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DEPARTMENT OF NATURAL RESOURCES

GEOLOGY OF THE TESLA QUADRANGLE CALIFORNIA

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DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO

STATE OF CALIFORNIA
EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO
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GEOLOGY OF THE TESLA QUADRANGLE CALIFORNIA

By
ARTHUR S. HUEY

LETTER OF TRANSMITTAL

To His Excellency
The Honorable Earl Warren
Governor of the State of California

Sir:

I have the honor to transmit herewith Bulletin 140, "Geology of the Tesla Quadrangle, California", prepared under the direction of Olaf P. Jenkins, Chief, Division of Mines, Department of Natural Resources. This report includes detailed geologic and economic mineral maps of a specific area in Alameda and San Joaquin Counties. It is one of a series of such reports on specific areas in California which the Division of Mines is publishing. Three previous reports covered the San Benito, Jamesburg, and San Juan Bautista quadrangles.

The following report and geologic and economic mineral maps of the Tesla quadrangle have been prepared by Arthur S. Huey in partial fulfillment of the requirement for the degree of Doctor of Philosophy at the University of California. The report is of particular interest because it describes many typical features of the California Coast Ranges and includes a description of economic mineral resources such as coal, clay, chromite, glass and foundry sand, gravel, lime rock, magnesite, manganese, and tuff. The results of this investigation are basic and fundamental to the understanding of the state's mineral deposits and related geological features.

Respectively submitted,

WARREN T. HANNUM, Director
Department of Natural Resources

May 4, 1948

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GEOLOGY OF THE TESLA QUADRANGLE, CALIFORNIA*

By Arthur S. Huey **

ABSTRACT

The Tesla quadrangle comprises an area of about 240 square miles in Alameda and San Joaquin Counties, California. The area includes part of the Diablo Range and small portions of the Livermore and San Joaquin Valleys.

The stratigraphic section is typical of the California Coast Ranges; the rocks range in age from Jurassic to Recent. The oldest rocks, the Jurassic Franciscan group, consisting chiefly of sandstone, shale, and chert, occupy most of the southern half of the quadrangle. Serpentine occurs in large irregular masses, and other rocks, such as diabase, basalt, and glaucophane schist, are restricted in their occurrence. The Cretaceous rocks include the Horsetown, Panoche, and Moreno Grande formations. The Moreno Grande is an enlargement of the original Moreno to include equivalents of the *Pachydiscus* silt member, which were mapped as part of the Moreno north of Pacheco Pass. The Tesla formation of middle Eocene age includes white and buff sands, carbonaceous shales, anauxitic clays, and a little coal. Sandstone formerly mapped as Briones in Arroyo Valle is regarded as Oursan (?) sandstone (middle Miocene). The upper Miocene is represented by two members of the San Pablo group, the Cierbo white pebbly sands, and the Neroly formation consisting of blue sandstones, andesitic boulder conglomerates, and tuffaceous shales. Fringing the southeast margin of Livermore Valley are the Livermore gravels (Plio-Pleistocene). The Tulare formation (Plio-Pleistocene) is found only in the extreme northeast part of the area. Quaternary terrace deposits, landslides, and alluvium complete the stratigraphic column.

The rocks are involved in a complex of folds and faults. The major faults are classified into two groups: (1) the transverse faults which trend eastward, and (2) the longitudinal faults which trend northwestward. The average trend of the regional folding is intermediate between the trends of the two fault groups. The principal time of regional deformation was post-Neroly, possibly Pleistocene.

Economic resources include coal, clay, chromite, glass and foundry sand, gravel, lime rock, magnesite, manganese, and tuff. Important contributions to the state's output of manganese have been made by the many manganese properties in the area. About 25 wells have been drilled and abandoned in an unsuccessful search for a commercial accumulation of petroleum.

INTRODUCTION

The geology of the Tesla quadrangle is typical of the Coast Ranges of California. Rock formations ranging in age from Jurassic to Recent are involved in a complex of folds and faults. Sedimentary rocks predominate; igneous rocks are limited in occurrence. Economic interest in the area is furnished by minor occurrences of such minerals as coal, clay, chromite, magnesite, manganese, glass and foundry sand, and petroleum.

Location and Accessibility

The Tesla quadrangle comprises an area of about 240 square miles covering parts of Alameda and San Joaquin Counties, California. Its location with reference to neighboring towns and gas fields of central California is shown on the accompanying index map (fig. 1). The area includes a part of the Diablo Range and small portions of the Livermore and San Joaquin Valleys. No towns are located within the area. Altamont, Greenville, and Midway in the northern part of the area are railroad sidings and maintenance stations. The quadrangle takes its name from the old abandoned mining camp of Tesla, which once had a population of two thousand but today has only tailing dumps and foundation scars to indicate a former site of development.

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* Based upon a dissertation submitted in partial satisfaction of the requirements for the degree of Doctor of Philosophy in Geology, in the Graduate Division of the University of California, Berkeley, California, 1940. Manuscript submitted to the Division of Mines for publication October 1947.

** Geologist, The Hancock Oil Company, Long Beach, California.

FIGURE 1. Index map, showing location of Tesla quadrangle.

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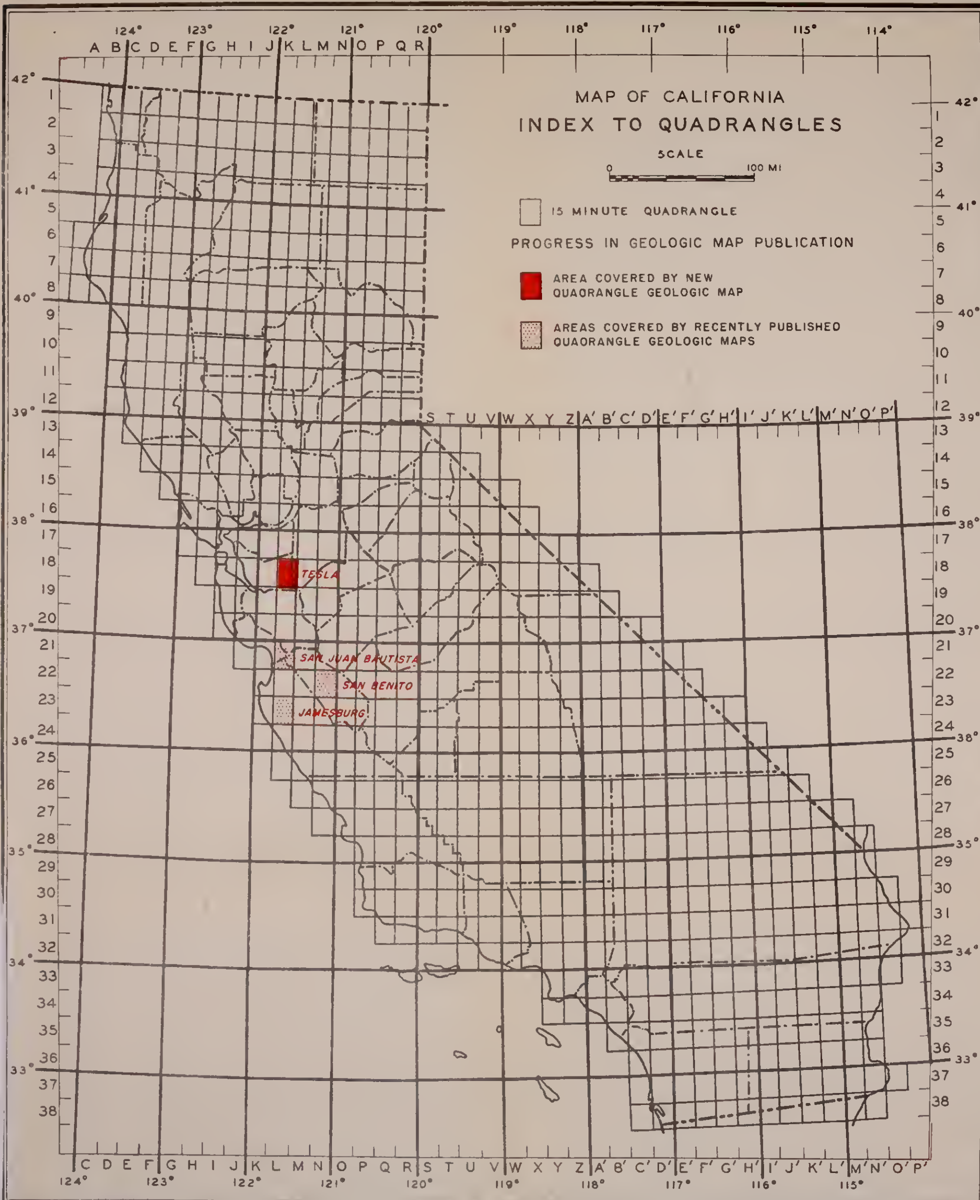
MAP OF CALIFORNIA
INDEX TO QUADRANGLES
SCALE
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15 MINUTE QUADRANGLE
PROGRESS IN GEOLOGIC MAP PUBLICATION
AREA COVERED BY NEW QUADRANGLE GEOLOGIC MAP
AREAS COVERED BY RECENTLY PUBLISHED QUADRANGLE GEOLOGIC MAPS
TESLA
SAN JUAN BAUTISTA
SAN BENITO
JAMESBURG

The area is quite accessible. It is best reached from Oakland on the west or from points in the San Joaquin Valley on the east by way of U. S. Highway 50. This new four-lane highway replaces the old winding Altamont Pass road as the main carrier of east-west traffic in the northern part of the area. To the south, other roads which cross the range are the Patterson Pass road and the Tesla road into Corral Hollow. A surfaced road in Arroyo Mocho crosses the area diagonally and leads from Livermore Valley southeastward beyond the limits of the quadrangle to Mt. Hamilton. The road into Arroyo Valle from Livermore is surfaced in part and ends blindly where the canyon narrows in Franciscan rocks. Other roads, generally in poor condition and private, reach to various parts of the area. The only areas of difficult accessibility are in the southern third of the quadrangle where the relief is greatest and the country has not warranted development.

The Western Pacific and the Southern Pacific Railroads cross the area in the northern part through Altamont Pass. The branch railroad shown on the original quadrangle map in Corral Hollow has long been removed since the coal and clay development ceased.

Field Work

About 6 months were spent in the field during the summers of 1934, 1935, and 1936. Numerous week-end trips were made into the area from 1937-40 to complete the study. Supporting the field work were laboratory and general research done principally at the University of California, Berkeley, California. Geologic observations were plotted on the U. S. Geological Survey topographic map, the Tesla 15-minute quadrangle, contour interval 50 feet, scale 1:62,500. The townships of this quadrangle take survey reference from the Mt. Diablo baseline and meridian.

In 1940 the Agricultural Adjustment Administration of the U. S. Department of Agriculture had the region photographed from the air as a part of an extensive areal survey of agricultural and grazing areas in California. Emergency measures during World War II made prints of these aerial photographs unavailable to the general public. The writer has not had an opportunity to review the geologic mapping in the field with the aid of these photographs but has examined under the stereoscope photographs of parts of the area. The use of these photographs would facilitate any future detailed investigations in the field.

Acknowledgments

This investigation was done under the direction of Dr. N. L. Taliaferro of the Department of Geological Sciences of the University of California, Berkeley. Others of the University of California faculty who gave helpful suggestions or criticism were Professors G. D. Louderback, C. D. Hulin, C. A. Anderson, and the late B. L. Clark. Assistance with the paleontology of the field collections was contributed by Dr. R. A. Bramkamp, Dr. Arthur S. Campbell, Dr. R. A. Stirton, Mrs. P. Rossello Nicholson, and the late Dr. F. M. Anderson. Paleobotanical identifications were contributed by Dr. R. W. Chaney and Dr. Carlton Condit. Visitors in the field included Dr. Cordell Durrell of the University of California, Los Angeles, and Dr. P. W. Reinhart, Shell Oil Company, Incorporated. Mr. M. J. Bartell of the San Francisco Engineering Department was very cooperative concerning data on the Hetch-Hetchy


38°30'
S O N O
M A R I
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SAN FRANCIS
P A C I F I C
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O C E A N

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tunnel which crosses the Tesla quadrangle as a part of a development for supplying water to the city of San Francisco. Others to whom the author wishes to express appreciation are Dr. F. P. Vickery of the Sacramento Junior College, Dr. Paul P. Goudkoff, and Mr. Alfred Vitt, Seaboard Oil Corporation. The hospitality and courtesies of many of the ranchers are also acknowledged.

Previous Work

No comprehensive report on the geology of the Tesla quadrangle has so far been published, but many workers have made contributions toward an understanding of the geology of the area. Among the earliest writings are some notes by Brewer [1] describing the occurrence of fossil leaves in Corral Hollow and predicting economic failure for the Tesla coal mines then in operation. Volume I of the Geological Survey of California as edited by Whitney (1865) included two short cross-sections in Corral Hollow, an analysis of the Tesla coal, and a few notes by W. M. Gabb on some brackish-water fossils (Eocene) in Corral Hollow. The Pliocene tuffs and conglomerates containing andesite boulders which occur north of Corral Hollow are given early reference in the writings of Turner [2]. The "San Pablo formation" as it occurs north of Corral Hollow was briefly described by Weaver [3]. The water-supply and marginal geology of Livermore Valley were discussed in separate papers by Lawson [4] and Branner [5]. The report by Anderson and Pack [6] on the geology and oil resources of the west border of the San Joaquin Valley includes a sketch map of the geology of the northern part of the Tesla quadrangle based upon reconnaissance mapping by R. W. Pack and E. L. Ickes. This report also describes the formations present and gives a brief history of the early wells drilled for oil in the Tesla area.

For a number of successive summers around the early twenties, the Stanford University Geological Survey was engaged in mapping the Tesla and several neighboring quadrangles, including the Pleasanton, San Jose, and Mt. Hamilton quadrangles. The maps and full results of this work were never published, but Vickery [7] in a doctor's thesis analyzing the geologic structure of the Livermore region introduced a generalized map of the above named quadrangles as surveyed by the Stanford parties. The published form of this structural analysis by Vickery [8] did not include the generalized map of the four quadrangles. Clark [9] and Taff [10], writing separately on the Mt. Diablo region, made

[1] Brewer, W. H., Up and down California in 1860-64, Yale Univ. Press, 1930.

[2] Turner, H. W., The geology of Mt. Diablo: Geol. Soc. America Bull., vol. 2, pp. 383-414, 1891. . . . Rocks of the Coast Ranges of California: Jour. Geology, vol. 6, pp. 493-499, 1898.

[3] Weaver, Charles E., Stratigraphy and paleontology of the San Pablo formation in middle California: Univ. California, Dept. Geol. Sci. Bull., vol. 5, pp. 243-269, 1909.

[4] Lawson, Andrew C., Report on the geology and underground water supply of Livermore Valley, in The future water supply of San Francisco, a report . . . by the Spring Valley Water Co., pp. 223-230, 1912.

[5] Branner, J. C., Report on the geology of Livermore Valley, in The future water supply of San Francisco, a report . . . by the Spring Valley Water Co., pp. 203-222, 1912.

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

[7] Vickery, F. P., The structural dynamics of the Livermore region, Ph.D. thesis, Stanford Univ., 1925 (unpublished).

[8] Vickery, F. P., The structural dynamics of the Livermore region: Jour. Geology, vol. 33, pp. 608-628, 1925.

[9] Clark, Bruce L., Tectonics of the Mt. Diablo and Coalinga areas, middle Coast Ranges of California: Geol. Soc. America Bull., vol. 46, pp. 1025-1078, 1935.

[10] Taff, J. A., Geology of Mt. Diablo and vicinity: Geol. Soc. America Bull., vol. 46, pp. 1079-1100, 1935.

brief references to the geology in parts of the Tesla quadrangle. The stratigraphy of the Tesla quadrangle was discussed by Huey [11]. Allen [12] described the occurrence of Eocene anauxitic clays and sands in Corral Hollow. The most recent paper is one by Campbell and Clark [13] describing the Upper Cretaceous radiolarian fauna contained in a sample of limestone concretion collected by this writer near Corral Hollow.

Besides the published works mentioned above, there are several unpublished reports on the geology of parts of the area, such as the geological reports on the Hetch-Hetchy project made by Bailey Willis and G. L. Green for the San Francisco Engineering Department and various private geological investigations made by oil company geologists.

GEOGRAPHY

Relief and Topography

The Tesla quadrangle contains portions of three topographic units: Livermore Valley, San Joaquin Valley, and the Diablo Range. Livermore Valley in the northwestern part of the area is a surface of low relief; average elevation is 550 feet above sea-level. A part of the San Joaquin Valley which cuts across the northeast corner of the quadrangle contains the lowest elevation in the area, approximately 95 feet above sea-level and is bounded approximately by the 250-foot contour line. The relief of the main topographic unit, the Diablo Range, increases in general toward the south. In the northern part of the area in rocks of Cretaceous and Tertiary age, the hills are smooth and rounded, and elevations range from about 500 feet to more than 2000 feet above sea-level. South of Corral Hollow in rocks principally of the Franciscan group, the topography is higher, more rugged, and characterized by deep youthful canyons and long smooth-topped ridges. Two thousand feet of relief is not uncommon from the bottoms of many of the arroyos to the tops of the ridges. The highest recorded elevation, 3820 feet above sea-level, is on Rose Flat near the southwestern corner of the quadrangle.

The relief of the area is well represented in plate 4, a photograph of a portion of a plaster relief model of the San Francisco Bay region on exhibit in the geological museum in Bacon Hall, University of California, Berkeley. Elevations and important place names have been added to aid the reader in his orientation of the area.

The physiographic state of development is late youth, and the drainage pattern of the area is well developed. The approximate accordant relationship of the summit levels along the ridges in the southern high country is suggestive of an old erosional surface of low relief, which in late geologic time was uplifted with a gentle northwesterly tilt and later dissected by erosion. Prominent terraces in Arroyo Mocho and Corral Hollow are indicative of recent uplift in at least three stages.

Climate and Vegetation

Semi-aridity characterizes the climate of the region. Summers are dry and hot, and day temperatures often reach 100 degrees Fahrenheit. Low morning fogs are often driven in from the west by the winds, and late summer afternoons are occasionally marked by winds of consid-

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[11] Huey, Arthur S., Stratigraphy of the Tesla quadrangle, California (abstract): Geol. Soc. America Proc. 1936, pp. 335-336, 1937.

[12] Allen, V. T., Eocene anauxitic clays and sands in the Coast Range of California: Geol. Soc. America Bull., vol. 52, pp. 271-294, 1941.

[13] Campbell, A. S., and Clark, B. L., Radiolaria from Upper Cretaceous of middle California: Geol. Soc. America Special Paper 57, pp. 1-61, 1944.

erable velocity. Spring and fall are quite comfortable and regionally picturesque. The mean annual temperature is approximately 58 degrees Fahrenheit, and temperatures below freezing are common in the winter. Rainfall is concentrated chiefly in the winter months, and some snow falls, principally at the higher elevations. The average seasonal rainfall ranges from about 10 inches in the low northeastern part of the area to about 26 inches in the high southwestern portion.

The vegetation cover varies with elevation, distribution of rainfall, rock or soil type, directional slope, and local features, such as streams and springs. Most of the area is covered by a short grass, chiefly naturalized wild oat. Sage is sparsely distributed. Cottonwood, sycamore, willow, pipestem, and oak occur along stream courses and at springs. Trees are more plentiful in the southern higher portion of the region and include several varieties of oak, cypress, buckeye, and juniper. A dense cover of chaparral and manzanita is common over areas of serpentinized rock. The California Experiment Station at the University of California, Berkeley, has collected data on plant species occurring at different elevations in the area, and such information is available at the station.

As a whole the region is open and the vegetation cover does not interfere with geological work. The best exposures are found along stream courses and in highway and railroad cuts. Exposures over much of the area are poor to absent, owing to a heavy soil mantle, and in these soil mantled areas special features such as soil color, pebble content, or vegetation contrast aid in the delineation of a formational contact.

Drainage and Water Supply

Although the drainage pattern of the area is well developed, the streams are all intermittent. The smaller gullies and creek bottoms are dry most of the year and contain water only during or for short periods after a rain. The larger water-courses, including Arroyo Valle, Arroyo Mocho, Corral Hollow Creek, and Mitchell Ravine are in the southern half of the quadrangle. These streams drain the areas of greatest relief and rainfall. They contain running water until the middle of summer, after which the water sinks below the surface and reappears as water-holes at intervals along the courses of the streams. The directional trend of these major drainages is in general northwesterly in conformance with the main structural trends in the southern part of the area. Arroyo Valle and Arroyo Mocho drain into Livermore Valley and contribute greatly to the subsurface water supply in the valley. For further information on the water supply of Livermore Valley, the reader is referred to the writings of Lawson,[14] Branner,[15] and M. B. Smith.[16] Near its source, Corral Hollow Creek flows northwestward, but makes a sharp change of direction near Tesla and flows eastward toward the San Joaquin Valley. The existence of what may be a wind-gap about 1000 feet north of the southwest corner of sec. 35, T. 3 S., R. 3 E., is suggestive that Corral Hollow Creek once drained out through Arroyo Seco into Livermore Valley but was captured and diverted toward the San Joaquin Valley by subsequent drainage developing in Corral Hollow in late geologic time.

[14] Op. cit.
[15] Op. cit.
[16] Smith, M. B., Ground water in the Livermore Valley, California, Master's thesis, Stanford University, 1934 (unpublished).

Springs are common throughout the area, occurring principally at stratigraphic boundaries and along fault traces. The representation of many of these springs on the geologic map illustrates their geologic relationship. The waters of only a few of these springs are good for human consumption; the others are alkaline, sulfurous, or otherwise mineralized.

Soil erosion is active in many parts of the area, where the grass cover is thin. Hillsides and valleys are being deeply dissected, and unless some restrictive measures are taken by the ranchers or proper authorities, serious damage to grazing lands and roadways will result.

Hetch-Hetchy Water Supply

The city and county of San Francisco at a total cost of about $105,000,000 constructed the Hetch-Hetchy water system to carry water from two impounding reservoirs in the Sierra Nevada to the San Francisco Bay region. The first bond issue to buy lands was authorized in 1908, and 26 years later, in October 1934, the Hetch-Hetchy water was admitted to the system. The water is carried along a system of 81.9 miles of tunnels and 72.7 miles of pipeline. The Coast Range division of the aqueduct includes a main tunnel 25 miles in length, of which about 14 miles is routed across the Tesla quadrangle. The finished tunnel is 10.5 feet in diameter and has a concrete lining which ranges in thickness from 6 inches to 3 feet. The tunnel is constructed on a grade of about 3 feet per mile and has a capacity of about 250,000,000 gallons of water daily. Five shafts were sunk to the tunnel grade. In the Tesla quadrangle, shafts were located in Arroyo Valle, Arroyo Mocho, and Mitchell Ravine. Another shaft, the Thomas, was located just east of the edge of the quadrangle. From cross-cuts at the bases of the shafts, the tunnel was driven both east and west until segments of the tunnel were joined between shafts. The sinking of the shafts began in the spring of 1927, and the last section of the tunnel was bored through in January of 1934. The cross-cuts at the bases of the shafts were so constructed that a parallel tunnel can be made from these control stations sometime in the future.

The route of the tunnel across the Tesla quadrangle is represented along the line of section H-H′ on plate 2. During the driving of the tunnel some changes in route were made in an attempt to gain better ground, as in the vicinity of Corral Hollow Creek where enormous underground pressures were encountered in the core of a tightly overturned anticline. Through the courtesy of Mr. M. J. Bartell of the San Francisco Engineering Department, the writer was privileged to read the geological reports on the tunnel by Bailey Willis and G. L. Green, and in section H-H′ their tunnel data have been combined with the surface geology. The writer was also allowed to examine the wall-rock samples which are kept in core-sheds in Livermore. The only unusual rock type observed was some crushed granodiorite encountered about a mile east of the Arroyo Valle shaft where it underlies the Livermore gravels.

The character of the formations penetrated in the tunnel and special geological features which were encountered will be brought out in subsequent pages, but a few interesting general facts are presented in this preliminary discussion. The progress in driving the tunnel through the various geologic formations, expressed in terms of feet of tunnel per month, is given in table 1.

*Table 1. Rate of tunnel progress through geologic formations.**

Age or formation	Lithology	Feet per month of tunnelling
Tulare	Sands and blue clay	553
Livermore	Gravels and sands	325
	Clays and shales	130 to 196
Neroly (San Pablo)	Sandstone	475
Upper Cretaceous	Shale	443
	Sandstone	360
Lower Cretaceous	Shale	310
Franciscan	Sandstone and shale	343
	Serpentine and schist	217
	Shattered zones	130 to 236

* After B. Willis.

Mr. Bartell in a discussion with the writer presented some interesting observations on ''working-ground,'' which hampered the driving of the tunnel at numerous places. The squeezing-in process was sometimes slow, extending over 2 weeks, or even several months. Ground moved in from the top or any part of the tunnel circumference, and ground upwellings with sufficient pressure to crumple the concrete floor of the tunnel were common. According to Bartell, there was a release of static pressure as the tunnel face was extended. He estimated that 500 cubic feet of material at the surface would occupy about 499 cubic feet at a depth of 1800 feet underground, and that every cubic foot of material squeezed into the tunnel represented a release of pressure of about 2000 pounds per square inch on about 500 cubic feet of material adjacent to the tunnel. These figures were theoretical, and variations occurred owing to heterogeneity of rock, parting planes, and other causes. Zones of swelling-ground generate considerable heat by friction, and Bartell, using a friction factor of 0.3, computed that working ground should show a temperature rise of about 15 degrees Fahrenheit through the loss of 2300 feet head in friction. Accordingly, during the driving of the tunnel, temperature observations were made, and a rise of temperature often served as a forewarning of working-ground in time to reenforce the timbering in the tunnel. The temperature at the bottom of the shafts averaged 64 degrees Fahrenheit, the average wall-rock temperature was 70 to 76 degrees Fahrenheit, and that of working-ground about 85 degrees Fahrenheit. The tunnel ventilating system, which removed about 14,000 cubic feet of air per minute at 4 pounds pressure per square inch, provided a means of measuring the heat removed from the tunnels. About 6,000,000 B.t.u. of heat was taken from the tunnel daily, and Bartell estimated that for every cubic foot of ground squeezed into the tunnel there were generated 240,000 B.t.u. of heat.

STRATIGRAPHY

General Statement

A variety of rock types and a stratigraphic section typical of the California Coast Ranges are present in the Tesla quadrangle. Sedimentary rocks predominate and include many interesting varieties, such as radiolarian cherts, manganiferous cherts, white quartz sands, coal, tuff, blue opaline-coated sands, and andesitic boulder conglomerates. Igneous and metamorphic rocks are confined to areas of Franciscan rocks in the southern part of the quadrangle.

The formations range in age from Jurassic to Recent. Some of the formations that are present in one part of the area are absent in other parts, and nowhere in the quadrangle do all of the formations occur in a complete stratigraphic sequence. The accompanying chart (fig. 2) presents a composite columnar section. All of the formations, except the Tesla and Moreno Grande, have been named by previous workers and are briefly described in the *Lexicon of Geologic Names of the United States* by Wilmarth.[17]

Jurassic System

Franciscan Formation and Related Igneous Rocks

The oldest rocks in the Tesla quadrangle are comprised in the Franciscan formation of Jurassic age. Sedimentary rocks consisting of sandstone and some shale and chert constitute the bulk of the formation, and limited occurrences of typical Franciscan metamorphic and volcanic rocks complete the group. Associated with these rocks are intrusions of diabase, basalt, and serpentinized gabbro and peridotite.

In mapping the Franciscan an attempt was made to differentiate areally the occurrences of the several rock types, to interpret the general regional structure and to zone or group the rocks stratigraphically. Those areas which consisted of a monotonous succession of beds of sandstone, shale, and chert were mapped in a rapid but detailed reconnaissance manner; more detailed observations were attempted in the more interesting and critical areas, such as the borders of serpentinized intrusions, areas of glaucophane schist, and fault zones, and along contacts with younger formations.

Distribution and Thickness. The Franciscan formation and related intrusive rocks comprise most of the southern half of the Tesla quadrangle and extend into adjacent quadrangles. A bottom to the formation is not exposed, nor can a top be distinguished. Difficulty was experienced in attempting to interpret a stratigraphic section across the folds and faults which involve the Franciscan rocks because of the following conditions: absence of marker beds of distinctive lithology or fossil content; lack of distinctive variation or grouping of the lithology vertically in the section; and general discontinuity of outcrop. Consequently, an attempt to measure a stratigraphic section in these rocks was abandoned. The thickness of the sediments, as obtained graphically from cross-sections E-E′ and H-H′ (pl. 3), is about 12,000 feet. Tolman[18] reported a section of 15,000 feet of Franciscan sediments in this area, and divided the section into three members. He took a dense bluish-gray arkosic sandstone in Corral Hollow Creek as the lower part of the section, the "Corral Hollow shales" with folded and crumpled cherts as the middle member, and the "Oak Ridge sandstone" as the upper member. As Oak Ridge is a divide in the northwest corner of the Mt. Hamilton quadrangle, Tolman probably extended his section into this area adjoining on the south. In the Tesla area sandstone is the predominant rock type throughout the section of Franciscan rocks; it is not characteristic only of the upper and lower portions. Likewise, shales and cherts occur throughout the section as interbeds in the sandstones, and although more numerous in

[17] Wilmarth, M. Grace, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, 1938.

[18] Tolman, C. F., and others, Nature and science on the Pacific Coast, San Francisco, Paul Elder and Co., 1915.

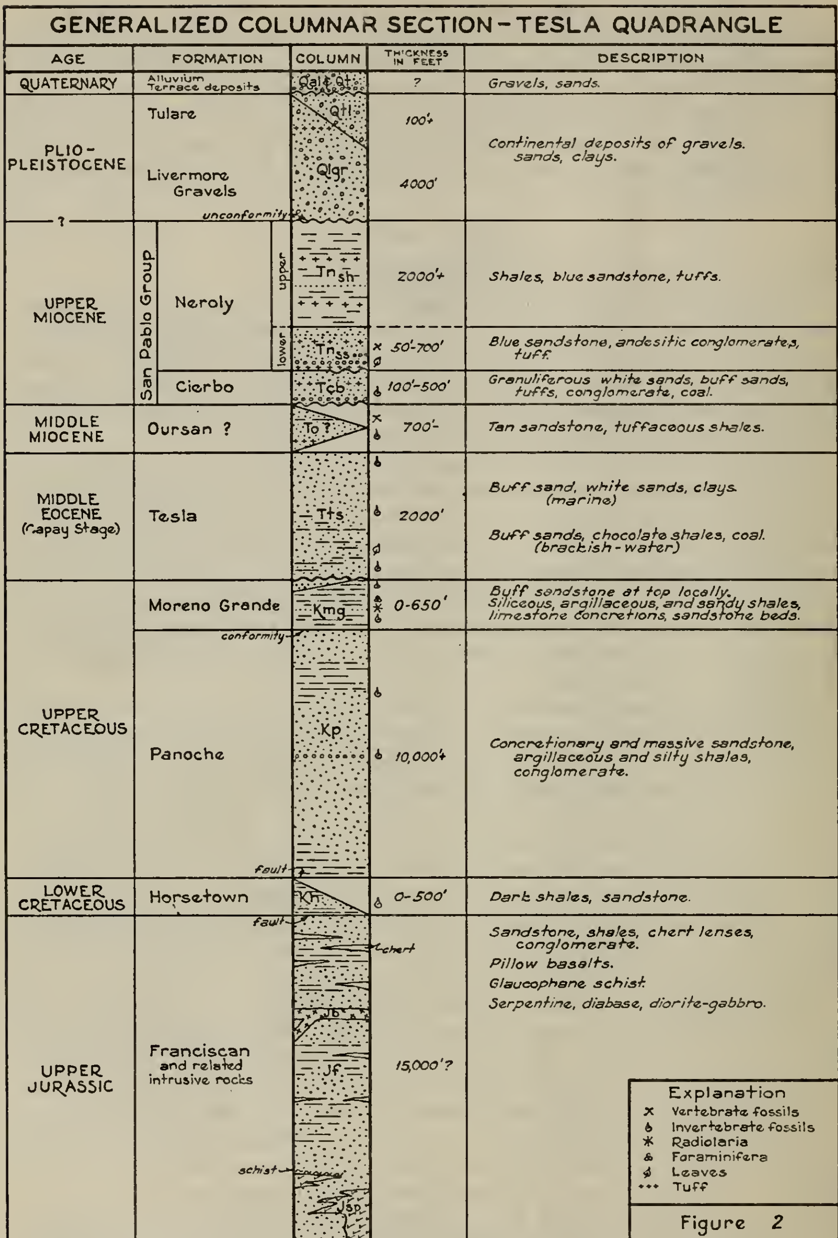

FIGURE 2. Generalized columnar section, Tesla quadrangle.

the middle portion of the section, they are subordinate and do not constitute a special grouping. For these reasons, Tolman's divisions are not recognized in this report, and the section of Franciscan rocks is left undivided.

Lithology. Sandstone is the principal sedimentary rock, comprising approximately two-thirds of the Franciscan formation. In outcrop it is characteristically massive, highly jointed and weathered. It is bluish to greenish gray, weathering to greenish brown and buff, well indurated and cemented, frequently cut by quartz veinlets and less commonly by calcite veinlets. Medium grain-size is predominant over coarse or fine. Angularity of grain, denseness of the rock, and an abundance of fresh plagioclase feldspar are characteristic features. Quartz is the predominant mineral of the sandstones averaging about 50 percent of the whole, orthoclase is common and constitutes 10 to 20 percent of the sandstone, fresh oligoclase and oligoclase-andesine are characteristic and may total 20 percent or more of the mineral assemblage. Muscovite is common, green or brown biotite is usually present, and hornblende and augite are sparse or absent. Minor constituents are magnetite, zircon, pyrite, titanite, and epidote. Calcite is prominent among the secondary minerals along with chlorite, zoisite, and sericite. Fragments of carbonized wood are found rarely in the sandstone in this area. Davis [19] and Taliaferro [20] have presented chemical analyses of Franciscan sandstones which indicate a relatively low percentage of silica and a high percentage of soda and potash as compared with the analyses of other sandstones. The high soda content was probably a contributive factor in the formation of glaucophane schist from the sandstone by pneumatolytic metamorphism. Taliaferro points out that chemical analyses of Franciscan sandstones correspond closely with that of granodiorite, which may have been the main source rock for the sediments.

Shale, though inconspicuous in outcrop, probably comprises about 30 percent of the formation, judging from its abundance in the wall-rock samples from the Hetch-Hetchy tunnel. It is generally dark in color—gray, green, brown, or red—and hard, silty, locally argillaceous or siliceous. A slate-like character, probably induced by depth of burial, was possessed by many of the shale samples examined from the Hetch-Hetchy tunnel. Rhythmic alternation of thin bands of shale and chert is common and in such groupings the shale is generally quite siliceous. Fragmentary carbonized plant remains are rare. Shales range throughout the formation interbedded with sandstone and chert, and in no portion of the section are they thick enough to allow stratigraphic grouping or mapping as a unit.

Streamer-like lenses of chert are common throughout the formation and may constitute as much as 5 percent of the formation. Some of these lenses of chert have been represented diagrammatically on the geologic map in order to illustrate the nature of their distribution. A few lenses are traceable for more than a mile. Some are as much as 100 feet thick, but few are thicker. Massive cherts, which are more common than the bedded cherts, are light green, gray, or white in color. Most of the bedded cherts are red, but some are gray in color. They are separated by thin

[19] Davis, E. F., The Franciscan sandstone: Univ. California, Dept. Geol. Sci. Bull., vol. 11, pp. 1-44, 1918.

[20] Taliaferro, N. L., Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, pp. 109-219, 1943.

shale partings. Red cherts in proximity to pillow basalts are particularly well developed in Arroyo Valle south to the Devil's Hole in secs. 3 and 10, T. 5 S., R. 3 E. Many of the bedding surfaces of the thin-bedded red cherts show an intricate network of quartz veinlets. In places some of the bedded cherts show a strong wavy contortion of the bedding, probably caused by structural deformation prior to final consolidation of the cherts. In a thin-section of red chert, several radiolarian tests were observed in the form of round specks of clear silica in a microgranular matrix of chalcedonic silica colored red by iron oxide. Davis [21] pointed out that the term "radiolarian chert" is somewhat misleading, as the contained radiolaria constitute only a fraction of the whole siliceous rock, and that an additional source for the silica of the cherts must be considered. In places the cherts are manganiferous, and locally low-grade manganese deposits are present in intimate association with chert. Other features shown by the cherts include veining, rhythmic banding, intricate brecciation, and metamorphism into glaucophane schist. The cherts occur in lenses throughout the formation and it is not possible to group them into one or two divisions that might correlate with the Ingleside and Sausalito cherts of Lawson's [22] five divisions of the Franciscan rocks in the San Francisco area.

Lenses of conglomerate are very restricted in occurrence, and nowhere in the area did conglomerate constitute a mappable unit. Most of the pebbles are less than an inch in diameter, but cobbles up to 4 inches in diameter were seen in places. Most of the pebbles are of varicolored cherts, sandstone, and shale, probably re-worked from other portions of the formation, so that the conglomerates in this area are chiefly intraformational in type. Pebbles of granite, quartzite, and porphyritic rocks, which have been noted elsewhere by Davis and Taliaferro and regarded as possibly having been derived from older formations, were not observed. Taliaferro [23] reports that the Franciscan conglomerates are coarser and more abundant in the western part of the central Coast Ranges, indicating a western source for the material.

A few thin lenses of limestone enclosed in shale and chert were observed, but they are of very limited occurrence.

Sedimentary features observed in the Franciscan rocks as they occur in the Tesla quadrangle seem to support the conditions of sedimentation described by Taliaferro.[24] He pictures the deposition of the Franciscan sediments in a shallow geosyncline that developed in a depressed area west of the ancestral Sierra Nevada following the Nevadan orogeny in upper Jurassic time. Reed [25] held that this geosynclinal basin was divided into two separate basins by a landmass called "Salinia", but Taliaferro [26] presents evidence against the existence of "Salinia" until late in the Cretaceous. In this sinking geosynclinal basin, a great thickness of shallow marine clastics, and chemical and organic sediments accumulated.

[21] Davis, E. F., The radiolarian cherts of the Franciscan group: Univ. California, Dept. Geol. Sci. Bull., vol. 11, pp. 235-432, 1918.

[22] Lawson, Andrew C., U. S. Geol. Survey, Geol. Atlas, San Francisco folio (no. 193), 1914.

[23] Op. cit., p. 140.

[24] Taliaferro, N. L., Geologic history and structure of the central Coast Ranges of California: California Div. Mines Bull. 118, pp. 119-162, 1941. . . . Geologic history and correlation of the Jurassic of southwestern Oregon and California: Geol. Soc. America Bull., vol. 53, pp. 71-112, 1942. . . . Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull. vol. 27, pp. 109-219, 1943.

[25] Reed, Ralph D., The geology of California, Am. Assoc. Petroleum Geologists, 1933.

[26] Op. cit., 1943, pp. 125-129.

No suggestion as to the probable direction of source for the detrital material is obtained in the Tesla quadrangle, but in other areas Taliaferro has observed a general westward coarsening of some of the Franciscan sediments, indicating a principal western source. The source area is pictured as a rugged highland composed of granodiorite, crystalline schists, quartzites, recrystallized black cherts, and quartz and feldspar porphyries. The lower slopes of the land area were probably well wooded, and after forest fires detrital carbonized wood was supplied to the basin of sedimentation. Rigorous climatic conditions, characterized by heavy rainfall and cold temperatures in the highlands, supplied large swift-flowing rivers with great quantities of unaltered detritus to be transported to the basin. Interspersed with the clastic sediments thus accumulating in the marine basin, were chemical and organic sediments in the form of foraminiferal limestone and radiolarian cherts. Davis,[27] after extensive studies of the cherts, favored the hypothesis that the cherts were formed through the chemical precipitation of colloidal silica belched from submarine volcanic springs. He regarded the radiolarian tests which are sparsely disseminated through some of the cherts as merely entrapped fossils, and not the primary source of the silica for the cherts. He also suggested that the rhythmic bedding of the shales and cherts may have been caused by a diagenetic segregation of silica and silt particles intermixed in a colloidal ooze. Widespread vulcanism was active especially in the later stages of Franciscan sedimentation, resulting in the outpouring of pillow basalts and andesites and in the intrusion of dikes, sills, plugs, and laccoliths. No record of the black shale deposition (Knoxville), which according to Taliaferro followed the Franciscan sedimentation in the same basin, was observed in the Tesla quadrangle.

Metamorphic rocks are of very restricted occurrence, and nowhere in the area do they define a complete border around an igneous body. Glaucophane schist, the most characteristic type, is generally found as a narrow band along a portion of the upper contact of a serpentine mass. However, some isolated masses of glaucophane schist occur peculiarly in localities where no igneous rocks are exposed but where there may be subjacent igneous bodies. Glaucophane schist derived from sandstone, shale, or chert is observable in the field, and the contact between schist and unaltered sedimentary rock may be quite sharp. Microscopic examination of a thin-section that was cut across such a boundary showed that the sharpness was retained even under magnification. Although a variety of metamorphic rocks was found, all of the types that were seen had been described from the Franciscan by previous workers. Ten thin-sections were made and examined, and the following types were recorded: glaucophane-muscovite schist, glaucophane-quartz-biotite schist, glaucophane-quartz-epidote schist, glaucophane-antinolite-muscovite schist, antinolite schist, tremolite schist, quartz-mica schist, and albite-glaucophane schist. These schists were probably developed by local pneumatolytic metamorphism marginal to or near basic intrusions. Taliaferro [28] reviews the several theories on the mode of origin of these schists and presents evidence to show that their formation probably required the introduction of some soda, magnesia, alumina, lime, water, etc., into the rocks undergoing alteration.

[27] Davis, E. F., The radiolarian cherts of the Franciscan group: Univ. California, Dept. Geol. Sci. Bull., vol. 11, pp. 402-408, 1918.

[28] Op. cit., 1943.

Some of the igneous rocks were formed contemporaneously with the sediments and are to be considered as part of the formation. These include the pillow-basalts, which were observed in the Arroyos Mocho and Valle. The rocks are dark brownish green, dense, and aphanitic. Alteration is generally well advanced, and in many of the thin-sections of these rocks the groundmass cannot be resolved for study under the microscope. The groundmass is commonly finely crystalline and composed of minute lath-shaped basic feldspars and grains of augite and magnetite. Phenocrysts of altered feldspar are uncommon. In outcrop the basalts are greatly jointed, fractured, and cut by numerous veinlets of calcite and quartz. The pillow-structure is poorly developed; the spheroids range from 1 to 3 feet in their greatest axial dimension. Rocks of this type are generally regarded as representing submarine lava flows.

Two small volcanic necks of basalt occur in the Arroyo Mocho in the NW ¼ sec. 32, T. 4 S., R. 4 E., and a large intrusive mass of basalt almost half a mile in areal extent occurs on the north side of Lang canyon near where it enters Arroyo Valle in sec. 29, T. 4 S., R. 3 E. Glaucophane schist is developed locally around the border of the large basalt mass.

Numerous large and small intrusive masses of serpentinized rocks occur in a southeastward-trending belt in the central southern part of the quadrangle. In outline they range from relatively small kidney-shaped or boat-shaped bodies, through a nearly circular mass measuring about a mile in diameter on Cedar Mountain, to irregular elongate intrusions measuring from a quarter of a mile to a mile in width and up to 4 miles in length. The rocks are bluish black to light bluish green, massive to nodular, internally sheared, and possessed with greasy or dull earthy lustre. Bastite and antigorite are the chief varieties and they are locally cut by veinlets of fibrous chrysotile. The serpentine was derived from the alteration of basic and ultrabasic rocks such as peridotite, pyroxenite, and gabbro. One sample of parent rock, which was classified in the field as a pyroxenite, under the microscope was seen to be composed chiefly of hypersthene. Powdery brick-red soil and a dense brush cover characterize large portions of the serpentinized areas. Some occurrences of silica-carbonate rock were noted in the serpentine in fault zones. Some deposits of good-grade magnesite and low-grade chrome ore, which are developed locally in the marginal portions of the serpentine bodies, as at Cedar Mountain, have been prospected and mined.

All of the structural relationships of the serpentine bodies are not clear, but the intrusions seem to be rudely sill-like or laccolithic. In places, however, the outlines of the serpentine masses cut irregularly and directly across the strike of the sedimentary beds. In general the serpentine belt parallels the axes of the folds in the Franciscan rocks, and in places the serpentine is in fault contact with Cretaceous rocks. These basic intrusions were probably emplaced before the sediments in the basin of deposition were deformed into folded and faulted structures, for the serpentines apparently are involved in these structures. The process of serpentinization of the basic and ultrabasic rocks probably took place near the close of or immediately following the magmatic intrusion.

The finding of what appeared to be hornblende-quartz diorite as float in the Arroyo Valle greatly interested the writer during the mapping, for the rock was apparently being derived from an area of Franciscan rocks—yet it seemed unlike the rock types usually described from the Franciscan. Tracing the float upstream led to the discovery of two interesting intrusive bodies, one of which is located in the NE ¼ sec. 32, T. 4 S., R. 3 E., and the other near the common north corner of secs. 3 and 4, T. 5 S., R. 3 E. Instead of being parts of a plutonic body of coarse-grained rock as anticipated, the intrusives are mainly composed of diabase and include large blocks of coarse-grained hornblende-quartz gabbro and hornblende-quartz diorite. Dr. Cordell Durrell, University of California at Los Angeles, who made a field trip with the writer to observe these rocks expressed the opinion that late in the stage of solidification of the diorite-gabbro magma the rocks had become auto-brecciated into blocks which were caught up in the still fluid phase of the magma as it invaded the Franciscan rocks and solidified as diabase. A number of thin-sections of these rocks were examined. A fine-grained, dark-gray rock, which was microscopically determined as uralite diabase, is typical of the main part of the intrusives. The rock is holocrystalline and consists of a coarse diabasic intergrowth of laths of bytownite (50 percent) and uralite (48 percent), a pale green amphibole with some of the crystals showing wormy cores of diopside and included small basal sections of hornblende crystals. Also found in the section were traces of interstitial quartz, iron minerals, and chlorite. After microscopic examination one of the blocky inclusions in the diabase was named hornblende-quartz gabbro. The rock is hypidiomorphic granular, and the grains average 2 millimeters in size. It consists of the following minerals: bytownite (55 percent), green hornblende (40 percent), quartz (3 to 5 percent), titanite, iron minerals, chlorite, and epidote. The bytownite has the following optical properties: 2V of 80 degrees, negative sign, symmetrical extinction angle of 40 degrees, average refractive index of 1.57, and twinning according to the albite, pericline, and Carlsbad laws. Two other thin-sections of the included phase were of coarse hornblende gabbro, consisting chiefly of green hornblende (70 percent) and bytownite (30 percent). One particularly interesting section was that of a hornblende-quartz diorite. The rock is hypidiomorphic granular; average grain size is half a millimeter. It consists of the following minerals: labradorite (45 percent), pale green hornblende (50 percent), diopside (1 percent), hypersthene (less than 1 percent) quartz (3 percent), and some minor secondary and accessory minerals. Some of the laboradorite crystals possess outer zonal rims of orthoclase and oligoclase, suggesting an interruption of the process of crystallization. Some of the hornblende crystals show poikilitic inclusions of and indentations by plagioclase crystals. That there has been some uralitization is suggested locally by amphibole rims around pyroxene cores. A few minute veinlets of serpentine cut through the section. This rock is also interesting because of dark-gray, fine-grained, autolithic segregations about an inch in diameter. The boundary of these segregations is not sharp, and aside from a paler aspect to the hornblende and a finer texture, their composition is identical with the enclosing phase. Cutting the diabase-gabbro intrusions in numerous places are 3-inch to 1-foot veins of serpentine, quartz-albite rock, and quartz-calcite-barite rock. Glaucophane schist is developed along the western margin of the southernmost diabase intrusive, and both of the intrusives are in fault relationship with Cretaceous rocks along part of their borders.

In the driving of the Hetch-Hetchy tunnel about a mile east of the Arroyo Valle shaft, a rock mass which Bailey Willis classified as shattered granodiorite was penetrated (see section H-H′, pl. 3). This rock is not exposed at the surface, being covered by a thick mantle of gravels.

Crushed grains from a crumbly sample of this rock were examined in index oils under the microscope and the following minerals were recognized: quartz, kaolinized and sericitized orthoclase, oligoclase-andesine, and badly chloritized and altered hornblende (?). The proportion of these minerals in the poor sample obtained by the writer was not determinable, so that the classification of the rock as granodiorite could not be confirmed. No such rock has ever been described from the Franciscan. The rock mass occurs along a projection of the Valle fault and is probably in fault-contact with Cretaceous rocks in depth. However, it is not known whether the granodiorite is intrusive into or faulted into the Franciscan rocks. If intrusive, this occurrence may be similar in type to the aforementioned diabase-gabbro intrusions which occur about 3 to 4 miles to the southeast; that is, rather than representing the shattered cupola of a granodiorite intrusive mass, it may be a large blocky inclusion in a diabasic intrusive.

Along the Tesla fault-zone in Corral Hollow and again near Carnegie a dike rock of feldspar porphyry occurs. The rock is badly weathered and fractured, and its structural relationship to other Franciscan rocks in the vicinity is not clear. In thin-section the matrix, which cannot be clearly resolved under the microscope, consists of a fine granular aggregate of feldspar and altered pyroxene (?). Cloudy phenocrysts, which are 2 to 3 millimeters in length, are of altered plagioclase showing albite twinning. This rock is of interest, as somewhat similar porphyries are found in some Franciscan conglomerates and in a prominent Cretaceous conglomerate on Rocky Ridge in the central western portion of the the area; however, it is not suggested that this local occurrence of dike rock served as a source for any of these conglomerates.

Structure. The dominant regional structures involving the Franciscan rocks are a series of long northwestward-trending folds that are complicated by faulting and igneous intrusions. Underground in the walls of the Hetch-Hetchy tunnel, countless faults and fracture planes are observed that are not in evidence at the surface. In the vicinity of Corral Hollow, the tunnel bored through a tight overturned anticline which was so intricately fractured and compressed in its axial portion that enormous pressures and moving ground greatly interfered with the progress of the tunnel. The Franciscan rocks are separated from the Cretaceous by three major faults, the Tesla, the Williams, and the Valle faults. The only younger formation which is in depositional contact with the Franciscan is the Plio-Pleistocene Livermore gravels. In Arroyo Valle a down-dropped fault-wedge of Cretaceous rocks occurs within the general area of Franciscan rocks. A generalized interpretation of the structures involving the Franciscan rocks is shown in the cross-sections E-E′, F-F′, G-G′, and H-H′ (pl. 3).

Age. The Franciscan is a difficult group of rocks to which to assign an age, because of: (1) the general absence of megafossils; (2) the unidentifiable character of contained radiolaria, foraminifera, and carbonized plant and wood fragments; (3) the lack of a discovered base to the formation; and (4) a generally faulted relationship to younger formations. No important contribution to the problem of the age of the Franciscan was found in the Tesla quadrangle. However, if a conclusion were drawn from the general stratigraphic relation of the rocks and their degree of induration, alteration, and deformation as compared with the formations of established age, it could be said that the rocks appear to be definitely older than Upper Cretaceous and at least as old as and probably older than Lower Cretaceous.

Taliaferro [29] has concluded that the Franciscan is confined to a comparatively short space of geologic time, probably Tithonian, Upper Jurassic. He reported the finding in 1936 of an ichthyosaur snout in a boulder of red radiolarian chert in the Carbona quadrangle (adjoining Tesla on the east) by Neil Smith, then a graduate student at the University of California. Although the boulder was found in a Tertiary conglomerate, the petrography of the chert and the associated radiolaria were interpreted by Taliaferro as Franciscan in type. In 1940 a second ichthyosaur snout was found in a similar boulder in Recent stream gravels in El Puerto Creek west of Patterson, California. The two ichthyosaur snouts were described by C. L. Camp,[30] who concluded that they were practically identical with Tithonian Upper Jurassic ichthyosaurs of Europe and with certain questionably Lower Cretaceous forms from Australia. Although the evidence of the age of the Franciscan as probably Tithonian Upper Jurassic from the ichthyosaur snouts is indirect, it constitutes the best fossil evidence to date.

Cretaceous System

Horsetown Formation

Rocks of the Horsetown formation (Lower Cretaceous) occur in two fault-wedge blocks along the Tesla fault zone on the south side of Corral Hollow. The larger wedge, which is narrow and lenticular in outline, is traceable for about 2 miles east and west across the northern parts of secs. 34 and 35, T. 3 S., R. 3 E. In this occurrence the rocks reach their maximum thickness of about 500 feet. The smaller wedge occurs near the east quarter corner of sec. 36, T. 3 S., R. 3 E. Other small masses of these rocks may occur along the fault zone, but unless fossils are found the lithology is not readily distinguishable from that of the Franciscan rocks.

Lithology. Dark-gray to almost black, hard, nodular, and concretionary shales are the dominant lithologic type in the Horsetown formation. Fossils are occasionally found in the limestone or sandstone concretions. Buff, fossiliferous, fine-grained sandstone characterizes the easternmost occurrence.

[29] Op. cit., 1943, pp. 190-195.
[30] Camp, C. L., Ichthyosaur rostra from central California : Jour. Paleontology, vol. 16, pp. 362-372, 1942.

Table 2. Checklist of Horsetown fossils.

	Localities Corral Hollow	12
Pelecypoda		
Pecten operculiformis Gabb	X	X
Pecten sp.		X
Cephalopoda		
Desmoceras (Holodiscus) cf. theoboldiencis Stoliczka	X	
" " lecontei Anderson	X	
" " papillatus Stoliczka	X	
Phylloceras shastalense Anderson	X	
Sonneratia rogersi Hall and Ambrose	X	C
Scaphopoda		
Dentalium	X	

X = present
C = common

Fauna and Correlation. Fossils of Horsetown age were found in Corral Hollow by the Stanford Geological Survey, and a list of the fossils is included in table 2. The writer found only two poor specimens in Corral Hollow; but at locality No. 12, at the side of a road in the NE¼ sec. 36, T. 3 S., R. 3 E., several well-preserved specimens of a small distinctive ammonite, *Sonneratia rogersi,* were found along with some pectens.

Dr. F. M. Anderson, who identified the fossils from locality 12, regarded them as a cool-water fauna and classified them as upper Horsetown (Lower Cretaceous) in age.

Relation to Adjacent Formations. The small eastern mass of Horsetown rocks appears to be a fault-wedge between the Franciscan and Panoche formations along the Tesla fault. In Corral Hollow the shales have a vertical attitude and are separated from the Franciscan by the Tesla fault zone. The upper contact with the Panoche formation of Upper Cretaceous age is not exposed but is characterized by a spring and a hummocky furrow on the west side of the canyon. This contact is interpreted as a fault, which is possibly related to the Tesla fault.

Panoche Formation

The Panoche formation (Upper Cretaceous) was first mapped across the northern part of the Tesla quadrangle by Robert Anderson and R. W. Pack [31] assisted by E. L. Ickes. They recognized that the formation as they mapped it locally included strata of Lower Cretaceous age (Horsetown formation of this report), which by more detailed mapping could be differentiated from the Panoche proper. In recent years there has been some tendency to divide the Panoche into different formations or establish new limits for the formation, but there is at the present time no agreement on this problem among stratigraphers. Except for the differentiation of the Horsetown beds, the sense in which the Panoche was originally mapped in this area is retained in this report.

Distribution and Thickness. Strata of Upper Cretaceous age occur in the northern and western parts of the quadrangle. South of Corral Hollow an east-west band is traceable for about 7 miles, the outcrop being from a quarter to more than half a mile wide. These rocks consist principally of massive and concretionary sandstone and minor amounts of shale, attain a maximum thickness of about 2000 feet, and dip steeply northward.

North of Corral Hollow, the axial portions of several anticlines are comprised of Upper Cretaceous rocks. On one of these, the Patterson Pass anticline, the Seaboard Oil Company ''Johnston'' 1 well was drilled to a depth of 5925 feet and abandoned. The well started in sands of the Cierbo formation (upper Miocene) and penetrated Panoche strata from an approximate depth of 95 feet to bottom.

No correlative of the hard conglomerate, which occurred between the depths of 1882 and 1933 feet, is known in the outcrop. However, the hard blue shales in the lower part of the hole are believed to be correlative with some argillaceous shales in the Altamont anticline about 3½ miles to the north.

In the broad Altamont anticline in the northern part of the area a thickness of approximately 7500 feet of Panoche rock is exposed. The

[31] Op. cit.

Summary of log of "Johnston" 1 well[32]

0–95′	sand and shale
95–504′	hard sand, shale streaks
504–1405′	hard shale, streaks of hard sand
1405–1455′	fault gouge and sheared rocks (Patterson Pass fault zone)
1455–1850′	hard blue shale, streaks of hard sand (brecciated zones at 1534 to 1548′, and at 1618–1638′)
1850–1882′	hard coarse gray sandstone
1882–1933′	hard conglomerate and sandstone
1933–5925′	hard dark blue silty claystone and shale, minor streaks of hard sandstone; average dip, about 23°; fragments of *Inoceramus* and *Baculites* found at intervals from 1965 to 3160′

new highway, U. S. 50, which crosses the anticline, has numerous roadcuts which give good exposures of these Cretaceous rocks. Section A-A′ (pl. 3), which represents a transverse section across the Altamont anticline, shows the following Cretaceous section:

3500′	buff, massive and concretionary sandstone, minor shale
3000′	argillaceous shales, interbeds of sandstone
1000′ (plus)	massive tan sandstone, becoming pebbly at base

The approximate boundaries of the above lithologic groupings are represented on the geologic map (pl. 1). The top of the section is overlapped on the west limb of the anticline by the Cierbo formation (upper Miocene) and on the east limb by the Neroly formation (upper Miocene), and at the base of the section is not exposed. Since the anticline is plunging southeastward, additional Upper Cretaceous section occurs to the northwest in the adjoining Byron quadrangle. In 1941, Shell Oil Company, Incorporated, "Nissen" 1 well was drilled in sec. 7, T. 2 S., R. 3 E. (Byron quadrangle) to a depth of 6563 feet and abandoned in hard dense siltstone believed to be Upper Cretaceous. The well was located on the axis of the Altamont anticline about 2 miles north of the Tesla quadrangle, and the entire Upper Cretaceous section penetrated by it underlies and supplements the Altamont outcrop-section described above. Hard, dense siltstone characterizes roughly 75 percent of the section encountered in the well and the balance consists of interbeds of hard, impermeable, fine-grained sandstone ranging in thickness from thin streaks up to a maximum of 250 feet.

In Arroyo Valle and along Rocky Ridge in the central western part of the area, an incomplete thickness of more than 9000 feet of Cretaceous rocks occurs dipping about 50° NE. These strata are overlapped by Tertiary strata and the base of the section is cut out by faulting. An approximate section of the Cretaceous rocks on Rocky Ridge is as follows:

4000–5000′	buff, massive to bedded, concretionary sandstone, minor shale and conglomerate
10–50′	conglomerate containing polished, well-rounded pebbles and cobbles
2500′	buff, massive sandstone, minor shale
2000′	shales, sandstone interbeds

The conglomerate in the middle of the section is traceable for more than 2 miles along Rocky Ridge and it continues to the northwest onto the Pleasanton quadrangle. This conglomerate is believed to be intraformational, as the lithology and attitudes of the sediments above and below it are quite uniform.

[32] Published with permission of Seaboard Oil Company.

To the southeast along the east side of Arroyo Valle a fault-wedge block of Cretaceous rocks is completely enclosed by the Franciscan complex. It is estimated that several thousand feet of sandstone and shale are present, but no measurement of the section was attempted. A conglomerate containing some fossiliferous sandstone boulders was found beside the road on the east bank of Arroyo Valle in the SE¼ sec. 29, T. 4 S., R. 3 E.

Lithology. Sand and sandstone probably characterize more than 60 percent of the Panoche sediments in this area. The sandstones are gray, weathering to tan or buff, fine to medium grained, massive to bedded, and often concretionary. The concretions are dark reddish brown, hard, cemented with iron oxide, ellipsoidal or spheroidal in shape, and range in size from a few inches up to 6 feet or more in diameter. Several heavy-mineral separations were made of representative samples of the sand and examined under the miscroscope. The mineral content of these samples was found to be similar, and their average composition as follows: the light minerals were identified as quartz (30 percent), altered orthoclase (60 percent), oligoclase-andesine (5 percent), biotite (5 percent), and muscovite (trace). The grains are angular, and the sorting is only fair. The heavy minerals, which comprise about one-tenth of one percent of a separation, consist of the following: magnetite, (abundant), ilmenite (common), zircon, brown tourmaline, green hornblende, rutile, zoisite, colorless garnet, and hematite. All but the first two heavy minerals are present in very small amounts. The general mineral assemblage suggests derivation from a source area of granitic rocks.

The shales are typically blue gray, weathering to brown, argillaceous to silty, thinly bedded, and locally concretionary. They weather to a deep soil-cover and are expressed by a smooth, subdued relief. Any organic content of the shales is inevident, and no foraminifera-bearing shales were found, although the hand lens was freely employed at shale outcrops and a number of trial washed samples were examined under the microscope.

Conglomerates are very uncommon among the Upper Cretaceous rocks in the area, and the only prominent bed of conglomerate occurs on Rocky Ridge in the central western part of the area. The Rocky Ridge conglomerate contains well-rounded highly polished pebbles and cobbles set in a plentiful matrix of buff sandstone. The cobbles range from about 2 to 5 inches in diameter. Some of the cobbles, such as those consisting of limestone, shale, and dark-brown concretionary sandstone, are sub-rounded, lack the high polish of the other cobbles, and probably represent the re-working of somewhat earlier Upper Cretaceous rocks. The polished and well-rounded cobbles apparently were derived from a distant and older source rock. They consist of dark-gray sandstone and quartzite, quartz and feldspar porphyries, black chert, quartz, and aplite. About a dozen thin-sections were made of this second group of cobbles, and a brief description of the petrography follows. The sandstone making up a majority of the cobbles is gray to dark gray, fine to coarse grained, poorly sorted, angular grained, well indurated and cemented. In thin-section the average mineral assemblage of the sandstone cobbles consists of quartz (60 percent), altered orthoclase (25 percent), oligoclase (10 percent), biotite (less than 3 percent), augite (trace), and hornblende (trace). Minor accessory minerals include titanite, zircon, magnetite, and apatite; secondary minerals include calcite, zoisite, epidote, chalcedony, kaolin minerals, sericite, and chlorite. The sandstones are noticeably more quartzose and less feldspathic than the average Upper Cretaceous or Franciscan sandstone. Examination of a thin-section of a quartz porphyry cobble showed that the phenocrysts make up about 10 percent of the field, reach a maximum of 2½ millimeters, and consist chiefly of euhedral basal sections of quartz and a few prisms of orthoclase and oligoclase. The groundmass is a finely crystalline aggregate of quartz and orthoclase clouded by alteration. There is some accessory magnetite, and the secondary minerals include chlorite after biotite, iron minerals and kaolin. The rock is evidently hypabyssal in origin. Another rock variety determined is a feldspar porphyry in which small phenocrysts make up 10 percent of the rock and include orthoclase, oligoclase, and microperthite. The ground mass is a microcrystalline aggregate of quartz and feldspar, accessory rutile, and secondary mica, zoisite, and iron minerals. One unusual type is a pitchstone porphyry, which in hand specimen is black in color and has a resinous lustre. The phenocrysts make up 15 percent of the rock, reach a maximum size of 4 millimeters, and consist of embayed euhedral crystals of quartz (30 percent), cloudy orthoclase (25 percent), altered oligoclase (40 percent), and microperthite (5 percent). The goundmass is irresolvable but appears to be devitrified glass with an index of refraction of less than 1.54. In this groundmass there are a few tiny shreds of biotite, specks of magnetite, and a few vesicles that are lined and infilled with chalcedony, tridymite, and finely crystalline quartz. A thin-section of black chert was seen under the microscope to be a minutely brecciated and recemented aggregate of microscopic colorless and black chert particles. Fine quartz veinlets cut across the section.

A heavy conglomerate containing a cobble assemblage similar to that of Rocky Ridge was examined near the axis of the Altamont anticline in sec. 7, T. 2 S., R. 3 E., Byron quadrangle. This locality is about 1½ miles north of the northern edge of the Tesla quadrangle. In addition to the types of cobbles already described, rare quartz-diorite cobbles were found. An unusual feature of this conglomerate was the occurrence of numerous large boulders of hard red-brown sandstone concretions, some of which measured 2½ feet in diameter. As this horizon was traced from the west limb of the anticline around to the east flank, the heavy boulder conglomerate graded into a granuliferous and pebbly gritstone, suggesting a probable western source for the material.

The conglomerate which was penetrated in the Seaboard Oil Company "Johnston" 1 well (sec. 13, T, 3 S., R. 3 E.) between the depths 1882 and 1933 feet was very well indurated and cemented, had a sandstone matrix, and carried rounded pebbles and cobbles (up to 4 inches in diameter) of limestone, shale, sandstone, and quartz.

Conditions of Sedimentation. The Panoche sediments are believed to have accumulated in a shallow marine basin. The finding of a few marine fossils in the rocks supports the concept of a marine environment. The general uniformity of the lithology from the lower part to the top of the formation indicates a probable maintenance of the same source for a period long enough for the deposition of many thousands of feet of beds, and may indicate a balance between a slowly subsiding basin of deposition and a slowly rising source area. The laying down of boulder conglomerates marks the interruptions of this balance. The types of cobbles in the conglomerates suggest a re-working of other similar Cretaceous rocks and the introduction of rounded and polished boulders derived from a distant and probably older source rock. A general absence of rock types that are found in the Franciscan and Sur series is to be noted. Turner [33] in writing of Cretaceous conglomerates at Mt. Diablo noted that some of the cobbles were a variety of quartz porphyry which is indistinguishable from a type that is common in the foothills of Calaveras County in the Sierra Nevada. The petrography of the sands and sandstones suggests a source area of granitic rocks. Thus, certain features of the sediments suggest that the Sierra Nevada may have served as the principal source; however, a western source for a least part of the material is suggested by the westward coarsening of the conglomerate of the Altamont anticline in the Byron quadrangle.

Fauna and Correlation. Fossils were found in the Upper Cretaceous rocks in only a few places. The late Dr. F. M. Anderson of the California Academy of Sciences contributed the fossil lists given below.

Table 3. Checklist of some Upper Cretaceous fossils

	Localities		
	X	XI	XIII
Pelecypoda			
Aphrodina nitida (Gabb)		X	
Cucullaea sp.		X	
Glycimeris sp.		X	
Inoceramus cf. vancouverensis Shumard	X		
Mactra ashburneri Gabb		X	
Gastropoda			
Anchura californica (Gabb)		X	
Gyrodes cf. expansus Gabb		X	
Turritella petersoni Anderson		X	
Cephalopoda			
Baculitus chicoensis Trask	X		
Baculites inoratus Meek	X		
Baculites cf. vagina Forbes		X	
Desmoceras colusaense (Anderson)		X	
Desmoceras cf. selwynianum Whiteaves	X		
Lytoceras alamedense Smith	X		
Lytoceras cf. cala (Forbes)	X		
Metaplacenticeras pacificum (Smith)	X		
Metaplacenticeras californicum (Anderson)	X		
Parapachydiscus suciaensis Meek	X		
Parapachydiscus cf. arbucklensis nov.	X		
Parapachydiscus canadoceras sp.			X
Fossil wood containing boring shells (*Turnus* Gabb)		X	

Locality X on the old Jordan ranch is on a small flat on the east side of Arroyo Valle in the SE¼ sec. 11, T. 4 S., R. 3 E. A few fossils were also found on the west side of the creek at approximately the same horizon. J. P. Smith in 1900 published two lists of fossils said to have been found there prior to 1895 by L. G. Yates, a Livermore dentist. Anderson in a personal communication dated February 21, 1939, wrote that some of Yates' fossils must have come from Shasta County and that the lists published by Smith included forms not found at the Jordan ranch locality. Anderson's revised list of fossils from the locality is given in the preceding checklist, and he determined them as lower Senonian in age and representative of the Panoche formation. These fossils occur about 2500 feet above the Rocky Ridge conglomerate.

[33] Op. cit., 1891.

At locality XI in the SE¼ sec. 29, T. 4 S., R. 3 E., two fossiliferous sandstone boulders yielded a fauna distinctly different and older than the assemblage from the Jordan ranch locality. Anderson classified them as Cenomanian and probably correlative with faunas in the lower part of the Chico (his Pioneer group). Anderson (written communication, February 21, 1939) regarded the conglomerate at locality XI and the Rocky Ridge conglomerate as marking the base of restricted Panoche resting unconformably on an older Pioneer group (lower Chico).

Locality XIII is in a railroad cut on the Altamont anticline near the east quarter-corner of sec. 27, T. 2 S., R. 3 E. The large ammonite *Parapachydiscus canadoceras* sp., which was found there in a shale concretion, is indicative of the upper Panoche (upper Senonian), according to Anderson.

Problem of Dividing the Panoche. A division of the Panoche (as originally described by Anderson and Pack [34]) into two component formations, restricted Panoche and Chico, was suggested by F. M. Anderson and G. D. Hanna [35] and by Taff.[36] Later F. M. Anderson [37] proposed the Chico series to replace the Chico group of Anderson and Pack and divided the series into three groups, the Moreno, Panoche, and Pioneer. The latter two groups coincide approximately with the original Panoche formation; the base of the Panoche group was taken at the horizon of some conglomerates containing sandstone boulders with Turonian or older Cretaceous fossils. Taliferro [38] proposed that the Upper Cretaceous strata of the California Coast Ranges be divided into the Asuncion and Pacheco groups separated by an unconformity marking the Santa Lucian orogeny. Under this terminology the upper part of the original Panoche formation was included in the upper or Asuncion group and the lower part relegated to the Pacheco group, excluding any Lower Cretaceous or older strata. In contrast with a pronounced angular unconformity separating the two groups in the Santa Lucia Range, Taliaferro referred to a generally disconformable relationship along the east side of the Diablo Range. The base of the Asuncion group (like the base of Anderson's Panoche group) was taken at some conglomerates containing boulders with Turonian fossils. Taliaferro [39] elaborates further on the occurrence of these conglomerates, stating:

> "It is doubtful that these heavy conglomerates all occur at the same horizon; they are lenses and cannot be traced continuously. They do not represent an unconformity locally, but they definitely reflect an uplift, or uplifts, on the west and the exposure of the early Upper Cretaceous sediments."

Kirby,[40] in writing of the Upper Cretaceous stratigraphy of the west side of the Sacramento Valley, reports that the Chico series there represents both the Pioneer and Panoche groups of F. M. Anderson or the Pacheco and lower Asuncion groups of Taliaferro. However, he was unable to recognize a boundary for such groupings or point to any

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[34] Op. cit.

[35] Anderson, F. M., and Hanna, G. D., Cretaceous geology of Lower California: California Acad. Sci. Proc., 4th ser., vol. 23, no. 1, pp. 1-34, 1935.

[36] Op. cit.

[37] Anderson, F. M., Synopsis of the later Mesozoic in California: California Div. Mines Bull. 118, pp. 183-186, 1941.

[38] Op. cit., 1941.

[39] Taliaferro, N. L., Cretaceous and Paleocene of Santa Lucia Range: Am. Assoc. Petroleum Geologists Bull., vol. 28, p. 485, 1944.

[40] Kirby, James M., Upper Cretaceous stratigraphy of west side of Sacramento Valley south of Willows, Glenn County, California: Am. Assoc. Petroleum Geologists Bull., vol. 27, pp. 279-306, 1943.

significant indication of the Santa Lucian orogeny there. Goudkoff,[41] describing the stratigraphic relations of the Upper Cretaceous in the Great Valley of California on the basis of the microfauna from wells and outcrop sections, shows on a correlation chart that the separation of Anderson's Panoche and Pioneer groups would fall between his G-2 and H zones; but he does not refer to any unconformity, disconformity, or missing foraminiferal zone at this boundary.

The problem of the suggested division of the Panoche requires a proper interpretation of the conglomerates that contain the fossiliferous boulders with Turonian or older fossils. It is evident that more research is needed in both the field and laboratory for a clear understanding of these conglomerates and their stratigraphic relations to the sediments above and below. The problem is not simple, for if there were a prominent conglomerate horizon, traceable throughout most of the Diablo Range and containing fossils reworked from the underlying sediments, Anderson and Pack would have recognized such an important feature and set up their Upper Cretaceous stratigraphy to conform with this break. Instead, they found these conglomerates at no less than three different horizons and they were impressed with the rapid lateral disappearance, in a few thousand feet, of great conglomerate lenses aggregating almost a thousand feet in thickness. Their description of these conglomerates[42] reflects how interested they were in finding a correct stratigraphic interpretation, and they concluded finally that the conglomerates were intraformational. Although numerous references have been made to the finding of Turonian fossils in boulders in the Panoche conglomerates, very few lists of the fossils have been published. Stewart[43] recently published the faunas found in several such fossiliferous boulders from five localities in the Reef Ridge area of the southern part of the Diablo Range, where several beds of conglomerate occur in the upper 2000 feet of the Panoche formation. He reports that the Upper Cretaceous fossils found in the boulders represent a fauna that has not been recognized in any section in the Reef Ridge area. To this writer's knowledge, no one has yet reported finding a Turonian fauna from Panoche sediments in place and clearly underlying a conglomerate horizon containing the fossiliferous boulders. Thus the possibility remains that the fossiliferous boulders were not derived from the strata underlying the conglomerates, but from early Upper Cretaceous rocks that became exposed on the margin of the basin of deposition. Several geologists, among them Anderson and Pack, and N. L. Taliaferro, have expressed the opinion that there is no indication of a break in deposition between the conglomerate lenses and the underlying sediments. Finally, no one has yet reported that he has mapped a contact along the east flank of the Diablo Range that would divide what was originally defined and mapped as Panoche into two separate stratigraphic units. For these reasons this writer believes that the proposed division of the Panoche into separate formations or groups needs further supporting evidence.

As the problem applies to the Tesla quadrangle, the Panoche formation is left undivided, and the several conglomerates, such as the one on Rocky Ridge, are regarded as intraformational for want of evidence to the contrary.

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[41] Goudkoff, P. P., Stratigraphic relations of Upper Cretaceous in Great Valley, California: Am. Assoc. Petroleum Geologists Bull., vol. 29, pp. 956-1008, 1945.

[42] Op. cit., pp. 43-44.

[43] Stewart, Ralph, Geology of Reef Ridge, Coalinga district, California: U. S. Geol. Survey Prof. Paper 205-C, pp. 88-89, 1946.

Relation to Adjacent Formations. The Panoche formation shows several types of relationship to the adjacent formations. It is in fault contact with the Franciscan and Horsetown formations; it is overlain gradationally by the Moreno Grande formation; and it is overlain unconformably by the Oursan(?), Cierbo, and Neroly formations, and the Livermore gravels.

Moreno Grande Formation

Along the south side of Corral Hollow, Anderson and Pack,[44] assisted by Ickes, first mapped and set apart from the Panoche formation a narrow east-trending belt of shale, which they called the Moreno formation because of its resemblance in character and general stratigraphic position to that formation as it exists farther south in the Diablo Range. They postulated that these shales with their organic content were probably the source beds for the oil which occurs in seepages and which was produced on a minor scale from a few wells on the old Hamilton ranch in sec. 15, T. 3 S., R. 3 E. The present writer in 1936[45] and again in 1940[46] followed Anderson and Pack in calling these beds Moreno. Since that time his work in other parts of the Diablo Range along the west border of the San Joaquin Valley and the contributions of other geologists, indicate clearly that the Moreno as originally mapped is more inclusive than the Moreno as originally defined, and that some clarification of the stratigraphic relationships of the Upper Cretaceous in this region is needed. The term Moreno Grande, signifying greater or enlarged Moreno, was first proposed by Huey and Daly in a joint paper read before the Pacific Section of the American Association of Petroleum Geologists meeting at Los Angeles in November 1941.[47] North of Pacheco Pass the Moreno Grande comprises what Anderson and Pack mapped as Moreno and the maximum section is developed at Garzas Creek. Southward to the Coalinga region the Moreno Grande includes the restricted Moreno, the Brown Mountain sandstone, and the *Pachydiscus* silt[48] as members. The top of the underlying Joaquin Ridge sandstone member of the Panoche in this southern area correlates approximately with the top of the Panoche as mapped by Anderson and Pack in the area north of Pacheco Pass. A separate publication is planned to describe more fully the Moreno Grande and to present the basis for the correlations outlined above. That the mapped Moreno north of Pacheco Pass includes equivalents of Upper Cretaceous beds down to the top of the Joaquin Ridge sandstone in the Coalinga region was shown by Goudkoff[49] in a correlation chart based on microfaunal studies. Taliaferro[50] has stated that the proposed Moreno Grande is "the best approach toward the solution of the Moreno problem" that has been presented.

Distribution and Thickness. Only the lower part of the Moreno Grande formation is present in the Tesla quadrangle. It occurs as a narrow east-trending band for about 5 miles along the south side of Corral Hollow. The subdued topographic expression of the formation

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[44] Op. cit.
[45] Huey, A. S., op. cit.
[46] Huey, A. S., The geology of the Tesla quadrangle of middle California, Ph.D. thesis, Univ. California, Berkeley, 1940.
[47] Huey, Arthur S., and Daly, J. W., A discussion of part of the Upper Cretaceous along the west border of the San Joaquin Valley. (Unpublished paper read before the Pacific Section, Am. Assoc. Petroleum Geologists, Oct. 16, 1941.)
[48] Also called Ragged Valley shale.
[49] Op. cit., fig. 2.
[50] Op. cit., 1944, p. 472.

and the dark red-brown soil containing platy shale fragments aid in the delineation of the upper and lower contacts which are generally not exposed. North of Corral Hollow in anticlines which bring Cretaceous rocks to the surface, the Panoche is overlain by sands of the Cierbo formation (upper Miocene) and the Moreno Grande is absent, except for one occurrence in the central western part of sec. 24, T. 3 S., R. 3 E.

The generally poor exposures of the formation were unsuited for the measurement of a section, but the thickness here is estimated to reach a maximum of about 650 feet.

Lithology. The Moreno Grande in this area consists of shale and minor amounts of sandstone. The shales are dark gray to brown, weathering in places to purplish brown and generally supporting the development of a dark brown soil cover. Much of the shale is argillaceous, some is sandy, and thin partings of fine sand are common. In places the shale is carbonaceous and very dark in color. A thin platy variety containing abundant foraminifera is common as platy fragments in the derived soil cover, but few good outcrops are found. Buff-colored limestone concretions occur sparsely in the shales. From one of these concretions a rich radiolarian fauna and an ammonite were obtained. Although the organic content of the shales is probably low, it is judged to be distinctly greater than that of any other shales in the area, as evidenced by the presence of foraminifera, diatoms, radiolaria, fish remains, megafossils, and carbonaceous matter. These shales were probably the source beds for the small amount of oil that was found on the old Hamilton ranch in the S½ sec. 15, T. 3 S., R. 3 E.

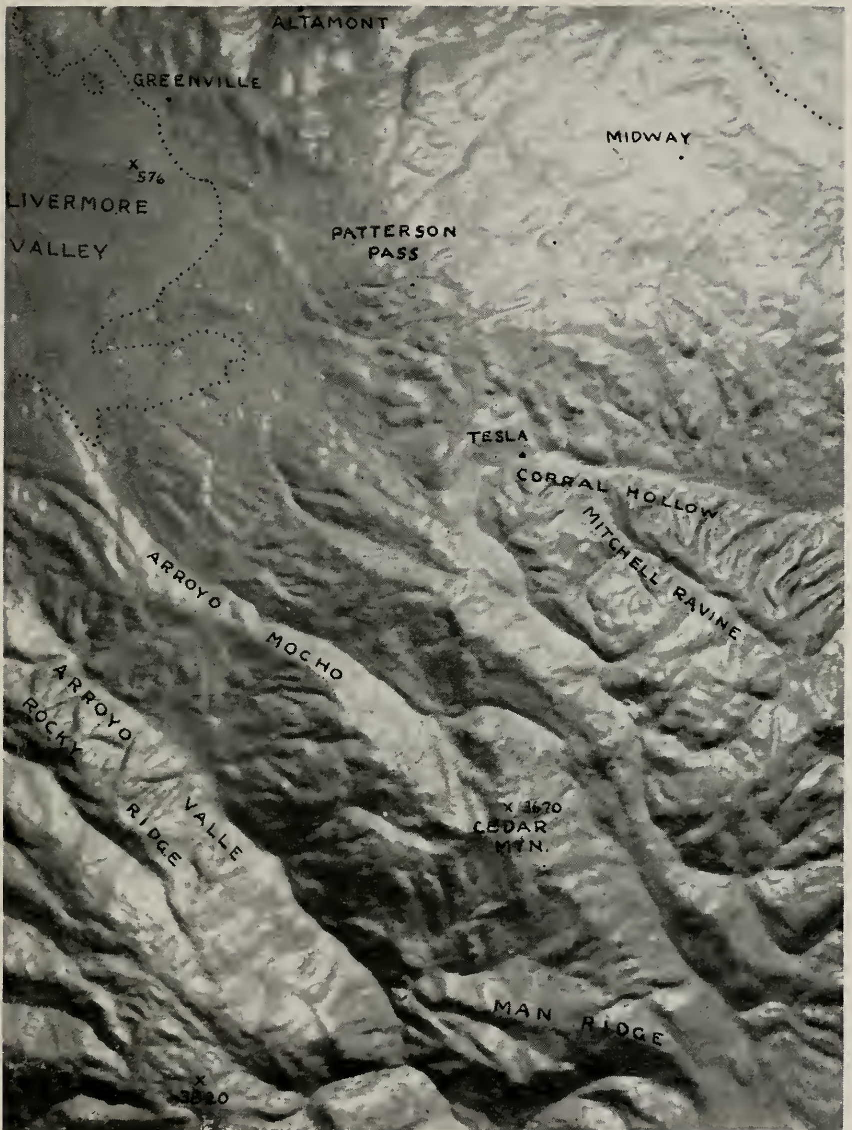
At Tesla and westward for about a mile a massive and concretionary sandstone occurs at the top of the Moreno Grande. The sand is light gray weathering to buff; it is fine grained, massive to concretionary, and locally carries considerable coarse biotite. The exposures of this sand are poor and limited, but it is estimated that a thickness of about 150 feet is developed. This sand is probably older than the Garzas sand.

Fauna and Correlation. The poor exposures of the Moreno Grande were unsuited for the detailed sampling of a section for microfaunal study, but foraminifera were observed in the shales in a number of places. Foraminifera from a shale sample at a locality about 100 feet east of the Tesla road near the center of sec. 27, T. 35 S., R. 3 E. were identified by Dr. A. S. Campbell as follows:

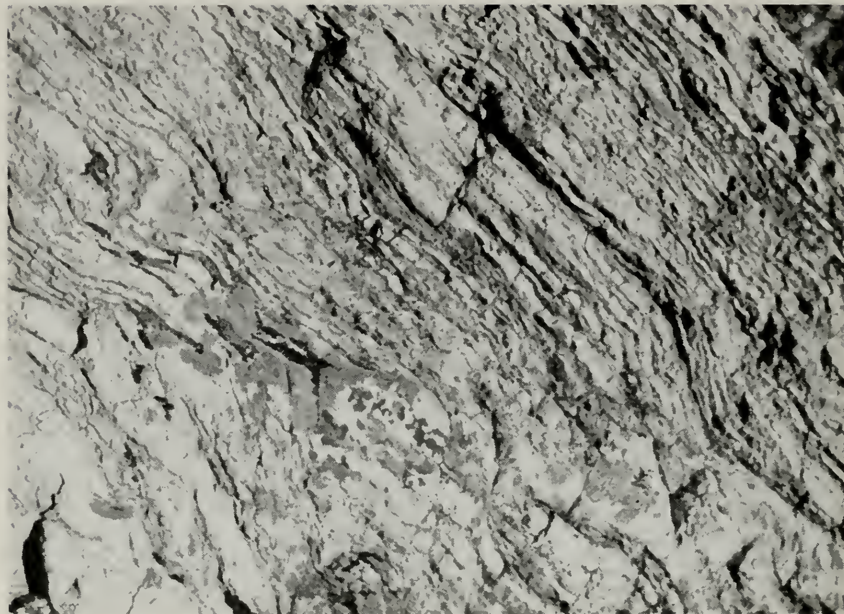
Bulimina obtusa d'Orbigny
Bulimina spinata n. sp. Cushman and Campbell
Eponides umbonella (Reuss)
Gaudryina navarroana Cushman var.
Globigerina cf. triloba Reuss
Globotruncana arca (Cushman)
Gyroidina depressa (Alth)
Nodogenerina lepidula (Schwager)
Nodosaria monile v. Hagenou
Nodosaria spinifera Cushman and Campbell
Nodosaria sp. (smooth)

A few radiolaria were also present in the sample. The above fauna would appear to fall in Goudkoff's D-2 zone[51] and be correlative with the *Pachydiscus* silt of the Coalinga region.

[51] Op. cit., range chart, pp. 968, 969.



RELIEF MAP OF TESLA QUADRANGLE
Showing important place names. Photograph of a plaster relief model in the Geological Museum of the University of California, Berkeley.



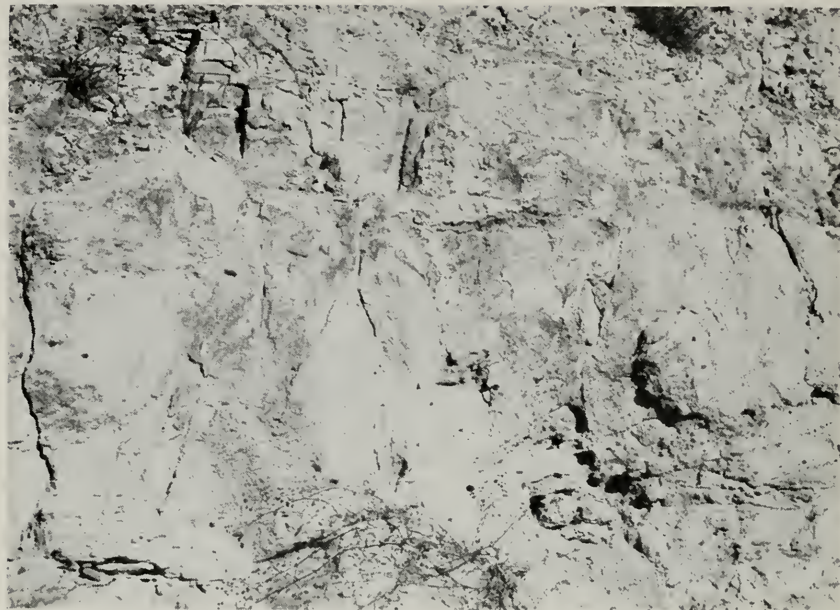
A, BEDDED FRANCISCAN CHERT IN ARROYO MOCHO.

B, PILLOW STRUCTURE IN FRANCISCAN BASALT
Along Arroyo Mocho road in sec. 13, T. 4 S., R. 3 E., M.D.

A, OUTCROP OF WHITE SAND OF TESLA FORMATION IN CORRAL HOLLOW

Leaves are present in the carbonaceous shales to the left of the white sand. Note the truncation of the overturned beds by a terrace. Looking west, in northern part of sec. 33, T. 3 S., R. 3 E., M.D.

B, COPY OF OLD PHOTOGRAPH SHOWING TESLA MINING CAMP, ABOUT 1910.

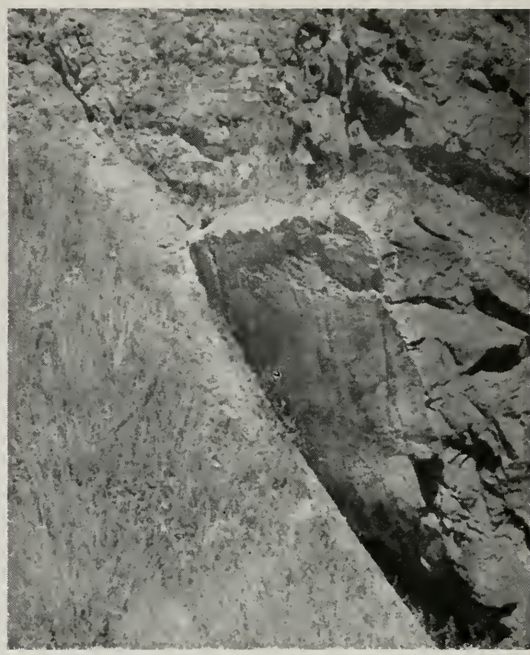


A, CROSS-BEDDED AND PEBBLY WHITE SAND OF CIERBO FORMATION
In a roadcut near the center of sec. 26, T. 2 S., R. 2 E., M.D.

B, ANGULAR UNCONFORMITY
Between Cierbo formation and underlying Panoche formation in a railroad cut in sec. 36, T. 2 S., R. 3 E., M.D.

A, ANDESITIC BOULDER CONGLOMERATE OF NEROLY FORMATION
In SE¼ sec. 6, T. 3 S., R. 4 E., M.D

B, BASAL ANDESITIC GRAVELS OF NEROLY FORMATION
Resting with angular unconformity on sandstones and shales of Panoche formation. View of north side of roadcut along U.S. Highway 50 in SE¼ sec. 24, T. 2 S., R. 3 E., M.D.

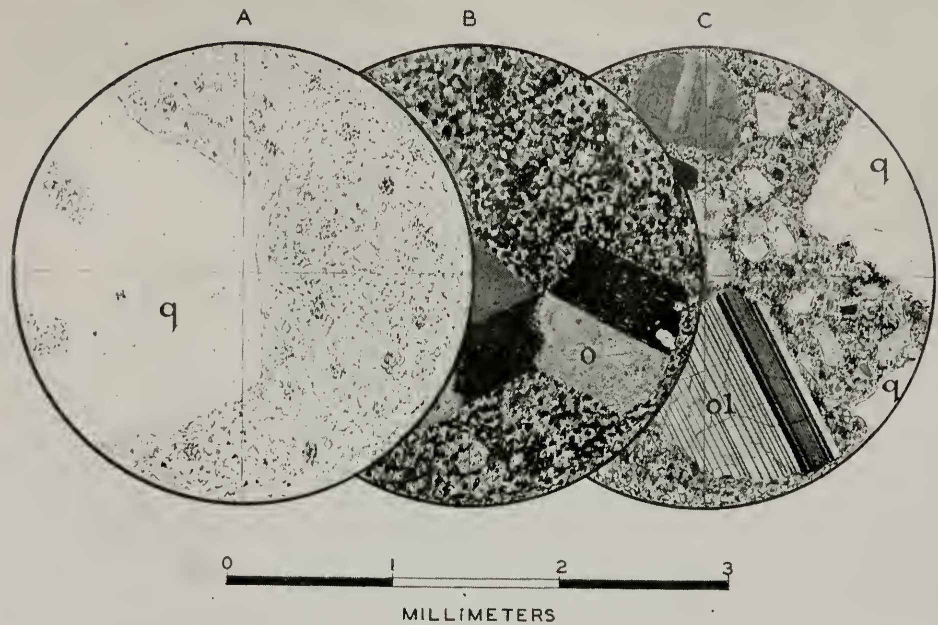


A, SLICKENSIDED FAULT-PLANE SURFACE

In Greenville fault zone in cut of Western Pacific Railroad near the southwest corner of sec. 30, T. 2 S., R. 3 E., M.D. The fault plane has a dip of about 70 degrees, and striations on the surface are nearly horizontal.

B, SHARP FOLD IN NEROLY BLUE SANDSTONE

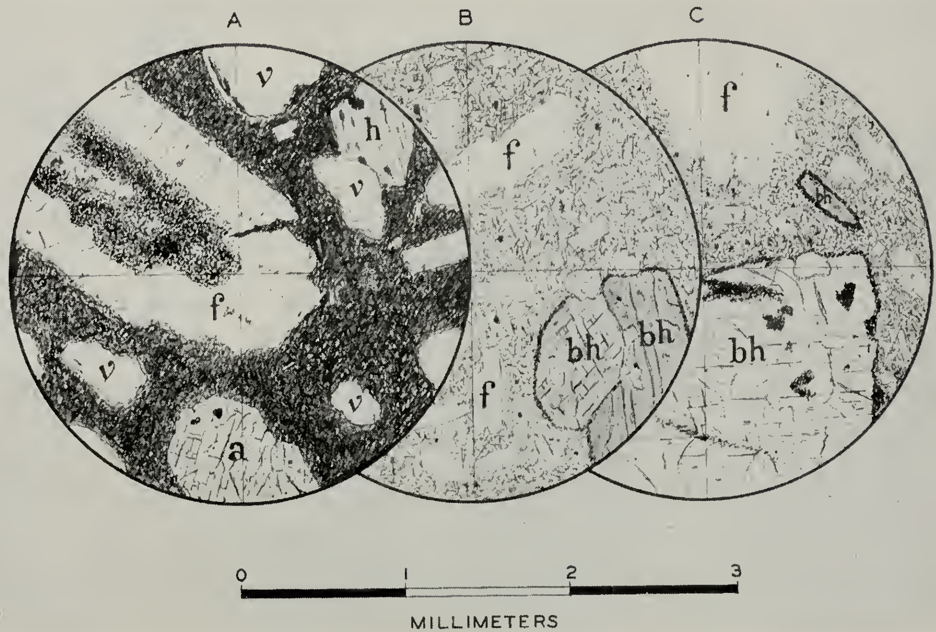
Smooth surface to left is in upper Neroly shales, and Cierbo formation underlies blue sandstone, upper right. View east, in southern part of sec. 4, T. 3 S., R. 4 E., M.D.



BOULDERS FROM PANOCHE CONGLOMERATE ON ROCKY RIDGE

Explanation: q = quartz; o = orthoclase; ol = oligoclase.

A, Quartz porphyry: Hexagonal phenocryst of quartz in a groundmass of finely crystalline aggregate of quartz and orthoclase clouded by alteration; plane polarized light. *B*, Orthoclase porphyry: Phenocrysts of orthoclase showing Carlsbad twinning in a groundmass of micrographic intergrowth of quartz and orthoclase; crossed nicols. *C*, Sandstone: Coarse grained, inequigranular, poorly sorted; angular particles consist of quartz, orthoclase, and oligoclase; crossed nicols.



ANDESITIC BOULDERS FROM NEROLY CONGLOMERATE (PLANE POLARIZED LIGHT)

Explanation: a = augite; bh = basaltic hornblende; f = plagioclase feldspar; h = hypersthene; v = vesicle lined with opal.

A, Hypersthene-augite-plagioclase andesite porphyry: Phenocrysts of hypersthene, augite, and labradorite, the latter with a "dust-charged" zonal core; groundmass is a pilotaxitic field of microlites of oligoclase-andesine, augite grains, and magnetite dust; vesicles are lined with brownish opal. *B*, Hornblende-plagioclase andesite porphyry: Phenocrysts of basaltic hornblende and zoned plagioclase; groundmass has pilotaxitic texture and carries microlites of oligoclase-andesine. *C*, Hornblende-plagioclase andesite porphyry: Phenocrysts of basaltic hornblende showing resorption rims and inclusions of feldspar; plagioclase phenocrysts are zoned; pilotaxitic groundmass.

At locality XIV on the east bank of Mitchell Ravine a small ammonite and minute specks thought to be foraminifera and radiolaria were found in a yellow-buff colored limestone concretion when it was broken open with a hammer. A thin-section of the sample was shown to Dr. Campbell who observed the outlines of foraminifera, some diatoms, and an abundance of well preserved radiolarian tests. These latter forms greatly intrigued Campbell and he asked for the remainder of the concretion which by then consisted of a few cubic inches of limestone, including a small ammonite. From this small limestone sample Campbell and Clark[52] recovered after treatment of the material in acid, the most extensive Cretaceous radiolarian fauna that has been recorded from North America. The fauna includes nine families, 25 genera and approximately 100 species. According to the above authors the fauna may be referred to as a *Saturnalis* or *Dictyomitra* fauna. The association of certain of the fossil species with recent Arctic forms indicated that the fauna lived in very cold water. The ammonite found with the radiolaria was identified by the late Dr. F. M. Anderson as *Lytoceras (Tragonites)* aff. *epigonus* (Kossmat), an Upper Cretaceous species found elsewhere in the *Pachydiscus* silt. The term Corral Hollow shale mentioned from Huey in the paper by Campbell and Clark[53] is replaced by the term Moreno Grande used in this report.

The sandstone in the upper part of the Moreno Grande from Tesla westward contained some Upper Cretaceous megafossils. A sample of sandstone float near Tesla contained *Acila (truncata) demessa* Finlay and two cephalopods, an ammonite and a *Nautilus* sp. At locality IX, a little northwest of the center of sec. 26, T. 3 S., R. 3 E., *Parallelodon (Nanonavis) brewerianus* Gabb and an ammonite were found.

Structure and Relation to Adjacent Formations. The Moreno Grande along the south side of Corral Hollow dips steeply northward at angles of 60 to 80 degrees into a syncline. The formation is overlapped by the Cierbo formation (upper Miocene) to the north. The contact with the underlying Panoche is nowhere well exposed but it appears to be conformable and gradational. The contact with overlying Tesla formation (middle Eocene) is unconformable. Angular discordance is slight, but there is progressive overlap to the east. The upper sand which is present west of Tesla is absent to the east at Mitchell Ravine and still farther east near Carnegie the Moreno Grande is completely lapped out by the Tesla formation. This unconformity marks an interval of time in which the cold-water marine conditions under which the Moreno Grande was deposited were replaced by the warm brackish-water conditions under which the lower part of the Tesla was formed.

Tertiary System

Eocene Series

Tesla Formation

The name Tesla formation was proposed by Huey[54] for a group of brackish-water and marine sediments of middle Eocene age that are typically and most completely exposed near the former mining camp of Tesla. The occurrence of coal, pottery clays, and quartz sand in the formation makes it one of economic interest.

[52] Op. cit.
[53] Op. cit.
[54] Op. cit., 1936.

Distribution and Thickness. The Tesla can be traced as a band for about 5 miles along Corral Hollow from Carnegie westward toward Livermore Valley. To the north no Eocene rocks occur on the flanks of the anticlines, having been completely overlapped by the Cierbo formation (upper Miocene) which in turn rests directly on the Panoche. This relationship means that either an old high in the northern part of the area prevented the deposition of the Eocene sediments or that they were deposited and later stripped off prior to the transgression of the Cierbo formation. This condition may be related to the buried arch in the vicinity of Manteca over which Miocene strata rest on Upper Cretaceous beds with the lapped-out Eocene strata preserved in the Sacramento basin to the north and in the San Joaquin basin to the south.

A maximum thickness of about 2000 feet of section is developed in the vicinity of Tesla. East of Tesla the Corral Hollow fault cuts out about 700 feet of the upper part of the formation, and west of Tesla the upper part of the formation is progressively overlapped by the Cierbo formation.

Lithology. The Tesla formation is characterized by a variety of sedimentary rocks including white quartz sand, buff sand, iron- and manganese-stained concretionary sand, dark carbonaceous shales, lignite seams, and white to light blue clays. The sediments show considerable variation both vertically and laterally. Brackish-water sediments, in general, characterize the lower part of the formation, and marine sediments predominate in the upper part. The occurrence of the white quartz sand at several horizons in the section serves to bind the variable group of sediments into a whole unit.

A paced section along the Tesla road in the center of sec. 25, T. 3 S., R. 3 E., illustrates the variable lithology. The top of the section is locally in fault contact with the Cierbo formation and about a quarter of a mile to the west, 100 feet of additional section underlies a basal gravel of the Cierbo. From top to bottom, the section along Tesla road is as follows:

40′	Fine white quartzose sand, some shale.
700′	Buff sand, fine grained, concretionary, massive. (Marine fossils including *Turritella merriami* Dickerson occur near the top and base of this unit.)
80′	White sand and clays, some gray shales.
250′	Buff sand, finely micaceous, massive, concretionary, and gypsiferous.
60′	White to light gray sandy shales and clays with limonitic staining.
20′	White quartz sand.
10′	Dark carbonaceous shales.
50′	Buff sandstone, fine grained, locally manganese-stained concretions.
160′	Gray to chocolate carbonaceous shales, minor sandstone. A thin lignite seam occurs about 40′ down in this unit.
150′	Buff massive to crossbedded and concretionary sandstone, minor amount of shale.
10′	Gray shales.
100′	Buff sandstone. Brackish-water fossils (*Anomia* and *Diodus*) occur about 60′ down in this unit.
125′	Carbonaceous shales, streaks of micaceous sands. Fossil leaves occur about 10′ down and brackish-water fossils including *Corbicula* sp. occur about 85′ down in this unit.
200′	Light gray to buff massive sandstone, some shales.
1955′	Total thickness of section.

At Mitchell Ravine to the east, the zone of brackish-water fossils containing *Corbicula* sp. occurs in the basal part of the section about 30 feet above the Tesla-Moreno Grande contact so that more than 200 feet of the lower part of the formation which is present at Tesla is missing. Also at Mitchell Ravine the upper 700 feet of the Tesla section is cut out by the Corral Hollow fault.

The white sands are fine to medium grained, well sorted, massive to finely cross-bedded, friable, locally gypsiferous, and generally finely streaked with limonitic staining. Heavy mineral separations from three samples of white sand were studied. Angular quartz averages about 75 percent of the total light minerals. However in one sample taken from the upper white sand, quartz comprised 95 percent of the minerals present. Orthoclase, much of which is kalonized and occurs in clay aggregates, constitutes from 10 to 22 percent of the light minerals. Microcline and oligoclase-andesine are present, each ranging from a trace up to 3 percent of a separation. Grains of black and lavender chert generally constitute from 1 to 2 percent of the light minerals. The micas are present in less than 1 percent proportion and most of the biotite is pale. Anauxite is present up to a percent or more. The heavy minerals comprise only about one-half of one percent of a separation but include an interesting list of minerals, mostly chemically resistant. Ilmenite and magnetite are abundant, ilmenite being predominant. Andalusite and euhedral zircon are very common, greenish-brown tourmaline is common, some barite is present, staurolite and pink to colorless garnet are present in small quantities. The sparse to very rare minerals include rutile, epidote, anatase, corundum, basaltic and green hornblende, brookite, sillimanite, and titanite.

Allen [55] has made a more comprehensive study of the Tesla sands and clays, and for additional petrographic details and discussion the reader is referred to his report. Allen in examining a number of white sands found anauxite ranging as high as 24 percent of the mineral assemblage.

The similarity of the mineral assemblage of the Tesla white sands with that described from the Ione sands by Allen [56] is striking. Allen suggested a Sierran source for the constituents of the Ione sands. A Sierran source for the Tesla white sands was suggested by Huey [57] (1936, 1940). Andalusite which is present in these sands occurs in the schists in the Sierras but has not been reported from the older rocks of the Coast Ranges. Tourmaline, zircon, magnetite, ilmenite, epidote, garnet, staurolite, in fact, about all of the heavy minerals from the Tesla white sands occur in the Sierran province. The low feldspar content, the presence of anauxite, the occurrence of minerals resistant to chemical weathering, and the absence or sparsity of such minerals as pyroxenes, amphiboles, and micas suggest a derivation of the minerals from an area undergoing intense chemical weathering. Allen [58] suggested a Sierran source for the material in the white anauxitic sands and clays at Tesla but postulated a second contemporaneous source probably in the Coast Ranges, for the mineral constituents such as fresh biotite, sparse glaucophane and albite, which he found in some of the micaceous sands alternating with the white sands and clays.

Petrographic examination of a sample from the upper buff sands showed 35 percent quartz, 60 percent feldspar much of which was kaolini-

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[55] Op. cit.

[56] Allen, V. T., The Ione formation of California: Univ. California, Dept. Geol. Sci. Bull., vol. 18, pp. 347-448, 1929.

[57] Op. cit., 1936, 1940.

[58] Op. cit., 1941.

zed, 4 percent altered biotite, and a heavy mineral assemblage essentially the same as that of the white sands. Allen [59] notes the occurrence of glaucophane, a characteristic Franciscan mineral, in a sample of the buff sand that he examined.

Associated with some of the chocolate-colored carbonaceous shales are streaks of black, very micaceous sand. This sand containing an abundance of what appeared to be fresh to slightly altered biotite seemed inconsistent with a source area that was undergoing intense chemical weathering. A petrographic examination of this sand showed quartz 10 percent, muscovite about 5 percent, and phlogopite with a sagenite web-structure as rare. It was surprising that 85 percent of the sample was composed of altered biotite and an alteration product of biotite, believed to be the mineral, jefferisite. The optical properties of this vermiculite were quite variable and the refractive indices of beta and gamma ranged from 1.455 to 1.560. The mineral was pseudouniaxial, negative in sign, and retained the basal cleavage of biotite. Among the heavy minerals zircon and hypersthene were common; andalusite, ilmenite, and magnetite rather common; and titanite, rutile, staurolite, brown tourmaline, and anatase sparse to rare. This was the only sample of the micaceous sands that was examined, but a question arises whether some of the other micaceous sand streaks may also be mostly composed of altered biotite and vermiculite rather than fresh biotite. Such sands would be consistent with a source area undergoing chemical weathering.

The white clays of the Tesla formation were not examined petrographically, but Allen [60] reports that the clays have similar chemical composition, optical properties, and X-ray patterns to the anauxitic clays near Ione.

Fauna and Flora. The fauna and flora found in the Tesla formation afford clues to the conditions of sedimentation and help fix the age and stratigraphic position of the formation. In general the fossils from the lower part of the formation (localities I to III inclusive) indicate a brackish-water environment, whereas those from the upper part (localities IV to VI inclusive) suggest marine conditions. Dr. R. A. Bramkamp kindly identified the fossils listed below.

[59] Op. cit., 1941.
[60] Op. cit., 1941.

Checklist of fossils from the Tesla formation

	Localities					
Pelecypoda	I	II	III	IV	V	VI
Acila gabbiana (Dickerson)						R
Anomia inornata (Gabb)	A	C				
Brachidontes cowlitzensis (Weaver & Palmer)					R	
Corbicula n. sp.?			A			
Diodus tenuis (Gabb)	C	A				
Glycimeris cf. meganosensis Clark & Woodford					X	
Nuculana cf. gabbi (Gabb)				A		
Pitar sp.					X	
Plagiocardium cf. brewerii (Gabb)					R	R
Spisula sp.					X	
Tellina cf. lajollaensis Dickerson						X
Gastropoda						
Turritella buwaldana Dickerson (mold)						R
Turritella merriami Dickerson					C	X

A = abundant R = rare
C = common X = present

Some of the fossil assemblages seem to constitute zones as they are found in several successive canyons in about the same stratigraphic position. The lowermost zone carries the brackish-water form, *Corbicula.* At Mitchell Ravine (locality III) this zone is about 30 feet above the top of the Moreno Grande and about 75 feet below the *Anomia-Diodus* zone. *Nuculana gabbi* occurs consistently about 30 feet above the base of the upper 700-foot unit of massive buff sand; and generally at a horizon about 10 feet above the *Nuculana* zone a group of marine fossils including *Turritella merriami* occurs. No fossils were found in the white sands, and although the sands looked like clean beach sands, it was not determined whether they were deposited under marine or brackish-water conditions. The white sands occur at several horizons in the formation and in association with sediments that appear to have been deposited under contrasting conditions. The late Dr. B. L. Clark informed the writer of his finding in the Eocene white sands near Mt. Diablo a gastropod, *Spiroglyphus tejonensis* (Arnold), and orbitoid foraminifera, *Discocylina* cf. *psilla,* which forms would suggest a marine environment of deposition for these sands.

In a south-facing bank at the foot of the Tesla grade (U. C. locality No. P-3718) in the SE¼ sec. 25, T. 3 S., R. 3 E., fossil leaves were found in chocolate-colored shales. Professor R. W. Chaney of the University of California, Berkeley, kindly supplied the following list of leaf species and suggestions as to their time range.

Leaf species from University of California locality P-3718.

Floral list	Suggested time range
Cinnamomum dilleri	Middle to upper Eocene
Cordia cf. rotunda	Upper Eocene to lower Oligocene
Cupania cf. oregona	Middle Eocene to lower Oligocene
Glyptostrobus europeus	Paleocene to upper Eocene
Laurus princeps	Middle to upper Eocene
Magnolia californica	Middle to upper Eocene
Nectandra presanguinea	Upper Eocene to lower Oligocene
Octotea ovoidea	Upper Eocene to lower Oligocene
Persea pseudocaroliniana	Middle Eocene to lower Oligocene
Polyalthea chaneyi	Upper Eocene
Rhamnus cf. cleburni	Paleocene to lower Eocene
Sabalites sp. (palm frond)	Eocene
Trochodendroides sp.	Eocene

Concerning the above leaf specimens, Dr. Chaney [61] writes:

> " . . . the flora is probably of middle Eocene age. All of the species are typically of Eocene age, and the details of migration are not sufficiently well known to make possible a final age reference.
>
> "All of the species fall in genera whose modern distribution is in latitudes 15 to 20 degrees south of the Tesla region. The representation of the *Lauracea* and the present-day occurrence of the modern equivalent of most of the Tertiary species, suggest an environment without frost and with abundant rainfall."

Age and Correlation. The occurrence of the index fossil *Turritella merriami* in the upper half of the formation indicates that the Tesla formation is middle Eocene in age and probably falls in what is currently called the Capay stage, which was proposed by Merriam and Turner [62]. According to Dr. Chaney, the flora listed from the lower part

[61] Written communication dated May 8, 1947.
[62] Merriam, C. W., and Turner, F. E., The Capay middle Eocene of California: Univ. California, Dept. Geol. Sci. Bull., vol. 24, pp. 91-141, 1937.

of the formation also indicates middle Eocene age, but the brackish-water fossils in this lower part do not lend themselves to definite age assignment since a few of the forms have been noted in beds purported to be Paleocene or older.

The Tesla formation in this area, as herein mapped, was earlier called Tejon by Anderson and Pack[63]. They mapped "Tejon" beds for a considerable distance along the west border of the San Joaquin Valley north of Coalinga. Part of what they mapped as Tejon is now differentiated as Domengine, some of it has been referred to the Lodo and Martinez (?) formations, and part of it is correlative with the Tesla formation. Stewart, Popenoe, and Snavely[64] have described a number of columnar sections and the involved faunas from the Panoche Hills northward into the Orestimba area. They described in the Orestimba area a section of 1800 feet of iron-oxide streaked white sands with ferruginous ledges and siltstones containing much carbonaceous material in portions. A brackish-water fauna, which occurred in the lower part of these beds, included *Diodus tenuis*, "*Placunanomia*" cf. *inornata*, and "*Psammobia*" *cylindrica*, the latter a Paleocene species. With some uncertainty they assigned these beds to the Martinez (?) formation and indicated their probable age as Paleocene. They noted both the lithologic and faunal similarity of these beds to some in Corral Hollow and postulated that both might belong to the same formation. This writer concurs in the suggested correlation of these two sets of beds, having previously used the formational name Tesla for the beds in the Orestimba area, where he directed some private unpublished mapping.

Structure and Relation to Adjacent Formations. The Tesla formation in Corral Hollow dips steeply northward and locally the beds are overturned in proximity to the Corral Hollow fault. In several cross-sections (pl. 3) the Tesla is represented in the subsurface as dipping down into a syncline and being overlapped to the north by the Cierbo formation (upper Miocene) without emerging on the north limb of the syncline.

The relation of the Tesla to the underlying Moreno Grande has already been described. The Tesla is overlain unconformably by the Cierbo formation. In places a gravel bed in the base of the Cierbo facilitates the mapping of the contact between the two formations. In Corral Hollow the Tesla formation is in fault contact with the Cierbo and the upper part of the Tesla is cut out along the Corral Hollow fault.

Miocene Series

Oursan? Sandstone

The Oursan sandstone was named by Lawson[65] for its occurrence at Oursan Ridge in the Concord quadrangle. In Arroyo Valle near the central western margin of the Tesla quadrangle, some massive buff sandstones, locally pebbly and reef-forming with minor interbedded shale, are herein assigned with some uncertainty to the Oursan sandstone. These beds had previously been mapped as Briones by the Stanford Geological Survey, but an invertebrate fauna found by the writer indicates that the beds are probably older than Briones.

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[63] Op. cit.

[64] Stewart, R., Popenoe, W. P., and Snavely, P. D., Jr., Correlation and subdivisions of Tertiary and late Upper Cretaceous rocks in Panoche Hills, Laguna Seca area, and Orestimba area, Fresno, Merced, and Stanislaus Counties, California: U. S. Geol. Survey, Oil and Gas Investigations Prelim. Chart 6, 1944.

[65] Op. cit., 1914.

The principal occurrence of the sandstone in the Tesla quadrangle is limited to the N½ sec. 3, T. 4 S., R. 2 E. It extends northwestward into the Pleasanton quadrangle. To the southeast the formation is completely overlapped by the Livermore gravels.

Lithology. Massive buff sandstone characterizes the bulk of the formation, which locally attains a thickness of about 700 feet. At the entrance of Arroyo Valle south of Livermore the road takes a sharp turn around a strike ridge of the sandstone which locally is pebbly and carries an abundance of shell fragments.

A heavy mineral separation of a sample of light gray weathering to buff, fine-grained sandstone from locality VIII in sec. 3. T. 4 S., R. 2 E., was examined petrographically. Quartz constitutes 40 percent of the light minerals. Shards of clear and brown glass with a refractive index of 1.50± make up 25 percent of the separation. Chert grains constitute 15 percent, and kaolinized feldspars make up 20 percent of the sample. Among the heavy minerals pale green hornblende is very common; magnetite, basaltic hornblende, brown biotite, and hypersthene are common; glaucophane, titanite, epidote, and ilmenite are scarce. The presence of glaucophane suggests a probable Franciscan source for the detrital material of the sediments, and the shards of glass attest to volcanic activity during the middle Miocene.

A few beds of light gray punky, tuffaceous and diatomaceous shale are interbedded with the buff sandstones.

Fauna and Correlation. At locality VIII in sec. 3, T. 4 S., R. 2 E., abundant but poorly preserved marine fossils were found in friable buff sandstone. Fossils from this locality were identified by Mrs. P. Rossello Nicholson of the Museum of Paleontology, University of California, Berkeley.

Checklist of fossils from the Oursan? sandstone (loc. VIII)

Pelecypoda	
Cardium sp.	X
Chione n. sp.	X
Chione sp. (cf. C. panzena Anderson & Martin)	X
Chione sp. (cf. C. temploreusis Anderson)	X
Cryptomya sp.	X
Dosinia merriami Clark	X
Mytilus sp. (cf. M. perrini Clark)	X
Nitidella sp.	X
Ostrea n. sp.	X
Pecten (Equipecten) andersoni Arnold	RC
Schizothaerus sp.	X
Siliqua sp. (?)	RC
Tagelus n. sp.	X
Thracia (?) n. sp.	X
Gastropoda	
Bullaria n. sp. (?)	RC
Calyptraea inornata Conrad	RC
Polinices (Neverita) recluziana var. andersoni Clark	X
Trophon sp.	
Arthropoda	
Balanus sp.	X

X=present
RC=rather common

The above faunal assemblage was regarded by the late Professor B. L. Clark[66] as middle Miocene (Temblor) and older than Briones.

[66] Oral communication.

Certainly, index fossils for the Briones, such as *Astrodapsis brewerianus* and *Pecten raymondi,* are conspicuous by their absence. However, the fauna bears some resemblance to one listed by Trask [67] from the lower sandstone member of the Briones in the San Pablo Bay region.

Vanderhoof [68] has described the fossil material from a sea cow, *Desmostylus,* which was found in these beds at the mouth of Arroyo Valle. Vanderhoof referred to the beds as Briones, following general usage in the area.

There is practically no chance to clarify the stratigraphic relations of this formation from the limited occurrence in the Tesla quadrangle; however, in the adjoining Pleasanton quadrangle to the west the key to this stratigraphic problem may lie in some work done towards a Master's degree by Harding.[69] He mapped a section of about 3000 feet of Briones formation carrying *Pecten raymondi* and *Ostrea bourgeoisii* in the Maguire Peaks area east of the Sunol fault. He found underlying the Briones with slight angular unconformity a middle Miocene formation comprised mostly of a tan sandstone resembling the Oursan sandstone that he had mapped west of the Sunol fault. Fossils found in this sandstone included *Pecten andersoni, Dosinia merriami, Tivela gabbi,* and *Cancellaria dalliana?* The lithologic and faunal similarity of this unit to the beds in question in Arroyo Valle is striking, and the stratigraphic position underlying definite Briones is clearly demonstrated. Although Harding noted a resemblance of these beds to the Oursan sandstone, he was not certain as to the assignment. The Tice and Claremont shales, which respectively overlie and underlie the Oursan sandstone in the area west of the Sunol fault, are not recognized east of that fault so that the assignment as Oursan had to be based largely on lithologic appearance and general stratigraphic position.

Structure and Relation to Adjacent Formations. The Oursan? sandstone formation rests with an angular discordance of about 15 degrees upon the Panoche formation (Upper Cretaceous) and is overlain unconformably by the Livermore gravels (Plio-Pleistocene). The beds dip 35 degrees homoclinally to the northeast. These structural and stratigraphic relations are represented in section B-B (pl. 3).

Cierbo Formation

The Cierbo formation was named by Clark [70] who classified it as the middle member of the San Pablo group of upper Miocene age. The formation, herein called Cierbo, was mapped and described as "undifferentiated Miocene" by Anderson and Pack.[71]

The Cierbo is a transgressive formation of widespread occurrence over the northern part of the area. Exposures of the Cierbo formation are limited and poor; but the occurrence of rounded quartz and black chert pebbles in the soil and the widespread occurrence of the large oyster, *Ostrea bourgeoisii,* aid in the recognition of the formation.

[67] Trask, Parker D., The Briones formation of middle California: Univ. California, Dept. Geol. Sci. Bull., vol. 13, p. 140, 1922.

[68] Vanderhoof, V. L., A Study of the Miocene Sirenian Desmostylus: Univ. California, Dept. Geol. Sci. Bull., vol. 24, pp. 169-262, 1937.

[69] Harding, John W. Jr., The geology of the southern part of the Pleasanton quadrangle, California, Master's thesis, University of California, 1940 (unpublished).

[70] Clark, B. L., The marine Tertiary of the west coast of the United States; its sequence, paleogeography, and problems of correlations: Jour. Geology, vol. 29, pp. 583-614, 1921.

[71] Op. cit.

Nowhere in the area is a good section of Cierbo sediments exposed, and no accurate measurement of the formation can be made. However, it is estimated that the maximum thickness is about 500 feet.

Lithology. Several different types of lithology are found in the Cierbo sediments. Beds of white quartzose sands resembling those of the Tesla formation are common. The sands are poorly sorted, coarse grained, massive to cross-bedded, friable, streaked with limonite, and carry rounded pebbles of quartz and black chert. Yellow or buff sands are also common. A conglomerate carrying rounded pebbles and cobbles of quartz, vari-colored cherts, lavender quartzite, and sandstone occurs locally in the SE ¼ sec. 24, T. 2 S., R. 2 E. Northwest of Tesla a conglomerate carrying angular pebbles and cobbles of Franciscan chert and sandstone characterizes the base of the Cierbo. Tuffs and carbonaceous brown shale are locally present. A bed of white tuff has been mined at the K-ola mine in sec. 27, T. 3 S., R. 3 E. The tuff is made up of 97 percent clear glass with a refractive index of 1.50, quartz (2 percent), kaolinized feldspar (1 percent) and traces of pale biotite and magnetite. Also in the tunnel of the K-ola mine several lignite seams, locally 2 feet thick, are associated with brown carbonaceous shales.

A sample of the white granuliferous sandstone was examined petrographically. Quartz makes up 70 percent of the sample. Kaolinized feldspar, chiefly orthoclase and a little microcline, constitute 10 percent of the sample. Black, gray, and green chert particles make up most of the remaining 20 percent. Heavy minerals represent only a small fraction of a percent of the sandstone, but they comprise a large number of mineral species. Of these magnetite and ilmenite are very common; zircon is fairly common; garnet, basaltic and green hornblende, andalusite, hypersthene, zoisite, and brown biotite are sparse; and titanite, brown tourmaline, staurolite, actinolite, and glaucophane are rare. There is some similarity between the above mineral assemblage and that described for the Eocene white sands, and it would appear that the Cierbo white sands may have derived the bulk of their constituent minerals from the same hypothetical source area, the Sierra Nevada. However, the presence of grains of actinolite, glaucophane, and chert suggests that areas of Franciscan rocks in the Coast Ranges were also supplying some of the detritus for the sediments.

Fauna and Correlation. The numerous fossil symbols indicated in the areas of Cierbo rocks on the geologic map mark the occurrence of the large oyster, *Ostrea bourgeoisii*, generally as fragments in the soil. A zone of this oyster characteristically occurs from 50 feet to 150 feet above the base of the formation. The parallelism of the oyster zone with the basal contact of the formation is well demonstrated on the southwestern flank of the Altamont anticline. Other marine fossils are generally limited in occurrence and poorly preserved, but at locality No. VII near the southern boundary of sec. 3, T. 3 S., R. 3 E., a fair collection was obtained. Mrs. P. Rossello Nicholson contributed the identifications which are listed below.

The occurrence of *Ostrea bourgeoisii* and *Pecten raymondi* in the formation is indicative of upper Miocene age, and the formation is considered as correlative with the Cierbo formation at Mt. Diablo.

Fragments of petrified wood are frequently found in soil of the Cierbo formation, and a few leaf impressions were noted in a tuff that outcrops at the K-ola mine.

Checklist of some Cierbo fossils

	Localities VII	K-ola mine
Gastropoda		
Acteon sp.	X	
Calyptraea sp.	C	
Littorina n. sp.	X	
Polynices kerkerensis Clark	X	
Pelecypoda		
Cardium sp.	X	
Cryptomya sp.	X	
Macoma andersoni Clark	X	
Mulinia gabbi	X	
Ostrea bourgeoisii Remond		C
Panope generosa Gould	X	
Pecten raymondi Clark		X
Pecten tolmani	C	
Solen perrini Clark	X	
Tellinia salmonea Carpenter	X	

X = present C = common

Relation to Adjacent Formations. The Cierbo, a transgressive formation, is structurally involved in the regional folding and faulting. Over most of the area it rests with angular unconformity upon Panoche rocks; this relationship suggests that there were some conditions of folding and erosion prior to the transgression of the Cierbo. In the vicinity of Tesla the Cierbo has both faulted and unconformable relationships with the Tesla formation. Nowhere in the area is the Cierbo found in conjunction with the Oursan ? sandstone. The Cierbo is overlain conformably to unconformably by the Neroly formation, which is the upper member of the San Pablo group. Apparently there are slight angular discordances between the attitudes of bedding in the Cierbo and Neroly formations in several places, but the vagueness of the bedding in the Cierbo makes the interpretation uncertain. Over most of the area a basal reef bed of the Neroly consisting of blue sandstone and tuffaceous shale rests sharply on the incoherent coarse white sands of the Cierbo. In the vicinity of Rock Cut in the SE ¼ sec. 25, T. 2 S., R. 3 E., and northward, the Cierbo is lapped out by the Neroly, which there rests unconformably upon the Panoche. This unconformity between basal Neroly gravels and Panoche sandstone is well exposed in a road cut at the east end of the new U. S. Highway 50.

Neroly Formation

The Neroly formation was named by Clark and Woodford [72] as the upper formation of the San Pablo group, which was defined originally to include only the Cierbo and Neroly formations. Anderson and Pack [73] described what is herein called Neroly as the San Pablo formation.

Distribution and Thickness. The Neroly was probably once a continuous sheet of sediments over the northern part of the area, but much of the formation was stripped off by eroison following a post-Neroly period or periods of deformation, and today the rocks are preserved chiefly in synclinal areas. The northeastern part of the area is well blanketed by blue sandstones, conglomerates, and shales of the formation.

[72] Clark, B. L., and Woodford, A. O., The geology and paleontology of the type section of the Meganos formation of California: Univ. California, Dept. Geol. Sci. Bull., vol. 17, p. 69, 1927.
[73] Op. cit., pp. 96-100.

To the northwest the Neroly extends into the Byron and Mt. Diablo quadrangles, and to the southeast it continues across the Carbona quadrangle and along the west border of the San Joaquin Valley.

In the Tesla area the Neroly is conveniently divided into two parts, as follows: a lower part consisting mainly of blue sandstone, some andesitic boulder conglomerates, and interbeds of tuffaceous clay shales; and an upper part consisting mainly of poorly exposed clays, and minor interbeds of soft brownish sands, gravels, and some blue sandstone. The lower blue sandstone unit ranges in thickness from about 100 to 700 feet, and the maximum thickness is developed along the north side of Corral Hollow. The upper shales reach a thickness of at least 2000 feet, but a measurement of their complete thickness could nowhere be obtained as the top of the formation is masked by the alluvium of the San Joaquin Valley. This division of the Neroly is an arbitrary one; and the contact, which is represented on the geologic map (pl. 1), does not everywhere occur at the same stratigraphic horizon.

Lithology. The most distinctive rock type in the Neroly is blue sandstone, which resembles the so-called "vivianitic" sandstones of the Etchegoin formation near Coalinga. The blue color of the sands is caused by opalescence from a dull opaline coating on the grains. This coating can be removed by boiling a sample of the sand in a solution of potassium hydroxide. Heavy mineral separations were made of two samples of the blue sands. The light minerals constitute about 87 percent of the sample. Quartz, oligoclase, and labradorite are sparsely present. Black microcrystalline to glassy lava particles containing microlites make up a large part of the light material, and these particles resemble the groundmass of many of the cobbles of andesite porphyry found in the Neroly conglomerates. The bulk of the light grains are opaque, somewhat magnetic, and angular in shape. The heavy minerals literally rain down during a separation and make up about 13 percent of a sample. Among the heavy minerals, augite is abundant; brown basaltic hornblende and hypersthene are very common; green hornblende, magnetite, and andesitic groundmass particles are rather common; titanite and epidote are sparse. The mineral assemblage suggests a source area of andesitic rocks. The absence of typical Franciscan minerals and the dissimilarity of the heavy mineral assemblage with that of the Tesla formation are noteworthy.

The Neroly conglomerates consist of rounded andesitic pebbles and cobbles set in a matrix of blue sandstone. The cobbles range from 2 to 5 inches in diameter. Seventeen thin-sections were studied of representative cobbles. Of these, six are augite-plagioclase andesite porphyry, five are hornblende-plagioclase andesite porphyry, three are hypersthene-augite-plagioclase andesite porphyry, and three are hornblende-pyroxene-plagioclase andesite porphyry. All of the andesite porphyries have many features in common, and differences in classification are based upon the characterizing phenocrysts of the rocks. It is convenient, therefore, to describe the rocks as a group, noting any special features. The phenocrysts constitute about 55 percent of a porphyry in thin-section and range in length from $\frac{1}{2}$ to 3 millimeters. Labradorite and andesine-labradorite ($Ab_{45}An_{55}$ to $Ab_{50}An_{50}$) make up from 65 to 90 percent of the phenocrysts. The feldspars show such features as albite and pericline twinning, delicate zoning, strong dispersion, "dust-charged" cores, and partial to complete resorption of some of their outlines. Augite is very common as a phenocryst, ranging to as much as 20 percent of the total phenocrysts. Some of the augite is present in euhedral basal sections having good cleavages. Twinning is common, and dispersion in the augite phenocrysts is strong. Hypersthene, which is present as a phenocryst in six of the thin-sections, constitutes a maximum of 30 percent of the phenocrysts in one sample. Hypersthene shows good pleochroism and well-developed pyramidal terminations of the prisms. Brown basaltic hornblende is another principal phenocryst in some of the porphyries, constituting from 1 to 10 percent of the phenocrysts. It appears in prismatic and euhedral basal sections having good cleavages, and shows resorption rims of magnetite dust. Some of the hornblende crystals are completely resorbed, and the magnetite dust retains the distinctive outline of the parent mineral. The hornblende is pleochroic from yellow to red-brown and frequently contains small feldspar inclusions. Pale biotite is very rare as a phenocryst.

The groundmass textures of the porphyries are dominantly pilotaxitic, some show a fluidal or trachytic tendency, and a few are hyalopilitic. The groundmass is dark to black in color. Under the microscope with the nicols crossed and a low power objective, the darkness of the groundmass suggests the presence of glass, but in most cases under high power the groundmass is seen to be microcrystalline to cryptocrystalline. However, three of the sections do appear to have a glassy base. In one of the sections examined, the groundmass is thoroughly oxidized and very red in color. Microlites of oligoclase-andesine are very common. Some fine augite is present, and magnetite is abundant as small specks in the groundmass. Vesicles are present in more than half of the sections. Many of the vesicles are lined with opal, which under the microscope is pale brown in color but which in hand specimen appears dull bluish. A few secondary minerals, such as epidote, sericite, calcite, and limonite are also present.

A few samples of tuff were examined petrographically and found to be composed of fine andesitic detritus.

Source Area for the Neroly Sediments. Turner[74] has described and illustrated from the Sierra Nevada some andesite porphyries which petrographically seem to be identical with the andesite porphyry cobbles herein described from the Neroly. In 1924 Louderback[75] pointed out the following:

> "The distribution and character of the andesitic conglomerates of the San Pablo correspond well with a derivation from the Sierra Nevada during the period of andesitic eruption."

In the Tesla quadrangle the Neroly conglomerates are most prominent in the eastern part of the area, so that their distribution is consistent with a Sierra Nevada source as suggested by Louderback. The tuffs and blue sandstones also carry andesitic detritus. All evidence seems to point to the Sierra Nevada as the probable source area for the detrital material in the Neroly sediments.

Fauna and Flora. No marine fossils were found in the Neroly in the Tesla quadrangle, but marine fossils are known from the Neroly in the Mt. Diablo area. The only fossils found were leaves, horse teeth, and petrified wood.

[74] Turner, H. W., The rocks of the Sierra Nevada: U. S. Geol. Survey Ann. Rept. 14, pp. 487-490, 1894.

[75] Louderback, G. D., Period of scarp production in the Great Basin: Univ. California, Dept. Geol. Sci. Bull., vol. 15, p. 16, 1924.

Teeth fragments and foot bones of a horse were found by Dr. P. W. Reinhart of the Shell Oil Inc. in a 10-foot gravel bed in the middle of the lower blue sandstone unit. The locality (University of California locality V-3620) is on a small ridge near a point where a fence crosses the ridge about 500 feet due west of the southeast corner of sec. 21, T. 3 S., R. 4 E. Dr. R. A. Stirton, formerly of the University of California, examined the teeth and classified them as belonging to *Nannipus* sp. From four other localities in the adjoining Carbona quadrangle teeth fragments found in the Neroly by Reinhart were identified by Stirton as *Nannipus* cf. *tehonense* and *Pliohippus* sp. Stirton,[76] on the basis of the teeth, regards the age of the Neroly as probably upper lower Pliocene, approximately equivalent to the Chanac beds of the lower San Joaquin Valley and older than the "vertebrate Jacalitos."

In the Tesla quadrangle a fairly regular zone of fossil leaves occurs from 10 to 30 feet above the base of the Neroly. Condit[77] has published on the fossil flora of the San Pablo, and two of his localities are in the Tesla quadrangle. Leaf collections made by the writer were presented to Condit for study and inclusion with the material he collected.

Partial list of the San Pablo (Neroly) flora, after Condit

	University of California Localities P 361 (Corral Hollow)	199 (Altamont Pass)
Flora:		
Alnus corrallina Lesquereaux	X	A
Betula multineruis Jennings	X	A
Cyperacites sp.		X
Equisetum sp.		R
Juglans oregoniana		A
Magnolia californica Lesquereaux	R	
Nyssa knowltoni Berry		R
Persea princeps Heer	C	R
Platanus dissecta Lesquereaux	R	R
Populus alexanderi Dorf	X	X
Populus balsamoides Goepp	C	R
Prunus chaneyi n. sp.	R	C
Salix sp.	X	C

A = abundant C = common X = present R = rare

Some of the conclusions reached by Condit[78] are as follows:

1. The flora is most similar to the present swampy coastal plain forest of the southeastern United States.
2. The climatic conditions were abundant rainfall evenly distributed throughout the year and a warm average temperature.
3. The age of the leaf-bearing beds of the Neroly is probably upper Miocene on the basis of the flora and indicated climate.

However, Condit entertained the possibility that the beds were transitional Mio-Pliocene. Chaney, Condit, and Axelrod[79] in a recent book on the Pliocene floras of California and Oregon now regard the age of the Neroly flora as probably transitional Mio-Pliocene and correlate the flora with those from Remington Hill and Table Mountain on the lower slopes of the Sierra Nevada.

[76] Stirton, R. A., Cenozoic mammal remains from the San Francisco bay region: Univ. California, Dept. Geol. Sci. Bull., vol. 24, pp. 339-410, 1939.

[77] Condit, Carlton, The San Pablo flora of west central California: Carnegie Inst. Washington, Contr. Paleontology 476, pp. 217-268, 1938.

[78] Op. cit., p. 250.

[79] Chaney, R. W., Condit, C., and Axelrod, D. I., Pliocene floras of California and Oregon: Carnegie Inst. Washington Pub. 553, 1944.

Fragments of petrified wood are common in the Neroly sediments. Mr. Dougherty, formerly of the University of California, identified one specimen as a dicot and another as larch (Larix) or Douglas fir (Pseudotsuga).

Age of the Neroly. The problem of whether the Neroly is upper Miocene, lower Pliocene, or transitional Mio-Pliocene has long been a matter of disagreement among geologists. In 1915 Clark gave a summary of the opinions of previous workers and assigned what was later called Neroly to the upper Miocene on the basis of the percentage of recent species in the invertebrate fauna. In 1924 Louderback reviewed the published opinions concerning the age of the San Pablo and postulated the probable derivation of the andesitic material in the San Pablo sediments from the Sierra Nevada during the period of andesitic eruptions. Condit in his study of the San Pablo flora originally favored an upper Miocene age, but later joined with Chaney and Axelrod in regarding the Neroly flora as probably transitional Mio-Pliocene. Stirton proposed a lower Pliocene age on the basis of the vertebrate remains.

In this report the Neroly is conveniently left assigned to the upper Miocene. However it is recognized that the more recent trend in stratigraphic assignment is to regard the formation as Mio-Pliocene transitional or as lower Pliocene. It seems appropriate to merely report the organic and physical evidence found in the Tesla quadrangle that may have a bearing on the age problem and therewith leave the problem to stratigraphers to settle from evidence more widely gained.

In the Tesla quadrangle no marine invertebrate fossils were found in the Neroly and the organic evidence is limited to the flora and vertebrate remains, for which respective age indications have already been mentioned. The sediments, the flora, and the vertebrate fauna all seem to indicate a broad coastal plain as a site of deposition. It is conceivable that this coastal plain may have been marginal to a marine environment of deposition in the Mt. Diablo area, from which Clark has described an invertebrate fauna. In support of this geographic setting, Axelrod [80] mentions plant species from the Neroly in the Mt. Diablo area that appear to have lived closer to a coast line than the species found in the Tesla area.

Leaving aside the conflict in age assignment based upon the different types of fossil remains, geological observations in the Tesla quadrangle seem to indicate a time interval of some extent between the periods of deposition of the Cierbo and Neroly. In the northeastern part of the area the Neroly laps out the Cierbo and rests with angular unconformity on the Panoche. In most places the Neroly overlies the Cierbo with sharp disconformity and in some places a slight angular discordance between the two formations is observed. This boundary marks a change from a marine environment of deposition for the Cierbo sediments to a broad flood plain or coastal plain as a local site of deposition for the Neroly. This distinct change in character of the sediments from the white quartzose pebbly sands of the Cierbo to the typically blue Neroly sediments composed of andesitic detritus must indicate a time interval sufficient to allow for at least a local withdrawal of the seas, a slight uplift of the lands, and the introduction of andesitic volcanic activity in the Sierra Nevada which is believed to have served as a source area for both sets of sediments. Whether this time interval represents the bound-

[80] Chaney, Condit, and Axelrod, op. cit.

ary between the Miocene and Pliocene or an interformational unconformity within the upper Miocene is problematical. It is significant however, to point out the physical evidence here for a break between the Cierbo and Neroly formations, which are classified as the upper two members of the tripartite San Pablo group.

Relation to Adjacent Formations. The contact between the Neroly and Cierbo formations and the unconformable relation between the Neroly and the Panoche in the northeast part of the area have already been described. On the east side of Livermore Valley the Neroly sediments are overlapped by the Livermore gravels, presently to be described. In the northeast part of the quadrangle the Neroly is overlain by the Tulare formation composed mostly of Franciscan detritus, but the contact is not exposed.

Tertiary-Quaternary System

Pliocene-Pleistocene Series

Livermore Gravels

The name, Livermore gravels, was applied in 1925 by Vickery [81] to a group of fresh-water gravels, sands, and clays bordering on the southern part of Livermore Valley.

Distribution and Thickness. These beds occupy an area of about 14 square miles in the central western part of the Tesla quadrangle. The deposits have a nearly plane surface gently inclined toward Livermore Valley, and topographically this surface averages from 250 to 500 feet of elevation above the general level of the valley. The tableland has been considerably dissected, but exposures are poor. The total thickness of the gravels was estimated by Branner [82] to be about 4000 feet.

Several odd occurrences of the gravels were found. One of these is in the lap of the syncline north of Corral Hollow. From this point the gravels can be traced westward to join the main extent of the gravels on the south side of the Livermore Valley. High on Rocky Ridge along the common boundary of secs. 23 and 24, T. 4 S., R. 2 E., a small outlier was found in which the gravels are dipping 20° NE. and resting with angular discordance on the Panoche sandstones on the north side of the Williams fault zone. Involvement of the gravels in the faulting is further evidenced by an occurrence of gravels noted by Bailey Willis [83] in a phase of the Williams fault zone in the Hetch-Hetchy tunnel.

Lithology. Massive buff gravels composed chiefly of Franciscan detritus are characteristic of the formation. Light gray to buff sands are common, and sandy clays make up a minor part of the formation. One ledge-forming tuff layer, which averages 10 feet in thickness, occurs prominently in the upper part of the formation in sec. 18, T. 4 S., R. 3 E.

A heavy mineral separation of a sample of light gray, fine sand from the NW¼ sec. 6, T. 4 S., R. 3 E., was examined petrographically. The light minerals consist of kaolinized feldspar (55 percent), quartz (30 percent), oligoclase-andesine (10 percent), chert particles (1 to 2 percent), chlorite (2 to 3 percent), and pale biotite (trace). Heavy minerals comprise 1.26 percent of the whole sample. Of these, basaltic hornblende is abundant; magnetite, chromite (?), and glaucophane are very com-

[81] Vickery, F. P., The structural dynamics of the Livermore region, Doctor's thesis, Stanford University; 1925 (unpublished).
[82] Op. cit.
[83] Unpublished geologic report on the Hetch-Hetchy tunnel for the San Francisco Engineering Department.

mon; zircon and green hornblende are rather common; titanite, epidote, actinolite and garnet are sparse. The general assemblage suggests a source area of Franciscan rocks, but the presence of basaltic hornblende may indicate a derivation of some of the detritus from another source, perhaps an area of Neroly rocks.

The tuff, which was mentioned above, contains the following light minerals: pale brown glass (10 percent; refractive index = 1.460), devitrified glass (80 percent), kaolin minerals (3 percent), quartz (2 percent), sericitized and kaolinized feldspar (4 percent), plagioclase (trace), chlorite (trace), and muscovite (trace). Among the heavy minerals, magnetite is abundant; glaucophane, basaltic hornblende, and epidote are very common; green hornblende and chromite (?) are sparsely present. Mineralogically this tuff does not appear correlative with the Pinole tuff east of San Francisco Bay.

The Livermore gravels are primarily fluviatile deposits laid down over a broad flood plain but may include lacustrine sediments under the alluvium of Livermore Valley.

Correlation. No fossils were found by the writer, but Branner [84] reports finding fresh-water fossils within 340 feet of the base of the formation at Cuesta Blanca on Arroyo del Valle.

The age and correlation of this formation are uncertain. Branner referred these beds to the Orinda formation, but the Orinda is now regarded as probably older. Vickery [85] postulated a correlation of the Livermore gravels with the Santa Clara formation (Plio-Pleistocene). Hannibal[86] also regarded these beds as correlative with the Santa Clara formation, from which he described some leaves. The late B. L. Clark [87] informed the writer that the Livermore gravels are probably correlative with the Tassajero formation, which he named some beds on the north side of Livermore Valley.

Relation to Adjacent Formations. Structurally the formation dips at angles of 10 to 30 degrees northward towards Livermore Valley. At different places it rests unconformably on the following formations: Neroly, Cierbo, Oursan ?, Panoche, and Franciscan. The formation extends out under the alluvium of Livermore Valley and was regarded by Branner [88] as an important conductor of water for the valley.

Tulare Formation

The Tulare formation is of very limited extent in the northeastern part of the area. Anderson and Pack [89] have described and mapped this formation as a narrow strip along the west border of the San Joaquin Valley from the Coalinga area northward to the eastern boundary of the Tesla quadrangle. The formation is poorly exposed locally, and characterized by a surface containing Franciscan detritus weathered from the gravels. This formation may be seen to better advantage in the Carbona and other quadrangles to the southeast. The deposits are fluviatile in origin and consist mainly of brown ill-sorted sands, gravels, and clays. Areas of Franciscan rocks have apparently supplied most of the detritus. No estimate of the thickness is made.

[84] Op. cit., p. 216.
[85] Op. cit., Jour. Geology.
[86] Hannibal, Harold, A Pliocene flora from the Coast Ranges of California: Torrey Botanical Club Bull., vol. 38, pp. 329-342, 1911.
[87] Oral communication, 1937.
[88] Op. cit., pp. 209-222.
[89] Op. cit., pp. 101-105.

Fauna and Age of the Tulare. No fossils were found locally in the Tulare. However, Vanderhoof [90] reports fossil remains of a camel, *Camelops hesternus,* and a ground sloth, *Mylodon harlani,* from the upper part of the formation in the Carbona quadrangle. The locality is near the Tesla portal of the Hetch-Hetchy tunnel in the NE¼ sec. 33, T. 3 S., R. 5 E. Vanderhoof regards the fauna as correlative with that of Rancho La Brea, or late Pleistocene in age.

Vanderhoof also reports that some camel bones were found by P. W. Reinhart at a locality near the base of the Tulare formation in the Carbona quadrangle and that these are tentatively regarded as Pliocene in age. From the evidence of vertebrate faunas from near the top and base of the formation, it may be said that the Tulare ranges in age from Pliocene to late Pleistocene.

Quaternary System

Terrace Deposits and Alluvium

Terraces were mapped in a few of the stream valleys. In Arroyo Mocho there are some well-defined terraces which suggest several stages of regional uplift during the Quaternary. Two levels and in places three levels of terraces are cut into the Livermore gravels. A veneer of gravels is discontinuous over the shelves, which are mainly erosional in origin. In Corral Hollow mapping of the terraces was done locally, except where the scale of the map and complexity of the geology interfered. On the south side of Corral Hollow between Tesla and Mitchell Ravine a terrace has been cut into the Moreno and Eocene rocks about 200 feet above the creek level. Another prominent terrace level is about 50 feet above the creek and carries a capping of about 15 feet of gravels.

Alluvial deposits complete the stratigraphic column. Portions of the Livermore and San Joaquin Valleys which are included within the Tesla quadrangle are alluviated. In Corral Hollow Creek near Carnegie, alluvial gravels consisting of andesitic pebbles from the Neroly and rock particles from older formations, have been excavated and graded for use as railroad ballast and in concrete.

STRUCTURE

For about 75 miles along the west border of the San Joaquin Valley from Panoche Creek northward to Hospital Creek, a rather simple homoclinal section of Cretaceous and Tertiary rocks dip valleyward under the alluvium. In contrast, northwest of Hospital Creek across the Carbona, Tesla, Byron, and Mt. Diablo quadrangles, the geologic structure is complex and characterized by numerous folds and faults.

Many of the structural features, including those within the areas of Franciscan rocks, have already been described or mentioned in the description of the stratigraphy. The main structural lines and axes, and the attitude and succession of the strata are represented areally on the geologic map (pl. 1). The interpretation of the subsurface structure is presented in the sections (pl. 3).

Folds

Altamont Anticline. The largest fold in the area is the broad Altamont anticline in the central northern part of the quadrangle. The limbs and axis of this fold, which was named by Anderson and Pack,[91]

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[90] Oral communication, 1937.
[91] Op. cit., p. 191.

are well exposed in road cuts along the old Altamont Pass highway and along the new U. S. Highway 50. The axis of this fold trends about 42 degrees west of north and can be traced for 4½ miles in the Tesla quadrangle and about 3 miles to the northwest in the Byron quadrangle. The plunge of the fold is to the southeast. Section A-A′ (pl. 3), which is a transverse section through the fold, illustrates the general symmetry of the fold. Dips on the east flank average 16 degrees; those on the west flank range from 12 to 36 degrees, making the west flank slightly steeper. Down-flank on both the west and east limbs, high-angle faults parallel the axial trend of the fold.

The northwest extension of the Altamont anticline in the Byron quadrangle is represented by Taff [92] on a geologic map of the Mt. Diablo area as abruptly but simply dissolving into a northwest-dipping homoclinal section of Cretaceous and post-Cretaceous rocks. However, a reconnaissance inspection of this area of structural change indicates a zone of faulting truncating the anticline and separating it from the homoclinal section to the northwest. This fault zone, which trends northeastward, is marked by numerous springs.

The Altamont fold involves principally rocks of the Panoche formation and to a minor extent Cierbo and Neroly formations. In section A-A′ a marked angular unconformity is represented between the Cierbo and Panoche formations on the west flank of the fold. This unconformity is interpreted as indicating that the inception of folding on this anticline was pre-Cierbo in age. It further allows for the possibility that Moreno Grande and Eocene sediments may have been deposited above the Panoche formation and then folded and eroded away prior to the transgression of the Cierbo formation. However, the absence of sediments of an age between that of the Panoche and Cierbo formations in the Altamont area may mean that a post-Panoche folded high, locally denied their deposition. Instead of a folded high, a positive fault block, the Altamont block, as postulated by Clark [93] would also have denied deposition of the missing sediments. However, the fault-block concept seems less applicable than either of the two preceding explanations mentioned, since there is evidence of pre-Cierbo folding but no direct evidence of pre-Cierbo faulting.

It is also significant that on the west flank of the anticline the Cierbo formation rests on the Panoche, while on the east flank the Neroly overlies the Panoche, and the Cierbo is lapped out. It is possible that the Cierbo was not deposited locally on the east flank of the Altamont fold. It is equally (if not more) possible that its deposition there was followed first by an accentuation of the ancestral Altamont fold and then by a stripping off of the Cierbo sediments prior to the deposition of the Neroly sediments. The significance of the Neroly-Cierbo overlap has already been discussed. The closing stages of the folding of the Altamont anticline were post-Neroly.

Small Faulted Anticline. A small faulted fold in the S½ sec. 8, T. 3 S., R. 4 E., is probably a continuation of the Altamont line of folding. The axis is not well defined in the smooth hills of Cretaceous rocks which make up the core, but it trends approximately S. 80° E.

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[92] Op. cit.

[93] Clark, Bruce L., Tectonics of the Valle Grande of California: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 228, 1929. . . . Tectonics of the Coast Ranges of middle California: Geol. Soc. America Bull., vol. 41, p. 776, 1930.

The Cretaceous rocks are overlain by Cierbo and Neroly beds on the flanks. The north limb of the fold towards the east is a sharp flexure which passes westward into a thrust fault that cuts out the Cierbo, bringing Cretaceous rocks in contact with overturned Neroly blue sandstone. Section E-E′ (pl. 3) is drawn through this structural complication.

Patterson Pass Anticline. The Patterson Pass anticline, which can be traced for about 7½ miles across the north-central portion of the area, is interesting because more than a dozen wells have been drilled along its flanks and axis in an attempt to find a commercial accumulation of petroleum. The fold plunges at both east and west ends. The west end of the fold is truncated diagonally by the Carnegie fault. The axial trend is about S. 80° E. in the western part, turning slightly to S. 70° E. in the east half. The central portion of the axis is cut diagonally by the Patterson Pass fault at the locality of the Seaboard Oil Company-Johnston No. 1 well (sec. 13, T. 3 S., R. 3 E.) and by a lesser fault about a third of a mile to the east.

Panoche rocks are exposed in the core of the anticline which is flanked by Cierbo and Neroly beds. Locally down flank on the south side poorly exposed Moreno Grande shale occurs in the NW¼ sec. 24, T. 3 S., R. 3 W. The occurrence of the Moreno Grande on the south side of the fold is significant for two reasons: first, it may be related with the showings of petroleum which were encountered principally in wells drilled on the south flank; and second, the occurrence strengthens the concept that Moreno Grande was deposited to the north of Corral Hollow and later almost entirely stripped off following a period of pre-Cierbo folding.

The age of the folding is post-Neroly and earlier than the several faults which cut the fold.

Patterson Pass Syncline. North of the Patterson Pass anticline and paralleling it roughly there is a broad synclinal area, the Patterson Pass syncline. The axis, which is discontinuous and interrupted by faulting, can be traced for about 6 miles. The axial trend is S. 65° E. in the western portion, turning to about S. 82° E. in the eastern portion. Rocks of the Neroly formation occur in the lap of the syncline, and rocks of the Cierbo and Panoche formations are exposed on the upturned flanks and in faulted areas.

The age of the fold is post-Neroly.

Midway Anticline. A small anticline, herein given the name of Midway anticline, extends southeastward (S. 35° E.) across secs. 10 and 14 in T. 3 S., R. 4 E. Panoche rocks are exposed in the core in two isolated patches, and Cierbo and Neroly beds occur on the flanks. The plunge at the northwest end is well exposed in the field. At the other end of the fold where the beds appear to lap around, a plunge to the southeast is implied, but the exposures are poor and the apparent closure may be a topographic rather than structural effect.

The age of the fold is post-Neroly.

Synclinal Area North of Corral Hollow. North of Corral Hollow the San Pablo rocks are involved in a discontinuous synclinal structure that trends eastward for about 3½ miles. The Corral Hollow fault cuts the axis diagonally in the western portion, a tear-fault offsets the axis just north of Tesla, and the Carnegie fault cuts diagonally across the syncline at the east end.

In the S½ sec. 24, T. 3 S., R. 3 E., the north limb of the syncline becomes the south limb of a small anticline, which in turn is cut on its north flank by the Carnegie fault.

The age of this fold is probably post-Livermore gravels (Plio-Pleistocene), as gravels which are believed to be a part of the Livermore gravels are folded and preserved in the lap of syncline. The fold is regarded as earlier than the several faults which cut it.

Faults

Greenville Fault. In the northwest portion of the quadrangle there is a fault which has been previously referred to as the Riggs Canyon fault by Vickery [94] and by Clark.[95] The writer prefers to give this fault a local name in the Tesla quadrangle to avoid involvement in a problem concerning the delineation, and even the existence, of the Riggs Canyon fault in the Mt. Diablo quadrangle.

The trace of the fault, which is herein designated as the Greenville fault, trends approximately S. 40° E. The fault zone is best seen in a railroad cut of the Southern Pacific Railway Company near Greenville, just north of the trestle across the old Altamont highway. Numerous gouged and slickensided surfaces occur defining a zone of disturbance nearly 500 feet wide. The slickensided surfaces possess characteristically a steep to vertical attitude with essentially horizontal striations. Near this locality, on the west side of the fault, beds of the Cierbo and Neroly formations dip northeastward into the fault; whereas east of the fault Panoche and Cierbo strata dip southwestward toward the fault. Northwest and southeast of Greenville the fault is traced principally with physiographic control. A sag pond occurs along the apparent trace about a mile northwest of Greenville. The southeast trace of the fault is lost in the NE¼ sec. 8, T. 3 S., R. 3 E.; and no structural connection to the southeast is observed in the field between the Greenville fault and the Carnegie fault which Clark [96] regarded as a continuation of the "Riggs Canyon" (Greenville) fault.

In addition to horizontal displacement, which was indicated from examination of the striations on the fault surfaces, vertical displacement has probably also taken place, and the area east of the fault is interpreted as upthrown. An estimated order of magnitude for the vertical displacement is 100 to 300 feet, but the estimate is questionable, as the base of the Cierbo formation in the west side of the fault is not exposed. The age of the Greenville fault is regarded as post-Neroly.

Midway Fault. The Midway fault, which was named by Vickery [97] cuts across the northeastern part of the area. From the vicinity of the junction of the old and new highways, the fault is vaguely traceable for about 3 miles to the southeast, and the northwestward extension of the fault in the Byron quadrangle was not surveyed. The trend of the fault is S. 40° E. The best evidence for the fault is seen on a small hill near the southeast corner of sec. 24, T. 2 S., R. 3 E. There the Cretaceous rocks appear to be upthrown approximately 100 feet on the northeast side; how-

[94] Op. cit.
[95] Op. cit., 1935.
[96] Op. cit., 1935, p. 1038.
[97] Op. cit., Jour. Geology, p. 614.

ever, this apparent vertical throw may have resulted from horizontal displacement along the fault. Nowhere is the fault exposed, and southeast of the locality just mentioned its trace is indirectly suggested by such physiographic features as furrows, sag ponds, and springs. Southeastward the fault may dissolve into the Midway anticline, since its trace is lost in the vicinity of the north end of that fold.

The age of the fault cannot be assigned more definitely than post-Neroly.

Black Butte Fault. The Black Butte fault is an important fault in the Carbona quadrangle, but its northwest extension onto the Tesla quadrangle is weakly expressed in the physiography. This fault was named by Reinhart [98] from its occurrence at the east base of Black Butte near Corral Hollow Creek in the Carbona quadrangle. Anderson and Pack [99] have mapped the trace of this fault across the Carbona quadrangle. From evidence in wells and in the Hetch-Hetchy tunnel in the Carbona quadrangle, the fault is known to be reverse in type and to dip about 45 degrees to the southwest. In that area Upper Cretaceous strata are thrust over Neroly (San Pablo) and locally over Tulare beds.

The age of the fault appears to be post-Tulare.

Patterson Pass Fault. An important fault, which is herein designated the Patterson Pass fault, was not recognized in previous published geological reports on the area. It cuts diagonally across the central part of the area in a curving southeasterly trace. The maximum vertical displacement on this fault is probably in the northern part of sec. 10, T. 3 S., R. 3 E., where a remnant patch of Neroly blue sandstone occurs on the northern downthrow side of the fault. The throw at this place is estimated at 500 feet (see section C-C′, pl. 3), but a throw of 100 to 200 feet appears to be more characteristic of other parts. Where the fault crosses the Patterson Pass anticline, the Seaboard Oil Corporation Johnston No. 1 well encountered it at the depth of 1400 feet. Other sympathetic fault zones were encountered at greater depths in the well. In core samples from the well, the fault plane dips about 80 degrees, and the slickensiding indicates shear displacement at an angle of 25 to 30 degrees from the horizontal. The Patterson Pass fault is classified as a diagonal oblique-slip fault.

To the northwest the fault apparently joins the Greenville fault. The two have some characteristics in common, such as strong horizontal components of displacement and high angularity, but differ in having their upthrow on opposite sides. To the southeast the Patterson Pass fault is represented as joining other faults, which are believed to be northwesterly diverging branches of the Tesla fault.

The fault is post-Neroly in age. It also appears to be post-folding since it cuts diagonally across the Patterson Pass anticline.

Carnegie Fault. The Carnegie fault, which was named by Vickery,[100] is a high-angle reverse fault striking N. 60° to 70° W. for more than 7 miles through the central portion of the quadrangle. It is nowhere well exposed. However, its trace can be mapped over the central hill in sec. 23, T. 3 S., R. 3 E., where the fault dips to the northeast and brings Cierbo sediments over Neroly beds. The fault cuts through the old Hamilton ranch on the south flank of the Patterson Pass anticline. Northwestward it truncates diagonally the west plunge of the Patterson Pass anticline and continues out under the alluvium of Livermore Valley.

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[98] Personal communication, 1936.
[99] Op. cit.
[100] Op. cit., Jour. Geology, p. 614.

The age of the fault is post-Neroly. However, Clark [101] believed that the fault was existent in "pre-Briones (lower upper Miocene) time" and he represented it as a continuation of his Riggs Canyon fault. In fact he referred to the Carnegie fault as the "Riggs Canyon fault" in both text and illustration. Not only is no connection observed in the field between the Carnegie and Greenville (or Riggs Canyon) fault, but the characteristics of the faults are quite different. The Carnegie fault is a relatively high-angle reverse fault striking in general eastward; the Greenville fault is essentially a vertical fault having horizontal and some vertical components of displacement and a southeasterly strike. Clark, in assigning the inception of movement along the Carnegie fault to the pre-Briones, was impressed with the difference in stratigraphic sequence north and south of the fault.

Corral Hollow Fault. Paralleling the Carnegie fault on the south but having an opposing dip and opposite relation of upthrow, is the Corral Hollow fault, which was named by Vickery.[102] This fault branches off at its east end from the Tesla fault, trends N. 80° W. up the north side of Corral Hollow, curves or shifts northward in the vicinity of Tesla, and then continues in the direction of N. 70° W. towards Livermore Valley. It is best seen just west of where it crosses the Tesla road in the NW $\frac{1}{4}$ sec. 25, T. 3 S., R. 3 E. There the dip of the fault plane is about 80° S., and the upthrow is on the south, defining a high-angle reverse fault. The throw at this place is roughly 300 to 500 feet, and the fault cuts out the upper part of the Tesla formation and more than the basal half of the Cierbo formation. East of this locality in Corral Hollow more of the upper part of the Tesla formation is cut out, and the throw on the fault is estimated to attain a maximum of at least 1500 feet. The change in throw along the trace of this fault from west to east is illustrated in the successive structure sections C-C′, D-D′, E-E′, and F-F′, on plate 3.

Clark [103] apparently regarded the Corral Hollow fault as also a part of the Riggs Canyon fault zone with a "sliver block" existing between the Corral Hollow fault and the local trace of his "Riggs Canyon fault", which is herein designated as the Carnegie fault. No field observations which were made by the writer could be interpreted as indicating any connection between the Corral Hollow fault and Clark's Riggs Canyon fault, other than that displacements along both faults may have taken place during the same period or periods of diastrophism and that both faults may have been formed in answer to the same set of forces acting on the region.

The age of the fault is believed to be post-Neroly and subsequent to the regional folding. However, Clark regarded this fault as related to his Riggs Canyon fault and as having been active in pre-Briones time.

The basis for Clark's reasoning, which was briefly mentioned in the preceding discussion of the Carnegie fault, is the difference in the stratigraphic sequence north and south of a fault zone that separated a positive northern block from a sinking basin on the south that received most of the sediments. For example, south of the Corral Hollow fault Panoche beds are overlain by a sequence of beds which include Moreno Grande,

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[101] Op. cit., 1935, pp. 1038-1039.
[102] Op. cit., Jour. Geology.
[103] Op. cit., 1935, p. 1038.

Tesla, and Cierbo formations; whereas immediately north of the Carnegie fault, the northernmost of the two faults in Clark's fault zone, Panoche strata are overlain by Cierbo beds and the Moreno Grande and Tesla sediments are characteristically missing. This change in sequence cannot be demonstrated as taking place abruptly, for a minimum distance of three-quarters of a mile separates the contrasting columnar sections in the outcrop. Then, too, this distance is necessarily foreshortened by folding and faulting; therefore, if the folds were unravelled and fault displacements allowed for, the distance separating the two sequences would comprise roughly 1¼ miles or more. Such a distance is sufficiently great to allow for the wedging out of beds by overlap and thinning. It should be noted also that the present distribution of the formations with respect to the Corral Hollow fault indicates that the beds on the south side of the fault are upthrown, which is opposite to the position they are supposed to have occupied in a sinking fault-basin during their deposition, according to Clark's concept.

In summary, the writer favors the concept that originally the Moreno Grande and Tesla sediments extended north of the line now marked by the Carnegie fault; that they were removed in a pre-Cierbo period of folding and erosion that was followed by the Cierbo transgression upon the exposed Panoche rocks. The faulting did not take place until after the deposition of the Neroly sediments and may have been contemporaneous with or subsequent to the last regional folding.

Tesla Fault. The most prominent fault in the area is the Tesla fault, which was named by Vickery.[104] South of Corral Hollow this fault forms the northern boundary of the area of Franciscan rocks. It can be traced for about 9 miles across the central part of the quadrangle; to the west it disappears under the terrace and alluvial fill of Livermore Valley, and east of the limits of the quadrangle it continues southeastward across the Carbona quadrangle. Locally, its average strike is N. 80° W. The plane of the fault zone is essentially vertical where the fault crosses Corral Hollow, but at Mitchell Ravine the fault plane dips steeply northward, which with the upthrow on the south makes it appear as a normal fault. However, the fault is believed to be dominantly reverse in type. In the walls of the Hetch-Hetchy tunnel near the Thomas shaft, the fault was observed by Willis [105] to be a high-angle reverse fault dipping about 65° SW. Exposures of the fault are rather poor, but the fault zone can be easily traced because of such features as springs, notchings of ridges, wide zones of disturbance, fault wedges of Horsetown rocks, and the lithologic distinction between Franciscan rocks on the south side and younger rocks on the north side of the fault.

Assuming a minimum thickness of 10,000 feet of Cretaceous strata, the throw on this fault is at least 14,000 feet near the east boundary of the quadrangle where Franciscan rocks are faulted into contact with upper Neroly sediments, cutting out the Horsetown, Panoche, Moreno Grande, Tesla, and Cierbo formations, and parts of the Franciscan and Neroly. The throw of the fault diminishes to the west, but it is probably measurable in thousands of feet throughout the trace of the fault. Near Carnegie several faults appear to branch off from the Tesla fault to the northwest.

[104] Op. cit., Jour. Geology, p. 614.

[105] Private report for the San Francisco Engineering Department on the geology of the Hetch-Hetchy tunnel.

The age of the fault is post-Neroly.

Valle Fault. Another fault bounding the area of Franciscan rocks is the Valle fault in the vicinity of Arroyo Valle in the western part of the area. This fault, striking about N. 60° W, bounds one side of an interesting fault wedge of Cretaceous rocks enclosed within the general area of Franciscan rocks. Northward its trace changes in direction to about N. 20° W., separating the Franciscan on the eastern and upthrown side from the Cretaceous on the west. It finally disappears into or under the Livermore gravels; its trace could not be established across the soft, poorly exposed sediments of the Livermore gravels. However, the fault was observed under the cover of the gravels in the Hetch-Hetchy tunnel. Section H-H′ (pl. 3), which combines surface data with subsurface information in the Hetch-Hetchy tunnel shows a mass of ''granodiorite'' on the east upthrown side and gravels overlying Cretaceous rocks on the downthrown side. The fault in the tunnel dips about 50 degrees to the west, or downthrown side, indicating a normal fault.

The fault is certainly post-Cretaceous, and it may have been active within or after the period of deposition of the Livermore gravels (Plio-Pleistocene) ; but its age cannot be established very closely.

Williams Fault. The Williams fault was so named by Willis [106] from its occurrence in the vicinity of Williams Creek. Vickery [107] called it the Del Valle fault, but Willis' assignment seems preferable.

This fault also bounds the Cretaceous wedge-block mentioned above. To the northwest it strikes about N. 70° W. and is a high-angle reverse fault with serpentine and Franciscan sedimentary rocks upthrown on the south side against Cretaceous rocks. It is traced with some difficulty, but physiographic features and formational contrasts aid in its delineation. It is represented in sections B-B′, E-E′, F-F′, and H-H′, plate 3. In the Hetch-Hetchy tunnel, the fault is a high-angle reverse fault, according to Willis.

The fault is post-Cretaceous; that it may be younger that the Livermore gravels (Plio-Pleistocene) is surmised on the basis of some gravels observed in the Hetch-Hetchy tunnel in a phase of the fault.

Summary-Analysis

The structural dynamics of the Livermore region, which includes the Tesla area, have been discussed by Vickery.[108] He classified the faults into two groups in accordance with their general directional trend. After plotting the fault trends and average direction of fold axes in several diagrams, he arrived at the conclusion that the region had been deformed by rotational forces, that is, a north-south force couple with the ''greatest force from the south.''

It is convenient to follow Vickery's general method of analysis in summarizing the structure of the Tesla area.

The major faults are classified into two groups: (1) the transverse faults, which trend eastward, and (2) the longitudinal [109] faults, which

[106] Willis, Bailey, in private report on Hetch-Hetchy tunnel for San Francisco Engineering Department.

[107] Op. cit., Jour. Geology, p. 614.

[108] Op. cit., Jour. Geology, pp. 608-628.

[109] This terminology differs from that of Vickery, who classified the first group as "branch faults" and the second group as "dominant faults."

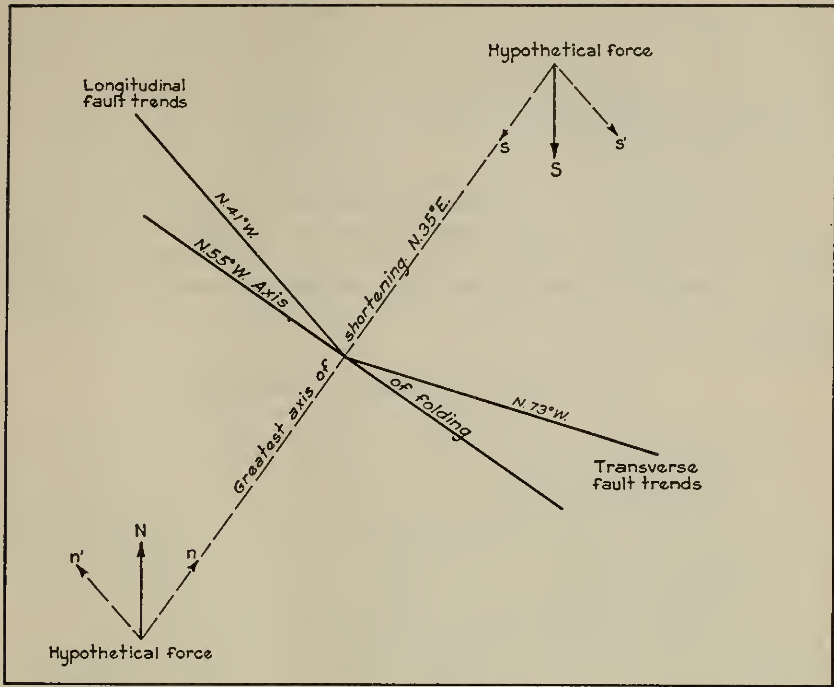

FIGURE 3. Diagram showing regional structural trends, Tesla quadrangle.

trend northwestward. The transverse faults, which comprise the most prominent faults, include the Tesla, Carnegie, Corral Hollow, and Williams. They are high-angle reverse faults having an average trend of approximately N. 73° W. With the exception of the Carnegie fault, they have the upthrown side on the south and dip at high angles principally to the south. The longitudinal faults include the Greenville, Midway, Patterson Pass, Valle, and Black Butte. The average trend of these faults is about N. 41° W., roughly parallel with the trend of the Diablo Range. The first three of this second group of faults are essentially vertical in attitude and exhibit strong components of shear-type displacement. The Valle and Black Butte faults dip at moderately high angles to the southwest and have opposite sides of upthrow.

The average strike of the regional folds is approximately N. 55° W. or intermediate to the trends of the two fault groups. The direction of greatest regional shortening is interpreted as normal to the axial direction of the folding or about N. 35° E.

The foregoing structural relationships are plotted in figure 3.

Any analysis of the forces causing the general pattern of folds and faults is extremely hypothetical and, perhaps, should be avoided. However, the presentation of a few conjectural interpretations can do no harm. The region may have been deformed by a set of rotational forces (N and S in the diagram), comprising a north-south force couple. These opposing forces were necessarily equal, although the release of stress by deformation may have been greater in certain directions because of differences in the thickness distribution of the rocks and other causes. Imaginary minor-force-components, such as *s* and *n*, may have operated opposingly in the direction of greatest shortening to form the folds, and minor force components, such as *s′* and *n′*, may have caused some shear type of displacement along the longitudinal faults. It is noteworthy that in this area no major fault broke with a northeasterly trend. However, in the Byron quadrangle to the north, a fault zone which truncates the Altamont anticline, trends northeastward and is seemingly a tear fault.

The principal time of regional deformation is believed to have been post-Neroly, possibly Pleistocene. Indications of earlier or pre-Cierbo folding were cited, but pre-Cierbo faulting as postulated by Clark cannot definitely be established. The folding, in general, is probably earlier than the faulting, or in part contemporaneous with some of the faulting.

OUTLINE OF THE GEOLOGIC HISTORY [110]

I. Upper Jurassic
   - A. Deposition of about 15,000 feet of Franciscan sandstones, shales, and cherts under marine conditions.
     1. Few intraformational outpourings of basaltic lava on the sea floor.
     2. Belchings of submarine silicious springs depositing colloidal silica and entrapping minute marine organisms.
   - B. Regional deformation accompanied by intrusion of basic plutonic rocks as sills and laccoliths.
     1. Extensive serpentinization in the late stage of intrusion.
     2. Some metamorphism marginal to the intrusive rocks.

———————Diablan orogeny———————

II. Lower Cretaceous
   - A. Deposition of more than 500 feet of dark shales and sands (Horsetown) under shallow, cool-water, marine conditions.

———————Unrecorded interval———————

(Slight regional deformation)

III. Upper Cretaceous
   - A. Deposition of 10,000 feet or more of sands and argillaceous shales in a shallow marine environment.
     1. Site of deposition was slowly sinking in pace with a slowly rising source area.
     2. Intraformational conglomerates represent times of oscillation of shoreline which may be related to the Santa Lucian orogeny.
   - B. Close of period marked by deposition of about 650 feet of shales and sands under cool-water, marine conditions.
     1. Minute marine organisms common in the shales.

———————Unrecorded interval———————

IV. Middle Eocene
   - A. Early deposition of dark shales, gray sands, and a few coal beds.
     1. Brackish water to swampy conditions.
     2. Warm temperature to sub-tropical climate.
   - B. Later marine deposition of white and gray sands, clays, and shales.
     1. Principal source area, the Sierra Nevada, was undergoing deep chemical weathering.

———————Unrecorded interval———————

[110] The main events in the geologic history of the area as interpreted from the rocks are outlined herein. An attempt is made to inter-relate the local history with that of a larger area now comprising central California. Many of the topical sentences in the outline constitute in themselves generalizations, the basis for which is described elsewhere in the paper.

V. Middle and upper Miocene
   A. Marine deposition of 700 feet or more of sands, shales, and tuffaceous clays in the western part of the area.
      1. Evidence of Franciscan detritus in the sediments.
      2. Indirect evidence of vulcanism during the middle Miocene.
   (Note: Before the transgression of the Cierbo seas—folding and stripping of some of the earlier sediments possibly occurred in northern high areas.)
   B. Transgression of Cierbo seas.
      1. Deposition of coarse sands, shales, tuffs, and a trace of coal.
      2. General marine conditions, local swamps.
      3. Sierra Nevada source area for the sediments.
      4. Indirect evidence of volcanic activity in surrounding area.

——————Slight folding and erosion locally——————

   C. Neroly deposition
      1. Spreading of coarse andesitic gravels and sands over a broad coastal plain.
         a. Abundant rainfall, warm average temperature.
         b. Coastal swamps.
         c. Horses roaming over coastal plains.
         d. Andesitic outpourings in source area (Sierra Nevada).
      2. Closing deposition of tuffs and shales.

——————Unrecorded interval——————

VI. Plio-Pleistocene
   A. Spreading of about 4000 feet of coarse gravels, sands, and clays over Livermore Valley area.
      1. Broad river flood plains and lakes.
      2. Source area: Franciscan rocks.
      3. Indirect evidence of some regional volcanic activity.
   B. Broad flood-plain deposits of gravels and sands along the border of the San Joaquin Valley.
      1. Source area: Franciscan rocks.
      2. Existence of camels and ground sloths in the area.

——————Unrecorded interval——————

(Main regional deformation—folding and faulting.
Stream terraces recording stages of uplift.)

VII. Recent
   A. Erosion of hills and valleys.
   B. Alluviation of stream courses and major valleys.

MINERAL RESOURCES

The Tesla quadrangle contains a variety of mineral deposits, including some notable potential reserves. Although none of its mines would be regarded as a major development, a number of small mines and workings have probably operated with profit, and collectively some mines, such as the manganese properties, have made important contributions to strategic needs during time of war. The accompanying economic mineral map (pl. 2) shows the location of the mines and prospects, and also the location of the abandoned wells that have been drilled for oil or gas.

Chromite

Chromite has been mined at the *Newman mine* on Cedar Mountain near the west quarter-corner of sec. 26, T. 4 S., R. 3 E. The chromite occurs in irregular segregations and as disseminated grains in a serpentine gangue near the margin of a large body of serpentine. When the writer visited the mine in 1936, the workings were abandoned but some sacks of ore were still at the mine.

Clay

The old *Tesla coal mine* was operated in its late history as a clay mine.[111] The clay is of good quality and occurs above the coal seam in association with the white sands in the Tesla formation. Exposures of the white to light-colored clays are poor at the surface, but good samples may be obtained from road-cuts, or recent workings, or by digging test pits. The clay from the old Tesla mine was transported on a branch of the Western Pacific Railway a few miles down Corral Hollow to brick and pottery plants at Pottery and Carnegie. This development was in full operation in 1911 when Anderson and Pack [112] were working in the area. It is said that a large brick company later bought out the mines and brick works. For many years following the shutdown the clays in this area were not worked, and time has erased much of the evidence of the old brick and pottery works.

During a revival of clay mining in 1928, the *Livermore Clay and Sand Company* operated a mine on the north side of the Tesla road in the NW¼ sec. 26, T. 3 S., R. 3 E. Again clay mining lapsed for a number of years until in 1939 the *Tesla Clay Company* operated a clay development south of the Tesla road in the northwest quarter of the same section. The clay is smooth textured, compact, white to light blue gray in color. V. T. Allen [113] studied petrographically samples of the white Tesla clay and found the clay to be anauxitic and possessing a refractive index gamma close to 1.566. He also listed some chemical analyses made of the clay, which is reportedly suitable for the manufacture of pottery and has been used successfully by a number of companies in the Bay region, including the *Technical Porcelain and Chinaware Company,* El Cerrito.

Coal

The history of the development of the mineral resources in the Tesla area really began with the *Tesla coal mine* in sec. 25, T. 3 S., R. 3 E. When Brewer visited Corral Hollow in October of 1861 the coal mines were already in operation. He[114] predicted that coal mining there would not prove profitable. In later years clay mining replaced the coal development.

The coal seam occurs in the lower brackish-water portion of the Tesla formation below the lower white sand and in association with sand and chocolate-colored carbonaceous shales. The seam, which is only about 6 inches thick at the surface, is lenticular. The writer was unable to gain access to the old underground workings, but Whitney[115] reported a maximum thickness of 66 inches for the coal seam in the mines. He reports that by October 1861 from 200 to 400 tons of low-grade coal had been mined. Whitney gives an analysis of the coal as follows:

H_2O	20.53 percent
Bituminous substance	35.62 percent
Fixed carbon	36.55 percent
Ash	3.94 percent

[111] Dietrich, Waldemar Fenn, The clay resources and ceramic industry of California: California Min. Bur. Bull. 99, pp. 38, 42-45, 207-208, 263, 1928.
[112] Op. cit., p. 211.
[113] Op. cit., 1941, pp. 274-277.
[114] Brewer, W. H., Up and down California in 1860-64, Yale Univ. Press, 1930.
[115] Whitney, J. D., Geological survey of California, vol. 1, p. 498, 1865.

Along the general strike of the Tesla coal horizon are evidences today of a number of old abandoned prospect diggings for coal. These prospects and their general location are as follows:

1. Sec. 32, T. 3 S., R. 4 E., near north quarter-corner. (Note: This prospect may also have been worked for glass sand.)
2. Sec. 30, T. 3 S., R. 4 E., near south quarter-corner in west bank of Mitchell Ravine.
3. Sec. 26, T. 3 S., R. 3 E., near the west line and in the northwest quarter of the section (*Livermore Coal Mine Company*).
4. Sec. 27, T. 3 S., R. 3 E., in the northeast quarter a few hundred feet west of the coal prospect in section 26 (*Livermore Coal Mine Company*).

Thin lenticular seams of low-grade coal occur locally in the Cierbo formation. One such occurrence is noted in the tunnel of the K-ola mine in the NW¼ sec. 27, T. 3 S., R. 3 E. Coal fragments are common in the dump at the caved entrance of a prospect adit on the south side of the Tesla road near the center of the same section 27.

Glass and Foundry Sand

The white sands of the Tesla formation are high in their content of quartz and low in ferromagnesian mineral content, hence they have been prospected and mined to some extent for use in the manufacture of glass. The petrography of the white sands was described earlier in the report, and for additional petrographic description of these sands, the reader is referred to V. T. Allen's paper.[116] Abandoned glass sand prospects are located near the north quarter-corner of sec. 32, T. 3 S., R. 4 E., in the NW¼ sec. 26, T. 3 S., R. 3 E., and near the center of the NW¼ sec. 25, T. 3 S., R. 3 E. The mining of glass sand in the Tesla area has been held back by the more ready accessibility and higher quality of the white sands near Mt. Diablo. The importation of high quality glass sand as ship ballast from Holland is also said to have competed in years past with the local development.

A current demand for good quality molding or foundry sand has revived the mining of sand, called "Livermore ganister," in the area. The *Tesla Clay and Sand Company* has a new development near the old Tesla coal mine in the western part of sec. 25, T. 3 S., R. 3 E. Mr. Lauren Wright, Associate Geologist with the California State Division of Mines, recently visited these workings and has kindly submitted the following information for inclusion in this report:

"The current operations of the Tesla Clay and Sand Company are confined to a single stratigraphic unit, apparently the same as that described by Dr. Huey as the 'lower white sand'. Both nodular clay and the so-called 'ganister' are mined by underground methods and marketed in the San Francisco Bay area.

"The term 'ganister' when strictly applied refers to a quartzite or silica rock. This rock, when crushed or mixed with fire clay, is used in foundry practice as a ladle-patching and furnace-lining material. The Livermore 'ganister', a natural mixture of siilca sand and clay, is used similarly and is also marketed as a naturally bonded molding sand.

"The physical properties and adaptability of Livermore 'ganister' have been briefly described by Donaldson[117] and by Wright." [118]

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[116] Op. cit., 1941, pp. 274-277.

[117] Donaldson, Harris M., and others, Foundry sands and mold materials: Am. Foundrymens Assoc., Northern California Chapt., Rept. 2, p. 119, 1945.

[118] Wright, Lauren A., California foundry sands: California Jour. Mines and Geology, vol. 44, pp. 37-72, 1948.

Gravel and Rock

In Corral Hollow east of Carnegie, loose gravels of the creek bottom have been excavated, graded, and piled into large gravel piles. The gravels are constituted principally of rounded andesite pebbles and cobbles from the Neroly formation admixed with standstone pebbles from older formations. For several years the gravels were used for railroad ballast by the Western Pacific Railway Company and in the early 1930's the gravel was used in concrete for the Hetch-Hetchy project.

A rock quarry in red Franciscan chert, located in the NW¼ sec. 14, T. 4 S., R. 3 E., is known as the *McLean red shale deposit*. The material has been used for roofing granules.

Lime Rock

Old lime rock workings are located in the southwest corner of sec. 32, T. 3 S., R. 4 E., and in the southeast quarter of the adjoining section 33 (*California Lime and Cement Company*). The rock consists of spar and travertine which was probably deposited by hot springs along the Tesla fault zone. The rock was mined for use in the brick and pottery works at Carnegie and Pottery, which were in operation around 1911.

An unimportant travertine prospect is located just north of the Patterson Pass road in the center of sec. 10, T. 3 S., R. 3 E. It is apparently an old hot-spring deposit along a minor fault.

Another lime rock prospect is located in the southwest corner of sec. 32, T. 3 S., R. 4 E., developed in Franciscan rocks about a quarter of a mile south of the Tesla fault.

Magnesite

Good quality magnesite ore was mined during World War I from two surface workings of the *Cedar Mountain magnesite mine* in the NE¼ sec. 27, T. 4 S., R. 3 E. The rock is white, porcellaneous, massive to mammillary; fracture is conchoidal. It occurs in large irregular masses in the outer margin of a serpentine body on Cedar Mountain. When last visited in 1936 by the writer, the deposit still contained considerable available ore.

Two other magnesite prospects occur in a serpentinized mass on the Hayes Ranch just south of the Williams fault in the southern part of sec. 24, T. 4 S., R. 2 E.

Manganese

For an excellent reference on the mineralogy, occurrence, genesis, history and utilization of manganese ore in California, the reader is referred to Bulletin 125 of the California Division of Mines (1943). In giving some of the highlights of the occurrence of manganese in the Tesla area, the writer has drawn freely from this bulletin.

The largest manganese mine in California, the *Ladd mine*, is located in the SE¼ sec. 2, T. 4 S., R. 4 E., just east of the boundary of the Tesla quadrangle in San Joaquin County. The mine was first operated in 1867 and in the first 7 years produced more than 5000 tons, most of which was shipped around Cape Horn to England to be used in the manufacture of chlorine. After 1875 the shipments to England were discontinued but the mine was operated until about 1902 and much of the production was used in the manufacture of batteries.

The mine was reopened during World War I and according to Trask, Wilson and Simons [119] about 10,000 tons of ore containing 44 percent manganese and 12 percent silica was mined for its last operation. Trask estimates on the basis of the size of the dump and underground workings that the Ladd mine has produced a total of about 30,000 tons of ore. The following description of the mine is from Trask, Wilson, and Simons.[120]

> "The mine was worked on three levels about 75 feet apart, and the ore was mined mainly from one bed, which lies in the white chert. This bed is 800 feet in length and 35 feet in maximum thickness. The part that was mined was from 1 foot to 16 feet thick. It consisted of high grade oxide ore which contained between 40 and 45 percent manganese and was generally richest near the base of the bed. The part that was not mined consists of stockwork oxide ore containing 15 to 20 percent manganese. It is estimated that there are 170,000 tons of such ore, averaging 18 percent manganese, the cut-off being placed at 10 percent. The maximum depth of oxidation is about 250 feet. Some 10,000 tons of carbonate and bementite ore containing about 20 percent manganese is inferred to be present below the zone of oxidation."

The manganese ore in this mine is a typical Franciscan sedimentary deposit laid down contemporaneously with the cherts with which the ore is interbedded. For a discussion of the genesis of Coast Range manganese deposits, the reader is referred to a discussion by Taliaferro and Hudson.[121] At the Ladd mine the chert beds associated with the ore are dipping about 50° NE., and black manganiferous rocks show along the strike, N. 50° W., for about a mile. To the northwest along the strike is the *Fabian mine* also in section 2. The Fabian mine may have produced as much as 2000 tons, but its workings are now flooded and no reliable estimate can be made. In 1917 the Fabian mine was taken over by the operators of the Ladd mine and its production combined with that of the Ladd mine.

The U. S. Bureau of Mines, in cooperation with the U. S. Geological Survey, explored the Ladd mine during 1940-41 by diamond drilling, drifting, cross-cutting, and trenching. This exploration program proved ore reserves of 232,000 tons having an average grade of 17.8 percent manganese.

The U. S. Bureau of Mines tested the Ladd mine ore at the pilot-plant of the government-owned Manganese Ore Company, Boulder City, Nevada. The process produced manganese metal by electrolytic deposition. A flow-sheet was drawn for a commercial electrolytic manganese plant to be built at Oakland adjoining an idle power-generating plant. In 1942 American Alloys and Chemicals Corporation made application to the War Production Board for a loan of $1,400,000 to purchase the mine, mining equipment, the power plant; to finance construction of the electrolytic plant; and to provide working capital. This loan was not granted.

The general area drained by Arroyo Mocho in the south-central part of the Tesla quadrangle is an important source of manganese, having yielded 4,600 tons from 16 properties. The principal mines have been the *Camp 9*, the *Man Ridge*, the *Section 14*, the *Graves*, and the *Black Jack*.

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[119] Trask, P. D., Wilson, I. F., and Simons, F. S., Manganese deposits of California, a summary report: California Div. Mines Bull. 125, p. 85, 1943.
[120] Op. cit., pp. 85-86.
[121] Taliaferro, N. L., and Hudson, F. S., Genesis of the manganese deposits of the Coast Ranges: California Div. Mines Bull. 125, pp. 217-275, 1943.

List of wells drilled for oil or gas in Tesla quadrangle

Index number	Location T	Location R	Location Sec.	Name of company and well	Date drilled	Total depth	Summary of well log	Remarks
			Alameda County					
1*	2S.	2E.	22	Alameda Oil Co. of San Francisco	?	1,175′		Well listed Div. Mines Bul. 118 (1943)
2*	2S.	2E.	26, SW.¼, NW.¼		1900±	1,100′	Gas show at 600′	Well mentioned by Anderson & Pack (1915)
3	2S.	3E.	20, NE.¼	Standard Oil Co., "Egan" No. 1	1908-1909	1,090′	Panoche	No shows. Converted to water well
4	2S.	3E.	27, NE.¼	Standard Oil Co., "Leonardo" No. 1	1908-1909	2,878′	Panoche	Oil show at 1,275′
5	3S.	3E.	7, 1,890′ N. and 50′ E. of SW. cor.	Bradford & Guardino "B. & G." No. 1	1945	500′±	Alluvium and Livermore gravels	Bailed oil emulsion at about 250′
6*	3S.	3E.	6	Atlantic & Western Oil Co., well No. 1	?	?		Well listed Div. Mines Bul. 118 (1943)
7*	3S.	3E.	6	Atlantic & Western Oil Co., well No. 2	Pre-1925	200′?		Well listed Div. Mines Bul. 118 (1943)
8	3S.	3E.	9, 900′ N. and 1,100′W. of SE. cor.	J. E. Coniff, "Calhoma" No. 1	1926-1929	1,523′	0-500′?, Cierbo sands 500′?-1,523′ Panoche	Oil shows claimed at, 498′, 975′, 1,335′ 1,500′ Liner (104′) set on bottom. Tested wet, trace gas
9	3S.	3E.	13, 330′ N. and 160′ E. of W/4 cor.	Seaboard Oil Corp., "Johnston" No. 1	1936	5,925′	500′± Cierbo/Panoche contact 1,405′-1,455′ Fault 1,882′-1,933′ Conglomerate 1,933′-5,925′ Mostly hard blue claystone	Few gas shows
10	3S.	3E.	14, 600′ N. and 500′ E. of W/4 cor.	George L. Craig, well No. 1A	1926-1927	1,602′	Panoche	Showing oil and gas at 800′. No tests
11	3S.	3E.	15, 2,250′ S. and 1,075′ W. of NE. cor.	A. M. Gilstrap, well No. 1	1931-1933	1,336′	Cierbo at surface	Gas show reported at 1,065′; oil show at 1,270′

12	3S. 3E. 15, 2,000′ N. and 1,500′ E. of SW. cor.	W. M. & S. Co., "Hamilton Ranch" No. 1	1910	450′	Cierbo at surface	
13	3S. 3E. 15, 1,800′ S. and 1,100′ E. of NW. cor.	W. M. & S. Co., "Hamilton Ranch" No. 2	1912?	600′	Cierbo at surface	
14	3S. 3E. 15, 1,500′ N. and 3,500′ E. of SW. cor.	Atlantic & Western Oil Co., "French" No. 1	1911-1921	3,150′	Panoche at surface	Originally drilled to 1,700′ by Independence Oil Co.
15	3S. 3E. 15, 1,500′ N. and 1,000′ E. of SW. cor.	Alisal Oil Co., well No. 1	1909-1910	979′	270′ Cierbo/Panoche contact	Pumped 5 to 10 B/D fluid, 30° gravity oil and 75% water
16	3S. 3E. 15, 1,400′ N. and 500′± E. of SW. cor.	15-3 Oil Co., "Hamilton Ranch" No. 1	Ca. 1900	800′	Cierbo at surface	Lost tools. No. tests
17	3S. 3E. 15, 2,600′ E. and 400′ N. of SW. cor.	15-3 Oil Co., "Hamilton Ranch" No. 2	Ca. 1900	1,200′	Cierbo at surface	Oil show at 640′
18	3S. 3E. 15, 500′ N. and 250′ E. of SW. cor.	Talbot Oil Co., well No. 1	1926-1927	510′	Cierbo at surface	
19*	3S. 3E. 15, SW.¼	Livermore Oil Co., "Hamilton" No. 1	1921-1923	612′	Several oil shows 515′-608′	Well reportedly pumped 15-20 B/D oil before water broke in
20*	3S. 3E. 15?, near SW. cor. sec. 15	Doane (?), well No. 1	Pre-1900	?	Well starts in Neroly; steep dips	
21	3S. 3E. 16, 25′ N. and 900′ W. of SE. cor.	Thomas & Hammill, well No. 1	1926	1,027′	Steep dips. Probably didn't reach Cretaceous	Oil show at 801′. Bailed water, little oil and gas
22	3S. 3E. 21, 150′ S. and 450′ W. of NE. cor.	Foster & Hammill, well No. 2	1928-1929	1,570′	Well starts in Neroly; steep dips	Few oil and gas shows
23	3S. 3E. 25, Near center		Pre-1915	1,800′	Tesla formation, near fault zone	No shows
	San Joaquin County					
24	2S. 4E. 33, Ca. 1,000′ W. of E/4 cor.	Tracy Oil Co., well No. 1	Pre-1915	3,100′	Starts in upper Neroly	Slight oil shows claimed. Trace gas
25	3S. 4E. 2, 2,718′ S. and 2,707′ E. of NW. cor.	Coast Exploration Co., "T. F." No. 1	1937	3,496	Tulare at surface. San Pablo/Cretaceous contact @1,690′±	On drill-stem test 2,600-2,700′ made estimated 20 MCF gas

* Well not located in field or shown on map.

The manganese mines and prospects in the Tesla quadrangle are tabulated below, arranged by counties according to location by section, township, and range. These mines are all typical Franciscan deposits. The production is classified in one column by letters following the scheme used in Bulletin 125. The letters have the following signification:

A. Production 1000 tons or more
B. Production 150 to 999 tons
C. Production 1 to 149 tons
D. No production

All but two of the mines named below are listed in Bulletin 125 with citations to state and other publications giving special information on individual properties. The *Dragi* and *Foscilina* mines were reported by Mr. Charles Scott.

List of manganese properties in the Tesla quadrangle.

Name of claim	Owner	Sec.	T.	R.	Class (production)
		Alameda County			
Kelly prospect	Mrs. Kelly	NW 5	4 S	3 E	D
Camp 9	Crocker Estate	NW 9	4 S	3 E	A
Nelson mines (2)	Holm Bros.	NW 10	4 S	3 E	B
Chaney	Frank J. Rodriguez	NE 12	4 S	3 E	C
Jumbo prospect	J. M. Beraudiere	NE NE 14	4 S	3 E	D
Black Jack	H. T. Beraudiere	NE 14	4 S	3 E	B
Beraudiere	J. M. Beraudiere	NW 14	4 S	3 E	C
Newman	Mabel Newman	SW 22	4 S	3 E	C
Dewhirst	Mrs. Amanda Dewhirst	22	4 S	3 E	C
Gallagher	Dan Gallagher	NW 19	4 S	4 E	C
Section 14	Lee Ogier	NE 14	5 S	3 E	B
Winegar	H. V. Winegar	SW 4	5 S	4 E	D
Man Ridge	Phil Winegar & Arthur Most	7	5 S	4 E	B
Graves	J. B. Graves	7	5 S	4 E	B
Foscilina		SW 8	5 S	4 E	C
Dragi		18	5 S	4 E	C
		San Joaquin County			
Ladd*	Connelly Ranch	SE 2	4 S	4 E	A
Fabian	Mack C. Lake	2	4 S	4 E	A
Scott	Charles Scott	34	4 S	4 E	D

* In Carbona quadrangle.

Petroleum

A few oil seeps, a small amount of produced medium gravity oil, and about 25 abandoned exploratory wells make a short story of the unsuccessful search for an economic accumulation of oil or gas in the Tesla quadrangle. Almost half of these ventures were shallow cable-tool holes drilled prior to 1912. The largest concentration of wells is near some old seeps on the Hamilton ranch in sec. 15, T. 3 S., R. 3 E.

Oil Seeps. Anderson and Pack [122] have described in detail some oil seeps located in two gulches in the southern part of sec. 15, T. 3 S., R. 3 E. The seeps occur in the coarse sands of the Cierbo formation just north of the Carnegie fault. Oil-stained sand can still be seen in the tunnel about 500 feet below the Alisal well in the southwest quarter of the section. The other tunnel mentioned by Anderson and Pack, which is located about 200 yards above the old Hamilton ranch house, is caved and the seep could not be seen. The dry oil sand reported as outcropping in the creek bottom a few yards below the tunnel was not found.

In 1944 a well being drilled for water on the Heifner ranch in the SW¼ sec. 7, T. 3 S., R. 3 E., encountered a sand at depth 241 feet from which a heavy oil-water emulsion was bailed. The writer interprets this occurrence as seepage oil from the Carnegie fault working laterally into the shallow sands of the Livermore gravels. This oil showing led Bradford and Guardino in 1945 to drill a shallow well adjacent to the abandoned water well to a depth of about 500 feet. The well was abandoned and presumably they obtained comparable showings. In the spring of 1947 a water well drilled on the ranch of the Mingoia Bros. near the north quarter-corner of the same section 7 was abandoned because of oil showings. A successful water well was then drilled about 1000 feet southwest of the abandoned well. These near-surface seepage indications are about 3 miles northwest of the seeps which also occur along the Carnegie fault in section 15.

Wells Drilled for Petroleum. Of the 25 wells drilled for oil or gas in the Tesla quadrangle about half have reported some minor oil or gas shows, but only one or two wells actually produced a few barrels of oil with water. The oil found on the Hamilton ranch occurs both in basal Cierbo sands and in upper Panoche sands. A reasonable speculation on the probable source of this oil would favor the shales of the Moreno Grande, which appear to have the highest organic content of any in the area. These shales crop out along the south side of Corral Hollow.

The wells drilled for oil and gas are shown on the economic mineral map (pl. 2) and are tabulated (see pp. 64-65) with supporting data as to location, date drilled, depth reached, log summary, and remarks.

Tuff

A white tuff bed in the Cierbo formation outcrops in the NW¼ sec. 27, T. 3 S., R. 3 E. The material is a compact fine white tuff. It was not mined at the surface, but from an adit several hundred feet long which was driven into the hill. A large mill was erected, which has since been removed, and the name of the mine "*K-ola*" was spelled out in large white letters in the rock, so that it could be read from an automobile on the Tesla road or from an airplane overhead.

A sample of the material was examined in oil under the microscope. The tuff is made up of 97 percent clear glass, refractive index 1.50; quartz (2 percent), kaolinized feldspar (1 percent), and traces of pale biotite and magnetite. Mr. T. T. Copeland, the owner of the property when the writer visited there in 1936, indicated that he had trouble finding a market for the material. There has been no activity at the site for years, and the inner portion of the tunnel has caved.

[122] Op. cit., pp. 136-137.

REGISTER OF FOSSIL LOCALITIES

Invertebrate localities

Loc. I (U. C. loc. A-3083) In creek bottom in north central part of sec. 32, T. 3 S., R. 4 E., about 500 feet south of mouth of creek
Stratigraphy: Basal part of Tesla formation
Lithology: Fine-grained sandstone
Fauna: Brackish-water pelecypods
Collector: A. S. Huey

Loc. II (U. C. loc. A-3082) In west bank of Mitchell Ravine near north quarter-corner of sec. 31, T. 3 S., R. 4 E.
Stratigraphy: Same horizon as loc. I, about 100 feet above base of Tesla formation
Lithology: Massive tan fine sand
Fauna: Brackish-water pelecypods
Collector: A. S. Huey

Loc. III (U. C. loc. A-3080) In east bank of Mitchell Ravine near north quarter-corner of sec. 31, T. 3 S., R. 4 E.
Stratigraphy: 30 feet above Tesla-Moreno Grande contact and 70 feet below horizon of loc. II
Lithology: Gray bedded sandstone
Fauna: Brackish-water pelecypods
Collector: A. S. Huey

Loc. IV (U. C. loc. A-3084) About 200 feet west of and above the Tesla road, near center of sec. 25, T. 3 S., R. 3 E.
Stratigraphy: About 700 feet below the upper white sand in the Tesla formation
Lithology: Buff fine-grained sandstone
Fauna: Marine pelecypods (middle Eocene)
Collector: A. S. Huey

Loc. V (U. C. loc. A-3081) Near center of sec. 25, T. 3 S., R. 3 E., east of Tesla road and beside a post on east bank of creek
Stratigraphy: About 690 feet below upper white sand in Tesla formation
Lithology: Soft tan sand
Fauna: Poorly preserved marine pelecypods and gastropods
Collector: A. S. Huey

Loc. VI (U. C. loc. A-3085) On side of ridge in western part of NW¼ sec. 25, T. 3 S., R. 3 E.
Stratigraphy: As float in upper portion of Tesla formation
Lithology: Hard light brown sandstone
Fauna: Marine pelecypods and gastropods (middle Eocene)
Collector: A. S. Huey

Loc. VII North bank, near bottom of creek at south quarter-corner of sec. 3, T. 3 S., R. 3 E.
Stratigraphy: About 300 feet above oyster zone which occurs near base of Cierbo formation
Lithology: Tan sandstone
Fauna: Marine gastropods and pelecypods (upper Miocene)
Collector: A. S. Huey

Loc. VIII In Arroyo Valle near center of NW¼ sec. 3, T. 4 S., R. 2 E.
Stratigraphy: About 50 feet above base of Oursan (?) sandstone
Lithology: Tan sand
Fauna: Abundant but rather poorly preserved marine gastropods and pelecypods
Collector: A. S. Huey

Loc. IX In south-facing bank along dirt road in central western part of sec. 26, T. 3 S., R. 3 E.
Stratigraphy: Not far below top of Cretaceous
Lithology: Massive tan sandstone
Fauna: Marine cephalopods and pelecypods (Upper Cretaceous)
Collector: A. S. Huey

Loc. X Old Jordan Ranch locality. On small flat on the east side of and above creek level of Arroyo Valle in the SE¼ sec. 11, T. 4 S., R. 3 E.; also on west side of creek
Stratigraphy: About 2500 feet above conglomerate on Rocky Ridge
Lithology: Tan sandstone
Fauna: Marine invertebrate (Upper Cretaceous)
Collectors: Lorenzo G. Yates and F. M. Anderson

Loc. XI Near road in bottom of Arroyo Valle in SE¼ sec. 29, T. 4 S., R. 3 E.
Stratigraphy: Reworked Upper Cretaceous fossils
Lithology: Fossiliferous sandstone boulders in conglomerate
Fauna: Marine invertebrates (Upper Cretaceous)
Collector: A. S. Huey

Loc. XII Beside road near east quarter-corner of sec. 36, T. 3 S., R. 3 E.
Stratigraphy: Horsetown formation (Lower Cretaceous)
Lithology: Light brown sandstone
Fauna: Marine cephalopods and pelecypods
Collector: A. S. Huey

Loc. XIII In cut of Western Pacific Railroad, near east quarter-corner of sec. 27, T. 2 S., R. 3 E.
Stratigraphy: Panoche formation (Upper Cretaceous)
Lithology: Concretion in argillaceous shale
Fauna: Large cephalopod; donated to California Academy of Science
Collector: A. S. Huey

Loc. XIV (U. C. loc. A-2615) In east bank of Mitchell Ravine in north central part of sec. 31, T. 3 S., R. 4 E.
Stratigraphy: About 250 feet below Eocene-Cretaceous contact in Moreno Grande formation
Lithology: Yellow-brown limestone concretion weathering out of shale
Fauna: Abundant well preserved radiolaria. Also foraminifera and an ammonite
Collector: A. S. Huey

Vertebrate locality

U. C. loc. V-3620 About 500 feet due west of southeast corner of sec. 21, T. 3 S., R. 4 E., on small ridge near fence
Stratigraphy: In middle of lower blue sandstone member of Neroly formation
Lithology: Gravel bed
Fauna: Teeth and foot bones of horse
Collector: P. W. Reinhart

Leaf localities

U. C. loc. 199 In cut of Western Pacific Railway right-of-way near Greenville in west center of sec. 31, T. 2 S., R. 3 E.
Stratigraphy: Neroly formation
Lithology: Interbedded sand and tuffaceous clay
Flora: Fossil leaves of coastal plain type
Collectors: Carlton Condit and A. S. Huey

U. C. loc. P-361 In NE¼ NW¼ sec. 29, T. 3 S., R. 4 E., in creek bottom about 1 mile north of Corral Hollow road
Stratigraphy: At base of Neroly formation
Lithology: Gray tuffaceous claystone beneath a blue sandstone bed
Collectors: Carlton Condit and A. S. Huey

U. C. loc. P-3718 In south-facing bank at foot of Tesla grade in the SE¼ sec. 25, T. 2 S., R. 3 E.
Stratigraphy: Lower part of Tesla formation
Lithology: Chocolate colored shales
Flora: Abundant leaves (middle Eocene)
Collectors: A. S. Huey and others

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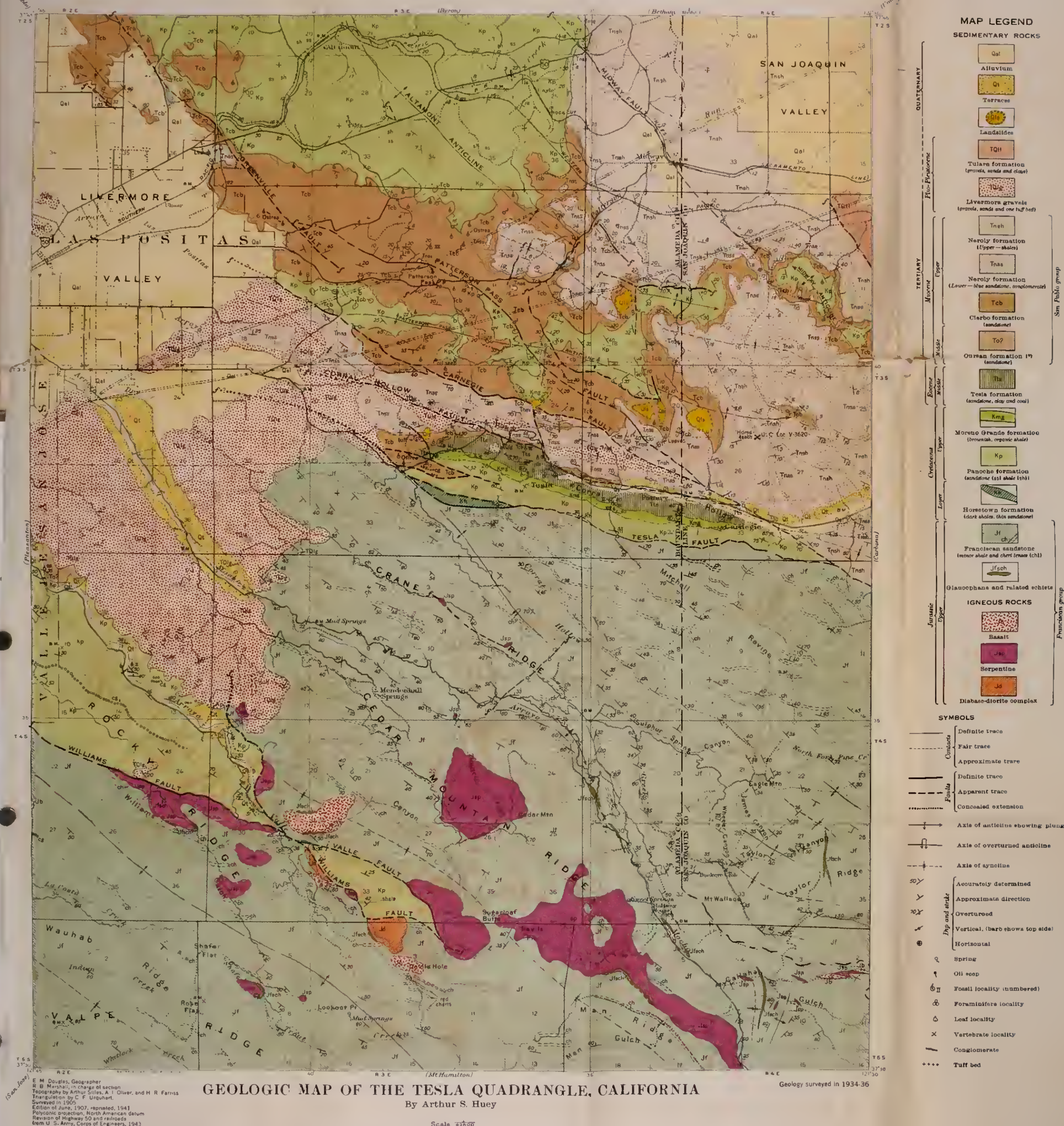
DIVISION OF MINES
OLAF P. JENKINS, CHIEF

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

BULLETIN 140 PLATE 1



E. M. Douglas, Geographer
R. B. Marshall, in charge of section
Topography by Arthur Stiles, A. I. Oliver, and H. R. Farmss
Triangulation by C. F. Urquhart
Surveyed in 1905
Edition of June, 1907, reprinted, 1941
Polyconic projection, North American datum
Revision of Highway 50 and railroads
from U. S. Army, Corps of Engineers, 1943

GEOLOGIC MAP OF THE TESLA QUADRANGLE, CALIFORNIA

By Arthur S. Huey

Geology surveyed in 1934-36

Scale 1/62500

Miles

Kilometers

Contour interval 50 feet
Datum is mean sea level

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4 Miles

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4 Miles

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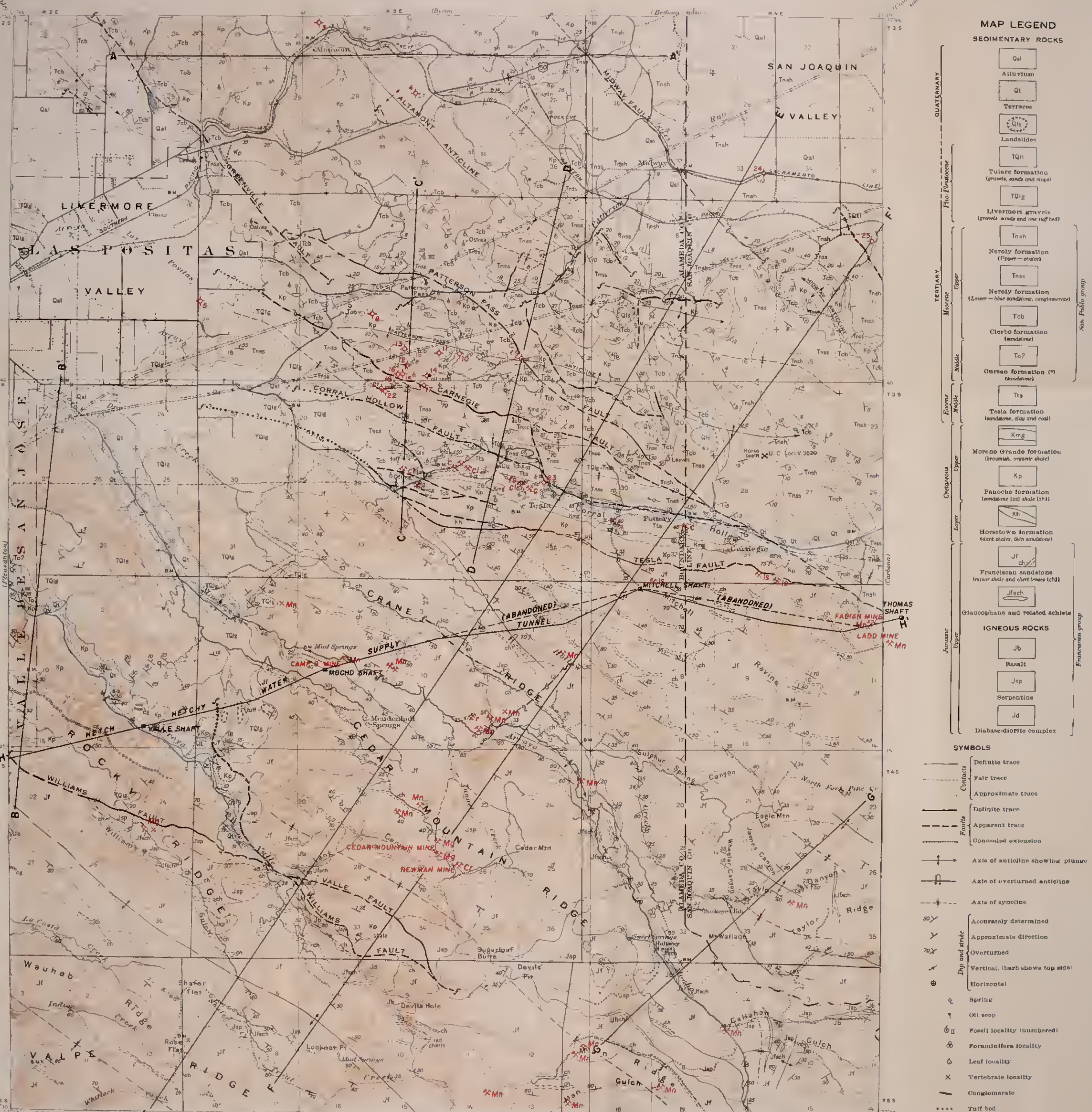

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ECONOMIC MAP OF TESLA QUADRANGLE, SHOWING SECTION LINES AND WATER SUPPLY TUNNEL

By Arthur S. Huey

Geology surveyed in 1934-36

Scale 1/62500

Contour interval 50 feet
Datum is mean sea level

BULLETIN 140
PLATE 3

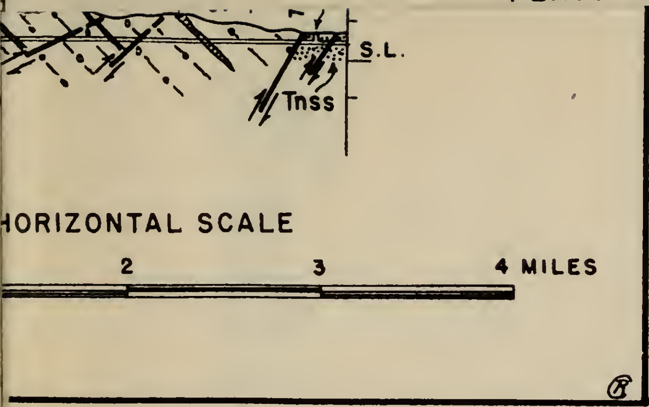

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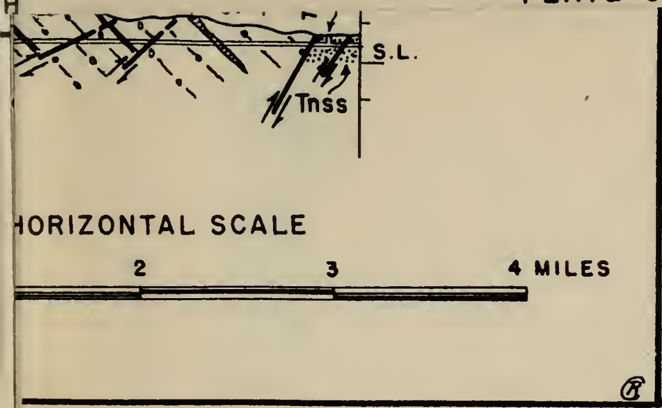
PLATE 3



STRUCTURE SECTIONS ACROSS TESLA QUADRANGLE, CALIFORNIA

Geology by A.S.Huey 1947

VERTICAL AND HORIZONTAL SCALE

1 1/2 0 1 2 3 4 MILES