Volcanic Rocks of the El Modeno Area Orange County California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 274-L

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By ROBERT F. YERKES

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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Description of extrusive pyroclastic and flow rocks of El Modeno volcanics of middle to late Miocene age

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A SHORTER CONTRIBUTION TO GENERAL GEOLOGY

VOLCANIC ROCKS OF THE EL MODENO AREA, ORANGE COUNTY, CALIFORNIA

By Robert F. Yerkes

ABSTRACT

The El Modeno volcanics form a series of extrusive pyroclastic and flow rocks which crop out near El Modeno, Orange County, Calif. The volcanics have been divided into three members. The basal unit is a basalt flow, which is overlain successively by a palagonite tuff and tuff breccia member and an andesite flow and flow breccia member. The volcanics are products of both subaerial and submarine extrusion of materials of intermediate composition. They are middle Miocene to early late Miocene in age and are tentatively correlated with the Glendora volcanics 25 miles to the northwest. The maximum outcrop thickness of the volcanics is 850 feet.

The extrusive volcanic rocks may be distinguished from the middle Miocene intrusive rocks in this region by their vesicular texture and characteristic alteration to crumbly, earthy masses. The intrusive rocks are commonly coarser grained, hard and dense, commonly contain biotite, have an ophitic texture, and alter to chlorite-epidote-feldspar rocks.

INTRODUCTION

The El Modeno volcanics are extrusive, largely pyroclastic rocks, in part marine, that crop out in an eight-square-mile area east of El Modeno, Orange County, California, on the west flank of the Santa Ana Mountains.

The volcanic rocks rest conformably upon the strata of the Topanga formation, which include at least two thin tuff beds (tu_1 on the geologic map, pl. 46). The El Modeno volcanics are made up of three members. The lowest member is the basalt flow member (*Temb*), which rests upon sandstone beds of the Topanga formation (middle Miocene) and includes at the top a thin stratum of marine siltstone not differentiated on the map. This member has a maximum thickness of 200 feet. Overlying the basalt flow member is the palagonite tuff and tuff breccia member (*Temt*), which ranges from 125 to 450 feet in thickness. This tuffaceous member is overlain by the andesite flow and flow breccia member (*Tema* , which has an average thickness of 200 feet. Locally overlying the andesite flow and flow breccia member is the La Vida member of the Puente formation (*Tplv*).

The El Modeno volcanics are of middle to late Miocene age and are tentatively correlated with the Glendora volcanics (fig. 55).

The detailed mapping of the volcanic rocks was undertaken as part of the geologic mapping of the west flank of the Santa Ana Mountains (Schoellhamer and others, 1954). In order to show details of the volcanic sequence, the geologic map which accompanies this report (pl. 46) has been prepared at a scale of 1 to 12,000. As shown on its index map, the geology of adjacent areas was mapped by D. M. Kinney and J. G. Vedder. John S. Shelton of Pomona College loaned a collection of thin sections of rocks from well cores from which some of the data of table 4 was taken.

Cores from wells drilled for oil show that volcanic rocks similar to those of the El Modeno volcanics underlie the oil-bearing sedimentary rocks of the Puente formation of late Miocene age beneath a large part of the eastern Los Angeles basin (fig. 56). In addition, they show that the lowest part of the Puente formation and the pre-Puente sedimentary rocks are cut by intrusive rocks of similar composition. A petrographic study of the El Modeno volcanics has been included in this investigation, partly to facilitate distinction between the extrusive and intrusive igneous rocks encountered in wells.

The terminology of the pyroclastic rocks, including the term palagonite, is the one proposed by Wentworth and Williams (1932, p. 45–53). Chlorophaeite, a widely used but ambiguous term, refers herein to a green to brown alteration product of ferromagnesian minerals and glass in basaltic rocks. The composition of the feldspar has been determined in some rocks by extinction-angle methods but in most cases by immersion of fragments in oils of known refractive index. Special studies were made with the universal stage as needed. The relative volumes of the constituents—phenocrysts, groundmass, cavity fillings, and clastic grains—were obtained by the point-counter method of Chayes (1949), except where otherwise noted, and are given as volume percentages of the whole rock.

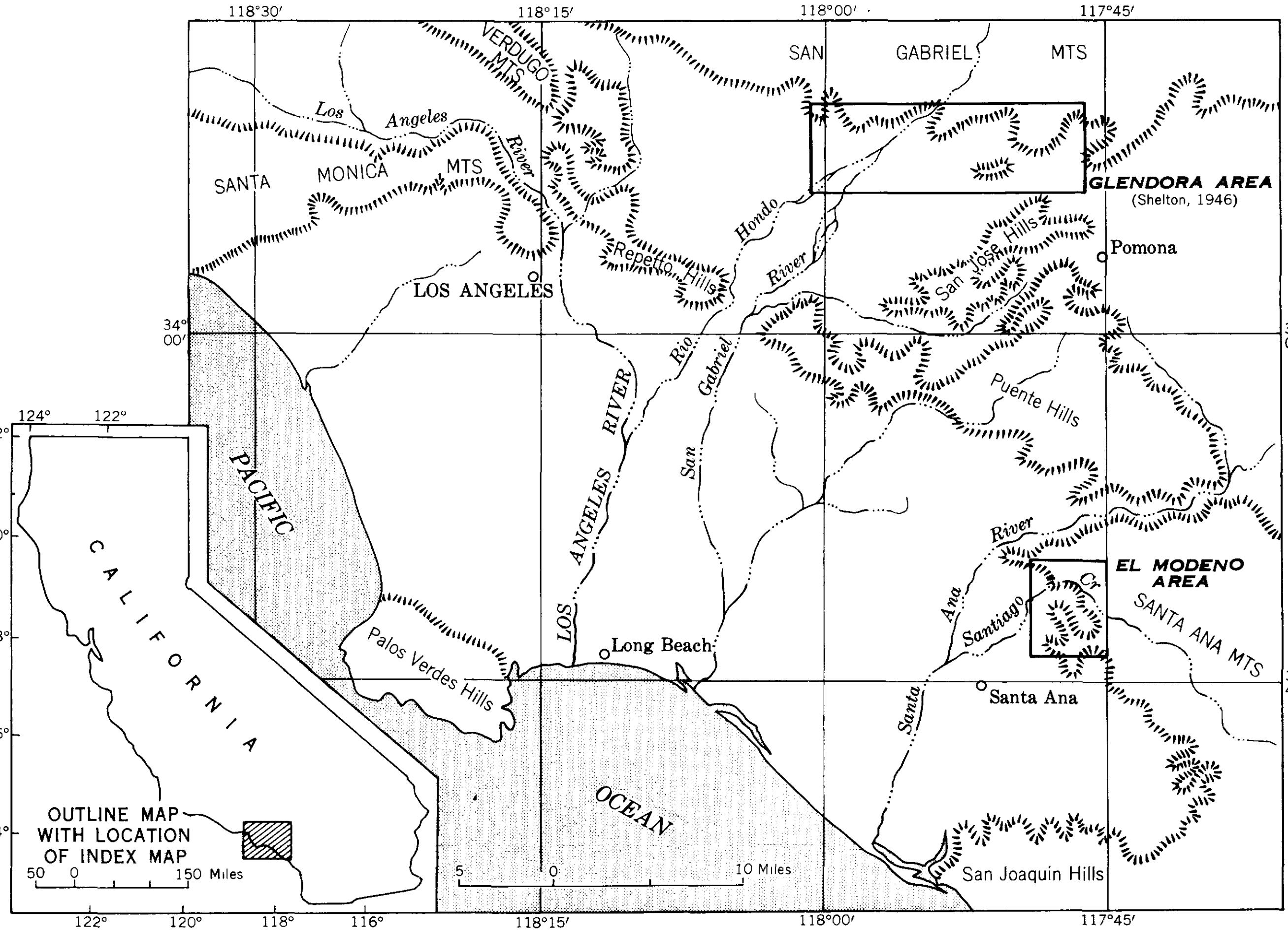

FIGURE 55. Index map of southern California showing location of areas underlain by El Modeno and Glendora volcanics.

PREVIOUS INVESTIGATIONS

English (1926) included the volcanic rocks of the El Modeno area under the designation intrusive and extrusive rocks of Tertiary age. Larsen (1948, p. 108) briefly described the El Modeno volcanics as a series of andesitic lava flows, clastic beds, and intrusives, which he mapped as a unit of Tertiary age.

No detailed study of the volcanic rocks has been published.

LOCALITIES FROM WHICH SAMPLES WERE OBTAINED

In this report rock samples that have been studied in detail are numbered in the order in which they are described. The following list is a key to their corresponding field numbers, the symbols by which the containing formation members are represented on plates 46 and 47, and the precise descriptions of the localities from which the samples were obtained.

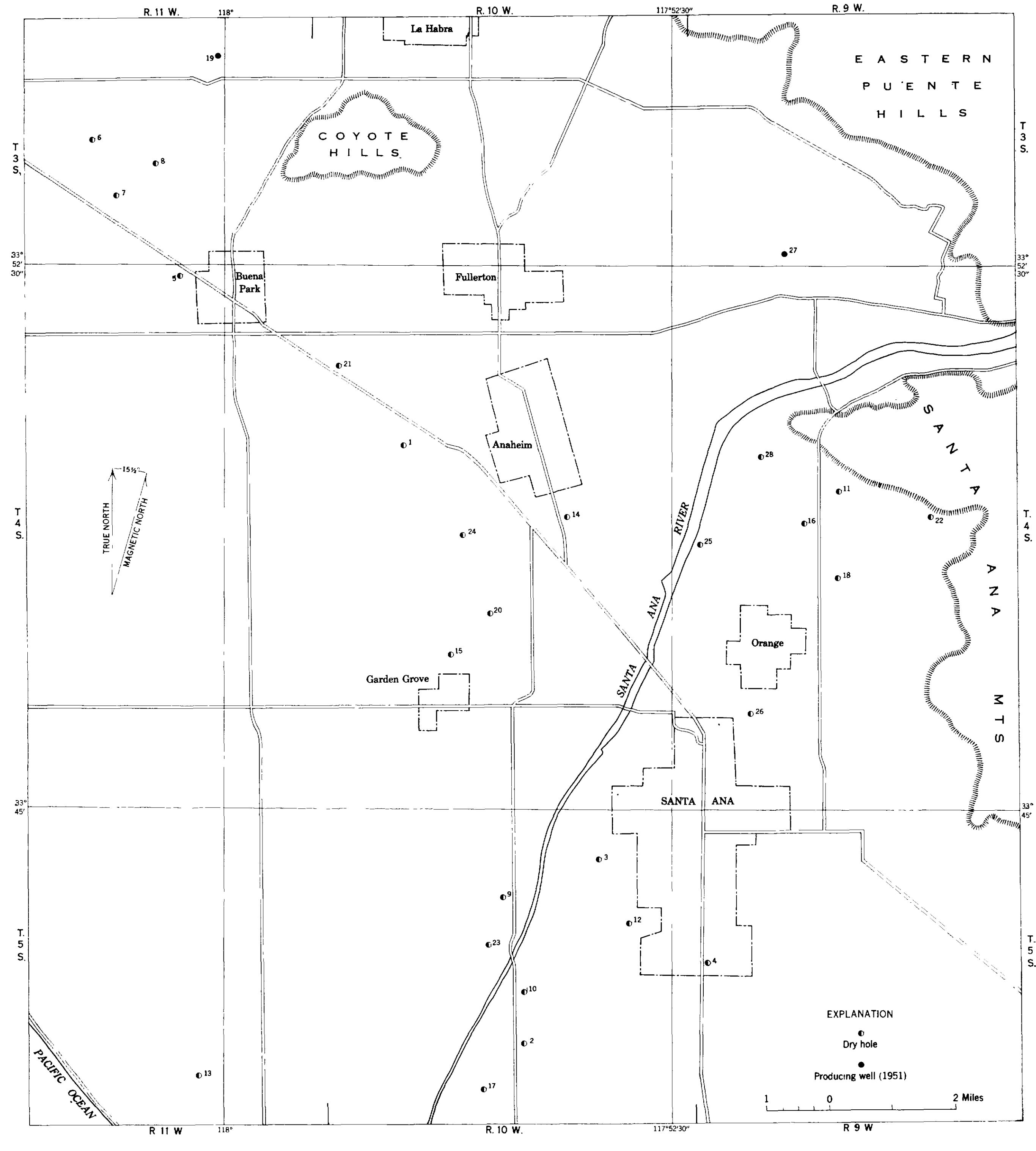

FIGURE 56.—Index map of eastern Los Angeles basin showing wells that were drilled into Miocene volcanic rocks.

Locality descriptions

Field no.	No. in this report	Rock unit, plates 46, 47	Description of localities (measurements in feet)
5b	1	tu_1	2300 E. and 225 S. of northwest corner projected sec. 36, T. 4 S., R. 9 W., Elev. 800.
6e	2	tu_1	Highway cut, 2250 N. and 200 W. of southeast corner sec. 26, T. 4 S., R. 9 W., Elev. 600.
8e	3	tu_1	Road cut, 2050 W. and 325 N. of easterly corner Irvine Block 15, Elev. 730.
19a2	4	tu_1	1450 W. and 925 S. of easterly corner Irvine Block 16, Elev. 590.
1a	5	*Temb*	2325 N. and 1725 W. of southeast corner sec. 15, T. 4 S., R. 9 W., Elev. 470.
5a	6	*Temb*	2925 S. and 75 W. of northeast corner projected sec. 35, T. 4 S., R. 9 W., Elev. 630.
6c	7	*Temb*	3775 E. and 1540 S. of northeast corner sec. 13, T. 4 S., R. 9 W., Elev. 1110.
6d	8	*Temb*	2050 E. and 575 S. of northwest corner sec. 13, T. 4 S., R. 9 W., Elev. 990.
7a	9	*Temb*	1600 S. and 425 W. of northeast corner projected sec. 35, T. 4 S., R. 9 W., Elev. 610.
7e	10	*Temb*	Road cut, 1200 E. and 2000 N. of BM 277, near southeast corner sec. 34, T. 4 S., R. 9 W., Elev. 415.
4e	11	*Temt*	2250 N. and 2150 W. of southeast corner sec. 26, T. 4 S., R. 9 W., Elev. 460.
2c2	12	*Tema*	Highway cut, 2075 N. and 400 W. of southeast corner sec. 26, T. 4 S., R. 9 W., Elev. 590.
1b2	13	Td_1	1200 N. and 875 W. of southeast corner sec. 23, T. 4 S., R. 9 W., Elev. 600.
6b	14	tu_2	Road, 900 S. and 3550 E. of northeast corner sec. 13, T. 4 S., R. 9 W., Elev. 1105.
11b	15	tu_2	1025 S. and 2300 E. of southwest corner sec. 26, T. 4 S., R. 9 W., Elev. 540.
13e	16	tu_2	2230 N. and 1300 W. of southeast corner sec. 26, T. 4 S., R. 9 W., Elev. 660.
14i	17	tu_2	1025 N. and 250 W. of southeast corner sec. 26, T. 4 S., R. 9 W., Elev. 800.
31d	18	tu_2	350 southwest and 3150 northwest from easterly corner of Irvine subdiv. Blk. 68, Black Star Canyon quadrangle; Elev. 940.
31e	19	tu_2	1950 southwest and 1000 northwest from easterly corner Irvine subdiv. Blk. 68, Black Star Canyon quadrangle; Elev. 900.

DESCRIPTIVE GEOLOGY

IGNEOUS ROCKS

TUFFS OF THE TOPANGA FORMATION

Two or more thin beds of white vitric tuff 5 to 10 feet thick (tu_1) are interbedded in sandstone of the Topanga formation; one is about 150 feet below the top, and another is about 325 feet above the base of the formation. These tuffs afford evidence of the earliest volcanic activity during Tertiary time. The tuffs are massive and well sorted, and many specimens are crowded with 0.5- to 2-millimeter opaque white glass bubbles. Fragments average 0.05 millimeter in maximum diameter, are angular, and include clear, colorless glass, plagioclase, micas, iron ore minerals, and, rarely, detrital quartz. The matrix is composed of fragmental and partly altered glass. Sparse fish scales and molds of small mollusks indicate marine deposition.

Glass fragments make up as much as 58 percent of the rocks but average about 40 percent. The index of refraction of the glass in four samples ranges from 1.494 to 1.504, with a mean of 1.498, all ± 0.002. These values suggest that silica is present in amounts greater than 70 percent (George, 1924, p. 365). Plagioclase crystals and fragments make up no more than 5 percent of the rock, and the composition of the plagioclase ranges between An_{30} and An_{50}; the average value for the rock is about An_{35}. The incongruity between the intermediate composition of the plagioclase and the silica-rich glass fragments suggests a composite source for the material. No massive volcanic rocks of silicic composition are known from outcrops or well cores in this region.

Data pertaining to four samples of the tuffs are shown in table 1. Samples 1 and 2 are from the tuff bed that crops out in Section 25 near the center of the map, 150 feet below the top of the Topanga formation, and samples 3 and 4 are from the bed 325 feet above the base of the formation, which crops out on both sides of Peters Canyon.

EL MODENO VOLCANICS

BASALT FLOW MEMBER

A vesicular, porphyritic olivine basalt (*Temb*) rests conformably on sandstone of the Topanga formation. The basalt is light gray to olive green or brown. A fresh specimen has not been obtained. The rock characteristically weathers to spheroidal masses. Commonly the rock is somewhat fresher and darker near the surfaces of spheroids or joints and is most deeply altered in the centers of the joint blocks. This anomalous characteristic is ascribed by Fuller (1938) to alteration due to entrapment of volatile materials. Where the volatile materials escaped, as near joints and fissures, alteration is less pronounced.

The texture of the rock is everywhere porphyritic and subophitic. Variation occurs mainly in the size of plagioclase phenocrysts and preservation of olivine. The principal minerals are plagioclase, olivine, chlorophaeite, and magnetite. Plagioclase phenocrysts average 0.5 millimeter in maximum diameter, but some

Table 1.—*Petrography of tuffs of the Topanga formation*

	Sample 1	Sample 2	Sample 3	Sample 4
Glass fragments......estimated percent..	58	20	30	60
Do......index of refraction [1]..	1. 494	1. 504	1. 447	1. 499
Plagioclase......estimated percent..	1	5	1	4
Do......alpha value [1]..	1. 557	1. 545	1. 554	1. 548
Do......estimated percent An..	53	35+	47	42+
Micas......estimated percent..	4	10	2	?
Ore minerals......do....	2	20	1	1
Matrix......do....	35	45	60	30
Other minerals [2]......do....	....	....	6	5

[1] Accurate to ±0.002.

[2] Includes detrital quartz, tourmaline, augite, and hornblende.

are as large as 8 millimeters. The plagioclase microlites of the groundmass average 0.05 millimeter in maximum diameter. Olivine crystals are well preserved only in rocks whose groundmass is made up of grains whose average diameter is less than 0.03 millimeter. The unaltered olivine phenocrysts are stubby anhedral grains.

The rock is everywhere massive and apparently consists of a single extensive flow; good exposures show pillow structures with siltstone seams (fig. 57). Flow structure is rare. Only sample 5, from a weathered outcrop in Cerro Villa Heights north of Santiago Creek (northwest corner of map area), shows flow structure of trachytic type. Vesicles are usually abundant and not oriented. They range from 0.01 to 16 millimeters and average about 1 millimeter in maximum diameter. The ready access to permeating fluids afforded by this vesicularity probably accounts in part for the deep alteration of the rock. The vesicles are commonly filled or lined with chlorophaeite or zeolites, or, rarely, with calcite.

The basalt flow member is generally between 10 and 200 feet thick, but it is locally absent. In the only unfaulted sequence (structure section C–C′, pl. 47) it is 200 feet thick. The upper surface of the flow shows no sign of penecontemporaneous erosion. Associated with the basalt at its upper contact is a limy siltstone bed that averages 4 feet in thickness, which weathers white or grayish white. The siltstone contains fish scales of probable middle Miocene or early late Miocene age (determination by W. Thomas Rothwell). On Burruel Ridge north of Santiago Creek, a bed of light-grayish-white claystone 20 inches thick locally occupies a similar stratigraphic position. The claystone bed

FIGURE 57.—Basalt flow member, Panorama Heights, showing vesicular basalt in pillows with siltstone seams. Pencil in center of photograph is five inches in length.

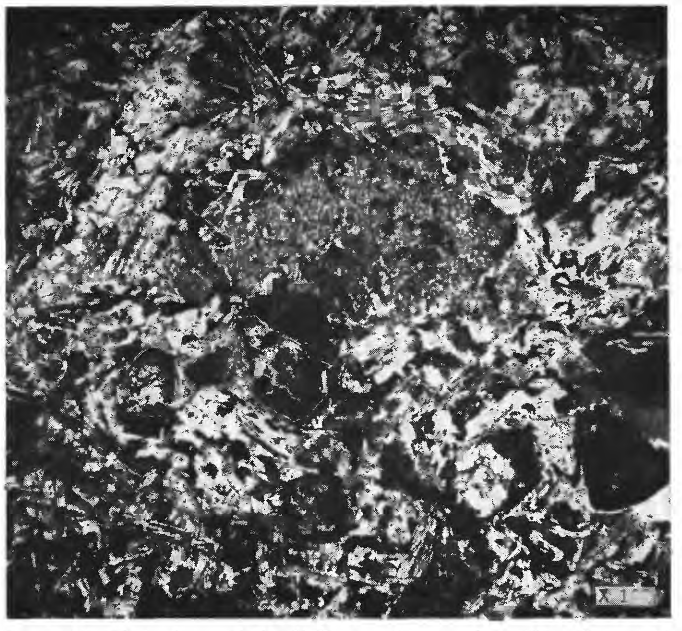

FIGURE 58.—Photomicrograph, basalt flow member, sample 9. Shows large (0.45-millimeter) pseudomorph of chlorophaeite and magnetite after olivine, with smaller pseudomorphs in lower half of view. Groundmass is composed of plagioclase microlites, granular augite, olivine, magnetite, and chlorophaeite. Plane polarized light.

crops out for a very short distance and rests on a remnant of the basalt flow member (near north end of structure section A–A′, pl. 47). The claystone contains an abundant fauna of silicified Foraminifera that are considered to be middle Miocene in age (see p. 326).

Petrography.—Samples 5 to 10 of the basalt flow member have been studied microscopically. These differ mainly in the amount and size of plagioclase phenocrysts; the groundmass is almost the same in all the samples, as shown in table 2. Each specimen contains large amounts of chlorophaeite, which is commonly present as pseudomorphs after olivine or pyroxene (fig. 58). Very little fresh olivine or pyroxene is found. It is estimated that olivine originally made up between 5 and 15 percent of the rock, while pyroxene formed from 5 to 10 percent. Wherever determined, olivine was optically negative, with $2V$ close to 85°. Pyroxene is of uniform character, apparently of a magnesian or diopsidic variety with positive elongation and range in Z to c from 37° to 40°.

The average composition of the plagioclase—close to An_{55}, the intermediate silica percentage of the essentially unaltered glass—(52 percent), and the moderate amount of olivine indicate that the rock is probably an olivine basalt, though it may be a basaltic andesite.

Chlorophaeite replaces olivine and pyroxene indiscriminately, as well as most of the glass formerly present in the groundmass, and fills or lines all cavities. It is nearly opaque and has a dark olive-green to yellow-brown color. It commonly occurs as isotropic or nearly isotropic structureless or spherulitic fibrous patches. The weakly birefringent fibers have parallel extinction and positive elongation and an index of refraction that is variable but close to 1.530. The weak birefringence is attributed to incipient formation of chlorite, which

TABLE 2.—*Petrography of the basalt flow member*

[The term chlorophaeite is used as defined on p. 313.]

No. of Sample	Megascopic texture	Groundmass texture	Composition	
			Phenocrysts (sizes are maximum diameter)	Groundmass
5	Holocrystalline: Porphyritic: Trachytic. Subophitic.	Indeterminate, badly altered.	Plagioclase 20.2 percent, maximum 10 mm, average 3 mm, albite and Carlsbad twins, An_{55-62}; chlorophaeite 24.2 percent, in fan-shaped aggregates of radiating needles filling cavities and as pseudomorphs after olivine and pyroxene.	Plagioclase microlites, in a basis of chlorophaeite and clay minerals, 48.8 percent: magnetite, well dispersed 0.01-mm grains, 5 percent.
6	Holocrystalline(?): Porphyritic: Subophitic.		Plagioclase 25.7 percent, fresh albite-twinned crystals up to 4 mm, average .67 mm, An_{53-58}; chlorophaeite 33.3 percent, in aggregates of spherulitic fibers with weak birefringence, parallel extinction, positive elongation, isotropic when fresh, index of refraction close to 1.520, about one-fourth in pseudomorphs after olivine and pyroxene, the rest filling cavities averaging 0.5 mm in maximum diameter.	Magnetite 11 percent in rod-shaped grains 0.005 mm by 0.05 mm; plagioclase microlites 15 percent, An_{25-60}; chlorophaeite basis 15 percent.
7	Holocrystalline: Porphyritic: Subophitic.		Plagioclase 42.7 percent, An_{50-63}; augite 4.7 percent; olivine 0.4 percent; chlorophaeite 33.2 percent; tridymite(?) trace, with alpha=1.480, biaxial positive, $2V=70°$.	Magnetite 6 percent; calcite 1.8 percent; apatite 1.2 percent; chlorophaeite and clay minerals 10 percent.
8	Holocrystalline: Porphyritic: Subophitic.	Generally intergranular; average grain size 0.01 to 0.05 mm; commonly near 0.03 mm.	Plagioclase 28 percent, averages 0.25 mm, An_{55-60}; chlorophaeite 30 percent as pseudomorphs after olivine and pyroxene; less devitrified glass 5 percent, filling cavities averaging 0.3 mm, index of refraction=1.580, pale olive-buff, clear, isotropic.	Plagioclase 23 percent, as microlites averaging 0.03 mm, An_{33-65}; unresolvable basis of chlorophaeite, clay minerals and magnetite, 14 percent.
9	Holocrystalline: Porphyritic: Subophitic.		Plagioclase 23 percent, as fresh albite twins, average 0.75 mm, An_{47-58}; chlorophaeite, 34 percent, as pseudomorphs after olivine and pyroxene.	Plagioclase 22 percent, as microlites averaging 0.03 mm, An_{39-60}; olivine 7 percent, grains averaging 0.03 mm, $2V=90°$; pyroxene 9 percent, in grains averaging .01 mm, Z to $c=31°$; magnetite 5 percent.
10	Holocrystalline: Coarsely porphyritic.		Plagioclase 41 percent, in large progressively zoned albite-twinned euhedrons averaging 0.5 mm by 2.1 mm, An_{42-61}; chlorophaeite 37 percent, in pale straw-colored fibrous pseudomorphs after olivine and pyroxene, parallel extinction, positive elongation, index of refraction just above that of Canada balsam, birefringence about .015.	Plagioclase 11 percent in microlites averaging 0.007 mm by 0.05 mm, An_{57-65}; magnetite 1 percent; chlorophaeite 10 per cent, in finely divided fibers; tridymite present in small 0.03 mm crystal.

also seems to cause a slight increase in the index of refraction.

The rare appearance of tridymite as vesicle lining is attributed to deuteric processes. Shelton (oral communication) reports similar occurrences in the Glendora volcanics. Other minor secondary minerals are calcite and zeolites.

PALAGONITE TUFF AND TUFF BRECCIA MEMBER

GENERAL DESCRIPTION

Resting conformably upon the thin limy siltstone bed associated with the basalt flow member are pyroclastic rocks (*Temt*) averaging 200 to 300 feet in thickness. The thinnest unfaulted sequence measures 125 feet and the thickest more than 450 feet. The color of this rock, either fresh or weathered, is light grayish buff or tan, in some occurrences with a greenish cast. The rocks in some exposures show lateral and vertical alternations of unsorted fragmental breccias with well-sorted and bedded tuffs.

PALAGONITE TUFF BRECCIAS

Angular blocks of light-gray vesicular augite andesite are abundant in the tuff breccias. They are as large as 8 to 10 inches in maximum diameter, but average 1 to 2 inches. These blocks, together with lapilli of similar composition, make up about 20 percent of the rock. The tuffaceous matrix of the breccias is in general vesicular, and the cavities are commonly filled or lined with palagonite and clay. The haphazard, unsystematic arrangement of the fragments in these deposits, as shown in figure 59, precludes the possibility that they are the product of reworking. The matrix of this rock has not been examined microscopically.

FIGURE 59.—Palagonite tuff and tuff breccia member, Panorama Heights. Palagonite tuff breccia with blocks and lapilli of vesicular augite andesite. An irregular contact between two such deposits appears in lower left corner. Handle of pick is about twelve inches in length.

BEDDED PALAGONITE TUFF

Interbedded with the fragmental rocks are much thicker and more extensive sequences of thinly bedded, well-sorted, and completely palagonitized tuffs (fig. 60). These are most prominent in the central and southern parts of the mapped area. Beds in these sequences range from 1/16 to 16 inches in thickness but average 1/2 inch. Fragments of volcanic rocks are common and are of granule size or smaller. Locally, small-scale cross bedding is seen. Some medium to coarse subrounded grains of quartz are present and calcite cement is common.

Petrography.—Sample 11 was selected as representative of the bedded tuff.

This sample is composed of medium, fairly well sorted grains; its texture is uniformly clastic (fig. 61). Clasts have sharp, angular boundaries and maximum diameter of 0.3 millimeter; some glass shards show the effects of flattening. The matrix is minutely vesicular palagonite; its sparse vesicles have a mean diameter of 0.05 millimeter.

The estimated composition is 35 percent plagioclase fragments (An_{30-60}): albite and carlsbad twins sharply defined, intensely zoned in both oscillatory and progressive fashion, with single crystals ranging from An_{70} at the cores to An_{30} at the rims; 1 percent augite and hypersthene(?); 5 percent rounded to subangular adventitious quartz grains; 4 percent partly digested glassy basalt in fragments 0.3 millimeter in mean diameter; 55 percent matrix: somewhat vesicular, rarely spherulitic and fibrous light-amber to deep brownish-black palagonite and some patches of calcite, the whole moderately charged with finely disseminated clay or dust particles. Some of the palagonite shows incipient crystallization by fairly definite extinction, but most of it is changed very little between crossed nicols, retaining its amber color throughout. The resolvable anisotropic detail

FIGURE 60.—Palagonite tuff and tuff breccia member, Panorama Heights. Bedded palagonite tuff. Heavy bed near center is eleven inches in thickness.

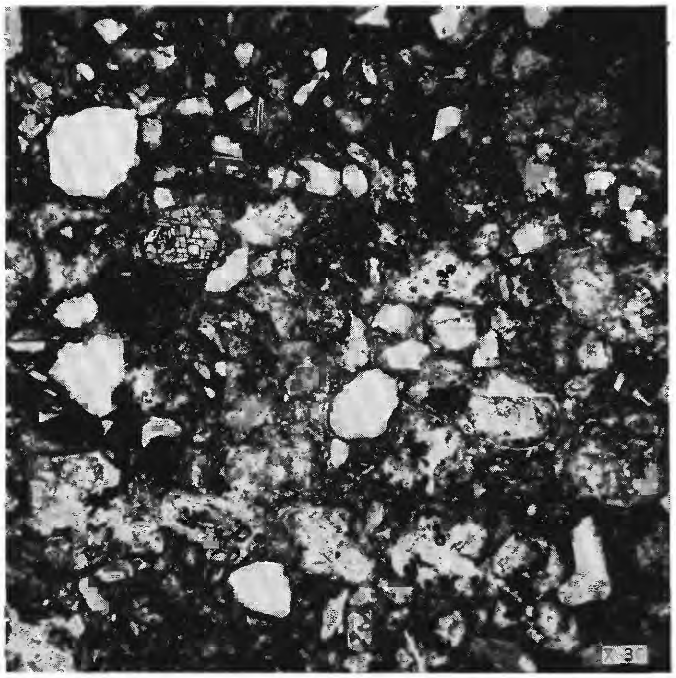

FIGURE 61.—Photomicrograph, bedded palagonite tuff and tuff breccia member. Adventitious quartz, plagioclase, augite, and altered olivine in a matrix of palagonitized tuff with calcite and clay minerals. Note angularity of grains. Crossed nicols.

takes the form of chloritelike plates with apparently higher indices of refraction. The mean index of refraction of the palagonite is 1.47.

ANDESITE FLOW AND FLOW BRECCIA MEMBER

GENERAL DESCRIPTION

A series of randomly interbedded light- to dark-gray and reddish vesicular calcic andesite flow breccias, lavas, and minor tuff breccias (*Tema*) rests conformably on the tuffaceous rocks and caps almost all the hills in the volcanic area. The lower contact of this unit is slightly irregular and rough but is essentially parallel to the bedding in the underlying tuffs. This series of flows and flow breccias is the most resistant rock in the sequence, as well as the youngest. Its thickness is commonly about 200 feet.

FLOW BRECCIAS

The andesite flow breccias are composed of coarsely vesicular angular blocks of light-gray porphyritic calcic andesite in a matrix of greatly altered fine-grained andesite (fig. 65.) The blocks are as large as 6 feet in diameter, but average 3 to 4 inches. They are characteristically quite fresh but some blocks present a varicolored appearance due to partial alteration. Blocks make up about 80 percent of the rock. At places altered glass or tuff is included in the matrix. Gravity sorting or other evidence of stratification was not detected. Radial and concentric cooling cracks are commonly present but rarely pronounced in the larger blocks (fig. 62). Microvesicles in the tuffaceous matrix are common.

LAVA FLOWS

The lavas are commonly hard, fresh, and light gray. In many places they are jointed and fractured. The rock is a vesicular porphyritic calcic andesite with the vesicles drawn out parallel to the lower contacts. Some of the vesicles reach a length of several inches. Chilling and baking of the lower contacts are nowhere pronounced. At one locality in the north-central part of the mapped area, just south of Santiago Creek, a reddish scoriaceous lava is overlain by a dense, blocky flow with prominent joints, which is overlain in turn by a second scoriaceous flow. These three flows are truncated at a low angle by a younger dense flow. The scoriaceous flows are commonly intensely altered and are reddish or yellow, whereas the denser rocks are gray and fresher. A few exposures are made up chiefly of ellipsoidal pillows with thin seams of baked siltstone or altered glass and tuff separating the pillows. The andesite of the lavas is not distinguishable from that of the blocks in the flow breccias.

Petrography.—Sample 12 is representative of the lavas.

This rock is light gray, hard, fresh-appearing and moderately vesicular (fig. 63). The vesicles are as large as 1 centimeter and average 2 millimeters in maximum diameter. The texture is porphyritic with phenocrysts that are as large as 0.38 millimeter and average 0.2 millimeter in maximum diameter. The texture of the groundmass is intergranular. Composition is 37.6 percent plagioclase, including many progressively zoned and albite-twinned crystals, in part andesine and labradorite phenocrysts

FIGURE 62.—Andesite flow and flow breccia member, gravel pit approximately one mile east-northeast of El Modeno. Large vesicular andesite block with radial and concentric cooling cracks in flow breccia. Pick handle about 12 inches in length.

Figure 63.—Photomicrograph, vesicular andesite from andesite flow and flow breccia member, sample 12. Augite, plagioclase, and vesicles lined with devitrified glass. The glassy groundmass is solidly charged with magnetite grains. Crossed nicols.

and in part andesine microlites; 36.3 percent augite; 16.3 percent chlorophaeite as alteration product of ferromagnesian minerals that may have included some olivine; 9.7 percent magnetite in well disseminated grains and rod-shaped aggregates; 0.1 percent apatite(?), as submicroscopic inclusions in plagioclase crystals. Tridymite and zeolites are commonly present in small amounts; secondary calcite is common. A zeolite from sample 14 was determined as a variety of phillipsite similar to wellsite. It had the following properties: Angle $\beta=126\frac{1}{2}°$; indistinct cleavage parallel to (010); twinning present with composition plane parallel (010) and perpendicular to b; optic plane and $Z(=b)$ perpendicular to (010); X to $c=52°$, Y to $c=38°$; optically positive; $2V$ ranges from 26° to 50°, with a mean of 42°; $\alpha=1.4971$, $\beta=1.4978$, $\gamma=1.5021$, all ±0.0004; birefringence 0.0050. The mineral is colorless and has strong negative relief in canada balsam.

The composition of the unzoned plagioclase phenocrysts ranges from An_{42} to An_{63}, and the mean composition of the microlites is probably close to An_{45}. The phenocryst zones range from An_{70} to An_{35}. The classification of the rock as a calcic andesite is thus somewhat arbitrary and is based primarily on the mean composition of the feldspar of several samples. Plagioclase constitutes as much as 60 percent of other samples.

HYDROTHERMAL ALTERATION

In the central and northern parts of the area, near the mouth of Santiago Creek, the rocks of the andesite flow and flow breccia member are more deeply altered than in the south. The ferromagnesian minerals are altered to chlorophaeite and chlorite, which gives the rock an overall deep-reddish to yellow or greenish color. Calcite and zeolites fill many cavities. Tridymite, specular hematite, and limonite are present in small amounts. The feldspar commonly remains quite fresh, whereas the tuffaceous matrix shows pronounced palagonitization and random addition of calcite.

LIMY VOLCANIC BRECCIA

Interbedded in the andesite flow and flow breccia member in the west central part of the mapped area is a 6- to 10-foot bed of deep red-brown limy volcanic breccia (*bx*). The rock is composed of vesicular and porphyritic augite andesite, in clasts of granule to block size, closely packed in a matrix of calcite grains whose maximum diameter is 0.1 millimeter. A few plagioclase crystals occur as clastic grains that average 0.3 millimeter in maximum diameter; the patchy, glassy matrix has an index of refraction of 1.555 ± 0.002.

UNDIFFERENTIATED VOLCANIC ROCKS

About 750 feet of undifferentiated volcanic rocks (*Temu*) crop out in a small area near the east margin of the map, just south of Santiago Creek. These are very poorly exposed but are known to include both the basalt flow and the andesite flow and flow breccia members of the El Modeno volcanics. The palagonite tuff and tuff breccia member also is believed to be present. The undifferentiated volcanic sequence was probably continuous with the differentiated volcanic sequence immediately to the west, but these sequences are now separated by faulting (see structure section A–A′, pl. 47).

ANDESITE DIKES

Steep or vertical, vesicular and porphyritic andesite dikes (Td_2) intrude both the palagonite tuff and andesite flow members as well as sandstone of the Topanga formation (fig. 64). Of the 16 andesite dikes mapped, twelve intrude the palagonite tuff member. The dikes are generally less than 10 feet thick and commonly less than 5 feet thick. Some of the dikes follow fault zones, especially those forming the contact between the palagonite tuff and andesite flow members. The dike rocks are commonly deeply altered and have a strong clayey odor. The rock at places shows a decrease in vesicularity and grain size toward the contacts, but it does not show notable chilling or development of glass. At some places the vesicles are elongated parallel to the walls of the dikes, but no prominent flow structure has been noted. The cavities are commonly filled or lined with zeolites and calcite. The dikes are all composed of porphyritic augite andesite identical with that described under the andesite flow and flow breccia member. The similarities in composition and field relations suggest that the dikes are nearly equivalent in age with the andesite flow and flow breccia member.

FIGURE 64.—Small vesicular augite andesite dike cutting palagonite tuff and tuff breccia member. Contact is at lower left. Locality is on north slope of small hill south of gravel pit, one mile east-northeast of El Modeno. Head of pick is about seven inches in length.

ASSOCIATED IGNEOUS ROCKS

Several minor occurrences of igneous rocks are associated with the El Modeno volcanics but are not considered a part of the main volcanic sequence. These include a volcanic breccia (*Temx*) that rests on sandstone beds of the Topanga formation, two widely separated basalt dikes (Td_1), and also a tuff in the La Vida member of the Puente formation, which overlies the El Modeno volcanics.

BRECCIA

Two poorly exposed outcrops of faulted and deformed breccia were mapped at the northeastern extremity of the central outcrop area, just south of Santiago Creek. The base of this breccia is apparently conformable upon sandstone of the Topanga formation. Where weathered, the rock is brownish gray. It has a rubbly appearance, owing to the presence of sharply angular lithic fragments ranging from 2 inches to 10 inches in diameter. The clasts are chiefly vesicular gray andesite similar to that of the andesite flow and flow breccia member of the El Modeno volcanics, but they also include tan coarse-grained sandstone. The matrix is a coarse-grained sandstone with some lithic granules, typical of the sandstone of the Topanga formation. The upper contact is not exposed. The thickness of the breccia is not accurately determinable but may be as much as 200 feet. The relation of this rock unit to the El Modeno volcanics is not clear.

BASALT DIKES

Two dense black basalt dikes (Td_1) cut the sedimentary rocks of the Topanga (Miocene) and Santiago (Eocene) formations. One of these is in Weir Canyon in the east-central part of the mapped area, and the other is in SE¼ Sec. 23, T. 4 S., R. 9 W. These dikes are 2 to 3 feet thick and have indistinct chilled margins. The two dikes are petrographically similar, and both are rather finely porphyritic with phenocrysts up to 0.7 millimeter in maximum diameter. The dikes are younger than the Topanga formation; they may be contemporaneous with the El Modeno volcanics, or they may be younger.

Petrography.—Sample 13 is representative of the dike that cuts sandstone of the Topanga formation.

This dike rock is dense, black, nonvesicular, and hyalocrystalline, with a finely porphyritic texture. The groundmass texture is intersertal to intergranular. Its composition is 36 percent unaltered plagioclase (An_{55-70}), in prominently twinned and progressively zoned crystals; 24 percent olivine, in phenocrysts up to 0.73 millimeter in maximum diameter, but 0.15 millimeter in mean diameter, commonly altered to antigorite; 10 percent rather poorly preserved augite; 14.5 percent magnetite, in well-disseminated grains; 13.5 percent antigorite and chlorophaeite, pseudomorphous after olivine and pyroxene and as alteration products of the glassy groundmass; and 1 to 2 percent deep-olive to light-brown basaltic glass.

TUFFACEOUS MATERIAL IN LA VIDA MEMBER OF PUENTE FORMATION

In the El Modeno area the base of the La Vida member of the Puente formation is characterized by a thin bed of light-yellow to buff or tan, somewhat sandy tuff or volcanic sandstone (Tu_2). The grains in this rock are between 0.5 and 1 millimeter in maximum diameter. The tuff consists mainly of colorless

FIGURE 65.—Photomicrograph, andesite flow and flow breccia member, sample 12. Porphyritic augite andesite, illustrating oscillatory twinning and selective alteration of plagioclase phenocrysts. Crossed nicols.

glass and plagioclase fragments with some quartz and lithic fragments in a matrix of strongly altered glass, usually an isotropic claylike material. The colorless glass commonly has an index of refraction between 1.477 and 1.523±0.002, indicating hydration; the average index of refraction is approximately 1.492. The average composition of the plagioclase is close to An_{50}. Table 3 summarizes the petrography of six samples from this unit.

A similar tuff occurs elsewhere on the contact between sedimentary rocks of the Topanga and Puente formations. On Burruel Ridge north of Santiago Creek this tuff is apparently interbedded in the basal part of the La Vida member of the Puente formation, and it is therefore mapped as a part of that member. The volcanic constituents of the tuff were probably derived from the El Modeno rocks and deposited locally as an older unit of the La Vida member.

TABLE 3.—*Petrography of tuffaceous sediments in La Vida member of Puente formation*

	Sample 14	Sample 15	Sample 16	Sample 17	Sample 18	Sample 19
Matrix type	Clay [1]	Glass	Glass	Clay [1] or sericite.	Clay [1]	Clay.[1]
Do estimated percent	55	45	65	40	83	60.
Do index of refraction [2]	1. 535±	1. 450±	1. 450±	1. 555±	1. 550±	1.550±.
Glass fragments estimated percent	10	5	few	35	5	10.
Do index of refraction	1. 523	1. 477	(?)	1. 490	1. 500	1. 520.
Plagioclase fragments estimated percent	5	15	10	25	5	10.
Do alpha value [2]	1. 557	1. 558	1. 558	1. 557	1. 556	1. 555.
Other fragments type	Quartz, siltstone.		Quartz	volcanic rock fragments.	quartz, calcite, muscovite.	20 percent quartz, muscovite.

[1] The clay matrix of these rocks is semicrystalline with average grain size less than 0.004 millimeter in maximum diameter. It is isotropic or nearly so, with refractive indices commonly less than that of canada balsam. Halloysite is apparently the only mineral which satisfies the optical characteristics of this clay matrix.
[2] Accurate to ±0.002.

The alteration of the groundmass glass to "palagonite" and then to a clay (halloysite?) is illustrated in a thin section of sample 14 (fig. 66) and is attributed to hydrothermal processes (Ross and Hendricks, 1945, p. 67, 71). Although most of these samples are believed to be pyroclastic in origin, perhaps deposited in water, the alteration of the matrix has commonly been so complete that the original nature of the rock is not clear. The substantial percentage of detrital quartz and foreign lithic fragments in some occurrences shows that the tuff may grade laterally into tuffaceous siltstone or sandstone.

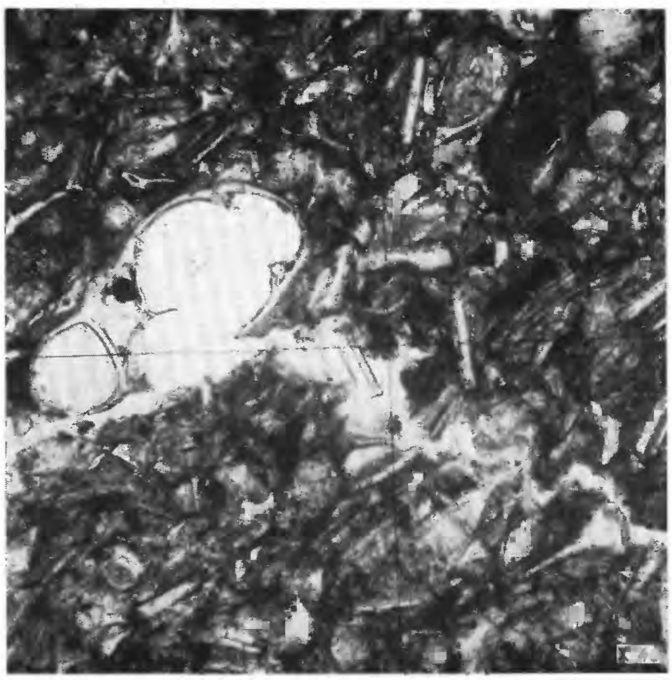

FIGURE 66.—Photomicrograph, tuff in La Vida member of Puente formation. Colorless glass bubbles and fragments in a matrix of palagonitized glass and montmorillonite. Plane polarized light.

SUMMARY OF PETROGRAPHY

Although the El Modeno volcanics include olivine basalts (or basaltic andesites), they are dominantly andesitic in composition. The basalt, the earliest rock in the sequence, is only slightly more ferromagnesian in composition than later extrusive rocks.

Mineralogically, these rocks are marked by the complete absence of the late reaction products biotite and hornblende.

Hypersthene is also apparently absent in the crystalline rocks, though possibly present in small amounts in pyroclastic rocks.

Fresh monoclinic pyroxene is usually present, at least as groundmass grains. It is generally colorless and without pleochroism, with positive elongation and an optic angle ranging from 50° to 60°. The extinction angle, Z to c, ranges from 37° to 40°—rather low for augite. The mineral appears to be an iron-poor diopsidic augite. Alteration of the augite phenocrysts as well as the olivine and glass to chlorophaeite is commonly complete. This type of alteration has been ascribed to the deuteric activity of entrapped volatile materials (Peacock and Fuller, 1928). Substantiating this interpretation is the deeply altered condition of the volcanic rocks penetrated by wells drilled for oil in this part of the Los Angeles basin. Even in occurrences where the volcanic works are rather definitely unweathered they present the same complete state of alteration.

Olivine is commonly present in most of the crystalline rocks. In the basaltic rocks it originally made up perhaps 5 to 15 percent of the volume, and in the andesitic rocks 5 percent or less. It generally occurs as ovoid grains in the groundmass, although larger pseudomorphs in nearly every sample have its characteristic orthorhombic shape. The optical properties are: $\alpha=1.660\pm0.002$, $\gamma=1.702\pm0.002$; (negative) $2V=84°$, about 80 percent forsterite and 20 percent fayalite in composition. The former phenocrysts of olivine are nearly always altered to antigorite and chlorophaeite with some magnetite. In some thin sections this alteration is incomplete and a crystal consists of a fresh core and altered rim.

Zeolites, which are attributed to hydrothermal solutions, occur widespread in all the volcanic rocks.

Plagioclase is the most abundant and the least altered mineral in every sample and ranges in composition from An_{30} to An_{65}. The average composition of the plagioclase fragments of the Topanga formation tuffs is An_{35}; it is An_{50} in the tuffs of the La Vida member of the Puente formation. In both the basaltic and andesitic crystalline rocks the plagioclase phenocrysts range in composition from An_{42} to An_{62}. The average composition in the basalt is An_{55}; in the andesite it is An_{45}. In the lavas of the andesite flow and flow breccia member many of the plagioclase phenocrysts show prominent progressive zoning. The groundmass feldspars in the crystalline rocks have either the same or more sodic composition than the rims of the phenocrysts.

Glass is abundant only in the tuffs interbedded near the top of the Topanga formation and at the base of the La Vida member of the Puente formation. Several samples of each of these tuff beds have been examined in an attempt to detect the course of differentiation of the source magmas. The values in the following summary were derived from the data of tables 1, 2, and 3, and from the text descriptions.

Rock Unit	*Average percent SiO_2 of glass*	*Average percent An of plagioclase*
Tuffs of the Topanga formation	70 plus	35.
Basalt flow member	52	55.
Andesite flow member	none	45.
Andesite flow member, limy breccia bed.	57	None.
Tuffs of the La Vida member	70 plus	50.

These data may indicate only minor changes in the general course of differentiation. Tuffs are poor guides to the character of their parent magmas, as sorting by wind may segregate the more siliceous material because of its lower specific gravity. Also, in the mapped area there is little evidence concerning the position of the vent or vents. Subsurface data show that the volcanics thicken westward, suggesting that the vents were some distance west of the El Modeno area.

An opaque mineral tentatively identified as magnetite is always present. It occurs in the zoned plagioclase phenocrysts as inclusions and in olivine grains as minute specks. In the groundmass of every sample it occurs as dendritic clusters or rod-shaped aggregates, as well as disseminated grains.

Apatite occurs occasionally as minute inclusions in plagioclase phenocrysts.

SEDIMENTARY ROCKS OF THE CENOZOIC SYSTEM

SILVERADO FORMATION

The strata of Paleocene age in the Santa Ana Mountains were named the Silverado formation by Woodring and Popenoe (1945). The westernmost outcrop of this formation in the mountains appears on the east margin of the mapped area, on the limbs and nose of a large westward-plunging anticline that makes up the core of the northern Santa Ana Mountains. The Silverado formation is unconformable on the Upper Cretaceous sedimentary rocks. About 500 feet of Upper Cretaceous strata are missing beneath this discordance on the crest of the mountains, about six miles east of the mapped area (Schoellhamer and others, 1954).

In this area the Silverado formation consists of five lithologic units recognized by Vedder (1950). In stratigraphic order, from bottom to top, these are: (1) a basal conglomerate bed; (2) a lower arkosic sandstone unit; (3) the Claymont clay bed; (4) a second arkosic sandstone unit; and (5) a marine sandstone bed. The basal conglomerate bed averages from 20 to 40 feet in thickness and consists of subrounded pebbles, cobbles, and boulders derived from the metasedimentary and crystalline rocks of the basement complex to the east. The matrix of the conglomerate is a red to buff coarse-grained micaceous and arkosic sandstone. At most exposures in the northern Santa Ana Mountains a thin bed of reddish sandy clay overlies the basal conglomerate and tends to stain the conglomerate outcrops a reddish color.

The lower arkosic sandstone unit is poorly sorted and cemented, and is predominantly massive or coarsely cross-bedded; it averages 100 feet in thickness in this area. The color of the sandstone is gray to buff; the angular grains of quartz and feldspar are medium-sized to coarse. Some beds up to 4 feet thick have the appearance of a rotten mica schist as they are composed almost entirely of biotite flakes. Thin beds of gray or brown sandy clay and siltstone are locally interbedded in the sandstone. At the top of this sandstone unit is a thick sequence of beds characterized by the alteration of biotite to the clay mineral anauxite.

A yellowish brown to reddish or black pisolitic clay of commercial importance, the Claymont clay bed, occurs about 120 to 150 feet above the base of the formation. The clay is a resistant bed, 2 feet in average thickness, which has an almost continuous outcrop. It is hard, massive, and brittle, with a conchoidal fracture. Quartz is usually abundant in the lower part of the bed as angular grains. The clay commonly contains abundant 3- to 8-millimeter pisolitic aggregates of quartz and clay, particularly in the upper part of the bed.

The thickest member of the Silverado formation is a coarse-grained arkosic sandstone unit, which rests on the Claymont clay bed and contains much biotite and anauxite. Locally, this member contains a hard white quartz sandstone bed about 20 feet thick, as well as thinner beds of varicolored sandy clays, siltstones, carbonaceous shales, and lignite. A meager fresh-water fauna occurs locally in the unit. The sandstone member is about 700 feet thick in the westernmost outcrops of the formation.

The marine member of the Silverado formation is about 300 feet in thickness, and consists of soft, gray, well-bedded fine- and medium-grained sandstone. A poorly preserved fauna of Paleocene age includes *Turritella pachecoensis* and *Glycymeris* cf. *major* (Vedder, 1950, p. 33).

SANTIAGO FORMATION

The sedimentary rocks of Eocene age in the Santa Ana Mountains were named the Santiago formation by Woodring and Popenoe (1945). Strata of the Santiago formation rest with apparent conformity on rocks of the Silverado formation, although fossil evidence indicates a disconformity or a hiatus between the two formations (Vedder, 1950, p. 35). The approximate thickness of the Santiago formation in this area is 700 feet.

The basal unit of the formation is a pebble-cobble conglomerate that interfingers irregularly with massive buff sandstone. The conglomerate is made up chiefly of well-rounded pebbles and cobbles of gray quartzite and reddish rhyolite, with less common clasts of light-colored plutonic rocks, set in a matrix of yellowish-brown coarse-grained sandstone. Locally this basal unit grades laterally into a massive, occasionally cross-bedded, coarse-grained arkosic and micaceous marine sandstone.

Buff to gray-brown fine- to medium-grained concretionary sandstone, containing a molluscan fauna of middle to late Eocene age, overlies the basal conglomerate unit. This concretionary sandstone unit has an average thickness of 125 feet.

The upper unit of the Santiago formation is conglomeratic sandstone of possible nonmarine origin that averages 450 to 500 feet in thickness. This sandstone is buff to brown, poorly cemented and massive, coarse-grained, poorly sorted, and of arkosic composition. Stringers of volcanic and quartzite pebbles form six-inch to one-foot discontinuous lenses in the sandstone. Large fragments of silicified logs are common and serve to distinguish this unit.

VAQUEROS AND SESPE FORMATIONS, UNDIFFERENTIATED

Nonfossiliferous sedimentary rocks of the Sespe formation of late Eocene to early Miocene age rest with apparent conformity on strata of the Santiago formation and grade upward and laterally into the fossiliferous marine strata of the Vaqueros formation.

Interstratified beds of variable maroon and white or buff conglomeratic sandstone are characteristic of the lower part of the Sespe formation; occasional thin bands of greenish-gray to red clay and mudstone appear higher in the section. Well-rounded pebbles and cobbles of varicolored volcanic rocks and gray quartzite, averaging about 3 inches in maximum diameter, are characteristic of the conglomeratic portions of the sequence. The matrix of these rocks is composed of angular quartz, weathered feldspar, and biotite in a semiconsolidated clay cement.

In the Santa Ana Mountains it has not been possible to differentiate the Sespe formation described above from the overlying marine strata of the Vaqueros formation. Mollusks characteristic of the Vaqueros formation are present locally in maroon and green beds that are typical of the Sespe formation.

The Vaqueros formation of early Miocene age (Loel and Corey, 1932) overlies the Sespe formation and also intertongues with it. The Vaqueros formation consists of medium- to coarse-grained gray to buff sandstone and conglomeratic sandstone with local greenish-gray sandy siltstone. Strata of the Vaqueros formation contain an abundant molluscan fauna which includes *Turritella inezana santana*, *Rapana* cf. *vaquerosensis*, *Olivella santana*, "*Terebra*" *santana*, and *Anadara* (*Larkinia*) *santana*, all of early Miocene age.

In the mapped area the combined thickness of these formations averages about 1,400 feet; elsewhere in the Santa Ana Mountains the thickness is as great as 3,000 feet.

TOPANGA FORMATION

The middle Miocene rocks of the Santa Ana Mountains were assigned to the Topanga formation by English (1926, p. 24). The strata of the Topanga formation rest with apparent conformity on beds of the Vaqueros formation. The thickness of the Topanga formation in this area is about 1,100 feet.

Buff-colored massive and thickly bedded medium- to coarse-grained gritty sandstones that are semiconsolidated and poorly sorted make up, with minor sandy siltstone and pebbly sandstone, almost the entire formation. Abundant molluscan fossils of middle Miocene age commonly occur near the base of the formation but are also found at higher horizons.

In the El Modeno area two or more thin beds of white vitric tuff are interbedded in the sandstone of the Topanga formation. These tuff beds are not found east of the mapped area.

PUENTE FORMATION

The sedimentary rocks of upper Miocene age in the Santa Ana Mountains have been called the Puente formation by English (1926, p. 26), using the name assigned by Eldridge and Arnold (1907) to similar strata in the Puente Hills north and west of the El Modeno area.

In the El Modeno area, strata of the Puente formation rest with apparent conformity upon the El Modeno volcanics. North of Santiago Creek and elsewhere strata of the Puente formation overlap rocks of the El Modeno volcanics, and the Topanga, Vaqueros, and Sespe formations. In one locality, about 2 miles east of the mapped area, about 700 feet of strata of the Puente, Topanga, and, perhaps, of the Vaqueros formations are missing below the base of the Soquel member of the Puente formation.

Schoellhamer and others (1954) have divided the Puente formation into four members in the Santa Ana Mountains. In ascending order these are: (1) the La Vida member, consisting of gray to black laminated siltstone which locally contains phosphatic nodules, and interbedded lenticular feldspathic sandstone and conglomerate beds; (2) the Soquel member, consisting of massive to moderately well bedded coarse-grained to granular poorly sorted buff sandstone with interbedded siltstone and local conglomerate beds; (3) the Yorba member, consisting of thin-bedded hackly chocolate-brown to pinkish gypsiferous and diatomaceous siltstone and local strata of sandstone and conglomerate; and (4) the Sycamore Canyon member (which does not appear on the geologic map, pl. 46), consisting of interbedded conglomerate, medium- to coarse-grained buff arkosic sandstone, and siltstone.

The La Vida member commonly contains a foraminiferal fauna of early late Miocene age that includes *Bulimina uvigerinaformis*, *Eponides rosaformis*, *Valvulineria grandis*, *Uvigerina subperegrina*, *Buliminella curta*, *Bolivina vaughani*, and *Epistominella capitanesis*—all referred to the lower part of the Mohnian stage of Kleinpell (1938, p. 121–131).

The average thickness of the Puente formation in this area is about 1,800 feet. In the type area in the Puente Hills, to the northwest of El Modeno, the formation reaches a thickness of about 11,000 feet.

QUATERNARY TERRACE DEPOSITS

Terrace deposits consisting of poorly sorted sand, gravel, and rubble are well developed within the mapped area, which includes the mouth of Santiago Creek. These deposits range in color from light gray to reddish brown.

The six levels of deposits along Santiago Creek are found at the following approximate elevations above the stream bed: 10 to 15 feet, 40 feet, 60 feet, 150 feet, 210 feet, and 300 feet. This group of terrace deposits was mapped downstream from the head of Santiago Creek by Schoellhamer and others (1954).

Along the south side of Burruel Ridge occur several isolated terrace deposits (*Qtu*) at elevations from 350 to 550 feet above the stream bed. Sedimentary rocks of the Puente formation have been thrust over high isolated remnants of terraces (*Qtd*) north of Santiago Creek.

STRATIGRAPHIC POSITION AND CORRELATION OF THE VOLCANIC ROCKS

The stratigraphic position of the El Modeno volcanics in the standard California section is known within close limits. The underlying Topanga formation contains a large molluscan fauna which includes *Turritella ocoyana* and other guides to Pacific coast middle Miocene strata. Interbedded near the base of the volcanic series is a marine siltstone bed that contains fish scales which are probably characteristic of the middle Miocene or lowest part of the upper Miocene. On Burruel Ridge, north of Santiago Creek near the north end of structure section $A–A'$ (pl. 47), the basalt flow member is overlain by a silicified claystone bed that contains a rich foraminiferal fauna including *Bulimina montereyana*, *Epistominella gyroidinaformis*, *Baggina robusta*, *Valvulineria californica obesa*, and *Nonion costiferum*. R. M. Kleinpell has recently examined this collection and considers it to represent the *Siphogenerina reedi* zone of his Luisian (middle Miocene) stage (oral communication). Resting conformably on the andesite flow and flow breccia member of the El Modeno volcanics is the La Vida member of the Puente formation, which contains Foraminifera diagnostic of the lower part of Kleinpell's Mohnian stage. The El

Modeno volcanics thus appear to be middle to early late Miocene in age.

Tentative correlation is made with the Glendora volcanics of Shelton (1946). The Glendora volcanics crop out about 25 miles north of the El Modeno area (fig. 55). They are predominantly andesitic massive flows and tuff breccias, but they are stratigraphically and lithologically more complex than the El Modeno volcanics. The Glendora volcanics are probably somewhat older than the El Modeno, as fossiliferous sedimentary rocks of the Topanga formation (middle Miocene) are interbedded with and locally overlie the volcanic rocks (Shelton, 1955, p. 79–80).

STRUCTURE

The structure of the El Modeno area is characterized by faulting rather than folding. The great displacement of some of the faults and the relatively small size of most of the fault blocks render structural interpretation hazardous.

FOLDS

The volcanics near the east edge of the mapped area are involved in a faulted syncline which lies between the large westward-plunging anticline that was penetrated by the National Securities Irvine 1 well and a horst block of rocks of the Sespe and Vaqueros formations which trends northward from Peters Canyon Reservoir, as shown in structure section *A–A′* plate 47. The main mass of El Modeno volcanics shown on structure section *B–B′* is on the west side of a second but smaller anticlinal fold that is faulted on both limbs. Evidence in the mapped area indicates that folding occurred after the formation of Miocene strata but prior to the formation of the Quaternary terraces. Sedimentary rocks of Pliocene age which crop out north and west of the mapped area are folded but the terrace deposits are undeformed. This evidence indicates that most of the diastrophism occurred during late Pliocene or early Pleistocene time.

FAULTS

Several large faults traverse the area from southeast to north-northwest. These are all steep normal faults downdropped to the west and reflect the northwest-trending regional structural pattern of the Santa Ana Mountains. The large fault that trends north-northwest through the mapped area has a displacement of 1,600 to 2,000 feet. Subsurface data indicate that this fault continues west-northwest of El Modeno for a distance of 12 to 15 miles beneath the alluvial cover of the Los Angeles basin, where it is called the Norwalk fault by oil company geologists. The smaller faults have similar trends and relative displacements. The faults truncate the fold structures and are probably Pleistocene in age. Low-angle reverse faulting thrusts sedimentary rocks of the Puente formation over Quaternary terrace deposits on the south side of Burruel Ridge, near the north edge of the mapped area.

DISCONFORMITIES IN THE VOLCANIC SEQUENCE

Two disconformities of local nature occur in the volcanic sequence in the east-central part of the mapped area. One occurs near the center of structure section *B–B′* where the palagonite tuff and tuff breccia member rests on a siltstone of the Topanga formation, with the basalt flow member missing. Just to the south, near the northeast end of structure section *C–C′*, the andesite flow and flow breccia member rests upon a similar siltstone (not mapped), with the basalt flow and palagonite tuff and tuff breccia members missing. These two members reappear in the complete sequence east of Peters Canyon.

MODE OF DEPOSITION OF THE VOLCANIC ROCKS

Submarine accumulation of at least a part of the basalt flow member is indicated by pillows with siltstone seams (fig. 57) and by the overlying fossiliferous marine siltstone. The alteration characteristic of the rock strongly suggests deposition in a hydrating environment.

Most of the palagonitic tuffs were deposited in water deep enough to effect fairly uniform sorting over a relatively large area; winnowing by winds probably facilitated the sorting to some extent. The angularity of the fragments precludes thorough reworking of former subaerial deposits. Alteration of glass to palagonite, which is characteristic of these tuffs, is considered by Peacock and Fuller (1928) and MacDonald (1949, p. 59) to be postdepositional, owing to ordinary weathering. Eruption of hot tuffaceous material directly into water or water-saturated sediments would accelerate this dehydration. Peacock and Fuller consider the formation of chlorophaeite to be a deuteric process, initiated at the time of deposition.

In the northern part of the central volcanic area several large blocks with distinct cooling cracks (fig. 62), occur in the andesite flow and flow breccia member, each block lying in a matrix of vesicular lava or palagonitic tuff. This is strong evidence for deposition of hot avalanche deposits characteristic of some volcanic explosions. At the same stratigraphic horizons in the southern part of the area, these features are missing and in their place are dense flows with occasional poorly developed pillow structure.

It is concluded from their lithologic and petrographic characteristics that the El Modeno volcanics were formed by both submarine and subaerial deposits of igneous material of intermediate composition. No evidence is at hand concerning the source of these volcanic rocks. The uniformity of the sequence and distribution of individual lithologic units throughout the series indicates a source capable of extruding large quantities of material over a wide area. Subsurface data suggest that the present area of outcrop lies at the eastern margin of the area of deposition and therefore probably at some distance from the position of the source vents.

SUBSURFACE DATA

Twenty-eight wells drilled for oil in the Los Angeles basin south of the Whittier fault and east of the San Gabriel River have penetrated volcanic rocks similar to those represented at El Modeno (see table 4 and fig. 56). Samples from these wells are commonly amygdaloidal, usually deeply altered and often pyritized. Generally they consist of fragmental or brecciated extrusive deposits of intermediate composition. The stratigraphic relations and lithologic character of the volcanic rocks penetrated by wells are apparently similar to those of the outcrops in the El Modeno area.

DISTINCTION BETWEEN EXTRUSIVE AND INTRUSIVE ROCKS

Several characteristics of the extrusive rocks of Miocene age of the eastern Los Angeles basin may serve to distinguish them from the dike and sill rocks that are often observed in the subsurface, intruding sedimentary rocks of Miocene age and older.

The stratigraphic position of the extrusive rocks seems to be sharply limited upwards, as they are not known to occur above the base of the La Vida member of the Puente formation. Dikes and sills do not crop out south of the Whittier fault zone, between the El Modeno area and the San Gabriel River, 10 miles to the west.

The stratigraphic position of these intrusive rocks is somewhat uncertain, but they apparently intrude no rocks younger than the lower member of the Puente formation.

Lithologic distinctions between extrusive and intrusive rocks are limited mainly to the state and type of alteration; textural distinctions are reliable only in the case of tuffaceous or bedded pyroclastic deposits. The intrusive rocks are commonly hard and dense although the ferromagnesian minerals are often replaced, whereas the extrusive rocks are commonly vesicular and severely altered to crumbly palagonitic masses, interpreted as evidence of submarine accumulation.

Petrographically, the intrusive rocks are characterized by chloritized ferromagnesian minerals. These minerals are commonly represented by pyroxene and olivine, occasionally by accessory biotite, and rarely by hornblende. Albitized feldspars are also seen. The rocks usually exhibit a diabasic, often coarsely ophitic texture. The extrusive rocks are characterized by such alteration products as chlorophaeite and palagonite; chlorite is rare. The presence of more than 10 percent of glass is generally reliable evidence of extrusive origin, as pointed out by Durrell (1953).

The composition of the extrusive and intrusive rocks of the eastern Los Angeles basin south of the Whittier fault may be quite similar. In most of the samples of each rock examined, the plagioclase was found to range between andesine and sodic labradorite in composition, except in the albitized intrusive rocks. Augite, or its alteration products, were present in all the crystalline samples; olivine, in perhaps half the samples of each type. As mentioned above, minor amounts of hornblende and biotite occur in the intrusive rocks but apparently never total more than 5 percent. However, these minerals have been seen only in rocks believed to be intrusive. The intrusive rocks may be somewhat more alkalic in composition and slightly younger than the extrusive rocks. While there is no structural evidence indicating a common source, it is conceivable that the few distinctive characteristics of each type are attributable entirely to their mode of emplacement, and that they are consanguineous and contemporaneous or nearly so.

DISTRIBUTION OF THE VOLCANIC ROCKS

The distribution of the volcanic rocks indicates that they were deposited over an area of about 770 square miles south of the Whittier fault (see fig. 56 and table 4). Only a few wells are known to have been drilled through the volcanic rocks into older sedimentary rocks. In these few wells the average thickness of the volcanic rocks suggests that they may thicken basinward (westward) from El Modeno at a rate near 100 feet per mile. There is no clear evidence in the subsurface data of an unconformity beneath the volcanic rocks, and well cores are not numerous enough to indicate which units of the sequence thicken westward.

TABLE 4.—*Log of wells drilled for oil south of the Whittier fault and east of the San Gabriel River, Calif., which penetrated middle or upper Miocene volcanic rocks*

[Measurements involving location, elevation, depth, interval, and thickness are in feet. Wells are now abandoned except wells 19 and 27, which were producing in 1951, and well 13, which was idle in 1953. Rocks examined microscopically are indicated with an asterisk (*)]

No. on Fig. 56	Operator	Well	Location	Elevation	Total depth	Year begun	Data on Volcanic Rocks			Well bottomed in—	Remarks
							Interval	Thickness penetrated	Overlain by—		
1	Amerada Petroleum Corp.	Anaheim Comm. 48-8.	325 N. and 2325 E. of southwest corner sec. 8, T. 4 S., R. 10 W.	118±	8, 946	1949	8348±-8615±	267±	Middle Miocene (?) sedimentary rocks.	Vaqueros and Sespe (?) formations undifferentiated.	Fragmental volcanic rocks with interbedded sedimentary rocks. Sandstone and shale of middle Miocene age from 8200± to 8348±, and 8615± to 8850±.
2	Bandini Petroleum Co.	Segerstrom 1	330 N. and 660 E. of intersection Huntzinger and Harbor Blvds., sec. 34, T. 5 S., R. 10 W.	32±	6, 882	1947	5571-6882+	1311+	Upper Miocene sedimentary rocks.	Volcanic rocks	*Hypersthene augite basalt and andesite tuff breccia. Data from Shelton (1954).
3	Continental Oil Co.	Santa Ana Comm. 1.	2310 S. and 1660 E. of Northwest corner sec. 14, T. 5 S., R. 10 W.	69±	4, 411	1935	4317-4411	94+	Pliocene (?) sandstone and conglomerate.	Volcanic rocks	*Calcic andesite and palagonitic tuff interbedded with sandstones of middle Miocene age.
4	Gale, Hoyt S.	Irvine 1	350 S. and 300 E. of northwest corner sec. 30, T. 5 S., R. 9 W.	52±	2, 224	1925	2158-2224	66+	Middle Miocene sedimentary rocks.	Volcanic rocks	Upper and middle Miocene sedimentary rocks 1750 (?) to 2158; fragmental volcanic rocks 2158 to 2224.
5	General Petroleum Corp.	Heath 1	330 S. and 330 W. of northeast corner sec. 34, T. 3 S., R. 11 W.	62±	11, 422	1944	11, 134-11, 422	288+	Pliocene sedimentary rocks.	Volcanic rocks	*Vesicular basalt at 11,276. Middle Miocene megafossils and Foraminifera in 2-foot limestone bed in volcanic rocks at 11,244. Data in part from Schoellhamer and Woodford (1951).
6	General Petroleum Corp.	La Mirada 46-1	275 N. and 2350 W. of southeast corner sec. 16, T. 3 S., R. 11 W.	85±	12, 629	1946	12, 582±-12, 629	47+	Middle Miocene sandstone.	Volcanic rocks	*Porphyritic basalt. Lower Pliocene sedimentary rocks 5800± to 11,197; upper Miocene sedimentary rocks 11,197 to 12,300; middle Miocene sedimentary rocks 12,300 to 12,582. Data from Schoellhamer and Woodford (1951).
7	General Petroleum Corp.	Librown 1	992 N. and 330 W. of southeast corner sec. 21, T. 3 S., R. 11 W.	68±	12, 600	1945	12, 080-12, 094 12, 480-12, 600	134+	Upper Miocene sedimentary rocks.	Volcanic rocks	*Altered basalt. Lower Pliocene sedimentary rocks 7060 to 11,524; upper Miocene sedimentary rocks 11,524 to 11,898; middle Miocene sedimentary rocks 11,898 to 12,080; volcanic rocks and interbedded middle Miocene sedimentary rocks 12,080 to 12,600.
8	General Petroleum Corp.	McNally 1	1525 S. and 2325 W. of northeast corner sec. 22, T. 3. S., R. 11 W.	120±	11, 606	1950	11, 525-11, 606	81+	Upper (?) Miocene sedimentary rocks.	Volcanic rocks	Fragmental basalt. Upper Miocene sedimentary rocks 11,080 to 11,525.
9	General Petroleum Corp.	Was 1	330 S. and 990 W. of northeast corner sec. 21, T. 5 S., R. 10 W.	57±	5, 955	1939	5655±-5955	300+	Middle Miocene sedimentary rocks.	Volcanic rocks	*Vesicular flow or tuff, 5655 to 5667; porphyritic basalt, 5794 to 5804: lower Pliocene sedimentary rocks 5550± to 5610; volcanic rocks and interbedded middle Miocene sedimentary rocks 5610 to 5955. Data from Schoellhamer and Woodford (1951), and thin sections.
10	Girard, P. M.	Mark Fisher 1	2300 N. and 600 E. of southwest corner sec. 27, T. 5 S., R. 10 W.	42±	5655	1943	5200-5650	450+	Lower Pliocene sedimentary rocks.	Volcanic rocks	*Fragmental (?) basaltic volcanic rocks. Data from Shelton (1954).
11	McKee Oil Co.	Kokx Comm 8-1	2460 N and 1510 E. of southwest corner sec. 16, T. 4 S., R. 9 W.	274±	4005	1946(?)	2145±-2176±	31±	La Vida member of Puente formation.	Vaqueros and Sespe formations undifferentiated.	Sandstones with *Turritella ocoyana* 3410 to 3475; Vaqueros and Sespe formations undifferentiated below 3700.
12	Morton & Sons	Thomas 1	2325 S. and 1000 W. of northeast corner sec. 23, T. 4 S., R. 10 W.	54±	4455	(?)	4368-4450 (?)	90±	Pliocene sedimentary rocks.	Middle Miocene(?) sedimentary rocks.	Fragmental volcanic rocks at 4368. Poor data.
13	Seguro Petroleum Co.	Copeland 1	1000 N. and 124 W. of southeast corner sec. 34, T. 5 S., R. 11 W.	64±	9110	1947	7570-7605	35	Upper Miocene sedimentary rocks.	Middle Miocene(?) sedimentary rocks.	Top of Miocene sedimentary rocks at 4100.
14	Shell Oil Co., Inc.	Matthis 1	200 S. and 220 E. of northwest corner sec. 23, T. 4 S., R. 10 W.	152±	5944	1937	4915-5944	1029+	Middle Miocene sedimentary rocks.	Volcanic rocks	*Altered olivine basalt. Lower Pliocene sedimentary rocks ? to 4600±; upper Miocene sedimentary rocks 4600± to 4770; middle Miocene sedimentary rocks 4770 to 4915. Data from Schoellhamer and Woodford (1951).

TABLE 4.—*Log of wells drilled for oil south of the Whittier fault and east of the San Gabriel River, Calif., which penetrated middle or upper Miocene volcanic rocks*—Con.

Measurements involving location, elevation, depth, interval, and thickness are in feet. Wells are now abandoned except wells 19 and 27, which were producing in 1951, and well 13, which was idle in 1953. Rocks examined microscopically are indicated with an asterisk (*)]

No. on Fig. 56	Operator	Well	Location	Elevation	Total depth	Year begun	Data on Volcanic Rocks: Interval	Data on Volcanic Rocks: Thickness penetrated	Data on Volcanic Rocks: Overlain by—	Well bottomed in—	Remarks
15	Standard Oil Co. of California.	Stanley Comm. 1	990 S. and 900 E. of northwest corner sec. 33, T. 4 S., R. 10 W.	100±	8704	1946	8140–8704	564±	Upper Miocene (?) sedimentary rocks.	Volcanic rocks	Hard, dark gray dense pyritic olivine basalt, pyroclastic at top; upper Miocene(?) sedimentary rocks 8108 to 8140.
16	Standard Oil Co. of California.	Taft Comm. 1	150 S. and 1300 W. of northeast corner sec. 20, T. 4 S., R. 9 W.	232±	3095	1948	3006–3095	89+	La Vida member of Puente formation.	Volcanic rocks	Fragmental volcanic rocks. Upper Miocene sedimentary rocks 2315 to 3006.
17	Standard Oil Co. of California.	Turley 1	325 S. and 2560 E. of northwest corner sec. 4, T. 6 S., R. 10 W.	40±	7275	1948	7170±–7190±	20±	Upper Miocene(?) sedimentary rocks.	Volcanic rocks	Fine grained light gray porphyritic andesite, deeply altered. Fragmental volcanic rocks interbedded at bottom (?).
18	Standard Oil Co. of California.	Tustin Comm. 1	540 N. and 1425 E. of southwest corner sec. 21, T. 4 S., R. 9 W.	269±	2380	1947	2332–2380	48+	La Vida member of Puente formation.	Volcanic rocks	Upper Miocene sedimentary rocks 1678± to 2332. Tuffaceous, fragmental and vesicular volcanic rocks.
19	Standard Oil Co. of California.	Woodward Comm. 1 (formerly Standard Oil Co. Lewis Comm. 1).	1950 N. and 2300 W. of southeast corner sec. 11, T. 3, S., R. 11 W.	195±	12, 184	1945	11, 224±–11, 420	196	Upper Miocene sedimentary rocks.	Middle Miocene sedimentary rocks.	Lower Pliocene 3480–8300; upper Miocene sedimentary rocks 8300 to 11,224±; middle Miocene sedimentary rocks 11,420 to 11,710; Vaqueros and Sespe formations, undifferentiated, 11,710 to 12,184. Data from Schoellhamer and Woodford (1951).
20	Superior Oil Co. & Continental Oil Co.	Garden Grove Unit 1-1.	2310 N. and 975 W. of southeast corner sec. 28, T. 4 S.. R. 10 W.	114±	7481	1953	7189–7481	292	Pliocene sedimentary rocks.	Volcanic rocks	Porphyritic andesite cored. Pliocene sedimentary rocks 3895 to 7189. Fragmental and flow volcanic rocks 7189 to 7481.
21	The Texas Co	Buena Park Unit 1-1.	1780 N. and 2200 E. of southwest corner sec. 6, T. 4 S., R. 10 W.	97±	9042	(?)	8866–9041	175±	Miocene sedimentary rocks.	Volcanic rocks	Fragmental volcanic rocks in part.
22	The Texas Co	Ragan 1	500 N. and 1400 W. of southeast corner sec. 15, T. 4 S., R. 9 W.	392±	5690(?)	1954	238–745	407±	Upper Miocene sedimentary rocks.	Lower Miocene(?) sedimentary rocks.	
23	Tide Water Associated Oil Co.	Martin 1	990 N. and 2240 W. of southeast corner sec. 21, T. 5 S., R. 10 W.	47±	6558	1948	6435–6558	123+	Upper Miocene sedimentary rocks.	Volcanic rocks	Pliocene sedimentary rocks ? to 6240±; upper Miocene sedimentary rocks 6240± to 6435.
24	Tide Water Associated Oil Co.	Nel-Cal-Lu Comm. 1.	1650 S. and 2425 E. of northwest corner sec. 21, T. 4 S., R. 10 W.	122±	8568	1947	7720±–7750±	30±	Pliocene(?) sedimentary rocks.	Vaqueros and Sespe (?) formations undifferentiated.	Lower Pliocene sedimentary rocks 7200± to 7720±; fragmental volcanic rocks cored 7734 to 7739.
25	Tide Water Associated Oil Co.	Olive-Orange 1	2060 S. and 390 E. of northwest corner sec. 19, T. 4 S., R. 9 W.	170±	4509	1941	4366–4509	409+	La Vida member of Puente formation, and Topanga formation.	Volcanic rocks	La Vida member of Puente formation 3670± to 4030±: Topanga formation 4030± to 4366.
26	Trustees Development Association.	Trustees Development 1.	350 S. and 1500 W. of northeast corner sec. 6, T. 5 S., R. 9 W.	175±	4144	1924	2100±–2135	35±	Upper Miocene(?) sedimentary rocks.	Vaqueros and Sespe (?) formations undifferentiated.	Coarse grained volcanic rocks: underlain by Topanga(?) formation. Poor data.
27	Union Oil Co. of California.	Chapman 29	1200 N. and 2500 W. of southeast corner sec. 29, T. 3 S., R. 9 W.	293±	10, 496	1936	7910±–8105±	195±	Upper Miocene sedimentary rocks.	Middle Miocene sedimentary rocks.	*Glassy basalt. Lower Pliocene 1888± to 2601; upper Miocene sedimentary rocks 2601 to 7910±; middle Miocene sedimentary rocks 8105± to 9128±; Vaqueros and Sespe formations 9128± to 10,496. Data from Schoellhamer and Woodford (1951).
28	Union Oil Co. of California.	Olive Comm. 4-1	75 N. and 180 E. of southwest corner sec. 8, T. 4 S., R. 9 W.	199±	4236	1948(?)	4086–4168±	74±	Upper Miocene sedimentary rocks.	Vaqueros and Sespe formations undifferentiated.	Tuffaceous rocks 4086 to 4168±. Upper Miocene sedimentary rocks 3450± to 4086±; Vaqueros and Sespe formations undifferentiated 4168± to 4236. Faulted section (?).

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