The Vasquez Series in the Upper Tick Canyon Area, Los Angeles County, California

by

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ABSTRACT

The Vasquez series of probable Oligocene age consists of interbedded sedimentary and basic volcanic rocks, and is well exposed in the vicinity of Tick Canyon, northern Los Angeles County, California. In this area the section is 4810 feet thick. The sediments are nonmarine deposits that were laid down under alternating lacustrine and fluviatile conditions in a semi-arid climate. The basic igneous rocks are extrusive, and comprise flows, flow breccias, and minor tuffs.

The beds occur in a sharply-folded syncline with a gentle southwesterly plunge. They are in fault contact with a much older, pre-Cretaceous complex of crystalline rocks, and are nonconformably overlain by the Tick Canyon formation of Lower Miocene age.

Sets of northeasterly- and northwesterly-trending faults cut the syncline. Movement along these faults was predominantly strike slip. Those of the northeasterly-trending set show much the larger displacements, and blocks on the southeast side are offset to the north with respect to blocks on the northwest side. Faulting appears to have been contemporaneous with the later stages of folding from pre-Tick Canyon to post-Mint Canyon time.

Vertebrate and invertebrate fossil remains were found in several beds, but none proved diagnostic as a means for dating the Vasquez series.

Mining for borate minerals was once an active industry in the area. Many gold prospects are present in the area underlain by crystalline rocks. Major faults in the area are water-bearing in places, and have important significance in regard to water supply.

INTRODUCTION

General statement

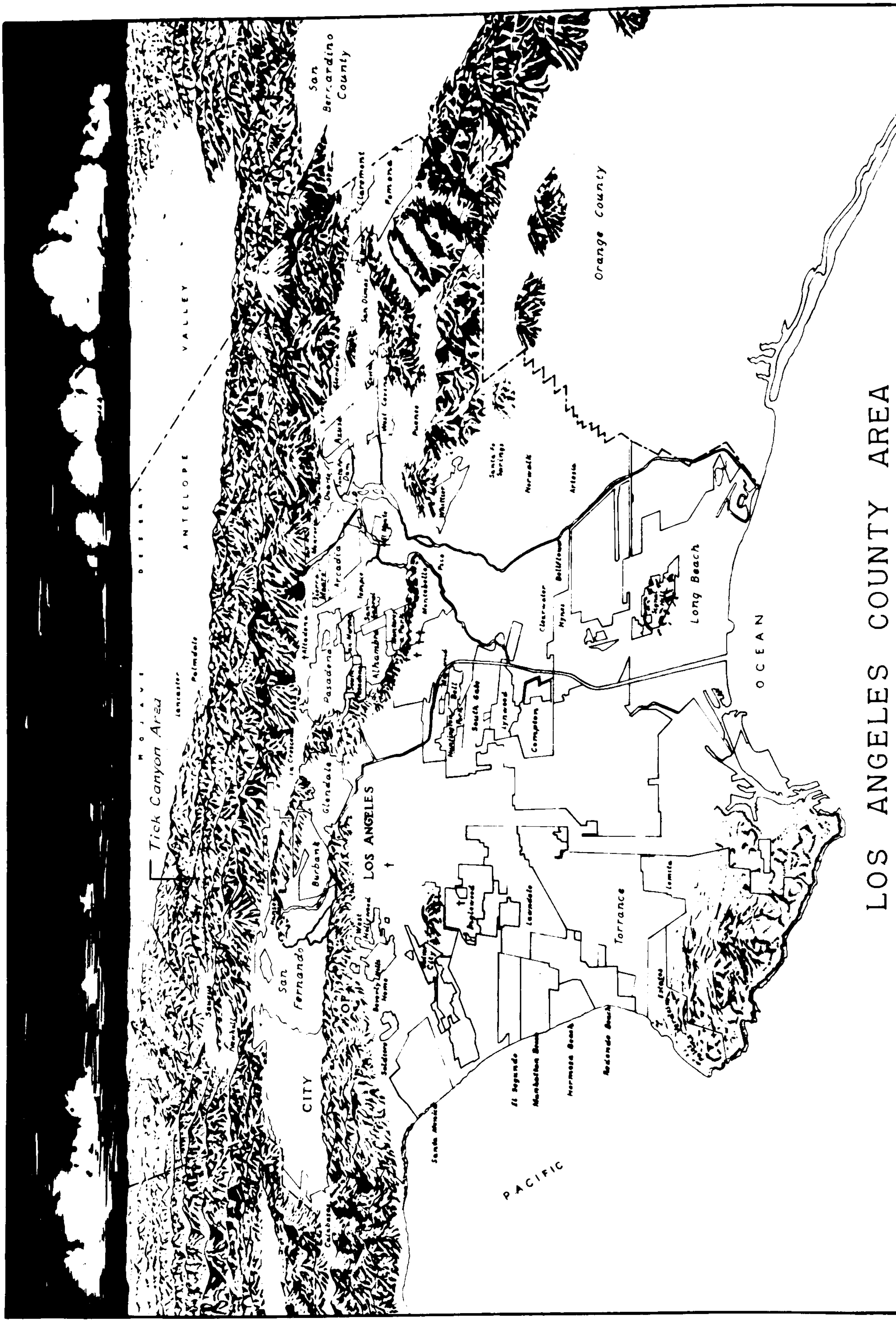
Excellent exposures of a part of the Vasquez series in the Upper Tick Canyon area, in the easternmost part of the Ventura Basin, afford an unusual opportunity for stratigraphic and structural analysis of a complex part of the Tertiary section of southern California. The unconformable relationship between the Vasquez series and the overlying Tick Canyon formation is also well exposed. The area has long been used for the training of student geologists in mapping techniques, generally at a scale of 1 inch equals 1000 feet. The present investigation was based on the assumption that more detailed mapping, on a scale large enough to delineate individual marker beds, would allow a more accurate interpretation of structure than has hitherto been obtained in this part of the Ventura Basin. The writer spent about 55 field days, during 1949 and the spring of 1950, in studying and mapping an area of about 3 square miles at a scale of 1 inch equals 500 feet. A portion of the U.S.G.S. Lang quadrangle, enlarged to a scale of 1 inch equals 500 feet, was used as a base on which the drainage and geology were transferred from the aerial photographs used as the base for the field mapping.

The writer is indebted to Dr. Richard H. Jahns for his introduction to the area, and for numerous instructive suggestions and criticisms throughout the course of the field work and the preparation of the manuscript. Mr. Lloyd C. Pray kindly gave a number of suggestions during the preparation of the manuscript, and participated in several provocative discussions in the field. Dr. Charles W. Merriam gave generously of his time and laboratory facilities in an attempt to find fossils in some of the most promising matrix material collected by the writer. Mr. Thomas Fahy examined several rock specimens in an attempt to find micro-fossils.

Geography

Tick Canyon is in the northern part of Los Angeles County, and about 32 miles north-northwest of Los Angeles, California. It is flanked by Mint Canyon on the west and Agua Dulce Canyon on the east, and is one of many nearly parallel southwesterly-draining canyons that empty into Soledad Canyon and the Santa Clara Valley in the eastern part of the Ventura Basin. Soledad Canyon drains westward into the wide Santa Clara Valley, which continues westward about 53 miles to near Ventura. The area mapped covers the upper part of the Tick Canyon drainage. Davenport Road, an all-weather route, crosses the southern part of the map area, and connects the Mint Canyon Road (U.S. Route 6) with the Agua Dulce Road (see pl. 1). It intersects the Mint Canyon Road about 6 miles north of Solemint Junction.

The topography is rough, and narrow V-shaped canyons are abundant. Remnants of terraces and gently sloping old-land surfaces are commonly present between the major drainage systems. In the map area the dominant topographic features are



LOS ANGELES COUNTY AREA

high, easterly-trending basaltic ridges and sub-parallel ridges of crystalline rocks to the north. Saddleback Hill and Skyline Ridge are the highest points, and are about 500 feet higher than the general altitude of the surrounding area (see pl. 1). The more resistant members of the sedimentary sequences in many places form low ridges that commonly give a fairly reliable indication of the gross structure of the underlying strata. In general the bedrock is well exposed. In places the bedrock exposures are poor, particularly on the north slopes of basaltic ridges and in areas covered by terrace gravels and recent alluvium.

The climate of the area is similar to that of a large part of southern California. The summers generally are hot, and temperatures above 100 degrees Fahrenheit are not uncommon. The winters usually are mild, but many days are cold and windy. The average yearly rainfall is about 10 inches, and vegetation in the area is typically Sonoran. The south slopes generally have a sparse cover of brush, whereas many north slopes have a moderate to dense cover of scrub oak and manzanita. Few people live in the map area, and most of the dwellings are to the east in the area drained by Agua Dulce Canyon.

General geologic setting

The Ventura Basin is an elongate depression in both a structural and topographic sense. Its axis trends westward from the headwaters of Soledad Canyon to the Pacific Ocean near Ventura. The eastern part served as a basin of deposition for a thick section of terrestrial sediments derived from surrounding highlands of crystalline rocks during much of Tertiary time. Marine formations were deposited contemporaneously in the western part of the basin, and interfinger with the nonmarine sediments. Faulting along the northern front of the San Gabriel Mountains removed the southern half of the basin. In general the Tertiary formations dip westerly, so that from east to west one passes successively through older to younger Vasquez, Tick Canyon, and finally Mint Canyon sediments.

The crystalline highlands that bound the eastern part of the Ventura Basin comprise the Sierra Pelona Ridge to the north, Parker Mountain to the east, and the San Gabriel Mountains to the south. Sierra Pelona Ridge is underlain by a complex section of pre-Jurassic metamorphic rocks that have been intruded by dioritic and granitic rocks. Parker Mountain is underlain by quartz diorite. The northern part of the San Gabriel Mountains, that flanks the eastern part of the Ventura Basin, is underlain largely by a white, feldspar-rich rock that has been referred to broadly as anorthosite. The igneous rocks are believed to be of Jurassic age, and form a part of a broadly exposed crystalline complex of pre-Cretaceous age.

The Vasquez series is the oldest Tertiary formation exposed in the eastern part of the Ventura Basin. It consists of approximately 9000 feet of well indurated sandstones, shales, and conglomerates, and 4000 feet of intercalated lava flows.[1]

1/ Sharp, R.P., Pan-American Geologist, No. 63, p. 314, 1935.

The sediments increase conspicuously in coarseness downward in the section, and to the southeast. Hershey[2] named this series

2/ Hershey, O.H., The American Geologist, Vol. 29, No. 6, 1902.

the Escondido, and considered it to be of Eocene age. The presence of limestone beds led him to believe that the series was deposited in static marine water. Kew[3] regarded it as probably

3/ Kew, W.S.W., U.S.Geol. Surv. Bull. 753, pp. 38-39, 1924.

part of the Sespe formation. Simpson[4] believed the series to be

4/ Simpson, E.C., Calif. Jour. Mines and Geol., Rept. 30, pp. 391-395, 1934.

the equivalent of the marine Topanga formation of the Los Angeles Basin, and of Middle Miocene age. Sharp[5] suggested the

5/ Sharp, R.P., op. cit., p. 314, 1935.

name Vasquez to replace the term Escondido which was preoccupied.[6] More recent work by Jahns[7] suggests an Oligocene age for

6/ Wilmarth, M.G., U.S. Geol. Surv. Bull, 896, Part I, pp. 698-699, 1938.

7/ Jahns, R.H., Amer. Jour. Sci., Vol. 237, p. 823, 1939.

the Vasquez series, which is compatible with Kew's earlier tentative assignment. The work done by the writer has thrown no new light on the age of these rocks.

The Tick Canyon formation, of Lower Miocene age, overlies the Vasquez series with a marked angular unconformity. It was named and described by Jahns,[8/] and was dated on the basis of

8/ Jahns, R.H., op. cit., pp. 819-821, 1939.

vertebrate remains. In the area northwest of Mint Canyon it consists of nearly 600 feet of red to brown siltstone and sandstones, with a coarse conglomerate at the base.[9/] Disconformably

9/ Jahns, R.H., Carnegie Inst. Wash. Pub. No. 514, Paper IX, p. 165, 1940.

above the Tick Canyon formation is the Mint Canyon formation of Upper Miocene age.[10/] It consists mainly of gray sandstones and

10/ Jahns, R.H., op. cit., pp. 819-824, 1939.

conglomerates, with an aggregate thickness of more than 4000 feet. The disconformity is at the base of a thick, persistent conglomerate member.

Characteristic differences in lithology readily distinguish the Vasquez series from the Tick Canyon and Mint Canyon formations in the map area. In general the Vasquez sediments are light or brightly colored, and are well indurated. Most are somewhat calcareous, and are in part largely arkosic and tuffaceous. Thin limestone beds are numerous throughout the section. Angular pebbles and cobbles of light-colored rocks, derived from the crystalline complex, characterize the conglomerate beds. The consistent absence of basalt fragments is remarkable. Basic flows, flow breccias, and tuffs, constitute a considerable part of the section.

In contrast, the Tick Canyon and Mint Canyon formations are more somber in color, thicker bedded, and less well indurated. Coarse, gray to brown sandstones and conglomerates predominate, although some varicolored siltstones do occur in the Tick Canyon formation. The pebbles and cobbles that compose the conglomerates are well rounded, and many of them consist of basaltic rocks presumably derived from the flows in the Vasquez series. No basalt flows or flow breccias are known to occur in the Tick Canyon or Mint Canyon formations.

Terrace gravels cap the Vasquez series, Tick Canyon and Mint Canyon formations in many places. They are associated with old surfaces of low relief, and form surfaces that in general slope gently to the south. Near Bouquet Canyon to the west they cap the Plio-Pleistocene Saugus formation, and are dissected to a depth of several hundred feet by the present drainage. They probably are chiefly of Pleistocene age, and represent two or more terrace levels. The broad upper drainage of Agua Dulce Canyon, to the east of the map area, represents essentially a Pleistocene surface that shows only incipient dissection (see pl. 1). The low divide between the Tick Canyon and Agua Dulce drainages, through which Davenport Road passes, appears to represent an old surface of erosion of comparable age. Mildly dissected terrace gravels cover a considerable area that is underlain by rocks of the Vasquez series adjacent to the map area on the northwest. To the south the drainage cuts sharply through the terrace gravels and underlying Tertiary formations to Soledad Canyon, leaving gently sloping terrace surfaces perched high on broad, southerly-trending ridges. Terraces associated with the high basaltic ridges are covered in large part by basalt fragments. In other areas the gravels were derived principally from the crystalline complex. Gently dipping basalt flows are covered in several places by a thick, dark brown, porous soil that is probably of Pleistocene age. These soils have been classified with terrace gravels for the purposes of mapping. It is apparent that during Pleistocene time the area was marked by a surface of low relief.

Recent alluvial deposits occur mainly as relatively narrow, discontinuous belts in the bottoms of canyons and gullies. In other places, where the Pleistocene surfaces have been little dissected, the recent alluvium forms broad flats similar to the one at the eastern edge of the map area (see pl. 2). The narrow belts are not shown on the map. The alluvium consists of fine- to coarse-grained, unconsolidated sands and gravels whose composition reflects the character of the bedrock of the area drained.

STRATIGRAPHY OF THE VASQUEZ SERIES

A detailed section of the part of the Vasquez series exposed in the map area is tabulated below. It is composite in order to avoid distortions due to structural complexities (see pl. 2 for location of traverses). The section is divided into members that are generally separated by more easily traceable conglomerate, tuff, and igneous members. In general the members are thinner and finer grained to the west of the measured section. They tend to be thicker and coarser grained to the east. Although the essential lithologic character of a specific member is generally the same in most parts of the map area, many of the members probably represent time units rather than lithologic units.

Measured section of Vasquez series

	Thickness (feet)
Member 34	
Basalt, dark greenish-brown, dense....................	100
Member 33	
Sandstone and siltstone, light brown to dark reddish-brown; sandstone coarse grained, with small pebbles in some beds; calcareous, poorly exposed...	50
Siltstone and sandstone, greenish gray, with interbeds of limestone 3 inches in average thickness; surfaces of some of the limestone beds covered with calcite (?) crystals; poorly exposed.......	30
Siltstone and sandstone, varicolored; brown, gray, red, purple, and green; mostly fissile, friable, thin bedded to laminated; lower part interlaminated with limestone..........................	110
Tuff, white with greenish cast, fissile.............	1/4
Siltstone, greenish gray to reddish brown, fissile;	

	Thickness (feet)	
contains several limestone laminae 1/4 of an inch thick; calcareous..........................	8	
Limestone, light gray, laminated to massive, dense to porous; locally contains numerous highly irregular cherty masses..........................	4	
Basalt, porphyritic, greenish brown, highly weathered, poorly exposed; about 25 feet thick in exposures north of Davenport Road..............	6	
Limestone, light gray, massive to laminated, poorly exposed in most places..........................	1	
Total thickness, member 33		209¼
Member 32		
Basalt, dark, dense, resistant; lower 4 feet black and amygdaloidal; thins to the east; forms high ridges....................................		270
Member 31		
Sandstone, arkosic, pale greenish-gray, friable; upper 2 feet finer grained and resistant, calcareous; poorly exposed..........................	38	
Sandstone, red; individual beds several inches to 2 feet thick separated by red silty seams; several minor light-gray arkosic sandstone beds; very uniformly bedded; calcareous..........	125	
Total thickness, member 31		163

	Thickness (feet)
Member 30	
Sandstone, arkosic, light gray, friable; pebbly at base; to east contains erratic well-rounded cobbles and boulders of quartz diorite and anorthosite as much as 3 feet across; calcareous; rarely exposed..	30
Member 29	
Sandstone, red, fine grained, with dark-red shaly partings; minor coarse-grained sandstone; beds range from a fraction of an inch to 1 foot thick; very even bedded; some beds contain numerous small fragments of shaly partings; some small-scale scouring; calcareous..................................	52
Member 28	
Conglomerate, red, massive, resistant; pebbles all angular light-colored granitic rocks as much as 2 inches across, average 3/8 inch across; very uniform contact; coarsens considerably to east; calcareous..	12
Member 27	
Siltstone and sandstone, fine to coarse grained, and fine-grained pebble conglomerate; red at top, grading to light brown at bottom; mostly massive; some graded bedding; some small-scale scouring in several of the thin finer-grained beds; some of the fine-grained sandstone contains mud cracks filled	

	Thickness (feet)
with red silt; worm tracks and borings; calcareous..	141
Member 26	
Conglomerate, light reddish-brown to light gray, massive, resistant; pebbles all light-colored granitic rocks, angular to sub-angular, average 3/8 inch across; discontinuous, irregular seams of sandstone form resistant knobs, with cavernous weathering; calcareous; coarsens to east.....	27
Member 25	
Siltstone and fine- to coarse-grained sandstone, light brown to lavender; siltstone predominant in the lower part; calcareous...........................	47
Member 24	
Conglomerate, light brown to lavender, massive; pebbles angular to sub-angular, light-colored granitic rocks with minor green, basic metamorphic rocks; sparse cobbles as much as 4 inches across; irregular sandstone lenses; calcareous..	19
Member 23	
Sandstone, light brownish-gray, and siltstone, reddish brown; beds a fraction of an inch to 2 feet thick; calcareous...........................	28

	Thickness (feet)
Member 22	
Conglomerate, light brown; pebbles light-colored granitic rocks with minor green, basic metamorphic rocks, average 1/8 inch across, cavernous weathering..	21
Member 21	
Sandstone and siltstone, light brown to gray, fine- to coarse-grained; calcareous; poorly exposed.... 46	
Sandstone, red, fine grained, calcareous; upper 2 feet very resistant.............................. 7	
Sandstone, tuffaceous (?), very light gray; probably grades into underlying bed...................... 14	
Total thickness, member 21	67
Member 20	
Tuff, white to pale greenish-gray; mostly fine grained, hard, massive, highly fractured.........	15
Member 19	
Siltstone, tuffaceous (?), dark greenish-gray, with white tuff and light-gray tuffaceous (?) sandstone..	29
Member 18	
Beds rich in borate minerals; main zones at top and bottom of member, 10 to 20 feet thick, separated by dark greenish-gray tuffaceous (?) shale and siltstone interbedded with thin beds rich in borate	

	Thickness (feet)
minerals; beds rich in borate minerals are white to light colored, porous to dense, massive to laminated, very calcareous; poorly exposed......................................	96
<u>Member 17</u>	
Siltstone, tuffaceous (?), light brown to white......	6
<u>Member 16</u>	
Arkose, brownish-gray to black, very fine grained, massive, tough, with conchoidal fracture; very resistant, forms small cliff for long distance; weathered surface brown...........................	1
Sandstone, tuffaceous, white to light brownish-gray, fine-to coarse-grained...........................	20
Total thickness, member 16	21
<u>Member 15</u>	
Siltstone, tuffaceous (?), light brown, and sandstone, light brownish-gray, coarse grained, pebbly in places................................	30
Limestone, light gray, laminated......................	1/4
Pebbly sandstone, light gray, massive; pebbles of anorthosite, angular to sub-angular, average 1/4 inch across..................................	15
Limestone, light gray, laminated......................	1/4
Siltstone and sandstone, brown, fissile, calcareous..	22
Siltstone, brown to red, thin bedded, fissile, calcareous......................................	5

	Thickness (feet)
Pebbly sandstone, light gray; pebbles light-colored granitic rocks with minor, green, basic metamorphic rocks, angular to sub-angular; calcareous	10
Sandstone, fine grained, and siltstone, brown to red, thin bedded, fissile, calcareous	26
Sandstone, pink, coarse grained; upper part silty, calcareous	2
Siltstone, lavender to gray, thin bedded, and sandstone, gray	40
Sandstone, light gray, fine-to coarse-grained; beds as much as 4 feet thick, somewhat pebbly in places; weathers brown	28
Siltstone, light gray to greenish gray, fissile	20
Limestone, very light colored, massive to laminated, dense	1/2
Basalt, with calcite amygdules as much as 3 inches across, deeply weathered, poorly exposed	5
Limestone, very light colored, laminated to massive	1/2
Total thickness, member 15	204½

<u>Member 14</u>

Basalt, dark gray, porphyritic, generally deeply weathered and poorly exposed; highly amygdaloidal in Tick Canyon	108

	Thickness (feet)
<u>Member 13</u>	
Sandstone, medium grained, grading downward into pebbly sandstone, coarse grained; brown, contains considerable biotite; pebbles of well-rounded crystalline rocks as much as 3 inches across..	30
<u>Member 12</u>	
Tuff, white to light bluish-gray, fine grained, dense, massive, highly fractured........................	5
<u>Member 11</u>	
Andesite, flow breccia, reddish brown to purplish brown; resistant, forms high ridges and bold cliffs..	190
<u>Member 10</u>	
Basalt, greenish black, dense, deeply weathered......	62
<u>Member 9</u>	
Sandstone, arkosic; grades from lavender and massive at top to reddish brown and thin bedded at bottom; medium to coarse grained........................	17
Sandstone, light reddish-brown at top to light gray at bottom; medium grained, calcareous............	6
Pebble conglomerate, greenish gray; pebbles mixed crystalline rocks, sub-angular to well rounded; sparse cobbles as much as 7 inches across; calcareous..	6

		Thickness (feet)
Sandstone, arkosic, light brownish-gray at top to light green at bottom; thin bedded, with thin pebbly zones; bottom part unusually well indurated..	22	
Total thickness, member 9		51
<u>Member 8</u>		
Tuff, arkosic, white, fine-to coarse-grained, dense.		16
<u>Member 7</u>		
Tuff, green, fine grained, grading downward into green, tuffaceous sandstone............................	4	
Sandstone, red, medium grained; contains fossil horizon..	2	
Total thickness, member 7		6
<u>Member 6</u>		
Basalt, top 30 feet dark purplish-brown, dense; bottom part lavender, highly amygdaloidal; some amygdules contain delicate natrolite (?) and analcite (?) crystals; several lenses of greenish-brown tuffaceous sandstone..............		170
<u>Member 5</u>		
Sandstone, arkosic, bright red to reddish brown, fine- to coarse-grained, with minor thin pebbly sections; beds range from a fraction of an inch to 2 feet thick, even bedded; some graded bedding and small-scale scouring................................		93

	Thickness (feet)
Member 4	
Basalt, several flows; mostly dark gray, porphyritic, dense; thick vesicular section 90 feet from top; bottom 15 feet black, amygdaloidal...	1380
Member 3	
Siltstone, tuffaceous (?), greenish gray...........	1/2
Limestone, light gray, laminated to massive, coarsely crystalline in places.................	1/2
Siltstone, tuffaceous (?), greenish gray, interlaminated with limestone; poorly exposed.......	5
Sandstone, arkosic, light gray to light brownish-gray, medium to coarse grained, with several beds of tuff, white, fine-to medium-grained, ranging from 1 to 3 feet thick; contact between tuff and sandstone gradational; several discontinuous pebble conglomerate beds, containing sub-angular to well rounded pebbles of crystalline rocks..................................	345
Conglomerate, greenish brown; consists mainly of anorthosite and quartz-diorite, ranging from pebbles to boulders as much as $1\frac{1}{2}$ feet across, sub-angular to well rounded; probably discontinuous; fine-grained pebbly section in lower part; poorly exposed..........................	15
Total thickness, member 3	366

	Thickness (feet)
Member 2	
Sandstone, medium to coarse grained, and pebbly sandstone, light gray to brown to reddish brown; overall color is reddish brown; beds average about 3 feet thick, mostly massive, even bedded, with pebbles angular to fairly well rounded; in general coarser toward unerlying member......................................	360
Member 1	
Fanglomerate, reddish brown to greenish brown, with poorly sorted cobbles common 1/4 to 1/2 foot across, rarely as much as 2 feet across, subangular to well rounded, crystalline rocks; mostly massive, even bedded; sandstone, reddish brown, about 20 feet thick, near top of member...	425
Total thickness, sediments of Vasquez series.....	2519
Total thickness, flows and flow breccias of Vasquez series..................................	2291
Total thickness, Vasquez series..........	4810

Sedimentary rocks

The Vasquez sediments exposed in the map area change markedly in general character from the bottom to the top of the section. Coarse conglomerates constitute a considerable portion of the lower part, where they consist largely of unsorted, sub-angular to well rounded pebbles, cobbles, and boulders. The large, well rounded fragments become progressively less abundant higher in the section. Above the andesite breccia (member 11), the coarse sediments are pebble to cobble conglomerates in which the pebbles and cobbles are angular to sub-angular and unsorted. The uniform thickness and composition, and massive, unsorted character suggest that individual conglomerate beds in the upper part of the section were sheets of sediments swept out on a broad, gentle basin. All of these conglomerate beds (members 24, 26 and 28) appear to become considerably coarser to the east, and suggest a source in that direction.

Most of the sediments in the upper part of the section are markedly finer grained than those in the lower part. The individual beds that compose the various members are remarkably continuous. Even bedding is the rule. Gradation of grain size along the strike of an individual bed appears to be gradual, and is generally from fine to coarse from west to east. Graded bedding is not uncommon. Scouring is confined to a few silty beds a fraction of a foot thick. Oscillation ripple marks and mud cracks are present in several of the fine-grained beds. Thin limestone beds, and interlaminated limestone and silt layers are numerous. Carbonate crystals are present on the upper surfaces of some of the thin limestone layers in member 33. Fragments of tuff beds, with casts of crystals on the bottom surface, indicate that the tuff was deposited on a crystal-covered surface. Beds rich in borate minerals are present, which are common accumulations in playa basins. Plant remains and the remains of water-dwelling animals have been found in several of the beds. All of these features indicate that the major part of the section in the Tick Canyon area was deposited under alternating sub-aqueous and sub-aerial conditions, probably in a semi-arid climate.

Igneous rocks

Flows of basalt and andesite are interlayered with the sediments, and constitute 2291 feet of the section in the Tick Canyon area. This represents more than half of the 4000 feet of basic flows indicated by Sharp 11/ for the entire Vasquez series.

11/ Sharp, R.P., unpublished master's thesis, California Institute of Technology, 1935.

No evidence of intrusive igneous bodies was observed by the writer. Sharp believes that some of the basic igneous rocks in the Ravenna quadrangle to the east show intrusive relationships.

Several of the volcanic flows are plainly composite. In Tick Canyon, members 10, 11, and 14 constitute an igneous section that is readily distinguishable as composite by the contrasting reddish- to purplish-brown andesite breccia that is flanked by dark-colored basalt. East of the Sterling fault the flanking basalt members are separated from the andesite breccia by tongues of sediments that thicken rapidly to the east (see pl. 2). Lenses of tuff or baked siltstone are present in the andesite breccia along the top of Skyline Ridge and the south ridge of Saddleback Hill. The lavender, vesicular basalt (member 6) contains several thin lenses of greenish-brown tuffaceous siltstone on the west side of Tick Canyon. A thick zone of vesicular basalt in member 4 lies 90 feet below the upper contact in Tick Canyon, and is flanked above and below by dense porphyritic basalt. Several other zones in this same thick member appear to be somewhat different in texture.

Several lines of evidence suggest an extrusive, rather than intrusive, origin for the basic igneous rocks in the Tick Canyon area. As well as could be determined, considering the composite nature of some of the flows, all of the basalt bodies are vesicular in places. Many of the igneous bodies, particularly members 4, 32, and 34, have a closely-spaced fracture pattern that forms large whorls. The fracture pattern may be ascribed to flow structure of a type commonly found in many areas of extrusive rocks. In this connection it is important to consider the enclosed sedimentary lenses, the sedimentary tongues that thicken to the east, and the general continuity of the other sedimentary layers. These lenses and tongues probably would be present in other parts of the area if the igneous rocks were intrusive. Tuff beds and zones of tuffaceous sediments are abundant throughout the section and furnish proof of recurrent extravasation. The tonguing of the sediments from the east, and the considerable thinning of the flows and tuff beds to the east and south, suggest that the center of extrusion lies to the northwest.

Fossils

A diligent search was made for fossils during the mapping of the area. Two beds were found to bear fossils, and, to the writer's knowledge, yielded the only remains yet found in place within the Vasquez series. One horizon is in a 1-foot thick limestone that is exposed on the east slope of a low ridge between Saddleback Hill and Davenport Road (see pl. 2). In places this bed contains a concentration of fairly straight rod-like bodies that are cylindrical in cross-section. The bodies are about 1/8 inch in average diameter, and as much as several inches long. Thin sections of the material show a concentric structure that is not diagnostic for identification of the form. The bodies are probably stems, twigs, or reeds that have been replaced by carbonate minerals. Fossiliferous material is abundant at this horizon in many places on the east side of the map area.

The most promising fossil-bearing bed is a thin red sandstone (member 7). At one place, on the west side of Tick Canyon and about 20 feet northwest of a small cut in the tuff member 8 (see pl. 2), numerous small bean-shaped bodies were found in this bed. They appear to be pelecypods, although a definite determination could not be made. A search in the same bed at several other places in the vicinity of Tick Canyon failed to uncover more fossiliferous material. Exposures of this bed are poor, however, and it is possible that a more intensive search may reveal diagnostic fossils.

Two fragments of fossil bone were found within 50 feet of one another in the bottom of an easterly-draining gully on the north side of Skyline Ridge (see pl. 2). The source of the fragments could not be located. The location of the fragments, however, make it unlikely that the fragments were derived from other than Vasquez beds.

The only other fossil found in the Vasquez series is reported[12/] to have been collected from a small amphitheater on the

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12/ Silver, L.T., oral communication, 1950.

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west side of Tick Canyon and north of the Sterling mine dump. The fossil was a fresh-water fish preserved in a talus block that presumably was derived from member 16. This fish has been identified only as Tertiary in age.

The scarcity of fossils in these Vasquez beds may be explained by the nature of the lakes that occupied the basin during deposition of these sediments. The highly saline waters and the intermittent nature of the lakes probably did not encourage development of a lacustrine fauna. These same bodies of water presumably would be equally uninviting as a watering place for land-dwelling animals.

STRUCTURE OF THE VASQUEZ SERIES

Folding

The rocks of the Vasquez series have been deformed in a complex way. This deformation is related to much larger-scale features in areas that have been mapped by Kew,[13/] Sharp,[14/] and

[13/] Kew, W.S.W., op. cit., 1924.

[14/] Sharp, R.P., op. cit., 1935.

Jahns.[15/] The tight folding and the faulting of beds of widely

[15/] Jahns, R.H., op. cit., 1940

ranging competency present a structural picture whose details are intricate and complex in many places, even though the general elements of deformation are rather straightforward.

The Vasquez beds in the map area form a large, tightly-folded syncline that plunges gently to the southwest. A small anticline in the trough of the syncline is parallel in trend and plunge. The axes of the folds appear to be nearly vertical. The trough of the syncline is nearly parallel to the trend of Davenport Road, and in general the steeply dipping beds north of the road lie on the north limb of the syncline (see pl. 2). The beds south of the road are on the south limb of the syncline in the eastern part of the area, and on the north flank of the small anticlinal fold (noted above) in the western part of the area. The small anticlinal fold, which lies in the trough of the syncline, is well outlined by low, sinuous ridges near the eastern edge of the mapped area (see pl. 2). The small synclines that flank this anticline are responsible for the scoop-like shape of the basalt layer (member 32) that forms Jeep Flat, as well as the V-shaped ridge formed by the same member south of Davenport Road. The breached anticlinal portion of the minor fold is well exposed in the valley immediately north of Davenport Road.

Faulting

Three well defined sets of faults are present in the area. One set is parallel to the trend of the Ventura Basin, and in the map area, forms the contact between the Vasquez sediments and the crystalline rocks to the north. The contact can be traced in many places by following a narrow zone of soft, porous, caliche-rich soil. The sediments near the contact are even bedded, poorly sorted, sub-angular to well rounded fragments of crystalline rocks, and are very steeply dipping or overturned. A zone of crystalline-complex fault-gouge is exposed about 30 feet northwest of the portal of a tunnel that enters the Vasquez sediments on the west side of Tick Canyon. Minor sub-parallel faulting is evident in several places in the area. In most places, however, the contact is too poorly exposed to clearly show the relationship.

The other two sets of faults appear to be closely related to one another. The major set strikes northeasterly, displaces blocks on the southeast side to the northeast, and has a much greater displacement than the other set. This general pattern of displacement toward the northeast is continuous along other faults in an area that extends to the east for several miles beyond the map area. The Sterling fault, the Water Witch fault, and the large fault at the southeast edge of the map area are part of this general pattern (see pl. 2). The horizontal displacement along the last mentioned fault is approximately 3000 feet.

The other of the two related sets of faults strikes northwesterly, and generally displaces blocks on the northeast side to the southeast. The faults of both sets appear to dip steeply, generally toward the east, and all show a major strike-slip component of movement. Numerous exposures of mullion structure show a gentle southerly plunge. Both sets of faults displace the contact between the Vasquez series and the crystalline complex. Faults of one set at places offset faults of the other set. The combination of the two sets makes a pattern that probably would be formed by compressional forces from the north and south. The folding may well have been in large part older than the faulting, and hence may have been the result of the initial onset of the same forces that produced the faulting. Much of the folding and faulting pre-dated the deposition of the Tick Canyon and Mint Canyon formations, as suggested by the distinct angular unconformity between the Vasquez and the little folded Tick Canyon beds. Some faults that cut both formations show considerable differences of displacement within each of the two formations.

The Sterling fault, east of the Sterling mine, is displaced about 500 feet along a fault of northwest trend (see pl. 2). The offsetting fault was deflected somewhat from its normal northwest trend, and passes through the incompetent beds that are rich in borate minerals (member 18). The northwest continuation of the zone of faulting in part assumes its normal trend where it crosses Tick Canyon. In part it continues to the west along the incompetent member 18 and displaces the thin tongue of Tick Canyon formation that caps member 18 on the west rim of the canyon. To the southeast the fault zone appears to become wider, and passes through the basalt gap (member 38). An understanding of the bedding-plane faulting, in the beds rich in borate minerals in the mine area, would be very important from the standpoint of future operation of the mine.

The low-angle fault that crosses the middle part of Skyline Ridge seems to be unique in the map area. Its strike is northeasterly, but its trace shows that it dips to the east at a low angle. A fault surface on a sloping basalt ledge, topographically below the faulted end of a tuff bed (member 12) near the top of the ridge, has a northeasterly strike and a 20° to 30° southeasterly dip. Crude mullion structure on the fault surface indicates movement normal to the strike. However, the actual displacement of the beds, especially the vertical beds north of Skyline Ridge, suggests that the movement along the fault was largely of strike-slip nature. The fault would thus be similar to the other northeast-striking faults in the area in all respects save that of dip.

The andesite breccia (member 11) that forms the south ridge of Saddleback Hill participates in a very puzzling structural feature. Its abrupt, rather arcuate ending at the east end of the ridge (see pl. 2) has been ascribed to such causes as a primary termination of the flow from the west, an erosional break in the flow, the termination of a sill, offset of the flow along a fault of northeast trend, and complex termination at or very near a center of eruption. This rather odd feature can be explained in terms of the competency of the thick flows relative to that of the softer sediments, and hence by complex structural adjustments during formation of the syncline. Various exposures throughout the map area indicate that the sediments tend to buckle or crumple during folding and faulting. On the other hand, the igneous members tend to be rigid, and resist close folding.

It is proposed that during the formation of the syncline, the shortening of the beds that overlie the andesite breccia caused development of the minor anticline in the trough of the syncline. The stiff, more competent part of the section, made up largely of thick volcanic flows, was offset along northeast-trending faults, partly in resistance to sharp folding, and partly to increase the volume of rock in the center of the syncline. The bedding-plane fault that enters the beds rich in borate minerals, between Saddleback Hill and Davenport Road (see pl. 2), is part of this same release, and is closely related to the fault that extends northeastward from the east end of Saddleback Hill.

The Vasquez-Tick Canyon contact

All exposures of the Vasquez-Tick Canyon contact in the map area show the geometric relations of a nonconformity. In places, such as the west rim of Tick Canyon near the Sterling mine, the angle between the dips of the two formations approaches 90 degrees. At other places, such as along member 32 on the north side of Davenport Road, the angularity is gentle. The tongue of the Tick Canyon formations extends eastward from the west end of the map area (see pl. 2). It forms a shallow syncline that is a reflection of the sharper syncline on the north limb of the anticline in the underlying Vasquez series. The parallel attitude of the shallow syncline formed by the Tick Canyon beds indicates that the deformational forces present in pre- and post-Tick Canyon time were similar. The Mint Canyon formation disconformably overlies the Tick Canyon formation, and apparently has been subject to the same deformation. It would then appear that these similar forces were active in post-Mint Canyon time.

Beds of the Tick Canyon formation of a widely differing character are in contact with the Vasquez series at various places in the map area. It would appear that the Tick Canyon formation was deposited on a highly irregular surface. A sedimentary breccia, consisting almost entirely of angular fragments of basalt, unconformably overlies the Vasquez series in some places adjacent to thick basalt members. It appears to be conformable with the Tick Canyon formation. At several localities north and south of Davenport Road, it is associated with various basalt members. This breccia probably represents slope wash from high basalt ridges, and undoubtedly is a basal part of the Tick Canyon formation.

A brown, pebbly to cobbly, coarse-grained sandstone of the Tick Canyon formation overlies much of the basalt ridge south of Davenport Road and Skyline Ridge. In Tick Canyon, near the sharp gap that leads to the Sterling mine, much of the Tick Canyon formation that overlies the basalt (member 32) consists of fine-grained, red to brown siltstones and sandstones. The Tick Canyon beds in both localities appear to have been deposited against basalt ridges quite similar in appearance to those now present in the map area.

ECONOMIC GEOLOGY

Of outstanding economic interest in the area are the deposits of borate minerals. The history of borax mining has been a succession of one type of deposit economically displacing another. The deposits in Tick Canyon were discovered by a prospector in November 1907, and were purchased shortly thereafter by the Sterling Borax Company of Los Angeles.[16] At

16/ Yale, G.C., Min. Res. of U.S., U.S.Geol. Surv., Part II, p. 635, 1907.

that time virtually all borate production in the United States had been obtained from dry-lake deposits. By 1911, however, the entire production was taken from two bedded deposits of colemanite, the Sterling mine in Tick Canyon and Lila C. mine at Ryan, California.[17/] The United States and Chile were at that

17/ Yale, G.C., and Gale, H.S., Min. Res. of U.S., U.S. Geol. Surv., Part II, p. 857, 1911.

time rivals for the position of the world's leading borate producer. The output of the Sterling mine was large until about 1920, when the mine was forced to close by the cheap methods of extraction of borax from the water of Searles Lake.

The borate minerals in the Tick Canyon area occur in the limestone beds and the thinly interbedded limestone and shale beds. The writer made no attempt to distinguish between those beds with or without borate minerals, except in the case of member 18 in which the Sterling mine was developed. It is probable that in places several of the other members that have limestone beds contain borate deposits, particularly members 15 and 33.

Colemanite, howlite, and ulexite are the principal borate minerals in member 18.[18/] Most writers[19/] believe that the coleman-

18/ Eakle, A.S., Univ. Calif. Publ., Bull. Dept. Geol. Sci., Vol. 6, No. 9, p. 181, 1911.

Foshag, W.F., Econ. Geol., Vol. 16, pp. 199-214, 1921.

19/ Storms, W.H., Calif. State Min. Bur., 11th Ann. Rept., p. 346, 1893.

Campbell, M.R., U.S.Geol. Surv. Bull. 200, pp. 8, 12, 1902.

Spurr, J.E., U.S. Geol. Surv. Prof. Paper 55, p. 21, 1906.

Ball, S.H., U.S. Geol. Surv. Bull. 308, p. 198, 1907.

Strong, A.M., Am. Inst. Min. Met. Eng. Trans., Vol. 40, p. 912, 1910.

ite type of borate deposit is the result of evaporation in alkaline lakes. Gale[20/] postulates the formation of colemanite de-

20/ Gale, H.S., U.S. Geol. Surv. Prof. Paper 85, pp. 3-9, 1913.

posits by hydrothermal replacement of limestone beds. More recently, Foshag[21/] has advanced the hypothesis of deposition of

21/ Foshag, W.F., op. cit., 1921.

ulexite in a playa basin. Uplift of the beds permitted free drainage, and sodium chloride solutions leached the ulexite, removing borax and leaving colemanite and other members of the borate series.

The Sterling mine consists principally of underground workings that were entered through shafts and tunnels in Tick Canyon. Most of these workings are inaccessible. A slumped portion of member 18 east of Tick Canyon and north of the mine dump indicates that many of the large stopes have caved. Dumps of mine waste and mill tailings attest a considerable amount of underground work. Two open cuts in member 18 are on the west side of Tick Canyon.

Short tunnels and small open cuts in other parts of the map area have been excavated in beds that appear to contain borate minerals, and principally in beds of member 18. The longest of the tunnels is low on the south slope of Skyline Ridge, and presumably was driven to cross-cut member 18. Many small open cuts have been made in the dense tuff beds.

Numerous small gold prospects are present in the northern part of the map area. They open faults and shear zones in rocks of the crystalline complex. The production of gold has probably been very small.

Water seeps are not uncommon at low topographic positions near the major faults in the area, and it is probable that most of the major fault zones contain abundant water at least in places. The writer located a well site a few tens of feet west of the Water Witch fault near the west end of Darling Road, and the well was drilled through rocks of the crystalline complex to a depth of 100 feet. It now provides a substantial flow of water. The water table at that point proved to be a depth of only 10 feet. The further utilization of water from the faults might well have important economic application in an area where water is much desired and not easily obtained.