems to lie about 50 feet south of the axis on the opposite side of the fault. As this fault does not expose Etchegoin strata, the total vertical displacement does not exceed 400 feet and may be considerably less.

The second cross fault cuts the main axis in sec. 30, near the west end of Wheeler Ridge, just east of Telegraph Canyon. Here again strata west of the fault and north of the axis are tilted westward at an angle of about 22°. It is uncertain, however, whether this tilting was produced by horizontal or vertical movement. The movement has resulted in horizontal offset of the Tulare-Etchegoin contact of about 500 feet and a somewhat smaller offset of the anticlinal axis. Relative northward displacement of the east block has certainly occurred, and this strong horizontal component may have been associated with uplift.

The oblique fault on the north limb of the anticline is in secs. 21 and 22 and trends N. 80° E. It has resulted in a horizontal displacement parallel to the fault of about 500 feet, and a stratigraphic displacement of about 250 feet. Whether movement along the fault has been vertical or horizontal is uncertain. In Coaloil Canyon Etchegoin strata along a hypothetical straight-line extension of this fault are vertical and much distorted, a condition which suggests that this fault may be a more extensive feature than is indicated on the geologic map. Lack of good exposures prevented the tracing of the fault farther than is shown.

BURIED STRUCTURAL FEATURES NORTH OF THE FOOTHILLS

The size and structural character of folds throughout the San Emigdio foothills, especially along the northernmost edge, suggest that folding has actually extended farther north, beyond its present exposed limits, and that structural features may be buried beneath the mantle of alluvium along the southern border of San Joaquin Valley. Partly buried folds, such as those of the Lost Hills and North Belridge, are present under similar conditions farther north along the western border of the valley, and large anticlines, topographically more prominent, occur in the Elk Hills and Buena Vista Hills only 15 to 20 miles northwest of the San Emigdio foothills. It therefore seems not at all unreasonable to suspect that folds and possibly faults lie buried beneath the alluvium along the southern border of the valley, especially west of a line extended north from the mouth of Grapevine Canyon.

One area north of the foothills between Santiago Creek and San Emigdio Creek has been prospected by oil companies for years and appears to be particularly promising for the presence of buried structural features. As shown on Plate 31 this area occupies a structural reentrant in the northern border of the foothills and lies eastward along the strike of the Pioneer anticline and Cienega syncline. (See pl. 41.) The well in sec. 28, T. 11 N., R. 22 W., drilled by the Standard Oil Co. of California, obtained cores of Pliocene rocks from depths of 2,384 to 3,670 feet that showed strata inclined 37° to 45° from the horizontal, and one core indicated that the dip is to the north.[75] Reliable evidence therefore shows that structural features occur beneath the alluvial cover of this area.

With a single exception there appears to be no topographic feature that suggests the presence of partly buried structural features in this area. This exception, however, is particularly noteworthy and has been mentioned in an earlier published statement.[76] It consists of an unusually sharp break in the profile of the alluvial fan of San Emigdio and associated creeks, a break which is conspicuous topographically and which appears as a striking surface feature when viewed from the edge of the foothills.

The character of the structural feature represented in a fragmentary manner by these breaks in the slope of the alluvial plain is uncertain. The major feature in the northern edge of secs. 34 and 35, which in effect is a prominent bulge in the slope of the alluvial plain, has a curving trend and a system of radiating consequent streams on its north and steeper slope, which suggest anticlinal folding. If this is the case, the steep north slope should represent the eroded north limb of the fold, the south limb being concealed beneath recent alluvial deposits. Another alternative is that this major feature is the result of faulting and that the area south of the steep north slope has been uplifted and may or may not represent a southward-tilted fault block.

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[75] This information is presented through the courtesy of Mr. G. C. Gester, chief geologist of the Standard Oil Co. of California. According to Mr. Gester, a survey was not made of the bore hole, and there may be some correction that should be made to the above-mentioned dips to account for deviation of the well from the vertical.

[76] Oil possibilities at Comanche Point and near Wheeler Ridge, Calif.: U. S. Geol. Survey Press Memorandum 13338, March 28, 1927.

The significance of the minor topographic break in the alluvial plain 1 to 2 miles farther northwest, in secs. 29 and 30, is even more uncertain. It may have resulted from the same structural feature that is reflected in the major topographic feature in secs. 34 and 35.

Structure section C–C′ (pl. 31) illustrates the observed structural conditions in the foothills to the south and one possible interpretation of the significance of the major topographic feature on the alluvial plain. It seems probable to the writer that the Standard Oil Co.'s well penetrated beds dipping south. If an anticline is present with a south limb dipping on an average of 45°, as indicated by the record of the Standard Oil Co.'s well in sec. 35, the north limb is probably somewhat steeper and may be almost vertical.

Although further testing of this area will be hazardous, the writer believes that the area warrants additional consideration. In view of the probable presence of an unconformity at the base of the Etchegoin and the varying thickness of the Etchegoin in this district, the depth of the top of the Maricopa can not be forecast. It seems entirely possible that the Maricopa is within 5,000 feet of the surface. Production might be obtained at the top of this formation or at deeper horizons within it.

The westward extension of this possible anticline, if drawn as a straight line, would pass between the Associated Oil Co.'s well No. 2 in sec. 32 and the Milham Exploration Co.'s well No. 2 in sec. 33, T. 11 N., R. 22 W. The altitudes of the top of the "brown shale" (Maricopa shale) in these and other wells are shown in structure section B–B′ (pl. 31) and strongly suggest that a line of uplift lies in this general vicinity. The straight-line extension of this structural feature would appear to pass near the Milham Exploration Co.'s well No. 1 in sec. 32, and it is interesting to note in this connection that this well obtained more encouraging shows of oil than any other well in this area.

In view of the known geologic history of this region it is only reasonable to conclude that this feature, itself practically a part of the recently deformed San Emigdio foothills, has resulted from Quaternary folding or possibly faulting in an area undergoing active alluviation.

FAULTS

Faulting has played an influential part in the structural development of the San Emigdio and Tehachapi foothills, particularly in the more intensely deformed San Emigdio district, where the stratigraphic displacements along faults vary within wide limits and reach a maximum of more than 10,000 feet. Strike faults are the general rule in the foothill belt west of Grapevine Canyon, but farther east cross faults approximately normal to the strike of the rocks are more common. Unfortunately the actual fault surfaces are nowhere well exposed, and as a result many questions concerning the character of these structural features must remain unanswered. Because of the tendency toward the northward overturning of all the numerous well-exposed folds of this region, the writer has concluded that this foothill belt has been deformed to a large degree by strong thrusts from the south. In conformity with this belief, it seems reasonable to conclude tentatively, on the basis of the facts presented below and the absence of additional data, that the strike faults are thrust faults and dip southward in the direction from which the thrusts have come.

PLEITO FAULT

The Pleito fault passes just south of Wheeler Ridge, at the base of the Pleito Hills, trends in a general westerly direction, crosses San Emigdio Canyon about 2 miles above its mouth, and continues into the area of complicated folding farther west. Between San Emigdio Canyon and Santiago Creek the Pleito fault lies at the northern base of a large isolated eastward-trending mass of granitic rock that forms the core of a major late Tertiary uplift.

The Pleito fault is the most prominent single structural feature in the Tertiary rocks of the San Emigdio foothills. It not only cuts across the entire length of these foothills but has a maximum stratigraphic displacement of at least 10,000 feet. Along this fault the Tulare formation (upper Pliocene) near Wheeler Ridge dips beneath Vaqueros and Maricopa shale (lower and middle Miocene). Where this fault crosses the ridge west of Pleitito Creek the Tulare is in contact with lower Vaqueros sandstone, whereas in the east wall of San Emigdio Canyon the upper part of the Etchegoin (lower, middle, and upper (?) Pliocene) abuts against Oligocene rocks.

West of Pleitito Creek this fault has a comparatively straight course approximately parallel to the regional strike of the rocks, and probably in this part of the district it is a comparatively high angle fracture. In the east wall of San Emigdio Canyon the eroded and somewhat obscure fault contact, as viewed in the direction of strike, dips about 45° SSE. Between Pleitito and Pleito Creeks this fault makes a decided curve to the northeast and, together with a branch fault, breaks squarely across and terminates the structural terrace which marks the eastward extension of the San Emigdio anticline. Farther east, between Pleito Creek and Wheeler Ridge, the contact between the faulted formations follows a sinuous course across ridges and valleys and undoubtedly dips south at a very low angle, even as low as 10°. Unfortunately, however, the soft Vaqueros shale on the hanging wall contains no good exposures, a fact that has resulted in considerable disagreement as to the steepness of this fault east of Pleito Creek. Some geologists are of the opinion that the present low-angle contact of Vaqueros shale and Tulare gravel is not the actual fault contact but has been produced by the slumping of Vaqueros shale from the upthrown block along a high-angle fault [77]; others consider that the present low-angle contact represents the dip of the fault. Landslides are certainly common in this foothill belt, but there seems to be no evidence that landsliding or slumping has produced the present low-angle contact. Neither does it seem possible to prove that the present areal distribution of formations along the contact is due entirely to faulting without slumping. However, in the west wall of the first large arroyo east of Pleito Creek it seems certain that slumping has not occurred and that the contact between Vaqueros and Maricopa shale and Tulare gravel dips to the south at an angle that apparently can not be greater than 40° to 45°. The angle may be considerably less, for the contact at this locality is very obscure.

Whether faulting, without slumping, has been the sole cause of the present distribution of formations along the Pleito fault and west of El Rincon, there seem to be at least strong suggestions that the fault is not one of a very high angle, and from the broad curving trend east of Pleitito Creek and the strong evidence throughout this district for horizontal thrusts from the south the writer believes that the prominent lobe of Miocene sediments south and southwest of Wheeler Ridge represents one block of a comparatively low angle thrust fault. The relation of this large lobe to the San Emigdio anticline suggests that horizontal thrusting along this fault has been most intense east of Pleitito Creek and that this thrusting has forced the large lobe of Miocene sediments to shear abruptly across the structural terrace that constitutes the eastward extension of the San Emigdio anticline.

FAULTS ACROSS LOWER MUDDY CREEK

In the vicinity of lower Muddy Creek the San Emigdio anticline appears to be broken along or near its crest by a strike fault that permits Maricopa shale on the north block to abut against much deformed greenish-gray clay and sandstone of the Etchegoin formation. This fault, which is the most northern fault shown in structure section A–A′ (pl. 31), is unusual in that the north block of Maricopa shale appears to be the upthrown block. The

[77] English, W. A., oral communication. See also Cunningham, G. M., The Wheeler Ridge oil field: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 499–500, 1926.

only other possible explanation is that this fault originated during a pre-Etchegoin period of deformation and that at this time soft pre-Maricopa shale on the south block was upthrown against relatively hard Maricopa shale. The pre-Etchegoin erosion that followed may then have provided a basin south of the fault in which Etchegoin sediments were deposited and later deformed by post-Pliocene folding.

Between this fault and the low topographic reentrant in middle Muddy Creek the structural features are obscure. The other fault shown in this area a short distance south of the fault just described is doubtful, and additional faults not exposed may actually exist.

FAULTS IN TECUYA CREEK

A small block of granite on the ridge west of Tecuya Creek has been thrust northward over all the Eocene sediments and has overturned a considerable section of the Vaqueros formation (lower Miocene). (See structure section F–F′, pl. 31.) This thrust fault crosses Tecuya Creek and from all indications passes eastward into a sharp overturned anticline that produces a pronounced bulge in the Tejon-Vaqueros contact east of Tecuya Creek.

Just east of Tecuya Creek and south of the above-mentioned fault the Eocene sediments dip south toward the major mass of granite of the San Emigdio Mountains and must therefore be in fault contact with it. This fault may not extend west of Tecuya Creek but for purposes of illustration it has been projected into structure section F–F′, Plate 31. This faulted relation may exist locally along the granite farther west in areas not covered by this investigation. It seems evident that the major crystalline mass of the San Emigdio Mountains forms a huge block which has been sharply uplifted and which locally is faulted and overthrust upon Tertiary sediments to the north.

CROSS FAULTS

Recognized cross faults, other than those of Wheeler Ridge (see pp. 306–307) and one fault across the western part of the Pleito syncline, are restricted to the Tehachapi foothills between Grapevine Canyon and the Tejone ranch. It is true that the Pleito fault acts locally as a cross fault, but throughout most of its length this feature has no similarity to the cross faults of the Tehachapi foothills.

Vaqueros deposits 2 miles east of the mouth of Grapevine Canyon are overturned and are offset along a fault that appears to trend N. 40° W. and to cut obliquely across their strike. The relative movement of the southwest block along this fault has been to the northwest, and the offset measured parallel to the fault is 4,000 to

5,000 feet. The fault extends southeastward into the basement complex and terminates an isolated synclinal body of Eocene sediments.

Another fault, apparently similar in every essential respect to the one just described, occurs 5 miles farther east-northeast, about 2 miles southwest of Tunis Creek. The trend of this fault is N. 55° to 60° W., and the relative displacement is in the same direction as on the cross fault farther west—that is, the southwest block has moved northwestward, and in this place the offset measured parallel to the fault is about 3,000 feet. Movement has dragged the massive beds of agglomerate on the northeast block so that they strike parallel to the fault and dip steeply to the northeast.

Two small cross faults about 2,000 feet southwest of the last-mentioned fault strike northwest and produce a similar horizontal offset of approximately 100 feet each.

By way of summary it may be said that the Tehachapi foothills are broken by several northwestward-trending cross faults, along each of which the relative movement of the southwest block has been to the northwest. This foothill belt, from east to west, has thus yielded progressively more and more to fault displacement, and it is to be particularly noted that this group of cross faults, or shear zones, is associated with Tertiary deposits which, in addition, show unmistakable evidence of progressively greater deformation as they are traced from the Tejon ranch southwestward and westward into the San Emigdio foothills. (See geologic map and structure sections H–H′, G–G′, and F–F′, pl. 31.)

FRACTURES IN THE BASEMENT COMPLEX

Folds and faults in the Tertiary deposits of the San Emigdio-Tehachapi foothills are shown in Plate 41 without the confusing details that appear on the geologic map. This structure map also shows the streams of the high San Emigdio and Tehachapi Mountains, which have carved deep gorges across the basement complex and which, it is believed, offer some suggestion of the presence or absence of fractures within these crystalline rocks.

These deep canyons show a striking tendency toward parallelism, all of them trending in a northwest direction parallel to the two known cross faults of the Tehachapi foothills. Another northwestward-trending fault has been mapped by Pack farther west, parallel to and within San Emigdio Canyon. The suggestion is obvious that the crystalline rocks of the San Emigdio and Tehachapi Mountains are broken by a series of northwestward-trending fractures. There is abundant evidence in the Tertiary rocks farther north that this entire region has been subjected to strong thrusts from the south; knowledge of this thrusting and the relation of these suggested fractures in the crystalline rocks to the San Andreas fault farther south make it appear probable that these fractures are potential shear zones developed in crystalline rocks north of the San Andreas fault as a result of thrusts originating farther south.

It does not seem probable that much horizontal displacement has occurred along any one of these fractures, for they do not appear to offset the sediments farther north. They may be fractures with little or no displacement, but they appear to be sufficiently prominent to have held a striking control over the drainage pattern of the crystalline rocks.

TEJON HILLS

The Tejon Hills lie in the southeastern part of San Joaquin Valley and flank the south end of the Sierra Nevada. They are composed of Miocene and Pliocene beds that rest directly upon the gently sloping surface of the basement complex. As compared to the hills of the San Emigdio district they have a relatively simple structure, which consists essentially of a gentle tilting of the sedimentary rocks that in general assumes the form of a broad anticlinal arch trending from the granite contact northwestward toward Comanche Point, the northwest extremity of the Tejon Hills. The topographically prominent granitic mass, or basement complex, east of the Tejon Hills is broken by faults that have displacements of several thousand feet, and it seems highly probable that folding in the sedimentary rocks is genetically related to these and other associated faults in the adjoining and underlying crystalline basement.

MAJOR FAULTS OF THE BASEMENT COMPLEX

WHITE WOLF FAULT

The basement complex adjoining the Tejon Hills on the east and northeast forms a prominent westward protrusion of the Sierra Nevada, the western point of which lies 3 miles northeast of Comanche Point and occupies what appears to be the corner of a huge rectangular block, whose sides extend to the northeast and to the southeast. The side that extends northeastward from the north end of the Tejon Hills forms a scarp that abuts directly against the flat alluvial floor of San Joaquin Valley without the customary intervening belt of Tertiary deposits. This scarp, which is fairly straight and is coextensive with a broad trough in the granite through the White Wolf ranch, is, from all indications, the result of uplift of the granite along a major fault. This fault is commonly called the White Wolf fault. Distinct evidence of shearing may be found in the crystalline rocks near the alluvium boundary. As stated on pages 316–317, there is good reason to believe that the White

Wolf fault extends southwestward beyond the granite and cuts off folded Tertiary beds at Comanche Point. Large-scale displacement is therefore believed to have occurred along this fracture as late as post-Chanac (post-Pliocene) time. This fault is probably a high-angle fracture, but whether it is a normal or reverse fault appears to be entirely a matter of conjecture.

TEJON CANYON FAULT

East of the Tejon Hills the upper surface of this large uplifted granite block has a mature or old physiographic aspect, and this old surface extends to the very western edge of the block, where it overlooks Tejon Valley, 2,000 to 2,500 feet below. This surface is characterized by broad valleys and comparatively low subdued ridges, and it is in striking contrast to the bold southwestward-facing scarp that bounds this block on the southwest and forms the northeast wall of lower Tejon Canyon. This scarp, which trends northwestward, marks the upthrown side of another major fault, herein called the Tejon Canyon fault.

The broad, shallow character and the orientation of Tejon Valley suggest that, prior to displacement along the Tejon Canyon fault, it was a part of that high series of old valleys farther northeast. Lawson[78] has concluded that diastrophic movements, including large-scale faulting in some areas, have produced this series of old valleys, which he has called the Tehachapi Valley system. The record of Miocene and Pliocene sedimentation and volcanism preserved in the foothills adjoining Tejon Valley does not, however, appear to be present in the Cummings Valley area, northeast of the Tejon Canyon fault. Lawson [79] reports the presence of late Tertiary deposits, consisting of alluvium, andesitic lava flows and tuffs, and fresh-water lake beds, in the Tehachapi Valley and Cache Valley areas. J. P. Buwalda[80] states that basalt also occurs in the Tehachapi Valley district, and that this basalt may well be roughly equivalent to the basalts along the south end of San Joaquin Valley. These two areas have apparently had a different geologic history, but whether this is the result of pre-Miocene movement along the Tejon Canyon fault is uncertain.

The maximum vertical displacement along this fault, to judge from the height of the scarp, is at least 2,000 feet near the mouth of Tejon Canyon. As the fault is traced northwestward the scarp decreases in height, and possibly the fault dies out within a few miles, although, as shown on Plate 31, it may be continuous with a similar northwestward-trending fault that cuts across the strike of the

[78] Lawson, A. C., The geomorphogeny of the Tehachapi Valley system: California Univ. Dept. Geology Bull., vol. 4, pp. 431–462, 1906.

[79] Idem, pp. 439–445.

[80] Oral communication.

Tertiary formations in the northeastern part of the Tejon Hills and apparently terminates against the White Wolf fault. This major northwestward-trending fault, or series of faults, is associated with a broad arching of the basement complex near the eastern border of the Tejon Hills, an arching that passes beneath the late Tertiary sediments and has probably directly formed the broad but prominent northwestward-plunging anticlinal nose in these sediments east of Comanche Creek. A northwest branch of the Tejon Canyon fault may accompany this arching in the basement complex and may also pass northwestward beneath the sediments to join the White Wolf fault at Comanche Point, but whatever the nature of this disturbance in the basement complex, its junction with the White Wolf fault has, it seems, produced a prominent anticlinal fold at Comanche Point.

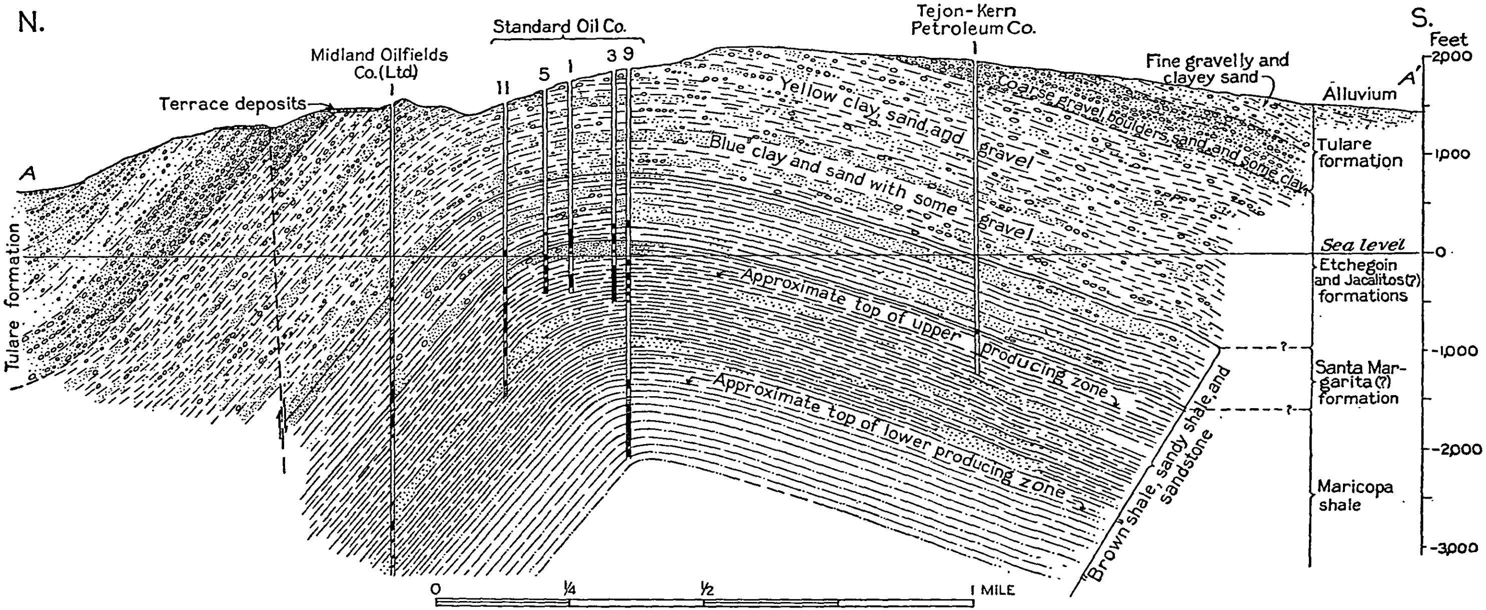
FOLDS

The broad northwestward-plunging anticlinal nose east of Comanche Creek appears to be the major structural feature in the sedimentary rocks of the Tejon Hills. It plunges beneath Comanche Creek, west of which it rises again to form the incomplete anticline at Comanche Point. Several minor and gently flexed folds occur on the flanks of the hills and trend in a northerly or north-northwesterly direction. These minor folds are paralleled by numerous faults, which are described below.

COMANCHE POINT FOLD

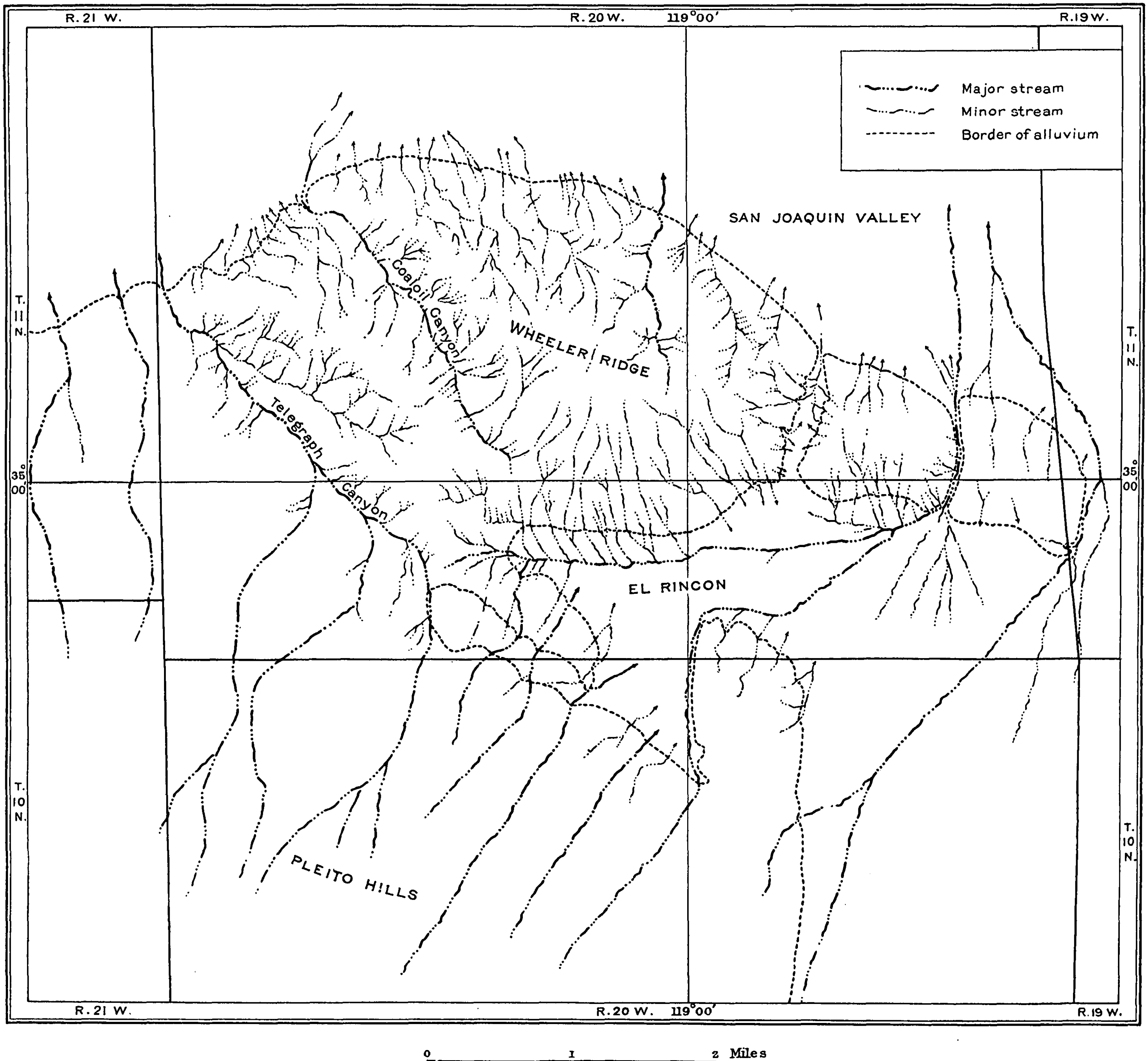
A prominent anticlinal fold occurs in the Miocene and Pliocene sediments at Comanche Point, in the northwestern part of the Tejon Hills. Owing to poor exposures in the western edge of the hills the trend of this fold is difficult to determine, but it appears to curve from N. 60° W. to N. 85° W. The north and south limbs of the anticline commonly dip at angles between 10° and 35°, although steeper dips occur in the much jointed Miocene sediments of this fold and may be associated with minor faults that are not shown on the geologic map.

The Comanche Point fold plunges about 10° SE., toward Comanche Creek, but there is no corresponding closure to the west, and it is apparent that this fold, or at least the exposed portion, is not a complete anticline, for only the eastern or southeastern part appears to be present. As shown by Plate 31 the two youngest formations, the Santa Margarita and the Chanac, are entirely absent on the northwest edge of the hills, along the axial part of the fold. Elsewhere in this district the Chanac formation, with its high content of coarse gravel, is comparatively resistant to erosion, even though practically without a hardening cement. Because of this fact, the recency of the latest deformation, and the absence, now and probably also in the past, of an unusually strong erosive agent along

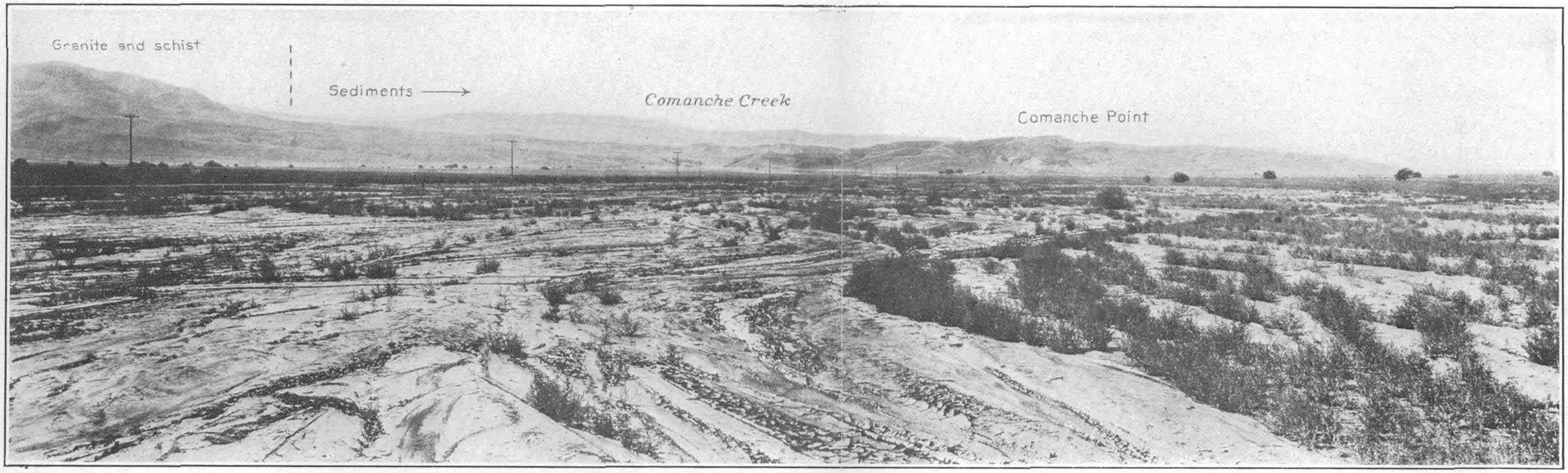


Solid black in well columns represents reported oil, gas, and oil and gas shows
Numbers on wells correspond to those on Fig. 9

STRUCTURE SECTION ACROSS CENTRAL PART OF WHEELER RIDGE

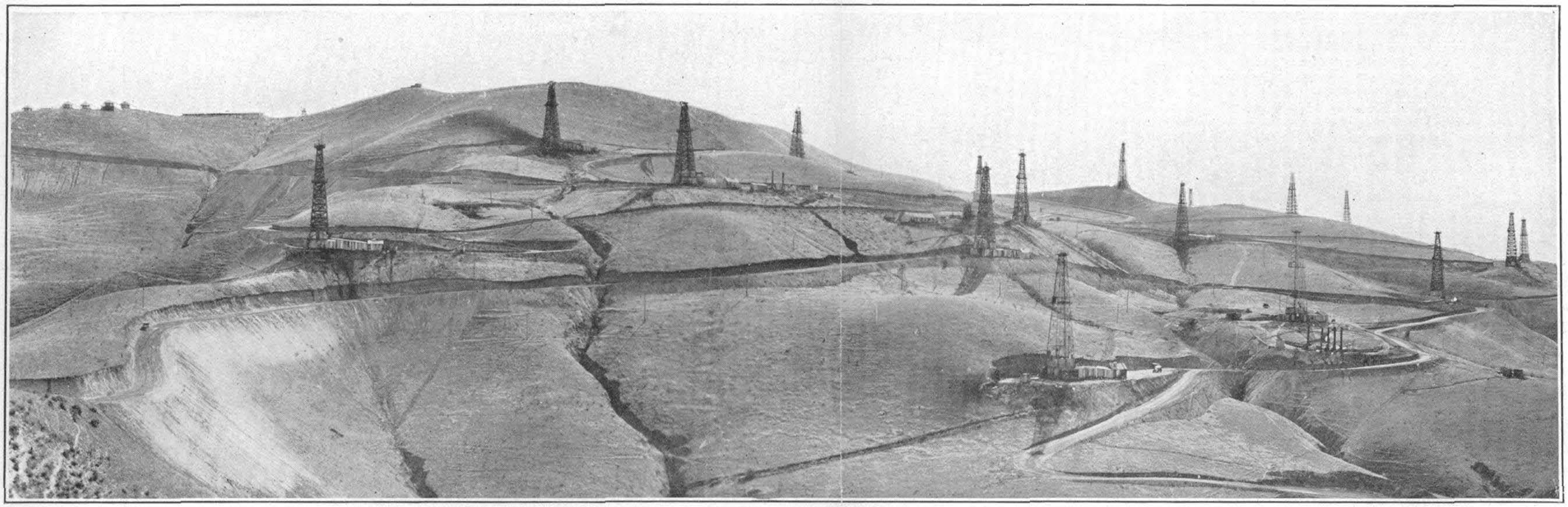


DRAINAGE MAP OF THE WHEELER RIDGE AREA



A. TEJON HILLS AS SEEN FROM THE NORTH

Note profile of old physiographic surface, which slopes gently westward from the granite toward Comanche Creek and which is now deeply incised by westward-draining arroyos.



B. PRODUCING OIL FIELD ON TOP OF WHEELER RIDGE

Photograph reproduced by courtesy of Standard Oil Co. of California.

the edge of the hills at this point, it is difficult to account satisfactorily for the apparent absence of the unexposed portion of this fold by the normal processes of erosion and deposition. It seems more probable that here, as elsewhere in this part of California, the structure is closely related in form to the topography and that this fold is broken by a fault along the northwest edge of Comanche Point—a fault that has permitted the Tejon Hills to be uplifted relative to San Joaquin Valley. This probability is strengthened by the fact that the southwest extension of the White Wolf fault, if drawn as a straight line, cuts across the northwest edge of Comanche Point.

The Comanche Point fold appears to be closely related to the plunging anticlinal arch east of Comanche Creek, and this arch in turn is genetically related to the broad arching, or arching and faulting, in the underlying basement complex. This northwestward-trending line of deformation may well have originated from stresses along the Tejon Canyon fault, and the Comanche Point fold has probably developed in Tertiary beds at the intersection of this northwestward-trending arch with the White Wolf fault.

MINOR FOLDS AND FAULTS

There are several minor folds in the Miocene and Pliocene sediments east and west of Comanche Creek, and most of them trend northward or northwestward. These features are small, and the anticlines show no indication of closed structure; the largest anticline, which plunges to the southeast, appears to strike directly into the main Comanche Point fold. (See pl. 41.) These minor folds are closely associated with practically parallel faults, the largest of which has a curving northerly trend and appears to cut across the entire central part of the hills. The fault contacts are commonly obscure, but in most places there are good indications that these faults are of the normal type and dip from 45° to 75°. The stratigraphic displacement may amount to several hundred feet along some of these faults.

In the central part of the hills the distribution of the Chanac and Santa Margarita formations suggests the presence of a southwestward-plunging anticlinal nose. Dip observations do not oppose this view, but this area is one in which faults are particularly abundant, and it seems at least possible that this apparent arching of the sediments has been produced entirely by faulting.

PERIODS OF DEFORMATION

The following table presents a summary of the geologic events in the southern border of San Joaquin Valley during the Tertiary period and shows their results in the localities affected.

Summary of geologic history during the Tertiary period in the southern border of San Joaquin Valley

Character of diastrophism	Time of occurrence	Result	Localities affected	Remarks
Widespread marine conditions north of the San Emigdio and Tehachapi Mountains during Eocene and Oligocene time permitted the accumulation of several thousand feet of sandstone, conglomerate, and shale. Marine sedimentation was probably interrupted at times by broad warping of the sea floor that produced erosional unconformities but no known angular discordance. Early Tertiary seas appear to have extended progressively more and more into the southeastern part of San Joaquin Valley, resulting in successive overlaps.				
Gentle warping of southern border of sea floor (?).	Near beginning of Vaqueros (lower Miocene).	Continental red beds intercalated with marine deposits.	San Emigdio foothills east of San Emigdio Creek.	No known folding.
Local uplift.	During early Vaqueros.	Tilting; angular discordance of 15° with overlying basalt.	Tehachapi foothills east of Pastoria Creek and possibly elsewhere.	
Volcanism.	During Vaqueros (lower Miocene).	Flows, agglomerates, and minor intrusions of andesite, closely followed by like features of basalt.	San Emigdio and Tehachapi foothills west of Tejon ranch.	
Marine sedimentation of sandstone, conglomerate, clay shale, and siliceous shale during remainder of lower and middle Miocene).				
Uplift and folding of sea floor.	Probably at end of Maricopa and before Santa Margarita.	Prominent folds that had dips of 5° to 35°.	Muddy Creek area; Tejon Hills.	
Marine sedimentation of Santa Margarita, Jacalitos, and Etchegoin sandstone, conglomerate, and shale, conformably overlain by continental deposits mentioned below. This sedimentation was in part simultaneous with next described uplift.				
Uplift of San Emigdio and Tehachapi Mountains.	From late Miocene throughout much of Pliocene.	Progressive development of extensive coarse alluvial-plain deposits in adjoining low-lying districts. Occurrence of Maricopa shale fragments in upper Etchegoin formation.	Tejon Hills. San Emigdio foothills.	Throughout the Pliocene. Only in Tulare and upper Etchegoin in area of exposed rocks.
Alluvial-plain and lacustrine deposits (Chanac and Tulare formations) laid down during above-described uplift of near-by mountains were themselves deformed near end of Pliocene time or early in Pleistocene time by diastrophism described below.				
Pronounced uplift and deformation of border of San Joaquin Valley.	End of Pliocene or early Pleistocene.	Uplift, folding, and faulting of old foothill belt and extension of this deformed belt northward. Intense deformation of Tulare, Chanac, and older formations.	Entire southern border of San Joaquin Valley.	By far the most pronounced period of deformation in Cenozoic time.
Development, during Pleistocene time, of a mature physiographic surface over this foothill belt, with broad alluviated stream valleys and extensive alluvial fans along the northern border of the foothills.				
Renewed uplift and deformation.	End of Pleistocene.	Bodily uplift of foothill belt, rejuvenation of streams, development of elevated stream terraces, and tilting of alluvial fans.	Probably the entire southern border of San Joaquin Valley, but particularly San Emigdio foothills.	Probably second in importance. Alluvial fans tilted 45° to 65°.
Development of extensive coarse alluvial-plain deposits in late Quaternary time, probably with minor intermittent periods of uplift.				

It seems probable that the high mountain areas immediately south of the San Emigdio and Tehachapi foothills underwent numerous uplifts during the Tertiary that are not mentioned in the above table—uplifts which did not deform the depositional basin to the north but which produced marked changes in the character of accumulating sediments. Such an uplift of the mountains might be postulated to account for the abrupt appearance of a coarse basal conglomerate at the base of the Maricopa shale in the Pleito Hills.

PHYSIOGRAPHY IN RELATION TO STRUCTURE

The last epoch in the geologic history of the southern border of San Joaquin Valley, but particularly of the San Emigdio foothills—that epoch in which the present land forms were developed—is one during which remarkable effects have been produced. This result has been attained principally because the last extensive deformation was a comparatively recent event and caused the development of youthful physiographic features in striking contrast to those which existed prior to this deformation and which still remain in fragmentary form throughout the foothill belt.

Back from the steep and deeply incised front of the San Emigdio foothills, both east and west of San Emigdio Creek, lie remnants of an earlier and much more mature physiographic surface. (See pls. 38, *B*, and 48.) The hill slopes, where untouched by the present system of drainage, are subdued and rounded and are associated with broad, flat alluvial stretches that cover considerable areas in the high parts of the hills north of the granite and between Santiago and Pleitito Creeks. These broad alluvial areas extend laterally to the very brinks of the deep canyons of San Emigdio, Los Lobos, and Santiago Creeks, where they form stream terraces from 100 to 400 feet above the canyon bottoms. (See pl. 38, *B*.) In interstream areas, particularly between Santiago and San Emigdio Canyons, these broad alluvial flats and the associated subdued hill slopes remain practically untouched by the youthful northward-draining canyons that are consequent upon the recent uplift of this foothill belt. Along San Emigdio Creek this Pleistocene alluvium extends in high terraces to the very mouth of the canyon, where it is continuous with old alluvial-fan deposits that are now tilted 25° to 90° N.

Smaller remnants of this more mature physiographic surface of the Pleistocene occur farther east, even as far as the Pleito Hills and Wheeler Ridge. The small valley along the Pleito syncline, at the very top of the Pleito Hills, is filled with an accumulation of coarse Pleistocene stream material, and the north slope of the Pleito Hills, just south of Wheeler Ridge, certainly has the appearance of a physiographically old surface now tilted northward and deeply incised by youthful canyons of the present drainage system. It seems probable, however, that the slumping and flowing of the soft Vaqueros clay shale has aided materially in the development of this smooth northward-sloping surface of the Pleito Hills, which so resembles a tilted peneplain.

The topographic form of Wheeler Ridge and its relation to stream drainage is particularly worthy of note. Its form, as seen in profile, is well illustrated in Plate 42, *B*, and the stream drainage of Wheeler Ridge and the adjoining area appears in Plate 45. In Plate 42, *B*, an unusually large gap appears in the eastern part of the ridge, and less prominent and higher gaps may be seen both to the east and to the west. Except for the easternmost indistinct gap shown in this picture, none of these gaps are occupied by streams, but their character and relations to present drainage force the conclusion that all of them have been carved by streams that flowed at one time across Wheeler Ridge from the south.

After extensive alluvial fans had been developed in this district during the later part of the Pliocene, the Wheeler Ridge anticline began to emerge from the floor of San Joaquin Valley, near the foot of a steep belt of foothills. This post-Pliocene deformation that produced the earliest Wheeler Ridge folding was only a part of more widespread diastrophism that affected the entire San Emigdio Mountains. This uplift probably resulted in increasing the activity of streams and in extending this increased activity for greater distances out over the alluvial plain from which Wheeler Ridge was beginning to rise. From the presence of numerous wind gaps along the crest of this ridge—gaps which because of their broad, flat-bottomed form and their lack of eroding streams can not be attributed to the present cycle of erosion—it is evident that some of the Pleistocene streams were successful for a time in maintaining their courses across this gradually growing anticlinal ridge. At a later time, however, the increased growth of the ridge forced these streams to abandon their channels, so that now all the major streams, on approaching Wheeler Ridge from the south, swing abruptly to the east or to the west in their attempt to avoid this prominent and comparatively recent obstruction.

Plate 45 shows these major streams in heavy lines and in the same way shows two large northward-draining streams in the central part of Wheeler Ridge, each of which has a broad, flat unoccupied stream gap at its head. The western of these two streams heads near the southern edge of the ridge, follows Coaloil Canyon, and flows directly across the axis of anticlinal folding. The eastern stream also heads several hundred feet south of the anticlinal axis.

The Pleistocene stream which carved the gap at its head and which continued across Wheeler Ridge may have laid down the elevated terrace deposits on the north flank of the ridge. (See pl. 39, *A*.)

The foregoing evidence supports the belief that the prominent wind gaps along the crest of Wheeler Ridge were carved by streams that once flowed across the ridge from the south. It seems probable that these streams antedated the anticlinal folding of Wheeler Ridge, but the evidence is not conclusive. There remains the possibility that these gaps are the work of streams that were superimposed upon an overthrust mass of Miocene shale that may have overridden Wheeler Ridge subsequent to the earliest anticlinal folding. Whether thrusting along the Pleito fault occurred before, during, or after the Wheeler Ridge folding, and whether the displacement was of a nature to permit the overriding of this ridge, has not been determined.

As a result of events during the Quaternary period, Wheeler Ridge stands out as a remarkable physiographic feature. Its present form is the result of pronounced anticlinal folding and accompanying erosion. Uplift by folding occurred intermittently, but its surface expression has been partially counteracted by the work of streams and other erosive agents. Stream erosion no doubt has been assisted materially by the degrading work of winds, but such wind action has left no record that is easily recognizable. Lowering of the ridge by erosion of streams and winds has not kept pace with uplift, which apparently is still active, but it has restrained the topographic expression of the anticline to the extent that the topographic relief is only about half the structural relief.

In the northern part of the Tejon Hills an old Pleistocene physiographic surface extends westward from the granite toward Comanche Creek. (See pl. 46, *A*.) It is now tilted westward at a gentle angle and appears to be arched, thus tending to conform to the major structure of this part of the hills. Intermittent streams that head in the granite to the east and flow westward into Comanche Creek have cut deeply into this tilted plain of sedimentary rocks but have left fairly broad boulder-covered interstream areas practically untouched.

In conclusion, there is abundant physiographic evidence along the entire southern and southeastern borders of San Joaquin Valley for the belief that this part of California has experienced in comparatively recent time a notable regional uplift, which is arbitrarily assigned to the end of the Pleistocene epoch. This uplift has rejuvenated preexisting streams, has produced striking changes in drainage, and has resulted in many new consequent streams, the combined effects of which have tended to destroy an earlier, more mature topography.

PETROLEUM

GENERAL CONSIDERATIONS

The southern part of San Joaquin Valley contains some of the most extensive and productive oil fields of the world. The Midway-Sunset and Buena Vista Hills-Elk Hills districts lie near the southwest corner and extend northward along the western border of this great valley; the Kern River oil field is situated along the eastern border of the valley only 35 miles from its south end.

The area studied in this investigation, which is situated along the southern border of San Joaquin Valley, lies between and near these rich producing areas and occupies a similar physiographic position with reference to the broad synclinal structure of the valley, the deeply buried strata of which are probably the source beds of much of the oil that is being produced along its border. These relations have been responsible for much speculation concerning the possibilities of obtaining oil in this more southern district and have led to much detailed geologic investigation and drilling by the oil companies of California. Additional encouragement is found in the presence, in the San Emigdio district, of rock formations similar to those associated with the producing beds in the Sunset-Midway oil field. It is evident, however, as previously stated in this report (p. 303), that the exposed structural conditions in the San Emigdio district are very complex and with few exceptions are difficult to interpret as being favorable for the accumulation of large quantities of oil. Wheeler Ridge is the only area which, before production was obtained, could have been said to be highly promising as possible oil-producing territory, and this area has been yielding oil since 1923. The Wheeler Ridge oil field and other areas worthy of consideration along the southern border of the valley are described below.

ORIGIN OF THE OIL

For a number of years geologists have considered that much of the oil produced in California has been derived from the middle Miocene organic shales of the Monterey group, a group that includes the lower part of the Maricopa shale of the southern and southwestern parts of San Joaquin Valley. Many have been equally certain that the fossil diatoms and foraminifers, but particularly the diatoms, contained in these shales either yielded oil by biochemical action or provided the organic substance from which most of the oil has been distilled. That the shales of the Monterey group contain an abundance of the remains of diatoms and foraminifers there is not the least doubt, but it is as yet uncertain that these organisms, of all the detrital substances present, represent the principal or most likely source of material for the development of large quantities of oil. In addition to these small diatom tests and foraminifer shells, without apparent organic substance, there is present in much of the shale a large quantity of truly organic débris that, under favorable conditions may have provided equally suitable if not more suitable material for the slow process of oil distillation.

In a previous paper [81] attention has been called to the presence in the Wheeler Ridge oil field of about 2,000 feet of Miocene sediments (Maricopa and Santa Margarita (?) shale) that contain considerable true oil shale—shale which has no free oil but which yields oil on heating. Thin sections of this oil shale reveal the presence of much dark-brown disseminated organic matter, most of which occurs in discontinuous bands or laminations. In this material David White has identified fragmentary spore cases and algal remains, and a few Foraminifera are scattered throughout some of the slides, but in all of them diatoms are either absent or very scarce. This shale was estimated to yield a maximum of at least 30 gallons of oil to the ton of rock. The subsurface beds that contain the oil shale were penetrated and cored by the Midland Oilfields Co.'s well on the north flank of Wheeler Ridge and were the only beds in the well from which shows of oil and gas were reported. The most striking relation appears, however, when it is noted that the beds that contain oil shale are stratigraphically equivalent to most of the oil-producing zones of the Wheeler Ridge oil field, only 1,000 feet south of the Midland Oilfields Co.'s well. If oil shale will yield petroleum under existing conditions, as is suggested by the experiments of McCoy [82] and Trager,[83] there is good reason to consider oil shale as a possible source for much of the oil produced at Wheeler Ridge and possibly in other fields of California.

Takahashi [84] has studied the organic content of marine muds, of marine shales in the oil fields of Japan, and of the diatomaceous shale of the Monterey group of California and has concluded that most of the oil in Japan and California has been derived not from diatoms but from the large quantities of organic débris which accumulated in the marine muds but which, because of its lack of hard parts, is not preserved as fossils. These conclusions are worthy of serious consideration. The solution of the problem of the origin of the California oil requires the presentation of many detailed facts concerning the character of organic matter present in and stratigraphically near oil-producing zones.

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[81] Hoots, H. W., Oil shale in a producing oil field of California: U. S. Geol. Survey Prof. Paper 154, pp. 171–173, 1928.

[82] McCoy, A. W., Notes on the principles of oil accumulation: Jour. Geology, vol. 27, pp. 252–262, 1919.

[83] Trager, E. A., Kerogen and its relation to the origin of oil: Am. Assoc. Petroleum Geologists Bull., vol. 8, pp. 301–311, 1924.

[84] Takahashi, J. R., Preliminary report on the origin of California petroleum: Econ. Geology, vol. 22, pp. 133–157, 1927.

WHEELER RIDGE OIL FIELD

HISTORY [85]

As early as 1910 Ralph Arnold and Robert Anderson recognized in Wheeler Ridge possibilities of a future oil field and recommended its early exploitation. The first well to test the area for oil was drilled in 1914 by the Henderson Oil & Development Co.; it was located in the prominent gap in the eastern part of the ridge, near the center of sec. 26. The well was abandoned at a depth of 2,920 feet without encountering a showing of oil. Another well was drilled in this same gap in 1921 by the Standard Oil Co. of California but was finally abandoned at a depth of 5,130 feet after unsuccessful tests for production had been made at several different horizons.

In 1922 the Standard Oil Co. of California began another well 2 miles farther west, in the NE. ¼ sec. 28, in the central and highest part of the ridge. This, the discovery well of the field, was completed at a depth of 2,185 feet and in January, 1923, was placed on production, with an initial daily output of 323 barrels of oil that tested 25.8° Baumé. Well No. 2 was drilled to a depth of 2,503 feet to test the productivity of deeper beds and was completed with an initial daily production of 231 barrels. More extensive drilling by the Standard Oil Co. and the General Petroleum Corporation has developed the present field, which, although small, has been a fairly steady producer. (See pls. 46, *B*, and 47.)

PRODUCTION

Prior to January 1, 1927, Wheeler Ridge had produced a total of 1,192,445 barrels of oil.[86] After the first well was placed on the pump in January, 1923, the production increased to a monthly output of 33,704 barrels in October, 1924. In March, 1925, 30,138 barrels of oil was produced from 16 wells, an average of 63 barrels a well a day. The average daily production of individual wells for this month ranged from 150 barrels for No. 14, in the eastern edge of the field, which was drilled during the preceding three months, to 17 barrels for No. 10, a recently deepened well in the northern edge of the producing area. (See fig. 9.) The record of highest initial production in the field—333 barrels of oil a day—belongs to No. 9, a deep well drilled near the highest part of the anticline. Within three months the production of this well declined to 186 barrels daily, and in nine months it was only 75 barrels. From March, 1925,

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[85] In preparing this short outline of the history of development reference has been made to a report by C. L. Kaiser, Summary of operations of California oil fields, vol. 9, No. 12, p. 25, California State Mining Bureau, 1924.

[86] Oil Weekly, Feb. 18, 1927, p. 130; amount compiled from data furnished by Federal and State bureaus, the American Petroleum Institute, and the Independent Oil Producers Agency.

AIRPLANE VIEW LOOKING SOUTHEASTWARD ALONG THE AXIS OF THE WHEELER RIDGE ANTICLINE

Showing the southern border of San Joaquin Valley east of Salt Creek. Photograph by H. A. Erickson.

AIRPLANE VIEW OF THE SOUTHERN BORDER OF SAN JOAQUIN VALLEY FROM SAN EMIGDIO CANYON TO COALOIL CANYON

Looking southwestward across the San Emigdio foothills, whose northern edge is trenched by deep, youthful canyons. Photograph by H. A. Erickson.

until February, 1927, the production of the entire field remained at about 1,000 barrels a day, but in order to maintain this production it was necessary to increase the number of wells from 16 to 26; the daily average production per well decreased, in the two years, from 63 barrels to less than 40 barrels. The total production to January 1, 1929, was 1,809,722 barrels. In February, 1929, the field produced 746 barrels of oil daily from 32 wells, which is a daily production of 23½ barrels per well.

The production to May, 1927, was limited to a small area in the central part of Wheeler Ridge. The first wells were drilled in the NE. ¼ sec. 28, but the producing field at that date extended eastward and included much of the NW. ¼ sec. 27. Two wells drilled outside of the producing area never produced oil and were abandoned; one was drilled by the Midland Oilfields Co. (Ltd.) high on the north flank of the anticline, and the other was drilled by the Tejon-Kern Petroleum Co. on the south limb of the anticline. The wells of the General Petroleum Corporation in the NW. ¼ sec. 28 and the No. 11 well of the Standard Oil Co. (see structure section, pl. 44) have been abandoned after yielding a comparatively small amount of oil.

The structure section (pl. 44) shows the distribution of oil-producing beds in wells that are probably representative of the field. Generally speaking, production is obtained from two zones, an upper and a lower, although there is no distinct line of separation between them. In the logs of some wells oil shows and some gas shows are recorded as scattered throughout the stratigraphic interval between the two zones and for several hundred feet above the shallower zone. The beds that contain these uppermost oil shows, which lie at depths of 1,500 to 1,700 feet near the axis of the anticline, have been called the "tar zone."[87]

At present most of the wells of the field are producing from the upper zone, those located in the higher part of the anticline at depths of 2,100 to 2,700 feet. Nos. 2, 9, and 15 of the Standard Oil Co. are obtaining oil from the lower zone at depths of 3,200 to 4,000 feet. According to Kaiser[88] a gas pressure of 500 pounds to the square inch accompanied the comparatively large initial production of No. 9. The present development indicates that the lower producing zone will not be as long lived as the upper zone, although the wells of the lower zone have initial yields comparable to the best of those of the upper zone.

Figure 9 shows the probable subsurface structure of the producing area. The production of individual wells is apparently not controlled entirely by structural height, although this factor probably

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[87] Kaiser, C. L., op. cit., p. 26. [88] Idem, p. 25.

more than any other will ultimately limit production to a relatively small area along the axis of the anticline. The oil sands appear to be discontinuous and can not be correlated as individual beds from well to well. In some wells they are much more abundant than in others, and in some wells the quantity and life of production are directly proportional to their number.

Although lenticular strata and variation in texture and degree of cementation in subsurface strata apparently affect the character of

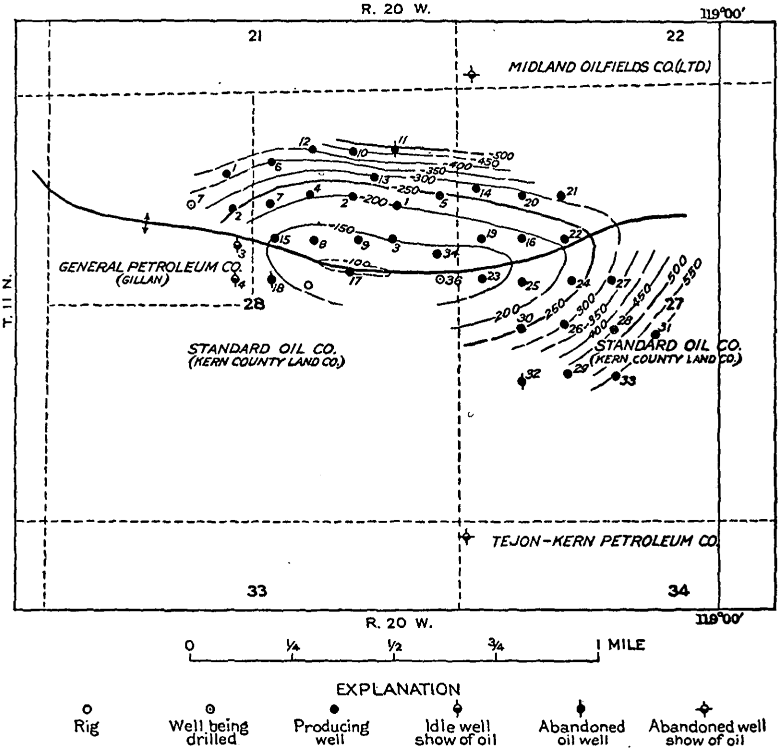

FIGURE 9.—Map showing probable subsurface structure of Wheeler Ridge producing area, Calif. Contour lines show distance below sea level of approximate top of upper producing zone; contour interval, 50 feet.

production in the Wheeler Ridge wells, it seems probable that crooked holes and lack of standardized usage for stratigraphic descriptions among drillers account for much of the apparent lateral variation in individual beds. Coring in some of the later wells drilled in 1927 and 1928 provided reliable evidence of lateral variation of beds and gave little encouragement for detailed subsurface correlations.

The gravity of the oil produced ranges from 21.3° to 31.5° Baumé. In general the lighter oils come from wells nearer the axial part of the anticline. All wells producing oil lighter than 24.7° Baumé occur above the −250-foot contour line, and, with the exception of No. 8, wells of heavier oil are lower structurally. These statements, however, are based on records of production up to March, 1925, and apply only to wells in the NE. ¼ sec. 28.

PROBABLE ULTIMATE LIMITS OF PRODUCING AREA

The western, northern, and southeastern edges of the producing area have been determined by oil wells that produced only small quantities of oil and have been abandoned. It seems probable that six or eight additional locations south of the anticlinal axis in the eastern part of sec. 28 and the western part of sec. 27 (see fig. 9) and about an equal number along and on both sides of the axis in the north-central part of sec. 27 will provide oil wells with fair production if development is continued. Present production is declining at a fairly rapid rate, and it is doubtful if additional wells finished in the present producing horizons will pay.

Well No. 36, near the axis in the eastern edge of sec. 28, drilled to test the productivity of deeper horizons, encountered an oil zone at 4,367–4,477 feet which contained a high quantity of light oil and which was estimated to be capable of producing about 40 barrels a day. Drilling is being continued at about 4,600 feet, and, should a highly productive light-oil zone be encountered, the Wheeler Ridge oil field would undergo considerable additional development.

OTHER AREAS POSSIBLY CONTAINING PETROLEUM

Wheeler Ridge is at present the only oil-producing area along the southern border of San Joaquin Valley, and it may be that no additional productive areas will be found. There are two conditions that tend to prevent the occurrence of additional oil pools within this belt, one of which is the complexity of structure in the Tertiary rocks of the foothill belt, and the other is the broad mantle of alluvium north of the foothills, which, except in a single locality, apparently conceals all trace of other structural features that may and probably do exist in the southern part of San Joaquin Valley.

Because of these two conditions there appear to be no areas within this belt that hold highly encouraging prospects of becoming future oil fields. Three areas, however, appear worthy of consideration, and at least two of them, the writer believes, warrant the drilling of test wells when market conditions demand additional production. Attention has been called to these areas in a previously published statement.[89] From west to east they are (1) a partly buried structural feature, possibly an anticline, 1 mile northwest of the mouth of

[89] Oil possibilities at Comanche Point and near Wheeler Ridge, Calif.: U. S. Geol. Survey Press Memorandum 13338, Mar. 28, 1927.

San Emigdio Canyon, near the north line of secs. 34 and 45, T. 11 N., R. 22 W.; (2) the structural terrace which forms the eastern extension of the San Emigdio anticline, near Pleitito Creek; and (3) the Tejon Hills.

PARTLY BURIED STRUCTURAL FEATURE NEAR MOUTH OF SAN EMIGDIO CANYON

GENERAL CHARACTER

The character and probable structural significance of the unusually sharp break in the alluvial plain along the north line of secs. 34 and 35, T. 11 N., R. 22 W., are considered on pages 308–309. The abundance of prominent eastward-trending folds and faults in near-by exposed strata and the presence of steeply dipping rocks where wells have cored subsurface beds in this district furnish evidence in favor of anticlinal folding or faulting in this vicinity. It is difficult to interpret satisfactorily the significance of the unusual topographic features there; in the writer's opinion the available evidence of structure on this alluvial plain may be reasonably interpreted as the expression of either folding or faulting. There appears to be no worth-while evidence tending to disprove either interpretation.

If the features in question are the topographic expression of anticlinal folding, it seems probable, from the form of the larger feature and the intensely deformed character of the folds exposed south of this area in the northern edge of the San Emigdio foothills, that the hypothetical buried anticline in secs. 34 and 35 is itself sharply flexed, perhaps too sharply to contain commercial quantities of oil or gas and be favorable for exploitation. The structural character of this feature might be satisfactorily determined, in advance of deep drilling, from data obtained from shallow core test wells. Structure section C–C′ (pl. 31) presents one possible interpretation of the available data.

The Standard Oil Co. of California drilled a well in 1928–29 near the center of the E. ½ sec. 35 to test the oil possibilities of the larger topographic feature. The well passed through the Tulare-Etchegoin contact at about 2,400 feet, encountered dips of 30° to 60°, and was abandoned without showings of oil or gas in what is probably Etchegoin at a depth of 3,782 feet. In view of the decreasing angle of dip toward the bottom of this well, it would have been interesting to see what results would have been obtained by this well at greater depths.

INDICATIONS OF THE PRESENCE OF OIL AND CONCLUSIONS

An asphalt seep occurs near the southeast corner of sec. 5, T. 10 N., R. 22 W., in Little Muddy Creek, due south of the Standard Oil

Co.'s well. Here heavy oil is slowly oozing from the unconformable contact of the Maricopa and Etchegoin formations and has impregnated the upper 50 feet of the Maricopa shale. This general horizon of unconformity has yielded shows of oil or oil and gas in several of the wells shown on the accompanying geologic map of this district. In some of these wells, at least, the oil has been tarlike, with low specific gravity.

At deeper horizons in some wells other shows of oil and gas have been encountered within or below the Maricopa shale, usually in beds recorded as sandstone. In some wells this oil is authentically reported to have been of greenish color and of comparatively high specific gravity.

The writer believes that the economic possibilities warrant careful investigation of this alluvial area between the Pioneer anticline on the west and the alluvial fan of San Emigdio Creek on the east. Existing data suggest that a buried anticline may be present, and there are encouraging indications of oil in the San Emigdio district at stratigraphic horizons that should be within reach of the drill along the axis of this or any other possible fold in the southern third of T. 11 N., R. 22 W. Folds farther north also may have elevated the Maricopa shale to accessible depths. The thicknesses of the Etchegoin and Maricopa shale probably differ considerably from place to place throughout the district, owing to the unconformity between these formations and known irregularities of deposition. It may be possible at structurally high points in the southeastern part of T. 11 N., R. 22 W., to drill through the entire Maricopa shale and test porous strata in the upper part of the Vaqueros formation.

EASTERN PART OF SAN EMIGDIO ANTICLINE

Along the lower part of Pleitito Creek and farther west the beds are steeply tilted. The San Emigdio anticline, a sharp overturned fold with its axis in soft clay shale of the Etchegoin formation, marks the trend of a major uplift along the northern edge of the San Emigdio foothills, west of Pleitito Creek. (See pls. 31 and 41.) East of San Emigdio Canyon this fold plunges to the west and, toward the east, follows a curving trend and passes into a structural terrace toward Pleitito Creek and continues to a point just east of Pleitito Creek, where it terminates abruptly against a southward-dipping fault. It seems reasonable that oil in commercial quantities should have migrated at some time from beneath San Joaquin Valley into this highly deformed anticline, but even though the fold is sharp and broken by a fault there are no oil seeps between Pleitito Creek and San Emigdio Canyon to suggest that oil has escaped from rock strata in this vicinity. Possibly oil has accumulated in the eastern part of this fold and against the fault that terminates it on the east and breaks across it in the neighborhood of its highest structural part.

Because of the complex overturning of this fold it belongs to that class of structural features generally considered to be unfavorable for exploitation and the retention of large amounts of petroleum, but nevertheless it seems to deserve some consideration. (See section D–D′, pl. 31.) This anticline may pass downward into an eastward-trending thrust fault, against which oil, migrating from beneath San Joaquin Valley, may have accumulated. Even though this condition prevails at considerable depth, the accumulation of oil along the Maricopa-Etchegoin contact and at deeper horizons may have been controlled entirely by structural terracing against the fault on the south that is shown on Plate 31.

The Union Oil Co. undertook to test this area in 1928. The first well (see location on pl. 31) drilled through Etchegoin strata to the bottom of the hole at 2,335 feet and encountered dips of 25° at 470 feet and 13° at 560 feet, slickensided beds from 560 to 670 feet, and dips of 65° to 80° from 600 to 2,335 feet. This well was abandoned because of steep dips. The second well is 1,000 feet south of the first and in May, 1929, had reached 2,963 feet in Maricopa shale. Dips of 70° to 90° were encountered in this well from 1,500 to 1,838 feet and of 10° to 30° between 1,838 and 2,963 feet. At the base of the Etchegoin 34 feet of thoroughly saturated tar sand was encountered between 2,631 and 2,665 feet, directly above the Maricopa shale.

One condition that may have prevented large quantities of oil from reaching the San Emigdio anticline is the possible existence of a thrust fault hidden along the northern edge of the foothills beneath Quaternary alluvium and landslides. Should such a fault be present, for which there is some theoretical evidence, oil has possibly accumulated at favorable localities north of the fault, instead of along the San Emigdio anticline.

TEJON HILLS

Two areas in the Tejon Hills are worthy of consideration for the possible production of small quantities of petroleum. One of these areas is on the anticline at Comanche Point, in the extreme northwestern part of the hills, and the other is along Tejon Creek in the central part of the hills.

The general structural character of the Comanche Point anticline is discussed on pages 316–317. Although two wells have been drilled in this vicinity—the Comanche Point Oil Co.'s well and

W. W. Stabler's well, both within 2,000 feet of the axis of this fold—no adequate test of the anticline has yet been made.

The well drilled by the Globe Petroleum Corporation just west of the central part of the Tejon Hills is near a feature that appears to be an anticlinal nose plunging southwestward beneath San Joaquin Valley. It is probable, however, that the structural relations in this vicinity have not been produced by simple folding; it seems more likely that this apparent anticlinal nose is the result, to a large degree, of displacement along the southern extensions of faults that are exposed near the top of the Tejon Hills 1½ miles northeast of the Globe well.

Shows of gas or of both oil and gas have been encountered by the four deep wells already drilled in this district. (See pl. 31.) One well, drilled by the Globe Petroleum Corporation, obtained strong shows of both oil and gas and during the summer of 1926 was producing more than enough gas to run a large four-cylinder motor used to pump irrigation water from this same well. Shale that carries organic material, foraminiferal limestone, and fossiliferous sandstone, all of Miocene age, crop out at or east of Comanche Point, but no oil seeps were found. Escape of oil along faults may never have occurred. Oil in commercial quantity is possibly present and may have accumulated in an anticline or against one or more faults, under structural conditions favorable for satisfactory exploitation. Sandy sediments of the Miocene of this district are considered to be a shore phase, possibly equivalent to the shale that carries organic material farther west beneath San Joaquin Valley. Miocene strata of approximately the same age are producing oil in the Poso Creek district, 30 miles farther north.

Although it does not seem probable that the Tejon Hills will ever produce large quantities of oil, the Comanche Point anticline and the area near Tejon Creek and northeast of the Globe Petroleum Corporation well are believed to be worthy of consideration for small yields. If a well is drilled to test the Comanche Point anticline it should be located on the axis of the fold 800 to 1,000 feet east of the hypothetical extension of the White Wolf fault, near the center of the N. ½ sec. 23, T. 32 S., R. 29 E. This partial anticline may terminate abruptly against the White Wolf fault, near the northwest edge of the hills, but it may continue farther west beneath San Joaquin Valley.

It is difficult to rate satisfactorily the chances for success at Comanche Point. It seems that the fold here may combine with the White Wolf fault to form closed structure east of the fault. Oil may exist in the basal Miocene sandstone in this fold, or it may have escaped across the fault into adjoining porous strata, or it may never have entered the anticline. Testing this deeply eroded fold should be comparatively inexpensive, for granite presumably would be encountered within 3,000 feet of the surface. Farther west the structural conditions are not known. If it were certain that the White Wolf fault exists as illustrated and that anticlinal folding extends west of it into San Joaquin Valley, the structural conditions might be considered favorable and probably would warrant the drilling of at least one deep well.

Before a test well is undertaken in the alluvium-covered area west of Comanche Point it seems advisable for those interested to attempt to obtain reliable data concerning the actual presence of an anticline, a partial anticline, a westward-plunging anticlinal nose, or other favorable structural conditions in this locality. Three or more shallow core-drill holes systematically located near the presumed extension of folding 1,000 to 1,500 feet west of the edge of the hills at Comanche Point may yield structural, mineralogic, and micro-paleontologic evidence of the presence or absence of folding beneath the alluvium. In advance of such testing it can only be said that the exposed structural conditions suggest that anticlinal folding may but does not necessarily continue west of Comanche Point.

The Globe Petroleum Corporation's well near Tejon Creek found encouraging shows of oil and gas. Possibly a well half to three-quarters of a mile northeast of the Globe well, near Tejon Creek and west of the largest of the above-mentioned faults, might obtain a small quantity of oil. However, because of the irregularities of structure and the apparent absence of a closed anticlinal fold in this vicinity, together with the unknown effect that faulting has had upon the accumulation of oil and gas, drilling another well would be accompanied by considerable risk. Near Tejon Creek in this locality granite is probably within 3,000 feet of the surface.

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