GEOLOGY OF THE SANTA MONICA MOUNTAINS
WEST OF THE MALIBU RANCH
VENTURA COUNTY
CALIFORNIA

A
THESIS
PRESENTED BY VINCENT C. KELLEY
TO
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For the Degree of Master of Science in Geology

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ABSTRACT

Structurally the western end of the Santa Monica Mountains is a broad east-west anticline with much of its south limb down-faulted beneath the ocean. A parallel series of Vaqueros and Temblor strata are exposed in the fold. Although the series is conformable, there appears to be a distinct lithologic as well as faunal difference between the two formations.

Conformably overlying the Temblor is a thick series of lavas and pyroclastics which aggregate about 13,000 feet. The total thickness of the Vaqueros and Temblor sediments is approximately 10,000 feet, and added to this is at least 1,000 feet of intrusive sills. Thus the entire conformable series has an aggregate thickness of about four and one half miles. As might be expected the lower strata are unusually indurated.

The Sycamore Canyon fault and its Blue Canyon branch are the major fractures of the area. These faults strike in a northeasterly direction across the trend of the fold and bound a wedge-shaped horst of Vaqueros and Temblor strata between downthrown Temblor rocks on either side.

INTRODUCTION

Geography - The Santa Monica Mountains extend for nearly fifty miles in an east west direction from the City of Los Angeles to the Oxnard plain and the Pacific Ocean on the west. The western two thirds of this range is cut off rather abruptly along its south side by the ocean. This coastal border swings southeastward away from the mountains in the vicinity of the city of Santa Monica, while the mountains continue eastward to a narrowing point back of Beverly Hills and Hollywood. The western part of the Santa Monica Mountains merges northward into the Simi Hills which separate the San Fernando Valley on the east from the Santa Clara River Valley on the west.

The area described in this report comprises about 40 square miles of the western end of the Santa Monica Mountains.

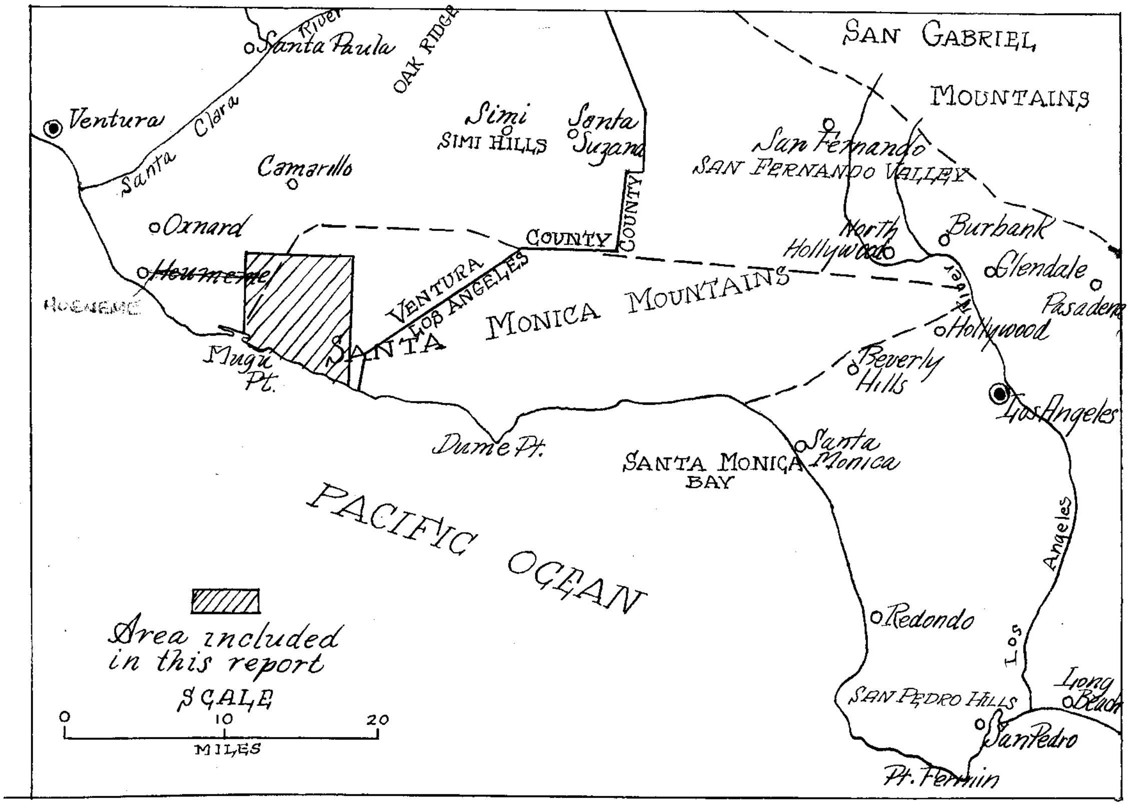

Fig. 1. Index map showing location of area covered in report.

(See Fig. 1) It includes most of the mountainous portion of the Guadalasco and a small southwest portion of the El Conejo land grants. The eastern boundary is a north-south line from a point on the coast about one mile west of the Los Angeles-Ventura county line. The north boundary is marked by the Long Grade Canyon road. The excellent new Roosevelt highway follows the ocean border on the south. Several secondary roads lead in and through the area making it on the whole fairly accessible.

The larger part of the region is now divided into two large ranches, the Hacienda Mugu and the Sierra Land and Water Company. The mountainous area is chiefly utilized for the pasturing of cattle. These ranches extend west into the flat, fertile Oxnard plain which is extensively cultivated, except on the low marshy portion directly back of the Mugu Lagoon.

The rainfall averages about fifteen inches annually which gives rise to a semi-arid type of vegetation, consisting chiefly of chaparral, sage, and Spanish bayonet with patches of grass and cactus developing on flats and gentle slopes. Tree growth is confined mostly to areas along the streams. Oak trees are found more often near the heads of the intermitt~~a~~ent streams on open flats, while in the lower courses of the streams and in deep canyons sycamore trees are predominant. Numerous attempts have been made to develop water from the seasonal streams and springs but these have supplied only minor amounts for domestic uses.

<u>Shell Mounds</u> - Almost every small bench and flat in this

portion of the mountains is strewn over with black ashy soil containing thousands of marine animals shells. The earliest inhabitants of this region were known as the Chumash Indians.[1] This tribe lived in small groups of one or several families scattered throughout the country. They were good fisherman and lived chiefly on raw and cooked sea food such as clams, abalones, etc. The deposits of shell and ash left by these inhabitants often reach six or seven feet in thickness. The top or youngest of these deposits is ~~are~~ known to be about one hundred and thirty years old while the oldest lower deposits are judged to be at least four hundred years old.[2] In addition to shells are found graves, implements, necklaces, beads, stoneware, and remnants of dwelling places.

Maps - The map used in this work is a photostatic enlargement of portions of the Huememe and Truinfo quadrangles of the United States Geologic Survey. The scale of the original maps is one mile to the inch. These were enlarged two and one half times to an approximate scale of two thousand feet to the inch. The contour interval of the Hueneme quadrangle is fifty feet, while that of the adjacent Triunfo quadrangle is one hundred feet.

Previous Work - Practically no mention has been made of this particular area until quite recently. The geology of the region has been known in some detail for at least ten years by various oil companies operating in the Los Angeles and Ventura basins but this knowledge has been largely confined

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1. U. S. Bur. of Ethnology Bull. 78 P. 572
2. Conversation with field members of L. A. Museum expedition

to the files of these companies. In 1924 N. L. Taliaferro [1] in a short paper presented a general succession of the rocks together with a generalized structure section through the south central part of Ventura County showing the structural relations between the formations of the western end of the Santa Monica Mountains and those of Santa Clara Valley and South Mountain. Evidently the occurrence of a very small amount of oil in volcanic rocks at the Conejo field caused some interest in the geology of this region. In connection with the Conejo volcanics Mr. Taliaferro [2] states as follows: "One of the most important centers of Miocene volcanism in the state lies in the western end of the Santa Monica Mountains. This region is often referred to as the Conejo Mountains and the name "Conejo volcanics" is here applied to all the series of volcanic and intrusive rocks occurring in that region."

Associated with these volcanic rocks are Miocene sediments which were accumulating during the volcanic activity. NB In the lower part of the section the sediments are dark olive-green shales, yellow sandstones, and thin-bedded cherty shale, all of which are frequently tuffaceous. The shales are extremely micaceous and contain an abundance of carbonized wood fragments and occasionally fish scales, but are not otherwise fossiliferous, and it is not definitely known what part of the series they represent. They are thought to be Lower Miocene. These sediments are very intimately associated with the volcanics and in places agglomerate grades both upward

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1. Am. Assoc. Pet. Geol. Bull., vol. 8, P. 789-810
2. Bull. A. A. P. G. vol. 8, P. 800 1924

and laterally into sandstones." This statement is supplemented with a rough section from Mugu Point Northward. (Fig. 22, opp. p. 32)

In a more recent paper by A. O. Woodford and T. L. Bailey brief mention is made of this region in connection with the description of a new occurrence of the San Onofre Breccia.[1] These authors discuss the occurrence of Franciscan metamorphic minerals in the Temblor sediments and the rapid thinning of these beds to the north and northeast.

Carl St. J. Bremner under the direction of Dr. W. S. Kew of the Standard Oil Company of California has mapped the area under consideration in detail that varies with the information desired. From conversation with Dr. A. O. Woodford it was learned that the Shell Oil Company has a similar map. Mr. Wayne Loel of Los Angeles has made a less detailed map of the region in connection with work for the Marblehead Land Company. None of this information held by private individuals has as yet been published.

<u>Present Work</u> - The field work for this report was done during the fall of 1931 and the spring of 1932. The problem has been primarily one of areal and general geology with the idea of doing as much detail as possible over a somewhat restricted area. Practically nothing was done with the faunas of the region largely because of the unfossiliferous nature of the rocks. A few fossils were identified but the age of the formations was obtained from others. A sincere attempt was made to map as many of the intrusive bodies as possible al-

1. Univ. of Calif. Pub. in Geol. Sc. vol. 17, P. 187-191, 1928

though it was found impractical to differentiate between sills and dikes. The sill-like bodies make up the bulk of the intrusives and they are larger and easier to map, whereas the dikes are often too small and too irregular to locate.

Acknowledgments - The writer wishes here to express his sincere appreciation to Dr. John P. Buwalda of California Institute of Technology, for the valuable advice and suggestions in the preparing of this report and the accompanying maps. In checking up the field work Dr. W. S. Kew very kindly compared the Standard Oil Company's maps with the author's map and made valuable suggestions in regard to fault problems. He also aided in furnishing his measurements of the thicknesses of certain horizons for comparison and suggested age relations for certain formations. To Dr. U. S. Grant of University of California at Los Angeles thanks is extended for identification of several faunas. Mr. Wayne Loel was particularly helpful in locating the transition zone between the Vaqueros and Temblor formations.

STRATIGRAPHY

General Characters - With the exception of the alluvial terraces and the recent stream alluvium, all of the rocks of the area mapped are Miocene in age. The strictly sedimentary rocks consist of a conformable series of marine strata of Vaqueros and Temblor age with a total thickness of 10,000 feet. A great thickness of volcanic rocks conformably overlies the marine series. According to Dr. Kew the volcanic series probably accumulated during Modelo time. In the eastern part of the Santa Monica Mountains there are considerable areas of basalt which intrude the Topango formation but do not intrude the overlying Modelo formation. But before the deposition of the Modelo, the Topango and older formations suffered considerable folding, faulting, and intrusion. It is possible, but seems hardly likely that such diastrophic forces should produce such widespread and pronounced effects in the eastern part of the range without affecting rocks of the same age only thirty miles to the west. Therefore, since the volcanic series in the west is conformable upon the Temblor formation they are most likely Temblor in age also. Only the lower horizons of the volcanic rocks are in the area mapped, but according to Dr. Kew this series has an aggregate thickness of 13,000 feet.

Succession of Rocks in the Western End of the Santa Monica Mountains

	Feet
Recent alluvium	
Unconsolidated breccia, gravel, sand and silt.	0-75
Pleistocene alluvial terraces	

	Feet
Poorly sorted reddish brown breccia, conglomerate, and sandstone with earthy matrix and crude bedding. Coarser toward the base and nearer the source. Marine sands and cobbles usually at the base.	0-100
Middle Miocene, Temblor Formation	
Late Temblor (?) Extrusives	
Boney Mountain Agglomerate:	
Andesitic, buff colored agglomerate and tuff with a few andesite and basalt flows. Angular and sub-angular fragments up to three feet in diameter with tuffaceous and ashy matrix.	3-4000
Serrano Basalt:	
Chiefly flows of basalt intercalated with some beds of tuff and agglomerate. Pillow lavas common.	300-2300
Sedimentary-volcanic transition member	
Pyroclastics, lavas, and sediments. Usually andesitic agglomerate at the base. Pillow lavas common. Sediments chiefly coarse sandstone with some thin bedded shale. Intrusive sills and dikes common.	300-1200
Temblor sandstone and shale member	
Gray to buff colored sandstones intercalated with olive-drab, thin-bedded shales. Occasional more massive sandstone facies as at the base and near the top.	7000
Temblor basal sandstone member	
Massive gray sandstone with a few shale beds. Increasingly shaly eastward until the horizon becomes indistinguishable	250
Lower Miocene, Vaqueros Formation	
Vaqueros black shale member	
Black organic shale with dense black limestone beds of concretionary origin regularly intercalated. Grades through dirty brown and sandy shales into massive Temblor sandstone above.	500-600
Vaqueros massive sandstone member	
Light gray massive sandstone alternating with distinctive calcareous sandstone beds produced by varying amounts of fossils and shell fragments. _Turritella ocoyana_ and	

	Feet
Pectin magnolia present at the top.	800-1100
Vaqueros marine sandstone and shale member	
Upper facies of black organic shale with some thin beds of light gray sandstone.	-300
Lower facies of thin-bedded sandstone and shale with occasional beds of more massive sandstone. Base not exposed.	-1000

Vaqueros Formation - Distribution and General Features: The Vaqueros formation occupies a relatively small wedge shaped area beginning in a tip at Mugu Point and widening eastward to Sycamore Canyon where it is faulted up against Temblor strata. An additional area occurs in a rectangular block of Vaqueros and Temblor strata near the head of Sycamore Canyon where it has been faulted from its original position. The total thickness of the Vaqueros is unknown because the base is not exposed.

On the whole the Vaqueros formation is quite different from the overlying Temblor formation. The upper members including the black organic shales and the massive calcareous sandstones have distinctive characteristics which make them easily recognizable. The lower member of intercalated sandstone and shale are quite similar to the Temblor sandstones and shales except for the abundance of metamorphic minerals in the latter. The rocks of the whole formation are unusually indurated and well cemented as might be expected in view of the great thickness of the series and the intimate association with an enormous amount of intrusive and extrusive material.

Age relations: The strata considered as Vaqueros in this paper are mapped into three units on the basis of lithology as outlined in the above table. Extensive work on the correlation of the Vaqueros and Temblor formations has been carried out recently, for early publication, by Wayne Loel and W. H. Corey. Mr. Loel [1] has suggested that the black organic shales are Vaqueros in age and that the upper portion of the black organic shale member probably represents the transition zone between the Vaqueros and Temblor formations. The underlying calcareous, fossiliferous sandstone member carries a Turritella ocoyana fauna at its top and this according to Loel is the upper Vaqueros. At the same horizon is found Pecten magnolia, a species entirely confined to the uppermost Vaqueros. The lower member of sandstone and shale is considered to be middle Vaqueros in age. It is identified by a reef containing a Turritella inezana fauna at the base of the black shale division as indicated in the table of rock succession.

Lower Member: The lower member of the Vaqueros is roughly about 1300 feet thick. A closer estimate of the thickness is difficult due to local faulting, folding, and intrusion. Although this member was mapped as a unit it can be roughly divided into two facies as indicated in the above table. The lower facies consists of alternating thin-bedded sandstones and shales with occasional more massive beds of sandstone which are especially prominent near the top of this

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1. Personal Communication. March 1932

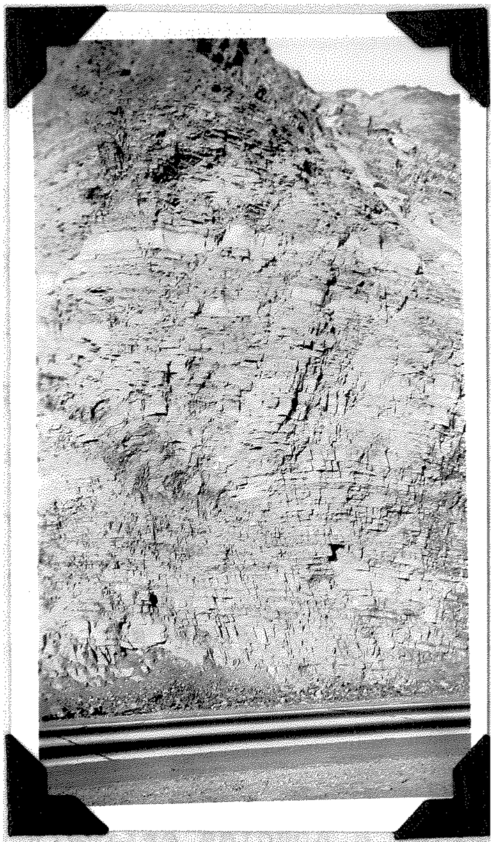

Fig. 2 Vaqueros sandstone and shale of the lower member

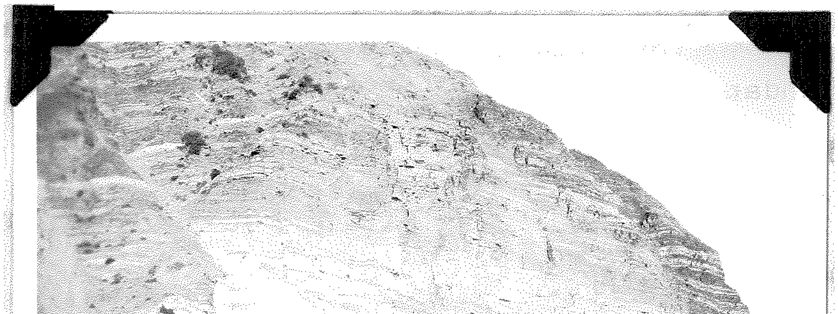

Fig. 3 Vaqueros sandstones and shales near the mouth of Sycamore Canyon.

division. The upper facies is almost entirely black organic shale with occasional thin sandstone beds. The sandstones of the middle Vaqueros are composed almost entirely of partially rounded grains of quartz and feldspar with minor amounts of muscovite, hornblende and hematite. The grain size rarely exceeds two millimeters in diameter and on the whole exhibits only an average degree of sorting. The average sandstone is medium grained, but fine grained sandstones are common with gradations into silty shales. (See Figures 2 and 3) Cross bedding is a distinctive feature of the more massive sandstone beds. The shales are very thin-bedded where intercalated with sandstone beds but in the upper black shale facies the shales are more massive due to the presence of considerable calcium carbonate. The interbedded shales are olive-drab colored and consist of finer material derived from a terrigenous source whereas the black shales are extremely fine and contain abundant organic matter and much pyrite. The black shale facies of this member differs from the black shale member of the uppermost Vaqueros in that it contains fewer of the hard black concretionary layers and more intercalated beds of light gray sandstone.

Middle Member: The massive calcareous sandstone member of upper Vaqueros is the most distinctive unit of the whole Vaqueros-Temblor series. Its hard massive character and light color causes it to stand out prominently wherever present. (See Figs. 36 and 39) It is composed of massive beds of sandstone separated by minor amounts of silty shales. A one inch pebble bed at the top of this member can be traced from Mugu Point eastward across the area into a cobble bed

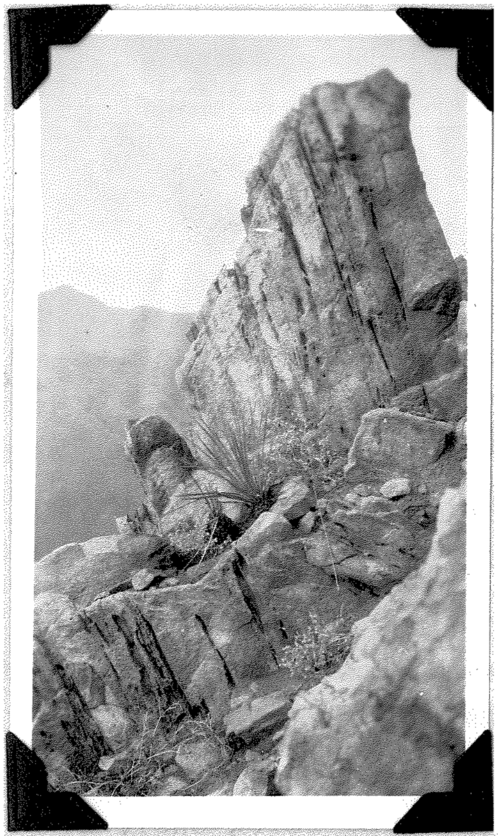

Fig. 4 Massive Vaqueros sandstone of the middle member. Near the junction of Sycamore and Serrano Creeks.

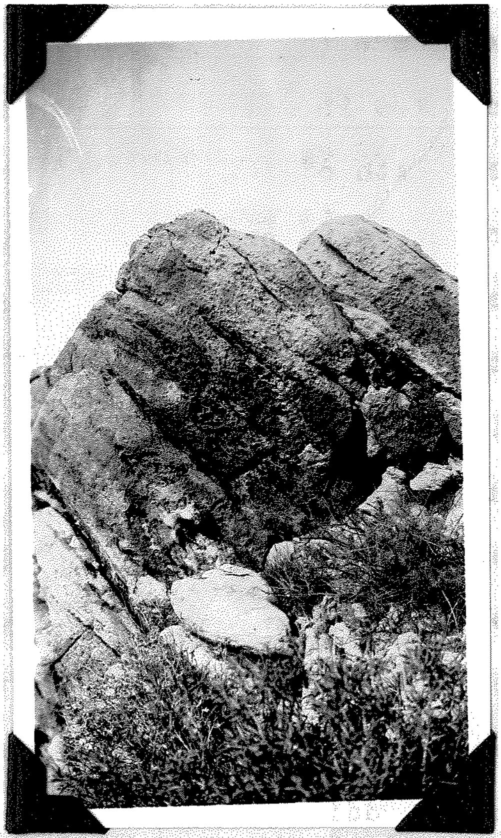

Fig. 5 Massive Vaqueros sandstone of the middle member, along the ridge between Sycamore and Blue Creeks.

three to four feet thick. Numerous beds throughout the member are composed almost entirely of fossil fragments and calcite with some fossils intact. Other beds are characterized by small lenses and discontinuous seams of fossil remains and calcium carbonate, which when weathered bring out the bedding structure (See Figs. 4 and 5) in a striking manner. These beds are in reality arenaceous limestones and make up at least one-sixth of the entire member. Where an abundance of shell fragments is present the rock takes on a bluish gray color. As a whole the beds of the formation are made up of sub-angular grains of quartz, feldspar and calcite and some hematite. The calcite which is so prevalent throughout the rock has probably been derived by solution of the fossil shells and redeposition of the calcium carbonate in the pore spaces of the sand as a cement. Cross bedding is a common structure of this member especially near the top and in the transition into the overlying shale member. Figure 6 shows characteristic cross-bedding of the member. Figure 7 includes Figure 6 and also shows the contact between this member and the overlying black shale member.

Upper Member: The black shale member is sharply contrasted to the underlying massive sandstones just described. There is, however, a narrow transition zone between the two in which the sandstone becomes more argillaceous and darker due to the introduction of organic material. At Mugu Point gradation between the two members are very well exposed. (See Fig. 7) The base of the member is marked by rather

Fig. 6 Characteristic cross-bedding of the middle sandstone member. Note the downward termination of the basalt dike.

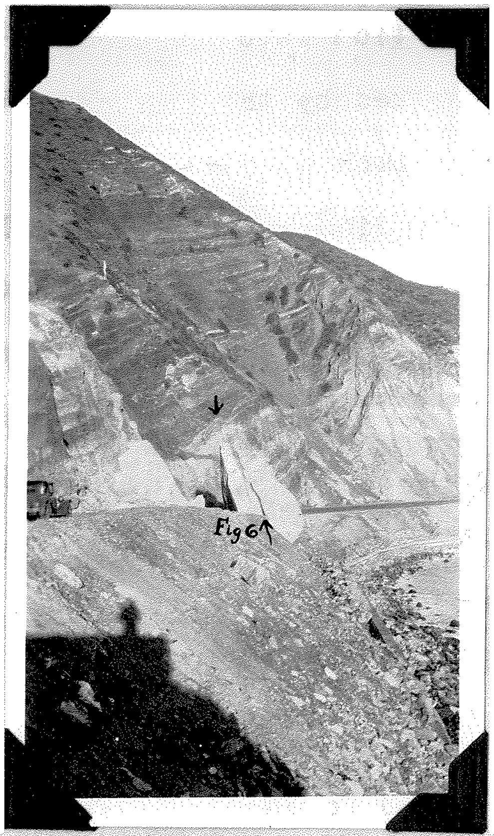

Fig. 7 Contact between the middle and upper Vaqueros members. Note the branching basalt dikes.

massive shales which display less of the fissility characteristic of most shales. Upward the shale becomes more thin-bedded and is intercalated with exceedingly hard, black, concretionary layers which on account of their lateral extent more nearly resemble black limestone beds. These layers range in thickness from ten to eighteen inches and their spacing is suggestive of a rhythmical recurrence. (See Fig. 8) Their mineral content causes them to weather to a gray or tan color on the surface. Near the upper limits there is a gradual transition into the massive Temblor sandstones. This change is marked by the appearance of sandstone beds and the passing from black to dirty brown shales while the concretionary layers disappear rather suddenly. Several sandstone dikes have been intruded upward into the black shales and clearly came from the underlying sandstone.

The beds of this member consist almost entirely of organic material, calcium carbonate, and small amounts of pyrite. The percentage of carbonate in the black shales was not determined, but a rough estimate of the amount in the concretionary layers indicates that it is at least fifty per cent. The pyrite is mostly in microscopic crystals but occasionally cubes up to one-half inch can be found. The most likely explanation of the pyrite, from its dissemination throughout most of the shale, is that it probably formed at the time of deposition or shortly thereafter. The high sulphur content so commonly recognized as present in the slimes and oozes forming black shales should certainly precipitate any iron present.

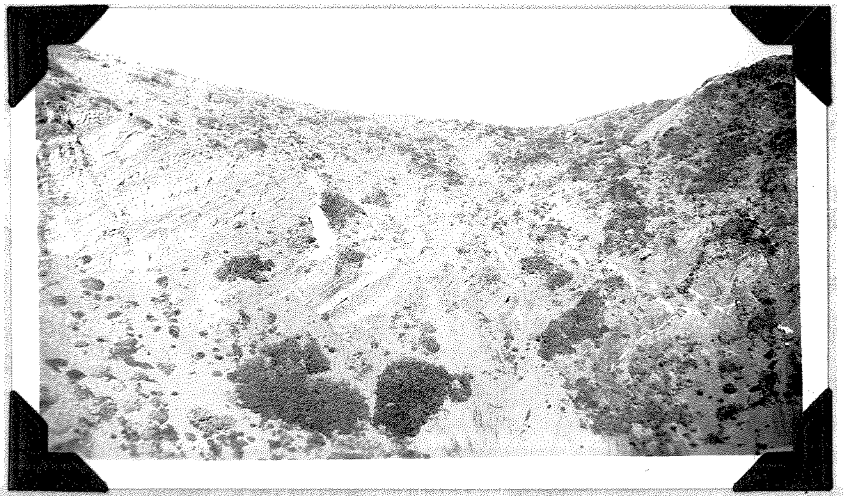

Fig. 8 Vaqueros upper black shale member at Mugu Point. Note limestone layers at left and offset sandstone dikes at right.

Large complex crystals of calcite of secondary origin are commonly developed along transverse jointing cavities. These crystals are sometimes coated with microscopic crystals of pyrite and possibly some pyrrhotite. Along minor faults where shearing and brecciations has occurred some secondary fibrous gypsum has formed through the generation of sulphuric acid which reacted with the calcium carbonate. The layers of black organic limestone are conceived of as secondary in origin also and probably began to form during the first stages of consolidation before the muds were deeply buried. The regularity and rhythmical occurrence of these layers suggests a steady migration of carbonate by diffusion with a rhythmical precipitation similar to the phenomenon known as Leisegang's rings. Rubey [1] mentions a similar occurrence in the Black Hills as follows: "the lateral continuity or persistence of these and of other concretions in the region and thelow carbonate content and relative impermeability of the inclosing shale beds lead the writer to believe with Tarr [2] that, for the most part, the concretions were formed before the muds were deeply buried."

The concretions under consideration are some times small lenses occurring in a series between the same layers but more often the lenses have grown to such lateral proportions as to resemble beds. Such layers can be traced for several hundred feet along the strike.

<u>**Temblor Formation**</u> - Distribution and General Features: The

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1. U. S. G. S. p. 165-A p. 11 1930
2. G. S. A. Bull. vol. 32 p. 373-384 1921

Fig. 9 Temblor lower massive sandstone member west of Mugu Point. Note the large basalt conduit.

Temblor formation has the largest areal distribution of any unit in the area. It has a total thickness including these sediments in the transition member at the top of 7-8000 feet exclusive of about one thousand feet of intrusive material. Its lithologic characters are not nearly as striking as those of the Vaqueros formation and for the most part it is marked by a monotonous repetition of sandstone and shale beds with occasional more massive layers of sandstone. It everywhere conformably overlies the Vaqueros formation.

Lower Massive Sandstone Member: This member is best exposed about one fourth mile northwest of Point Mugu along the Coast highway, where it is about 250 feet thick. (See Fig. 9) It was only possible to map these beds as a unit for about a mile and a half to the northeast along the strike. But while the member consists of a group of massive sandstone beds at the point shown in figure 9, toward the north-they split and interfinger with increasing amounts of shale until the member loses its massive nature and becomes unmappable. The sandstones are buff-colored and of medium grained texture for the most part although silty gradations into shales are present. The medium grained rocks are composed almost entirely of quartz and feldspar, chiefly orthoclase and microcline, while the silts and shales are made up largely of micaceous minerals. Calcium carbonate is the usual cement of the sandstones.

Sandstone and Shale Member: This member constitutes the bulk of the Temblor formation and is about 7000 feet thick.

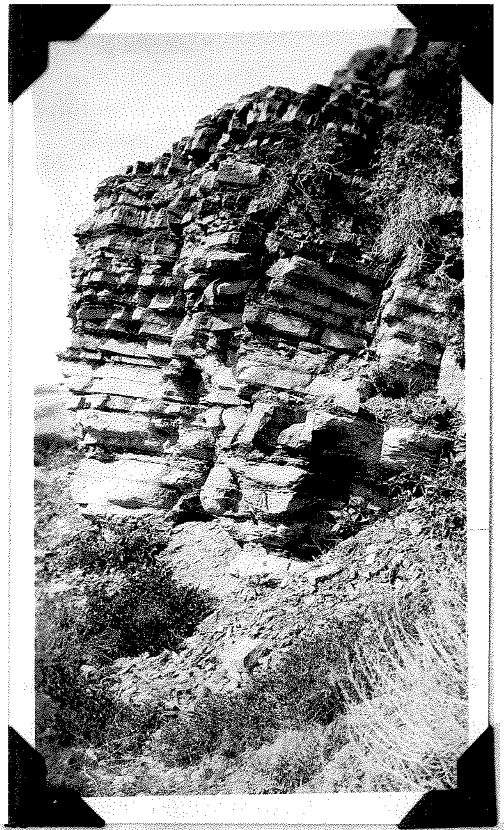

Fig. 10 Temblor medium-grained sandstone and thin-bedded shale one mile west of Mugu Point.

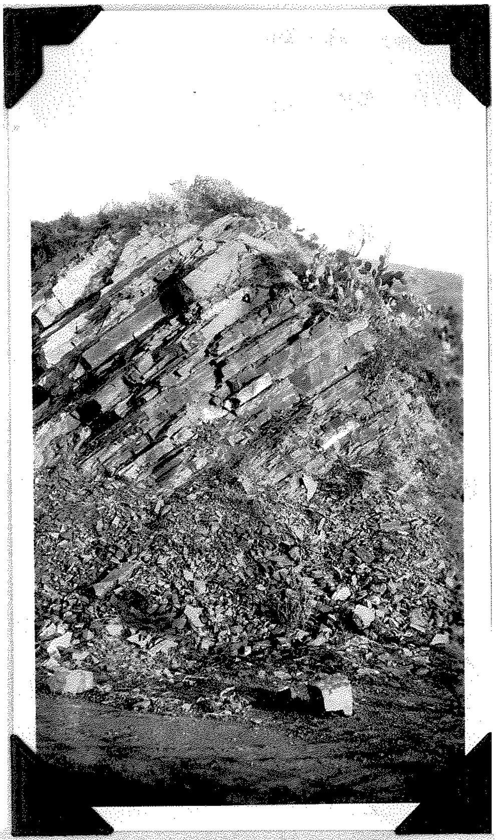

Fig. 11 Temblor shale at the western tip of the range.

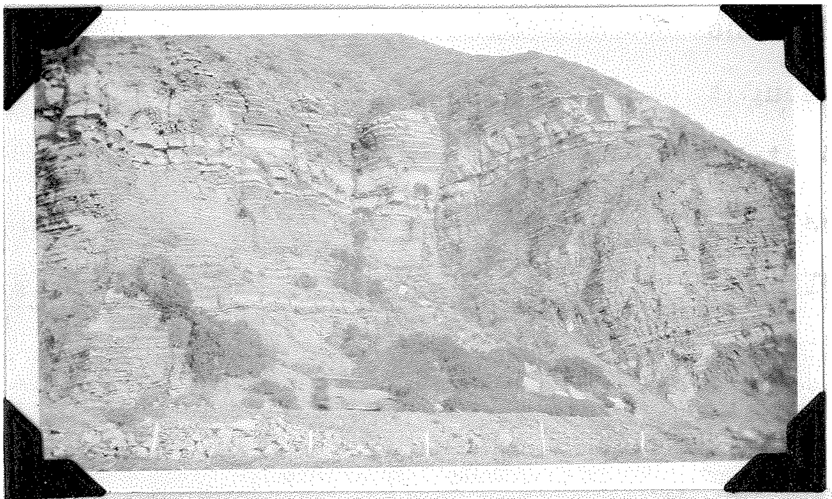

Fig. 12 Temblor sandstone and shale in the cliff back of Mugu Lagoon.

It is a monotonous aggregation of sandstone and shale intruded by numerous dikes and sills. The massive sandstone beds are gray to buff in color and occasionally show considerable continuity along their strike as in the case of the bed indicated on the map along the south flank of the La Joya hogback ridge. This eight foot bed can be readily traced for two and one-half miles. Figures 10 and 11 illustrate good exposures of typical Temblor.

The thinner sandstone beds which are regularly intercalated with the shales are apt to be arkosic and made up of metamorphic minerals in which case the beds are gray or green in color. Woodford and Bailey [1] in describing the northwestward continuation of the San Onofre breccia on the Malibu ranch make the following comparison: "Ten miles west of the Malibu occurrences, the exact locality being 1-1½ miles northwest of Point Mugu, there are several beds of massive, light gray, medium to coarse calcareous sandstone which contain abundant blue schist flakes up to three inches long. This sandstone is mineralogically similar to the Malibu breccia, and is thought to represent approximately the same horizon." A closer study shows that instead of several there are numerous such beds and not only sandstone containing "abundant blue schist flakes" but beds made up entirely of schist flakes which occur with frequent intermittence throughout at least the lower half of this Temblor member. However the deposition of metamorphic minerals with the quartzose sands is so ir-

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1. A. O. Woodford and T. L. Bailey-Northwestern Continuation of the San Onofre Breccia U. C. Pub. in Geol. Sc. vol. 17 #5 P. 189 1928

regular and variable that samples showing percentages of heavy minerals from nearly zero to one hundred can be obtained. On lithologic basis the San Onofre breccia of the Malibu is probably best correlated with the lower horizons of this member of Temblor of Mugu Point rather than with certain beds of that horizon. The most common minerals of the metamorphic facies are quartz, glaucophane, muscovite, albite, crossite and chlorite. On the whole the percentages of metamorphic minerals in the Temblor sandstones decrease from base to summit although quantitative proof of this statement has not been attempted.

Occasionally thin beds of siliceous shale are to be found and towards the middle of this member thin beds of buff-colored tuff appear intercalated with coarser red sandstones. However, the percentage of tuff to the terrigenous marine debris is negligible below the sedimentary volcanic transition member at the summit of the marine Temblor.

Sedimentary Volcanic Transition Member: This member marks the beginning of middle Miocene vulcanism and includes the beds from the first volcanic rocks to the uppermost sedimentary rocks. It is a very irregular accumulation made up of alternations of pyroclastics, lavas, and sediments and varies greatly in thickness as might be expected with a gradual and intermittent beginning of volcanic activity. However, the base of this member is nearly always marked by an andesitic agglomerate which varies considerably in thickness and texture. On the average acidic agglomerates and marine sandstone and shales constitute the bulk of the member but lava flows generally increase upward to the Serrano basalts above. The lavas exhibit compact, platy, and elipsoidal structures. The beds of this member undoubtedly accumulated on the ocean floor.

Serrano Basalt: This member is best developed on Serrano Flat and in general along the south base of Boney Mountain ridge. It is made up chiefly of lavas with some prominent beds of coarse agglomerate and tuff. The lavas are phases of basalt and andesite and vary in texture from compact aphanitic varieties to those which are distinctly porphyritic. Often the textures are very irregular and give the rock a blotchy appearance. A variety of colors are presented by the many flows including brown, olive drab, buff, purple, and reddish brown. The flows are highly vesicular near their tops and pillow structures are common as in the previous member. Where pyroclastics overlie lava flows, the finer material of the former has seeped and flowed down into the cracks and crevaces in the flow tops. Numerous small basaltic dikes cut across the flows and one dike, 20'-30' in width, of more resistant rock, is particularly prominent near the head of Little Sycamore Canyon.

Boney Mountain Agglomerate: The Boney Mountain agglomerate has an extensive distribution in the vicinity of Boney Mountain and along the south side of Potrero Valley. For the most part it is massive, hard, and crudely bedded, causing it to stand out in bold relief. The coarser agglomer-

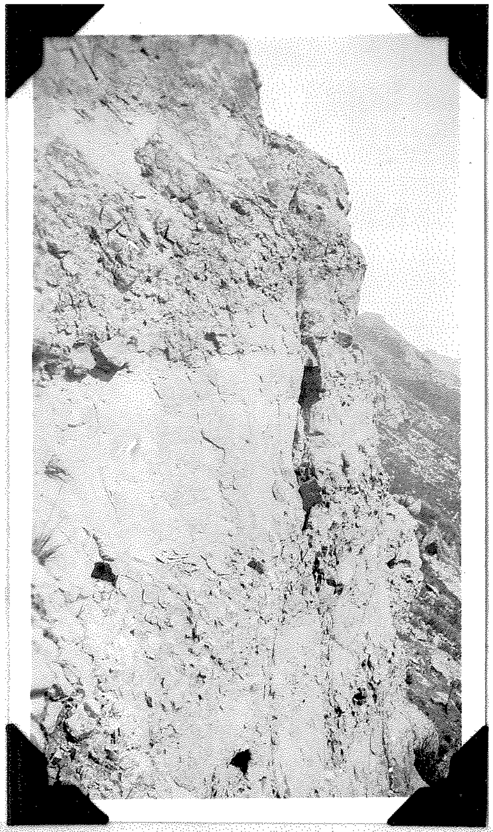

Fig. 13 Coarse agglomerate interbedded with tuff.

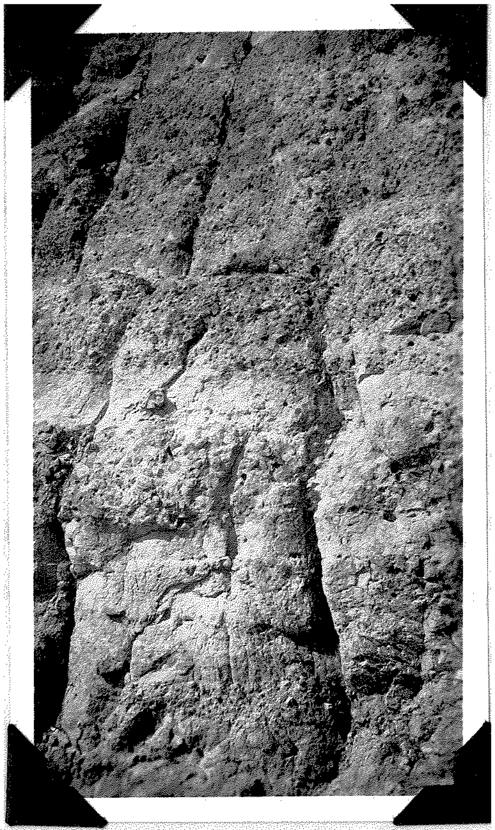

Fig. 14 Crudely bedded agglomerate and tuff.

Fig. 15 Fine-textured phase of andesite agglomerate.

ates are often so massive and lacking in bedded structure that it is extremely difficult to discover their attitude except at considerable distances. Figures 13 and 14 show some of the better bedded horizons of the agglomerate along the bold cliffs on the south side of Boney Mountain.

In its broadest section it is about 4,000 feet thick, but it thins rapidly toward the west. Single blocks two or three feet in diameter are not uncommon at certain horizons. Figure 15 shows a relatively finer grained sample of the agglomerate. The matrix is characteristically a grey tuffaceous mixture ranging in size from a two or three millimeters down to microscopic ash. Although the fragments are almost universally andesitic in composition, several massive beds throughout the section are made up of a heterogeneous mixture of acid and basic blocks displaying a wide variety of colors and textures within the same bed. Fragments taken from beds better stratified and sorted show effects of corrasion. In many cases sharp edges are entirely removed and the fragments could be described as sub-angular. This rounding may be due to subaqueous transportation or to rounding as bombs when ejected from a volcano, or as is most probable from both. There are also a few flows of andesite and basalt intercalated with the agglomerates. A few small basaltic dikes cut this member.

Source and Origin of the Vaqueros and Temblor Formations -

Although the Vaqueros and Temblor formations represent a continuous succession of sedimentation with no noticeable breaks there are differences in fauna and lithology. Within the last two decades careful paleontologic and stratigraphic work has shown that the Vaqueros has a very distinctive fauna of more tropical nature than that of the Temblor. [1]

A. O. Woodford [2] and later R. D. Reed [3] noted that minerals derived from the Franciscan schists were absent in the Vaqueros and present in the overlying Temblor.

The unusual mineral assemblage derived from the Franciscan schists came from a land mass, of which Catalina Island is a remnant, to the south and west from the present shore line. The more usual mineral assemblage which comprises the Vaqueros came from a land mass to the northeast.

Woodford further indicated a difference in the two mineral assemblages as follows:

"As between Eastern and Western Bedrock Complexes the following minerals appear to be diagnostic:

Eastern	Western
Orthoclase	Actinolite
Albite-twinned	Crossite
Biotite	Glaucophane
Common (green) Hornblende	Karinthine
Zircon	Untwinned Albite
	Lawsonite

Of these minerals orthoclase, albite twinned, and biotite are especially useful indicators of eastern origin, and glaucamphiboles of western."

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1. Wiedey - Trans. of the San Diego Soc. of Natural History Vol. V, No. 10 p. 105, 1928
2. A. O. Woodford-U. C. Pub. Geol. Sc. vol. 15 No. 7 p.180, 1925
3. R. D. Reed-Researches in Sedimentation in 1926-7. Report of the Committee on Sedimentation published by the National Research Council, Washington D. C. p. 77, 1927

Since there are no minerals diagnostic of Western land mass in the Vaqueros it is possible that there was no Western land mass as such at that time. On the other hand, this land mass may have been present but contributing nothing to the deposits, or if contributing, the bedrock complex was not yet exposed.

It is generally considered that there was a land mass to the southwest. Dr. Kew [1] in a sketch of the geology of the Santa Rosa Island says of the Vaqueros: "the lithology of the sediments, together with the abundance of fossils and their littoral type, indicate that the Vaqueros formation of the island was deposited in relatively shallow water and probably represents the south side of a basin of deposition, the westward extension of that on the mainland opposite."

Thus throughout the Vaqueros and Temblor time there appears to have been a gulf or inland strait roughly paralleling the present coast line bordered on the northeast and the southwest by land masses.

During Vaqueros time this trough was restricted as compared to that of Temblor. Loel [2] and Corey believe that the Vaqueros sea was roughly an east west gulf and speak of it as the "Santa Monica Embayment" with its opening into the ocean to the west.

Although a comprehensive study of the sandstones of the Vaqueros was not undertaken the few slides and numerous hand specimens examined indicated the minerals present were

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1. G. S. A. Bull. vol. 38, p. 648, 1927
2. Personal Conversation

very similar to those which Woodford cites as diagnostic of the northern land mass. However this does not mean that none of the material was derived from the south but rather what material that did come from the southern land mass was not from the Franciscan metamorphic complex which supplied the diagnostic minerals in the Temblor. Furthermore, the Vaqueros of the western end of the Santa Monica Mountains is interdigitated with wedges of continental material which, although very thin in the region under consideration, thicken rapidly toward the east and northeast.

A distinctive and unusual feature of the Vaqueros of this region is the two black organic shale members which aggregate a thickness of 6-800 feet. Similar black shales are not characteristic of the Vaqueros of the immediate surroundings. Dr. Kew describes no such shales in the Vaqueros of Santa Rosa Island [1] nor did he find them in a section across Oak Ridge to the north while Hoots [2] in his doubtful Vaqueros in the central part of the Santa Monica Mountains found nothing but sands and red beds.

There have been many hypotheses advanced for the origin of black shales, few of which can be made to harmonize. Some authorities have advocated an origin in deep water. [3] Schuchert [4] concluded "that black shales having wide distribution were more often deposited in closed arms of the sea" where

[1] G. S. A. Bull. vol. 38 p. 648, 1927
[2] U. S. G. S. Prof. Paper 165-c p. 94
[3] B. N. Clark Bull. 6 N. Y. State Mus. 199-201, 1913
[4] Schuchert-Pop. Sci. Monthly 598, 1910

"there was defective circulation and lack of oxygen resulting in foul asphyxiating bottoms." But both Ruedemann [1] and Ulrich [2] conclude that great depths and inclosed conditions are seldom if ever essential factors in the origin of black shale. Ulrich further states that "probably the real cause, if there is any that operated alike in all cases, remains to be discovered." In a later paper Twenhofel[3] reaches the conclusion: "that black hydrocarbonaceous shale may form in water so shallow that it is but a step to land conditions and that their presence is by no means an evidence of deep water."

It has been previously pointed out that the black shales of the Vaqueros contain an abundance of organic matter, calcium carbonate and some pyrite. In this connection Rubey [4] working with Cretaceous black shales of the Black Hills region comes to the conclusion "that the conditions most favorable for the formation and preservation of calcium carbonate, organic matter, and pyrite together would be relatively shallow water and rapid rate of accumulation and burial of organic matter."

In the case of oil shales Lilley [5] and others declare that slow anerobic decay is necessary and hence the water must be free from agitation.

In view of such a variety of hypotheses one hardly

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1. G. S. A. Bull. vol. 22, p. 234, 1911
2. G. S. A. Bull. vol. 22, p. 358, 1911
3. Am. Jour. Sc. vol 40, p. 276, 1915
4. U. S. G. S. p. 165-A, p. 13
5. Lilley - Geology of Petroleum and Natural Gas p. 70

knows what to conclude in regard to the black shales under consideration. Any statement would have to be more or less arbitrary because of the limited nature of the investigation. However, it seems that landlocking must have taken part, in view of the already postulated embayment of Vaqueros time although the accumulations of black shale may represent times when the land barriers were broken down. Landlocking further implies less agitation with more quiet water and if the waters are subject to currents which help to oxygenate the water than rapid accumulation and burial must have taken place to prevent aerobic decay of the organic matter. If, however, the foul undisturbed bottoms of Schuchert were existent then accumulation need not to have been so rapid as the anerobic bacteria would have readily preserved the organic matter.

Depth of water, outside of the abyssal depths can be dismissed in view of the conjecture and misunderstanding about what constitutes shallow or deep water. Trask [1] has shown that depth of water and distance from land are not as important in determining the texture of the debris as submarine topography. In his studies of the sedimentation off the coast of Southern California he found that coarse sediments were forming on ridges at greater depths than clays in some of the shallower basins nearer to land. "This", he states, "apparently is due to its (ridges and submarine topography) effect on circulation of water, which in turn influences the texture of the sediments accumulating on the sea bottom." He

1. Econ. Geol. vol 26, No. 1 p. 24, 1931

also found that in general the calcium carbonate content of the sediments is less in shallow water than in the depressions where it reached a maximum of 16 per cent. Similarly the organic content of the sediments was found to be greatest in the bottoms of the basins.

This work of Trask's, the early results of which have been published in the reference indicated, should prove of utmost importance in determining and understanding the conditions under which the Tertiary sediments of Southern California were deposited.

Thus, the black shales of the Vaqueros were most probably laid down on a quiet bottom in depression or basin in a landlocked sea with climatic conditions proper to account for an abundant supply of organic matter. But between the two organic shale members there is an intervening massive sandstone member approximately 1000 feet thick. To account for this in view of Trask's work, the basin must have been temporarily filled thus destroying it as a basin. Warping might also have entered in to produce a ridge or submarine high thus allowing sands to accumulate.

The source and origin of the Temblor has already been partly indicated. The San Onofre breccia has been found to extend in a broken fashion from the type locality at San Onofre Mountain to the northwest as far as the Malibu occurrences. This breccia is composed of extremely angular blocks and slabs as large as 10-15 feet in diameter mixed with earthy and fragmental matrixes. From the very coarseness and angularity of the breccia it would seem that a steep rugged escarpment of the Franciscan metamorphic complex must have existed only a short distance westward. The breccia thus represents the alluvial fan material at the base of this escarpment.

In the Santa Monica Mountains, as in the more southerly exposures, the San Onofre facies of the Temblor is not correlated with the very base of the formation. At Mugu Point the base is marked by massive gray sandstones which are relatively free from metamorphic minerals. But above the basal sandstones the diagnostic minerals of the southern land mass become more and more prominent.

Thus during Temblor time a formidable land mass existed to the south and southwest from which most of the sediments deposited in the embayment to the north were derived. Furthermore the 7000 feet of Temblor sediments which occur in the western end of the Santa Monica Mountains thin so rapidly to the north that it is entirely missing on South Mountain, a distance of only 20 miles. But the interbedded and overlying Monterey (Temblor) organic shales increase from zero to 2000 feet in the South Mountain region. In a northeasterly direction the terrigenous Temblor sediments thin to 100 feet in the western part of the Simi Hills, only 14 miles away. Thus it is clear that all of the terriginous sediments in the region under consideration were derived from the southwest and accumulated at a rather rapid rate. Much of the debris is arkosic and the formation on the whole unfossiliferous.

<u>Intrusive Rocks</u> - Distribution: The intrusive rocks are one

Fig. 16 Diabase sill in Temblor sediments. Note the fresh unweathered boulders at the right.

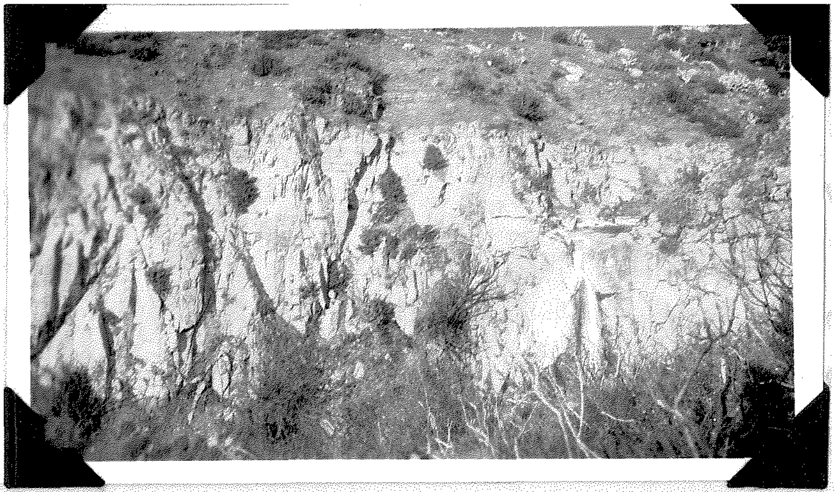

Fig. 17 An extremely resistant diabase sill south of Serrano Flat. Note the banding in the upper portion of the sill.

of the striking features of the area. In addition to the larger units depicted in geologic maps and sections there are countless smaller bodies too complex and too small to be mapped. An average estimate of the total thickness, in a maximum section of Vaqueros and Temblor, gives 1,000-1,200 feet of sill-like injections. Several intrusive sheets are two or three miles in lateral extent. On the whole the intrusive bodies are rather evenly distributed expecially along the strike. If there is any concentration of intrusions it is along the axis of the regional anticline where dikes appear to be more numerous.

Topographic Expression: As a rule the diabasic rocks do not outcrop prominently on ridge tops or canyon sides and their position can usually be predicted in advance by a notch or saddle along the crest of a ridge. Their susceptibility to weathering and hence to erosion has initiated many side canyons and therefore they most commonly occur on the north side of canyons where the dip is north, and on the south side of canyons where the attitude is south. The extreme susceptibility to weathering produces steep slopes wherever the sills are capped with the more resistant sediments and in this case the diabase is laid bare by the creep and slide of the weathered debris. Figure 16 illustrates this feature very well.

The weathered soil is characteristically olive drab in color. The presence of a sill can be detected in most cases from the weathered soil provided, as on north slopes, it is not disguised with an admixture of humus. At the base of steep slopes where the typical diabase is exposed large boulders of diabase are conspicuous. These boulders are fresh and little affected by chemical decomposition, but they are often well rounded as a result of exfoliation. One of the most distinguishing features of the weathered rock is a pure white kaolin which forms from the decomposition of the feldspars and deposits in joints and shear zones or as a cement, in some instances, in soil or debris covering the weathering diabase. White slabs of kaolin lying on a weathered slope are certain signs of diabase.

But although the diabase is extremely susceptible to chemical decomposition, it is highly resistant to corrasion. Thus sills that occupy notches on ridges may outcrop boldly in certain canyon bottoms as cliffs and potential waterfalls. (See Fig. 17) Sill-like bodies have had a decided influence upon the secondary lines of the drainage pattern.

Character: The sills and larger bodies, intrusive bodies, are predominantly diabase while the dikes and smaller injected sheets are basalt. Locally the larger basalt dikes often display ophitic texture while likewise the sills may be chilled locally to basalt as near contacts. The basaltic dike rock is genetically related to the sills and the larger dikes or multiples of dikes (Fig. 9) are in all probability "feeders" to the intrusive sheets.

Although the great bulk of the dikes can be dismissed as ordinary basalt dikes there are several dikes which diverge from the ordinary in texture and composition. These dikes are

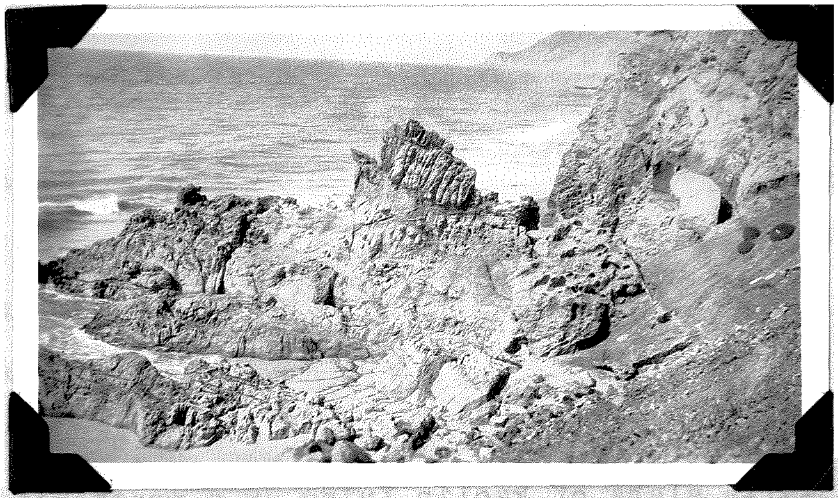

Fig. 18 A peculiar outcrop of diabase appar~~a~~ently due to the action of sea water. Mugu Point in the distance.

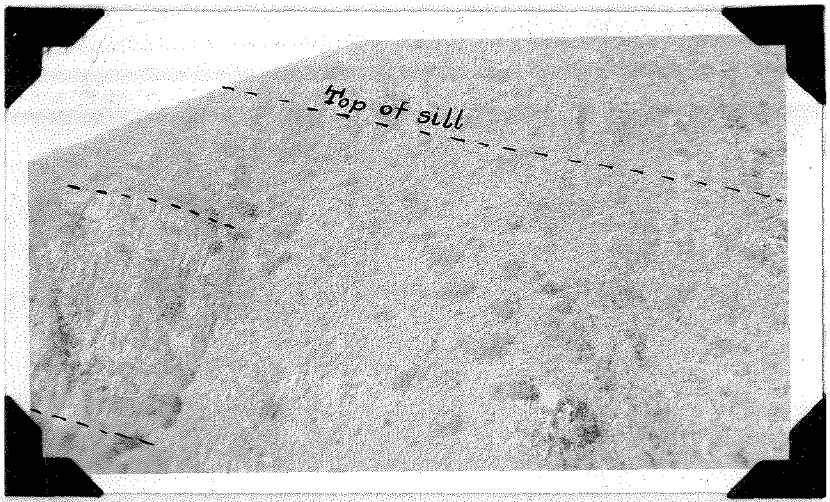

Fig. 19 The upper portion of a thick sill showing the development of a porphyritic center band.

porphyritic and apparently less basic. One notable example is the beautiful andesite porphyry dike which outcrops prominently near the mouth of La Joya Canyon and along the base of the black shales. The phenocrysts of this porphyry are plagioclase feldspar and are ½-¾ inches long. The ground mass is badly altered even in fresh specimens but is made up largely of microscopic hornblende and plagioclase feldspar. An exact duplicate of this rock occurs at the same horizon near the mouth of Blue Canyon four miles northeast and one flow in the Serrano Basalt member is very similar to this dike.

The typical diabase which makes up the bulk of the sills is almost identical in thin section to Figures 64 and 65 (Page 64) in Johannsen's "Descriptive Petrography of the Igneous Rocks". In addition to the plagioclase feldspar and augite, magnetite is quite noticeable. Several of the thicker sills have a peculiar porphyritic texture developed near their centers. This texture is especially developed in the large sill one and one-half miles northwest of Mugu Point and in the sill in Deer Canyon, one mile from the mouth. In the case of the former this feature is developed as a band parallel to the sheet and nearer the top than the bottom. This band is 60-70 feet thick as shown in Figure 19. Along the borders of this band, dike-like branches fray outward into the diabase. Figure 20 illustrates the manner. Thus in some respects it appears as though the more acid and porphyritic center of the sill had intruded the diabase. However, if such were the case dikes and individual intrusions of this rock ought to be found in other places than down the center

Fig. 20 Acid porphyritic band developed in diabase.

of the sill.

If the texture were the result of a gradual cooling from the margin inwards there should be a gradual development of the texture to the center, but instead the development is more nearly a sharp band. Furthermore, this band is more acidic with an abundance of phenocrysts of plagioclase feldspar. There is also an abundance of hornblende and augite and bladed magnetite or ilmenite.

It has also been suggested that the band may represent a secondary alteration which may have taken place in the final stages of cooling or shortly thereafter. This would be a deuteric alteration in the solid state. In support of this there are numerous small vugs developed resembling miarolitic cavities.

The phenomenon might also be due to immiscibility of two liquid phases brought about during the cooling process and after the sill had come to rest. The more acid lighter phase may have been migrating toward the top when stopped by congealment of the entire mass. The penetrations and fraying of the acid phase into the more basic phase would have been accomplished by any sort of movement after the segregation.

There are occasionally within the acidic band patches in which the texture is much finer but yet clearly a part of this phase. Distinct dikes to 2-3 inches in diameter of this fine-grained rock occur cutting the diabase at considerable distances from the acid porphyritic band. These dikes are thought to represent offshoots from this acid phase while it was still molten and after the diabase had congealed. A thin section of this dike rock shows that it is nearly all plagioclase and therefore is designated as the spessartite variety of camptonite.

Although the writer is not prepared to reach a final decision as to the origin of this phenomenon, he is inclined toward the last hypothesis.

The large sill mapped north of Sycamore Canyon near its head shows evidence of segregation. The base of the sheet is a melanocratic phase of the diabase while the upper portion is distinctly leucocratic and is perhaps andesite in composition.

Such segregation and banding as discussed above lend a structure to the sills, the lateral extent of which resembles flow structure. In some sills the lateral orientation of certain minerals suggests a structure due to movement. Figure 17 illustrates the lateral structure of many of the sills. However, it is the writers opinion that this structure is not due to movement but rather to some phenomenon after the sill had come to rest.

Contact Metamorphism: The effect of the intrusives upon the sediments is practically nil. Shales at the contact of larger sills show practically no effects. In one instance a little spotting was found in the shale right at the contact but this did persist for more than one-half an inch. It is highly probable that some effects of metamorphism could be discovered in the black organic shales by chemical tests.

Sandstones occasionally have been affected more than shales. Thus in several cases the sandstone at the contact may be baked and hardened to a noticeable degree.

Inclusions of sediment formed by stoping action of the magma do not occur and the only resemblances are the inclusions formed by the branching of the intruding bodies.

As might be expected the endomorphic effects of intrusion are much more apparent, although not on a large scale. The chilling effect of the walls on the thick sills is usually not noticeable for more than 8 or 10 feet. Thus in the sill one and one-half miles northwest of Point Mugu the chilled margin is from 2-10 feet wide. The top one foot is amygdaloidal and vesicular and below this there is a sharp change into the non-vesicular rock which rapidly changes from a porphyritic into the normal diabasic texture. Of the narrow vesicular band at the top the majority of the vesicles are confined to the top two inches.

STRUCTURAL GEOLOGY

Introduction - In the treatment of structure only such phenomena as faulting, folding, and intrusive forms will be discussed. Such structures as bedding, ripple marks, and flow lines have been previously touched upon and will not be further mentioned.

Plates I and II which accompany this report depict the major structures of the region and obviate need of supplementary explanation. However, the nature of the base map and its scale makes it impossible to show many of the smaller structures which complicate the larger ones. This is certainly true of the multitudinous complexities of the injected bodies. It was especially necessary to generalize Plate II in regard to the intrusive structures.

N. L. Taliaferro [1] in a short paper on the "Oil Fields of Ventura County, California" has constructed a generalized structure section across the south central part of Ventura County which illustrates the structural relation of the western end of the Santa Monica Mountains to the region to the north. Figure 21 is a reproduction of this section.

In regard to the structure in general Mr. Taliaferro says: "South of the Santa Clara Valley and west of the Santa Susana Mountains, the structure is, for the most part, comparatively simple.....South of the Simi-Las Posas uplift is the Santa Rosa fault which extends from Simi Valley on the east to the town of Camarillo on the west with a trend of

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1. A. A. P. G. Bull. vol. 8, p. 804, 1924

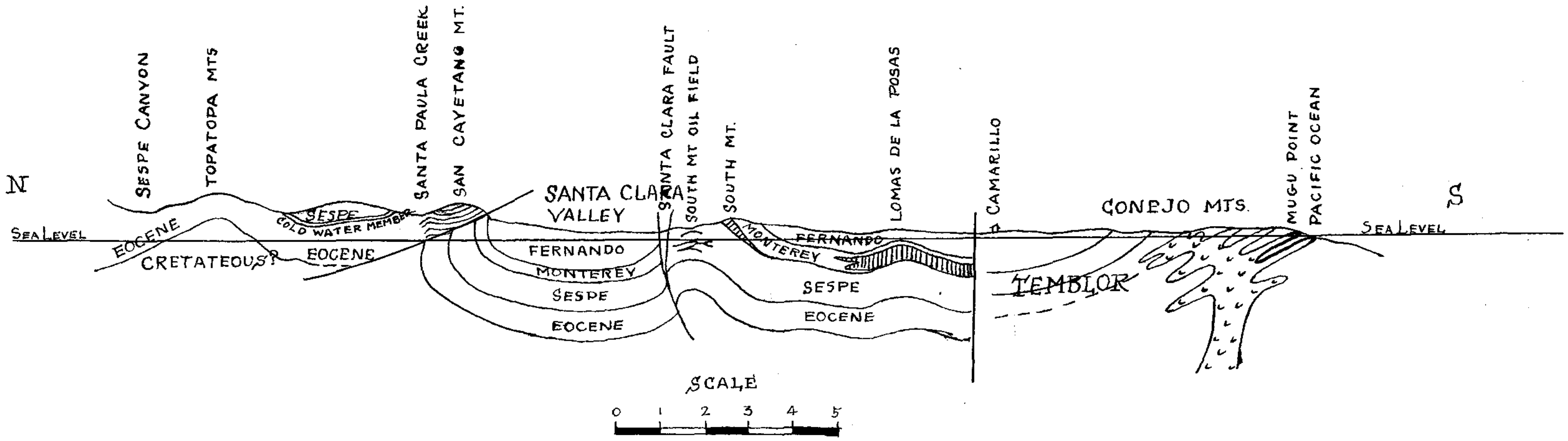

Fig. 21 Structure section across the south central part of Ventura County.
After Taliaferro

N 75° E. It disappears beneath the alluvium of Oxnard Plain near Camarillo, but it is thought that it turns rather sharply to the south-southwest along the front of the Conejo Mountains. It is a normal fault, down-thrown to the south, and is probably due to the great accumulation of volcanic material in the mountains to the south. It was probably formed progressively with the accumulation of the volcanics." In swinging the Santa Rosa fault south along the western border of the Santa Monica Mountains one must not be influenced by the physiographic break as this is reversed to the structural depression postulated. Magnetometer surveys of the Oxnard basin show no evidence of the postulated fault along the western termination of the range. [1] It should be noticed that there is an enormous discrepancy between the thickness of the Temblor on the south side of the Santa Rosa Fault and the Monterey (Temblor) on the north side. This may be due to a failure to indicate the thinning of the terrigenous Temblor to the north, or it may open up a new possibility that the Santa Rosa fault is an old pre-Miocene fault and that the south block was depressed and receiving sediments during all of Temblor while the north block received sediments only a portion of the time. Similar incidents are very common throughout the Coast Ranges. If such were the case it would account very easily for the enormous decrease in thickness in the Temblor between Mugu Point and South Mountain. The structural conditions so far discussed are general in nature and do not relate to the immediate area but are presented to show the

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1. Private conversation with Mr. Joshua Soske

broader relationships. Eastward the same general structures continue with several large faults of the Sycamore type cutting the range into irregular blocks while the intrusive and extrusive rocks become even more prominent.

Faulting - Faulting most likely has affected the strata of the area at several different periods, but because the rocks involved are all lower Miocene in age it is difficult to separateate these periods. In the eastern part of the range there is distinct evidence that faulting occurred during middle Miocene. In numerous places in neighboring regions faulting is found to have been active between the late Miocene and early Pliocene. Faulting and folding of even greater magnitude affected the entire Coast at the end of the Pliocene, and the Quaternary has not been without its faulting and rejuvenation. Therefore, although no ages can be assigned to faulting affecting the western end of the Santa Monica Mountains, it is very improbable that all the faulting occurred at one time.

In general the faults can be divided into three classes as follows: (1) large faults of considerable displacement and transversing the entire range, as the Sycamore and Blue faults; (2) numerous transverse faults of small displacement as the La Joya fault and the faults south of Long Grade Canyon; (3) countless minor faults too small in most cases to map and which have separated and broken the strata in every direction.

Of the last group of faults many were caused by the intrusion of the dikes and sills and the subsequent readjustments. Many more are doubtless the result of and subsidiary to the more extensive movements on the larger faults. They are of little significance and have only served to prevent more accurate and detailed mapping.

The second group of faults are difficult to locate because of the complications produced by the minor faults. Where the stratigraphic sequence is evident or where key beds are definite the displacement can be easily determined. On the other hand the key beds are often absent and outcrops may be so poor that while the fault may be located the nature of the displacements can only be inferred. This is largely the case in the rolling country south of Long Grade Canyon. In general the faulting is more easily determined in the Vaqueros formation where the stratigraphy has distinctive and contrasting lithologic characters.

The first group of faults are by far the most significant and all of the others may be considered subsidiary or secondary to these. Perhaps the most important fault of the region is the longitudinal one which bounds the south side of the range and upon which much of its elevation has probably occurred. The trace of this break has been largely destroyed in the area concerned by erosional attack of the sea. This east-west fracture is definitely located and of considerable magnitude in the Malibu region to the east. Thus back of Dume Point seven or eight miles east of this area the Modelo shales are sharply down-faulted against the Temblor and older rocks. This fault extends westward and strikes into the ocean somewhere in the vicinity of Little Sycamore Canyon. The

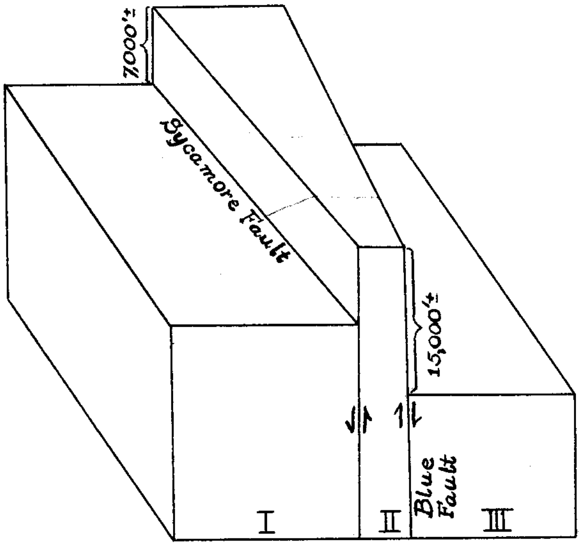

Fig. 22 Diagram illustrating the relation between the displaced blocks at the head of Sycamore Canyon.

east-west fault shown at the mouth of this canyon on Plate I is probably a branch or parallel slice to the large fracture. The southward dipping strata bend down sharply at this fault and at several places they stand vertically. It should be noticed from Plate I that the structural trend of the region is slightly north of east and that this trend is cut off at a sharp angle by the sea coast. Although this might be accounted for simply by erosion it also strongly suggests faulting. In further support of this, the strata become progressively more broken and sheared as one approaches the sea coast. Also the ascent from the ocean in this region is unusually steep, at least too much so to be due entirely to marine abrasion.

Therefore it is here postulated that much of the uplift of the range has been on an east-west fault along its southern base and that this fault lies beneath the ocean but not far from shore in the area under consideration.

Perhaps of no less magnitude is the Sycamore fault and its Blue Canyon branch. The rocks along these faults are considerably shattered and broken. The block lying between these two faults is especially sheared and fractured. However, the fault plane and the adjacent deformations are usually obscured by failure of outcrop or alluvial cover. The most striking evidence of faulting is the sharp truncation of structure and rock types. Thus to the west of the Serrano Flats the volcanic rocks abut sharply against the lateral extension of the Temblor and Vaqueros sediments.

Figure 22 illustrates the relations between the blocks

Fig. 23 Small tributary developed along the Sycamore fault as it leaves Sycamore Canyon.

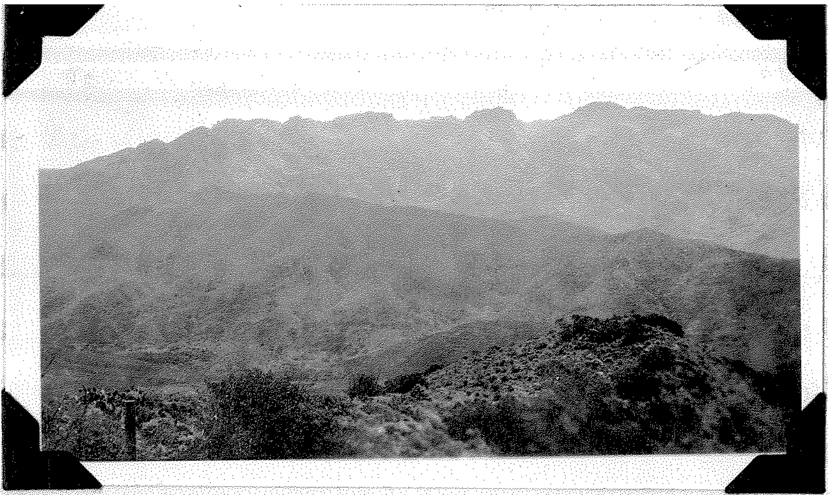

Fig. 24 Vaqueros horst in the middle distance upfaulted between Boney Mountain agglomerate in the distance and Temblor strata in the foreground.

involved postulating displacement by vertical component along. The horizontal result is a maximum displacement of 6 miles between blocks two and three in the diagram. (See Figure 24) It is believed that the movement on this fault was almost entirely vertical. Had the movement been horizontal the axis of the regional anticline would have been dislocated to the same extent as the beds. The axis has been offset somewhat but not at all to an extent comparable to that of the beds. Furthermore the offset of the axis might be accomplished entirely by a vertical movement provided that the axial plane of the fold is not vertical also.

The Sycamore fault is probably one of the oldest in the area. Several dikes and pipe-like bodies appear to have worked their way up along this fault whereas the same bodies or sills extended therefrom are broken by later faults.

Folding - The major fold of the area, and in fact the whole western end of the range, is a large east-west anticline, the limbs of which are exceedingly thick. The larger part of the south limb is beneath the ocean, probably down-faulted. Along the axis, the beds are crumpled, broken, and injected with a great amount of basalt and diabase. This, together with the downfaulting on the south limb, makes it difficult to determine the attitude of the axial plane, but in general the limbs of the fold are nearly symmetrical and the axis, plunges slightly eastward into the range (perhaps eight or ten degrees). This, of course, applies only to the portion studied and farther to the east the reverse may be true.

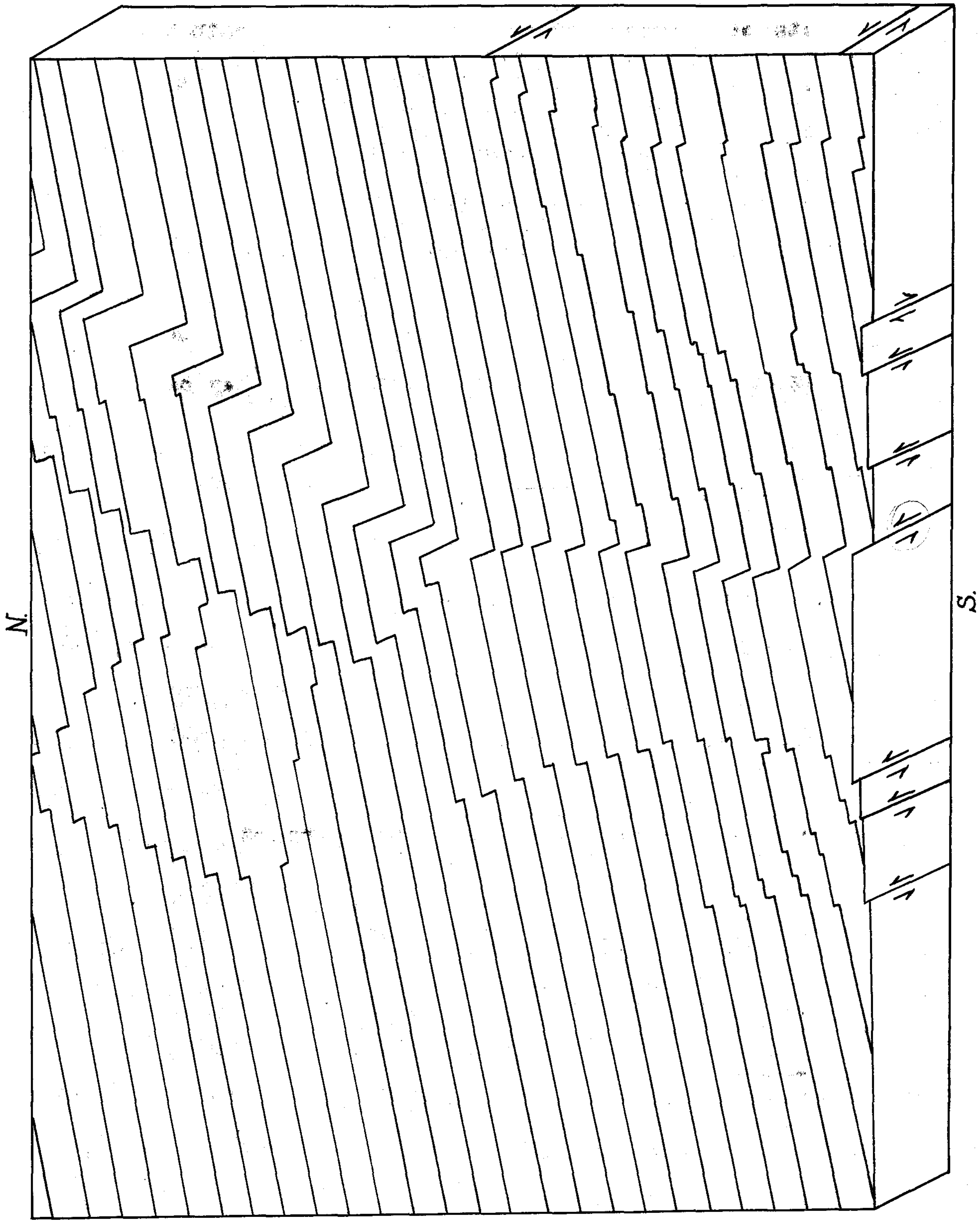

Fig. 25 Displacement stereogram of the area mapped.

Woodford and Bailey, in their consideration of the San Onofre breccia, state: "these outcrops occur on the south limb of the broad, westward plunging anticline which comprises the western part of the Santa Monica Mountains." In general the dip of the north limb is steeper nearer the axis of the fold.

There are one or two minor flexures, but these are more in the nature of imcompetent or drag folds. In some cases the beds are crumpled and folded locally as the result of faulting, and in other instances intrusions may have caused some crumpling of weaker shale beds. Furthermore if the axial plane of the drag folds can be used safely as a criterion, the indication is that the axial plane of the major fold dips is to the north.

Following out the postulate that most of the faults were produced by vertical forces, it is probable that a vertical force such as an intruding plug caused the anticline. According to Wayne Loel[1], in the Malibu region such a plug is exposed over considerable area with the intruded sediments lapping up in laccolithic fashion. It is the writer's observation that the intrusive sills and dikes increase in number and size eastward, especially along the crest of the fold.

Intrusive Forms - Dikes: The dikes are the most numerous of all intrusive forms, and their most striking feature is their branching and multiple nature. (See Figures 26 and 27) Figure 26 is a part of a larger group of dikes which in all probability were "feeders" to a larger intrusive sheet. There are several of these conduits of multiple and branching dikes exposed along the sea coast cliffs. Figure 9 and 47

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1. Private Conversation

Fig. 26 Multiple and branching dikes a part of a larger basaltic conduit. (Fig. 48)

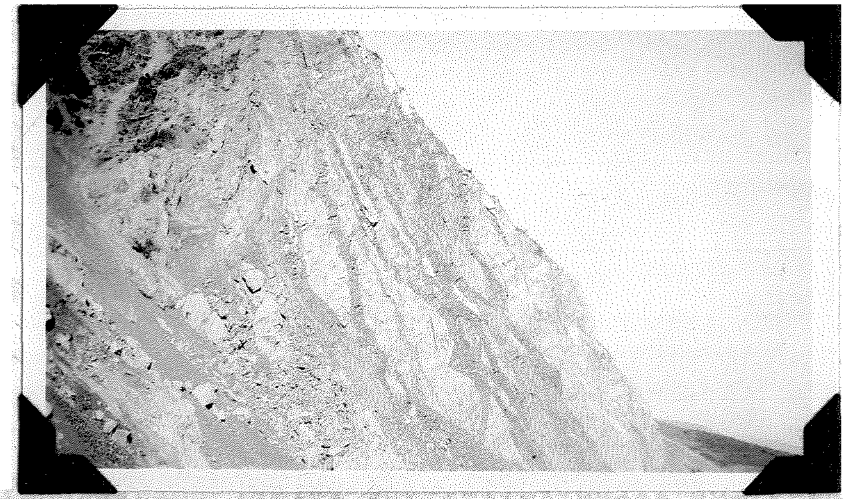

Fig. 27 Multiple and branching dikes cutting massive sandstone near Mugu Point.

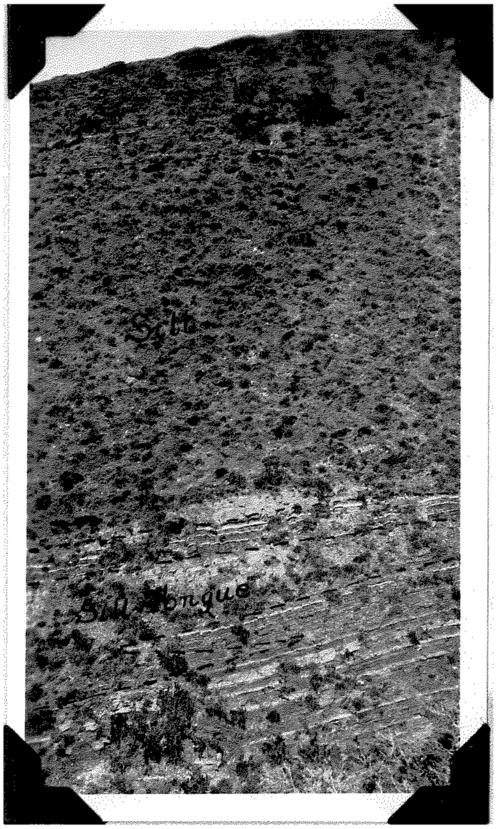

Fig. 28 Diabase sill cutting Temblor sediments near the western tip of the range.

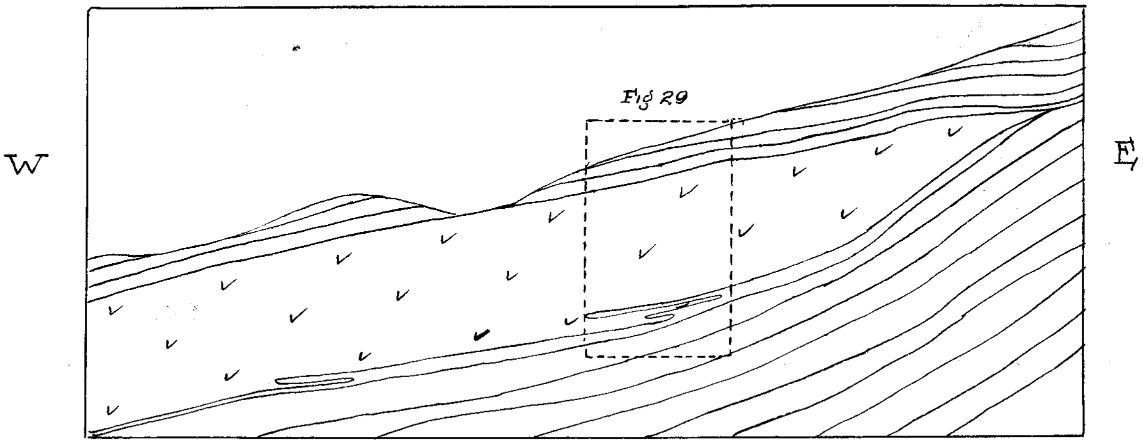

Fig. 29 Section illustrating the larger relationships of the sill shown in figure 29.

illustrate typical examples. In spite of the prominence of these conduits in no case was the writer able to actually trace them into or cutting across a sill. Of course the branching nature of the dikes makes it very difficult to trace such a body over anything but well exposed outcrops. Such well developed branching of dikes would seem to demonstrate a highly fractured or jointed rock, but it may have been that injection having once started the rapidly moving magma under high pressure formed its own opening, splitting the rock in advance. It seems probable that injection took place at a rapid rate and that the country rock was not greatly heated. The great amount of pyroclastics in the region certainly indicates vigorous activity for a time at least.

Sills: The sills of this region vary in thickness from several inches to two or three hundred feet. The longest sills traceable are two or three miles. The large sills usually vary considerable in thickness along their lateral spread. Where the sill bulges or thickens it might be considered a laccolith. But if arching of the strata constitutes a laccolith, than all sills are laccolith at their margins. Although many of the sills in the region show enough bulging to be considered laccoliths, for simplicity and convenience they will all be considered as sills.

The larger sills commonly have tongues or branch sills which fray outward into the adjoining beds. Figures 28 and 29 illustrate this feature. In some cases the branching becomes the main feature and the sill breaks up into numerous

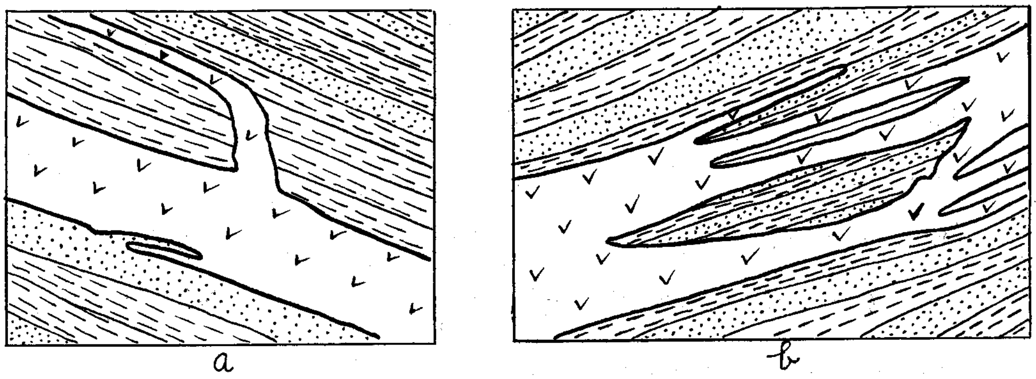

Fig. 30 Typical sections of branching sills.

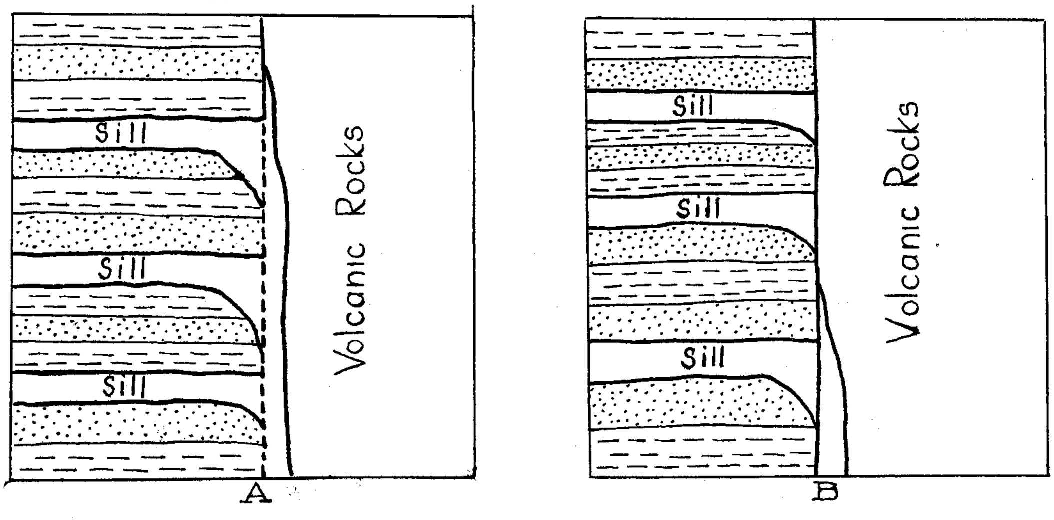

Fig. 31 (A) Post faulting intrusion following fault plane, (B) Post intrusive renewal of faulting.

sills with islands or shreds of strata intervening. This branching sometimes happens at the end of a sill where the sheet "frays out".

The type of sedimentary rock has had an important influence upon the intrusive form. Thus sills are restricted to rocks which have well developed stratification. The massive sandstone horizons never contain sills as do rarely the black shale members. This latter is probably due to the lack of confining or guiding beds of sandstone. On the other hand the alternating beds of sandstone and shale have proven excellent structures for the development of intrusive sheets.

Thus the intrusions are confined to trunk-like bodies passing through the massive members, but upon entering a more favorable horizon, the dikes branch and spread out in sheets along the stratification. While several sheets are penetrating the more favorable horizons, certain branches may find their upward movement restricted by a massive cap beneath which a sheet may spread until a fracture or joint through the cap is found, whereupon the magma will again move up as a trunk until another susceptible structure is encountered. Thus on a large scale multiple sills are formed.

In many cases the magma conduits were along faults. Figure 31 is an explanation of the sills directly west of the down-faulted volcanic rocks of Serrano Flat. The sills thicken considerably at the Sycamore fault as shown on Plate 1. Most of the pipe-like bodies have come up along previously formed fractures. The Blue fault has numerous multiple dikes and pipe-like bodies closely associated with it.

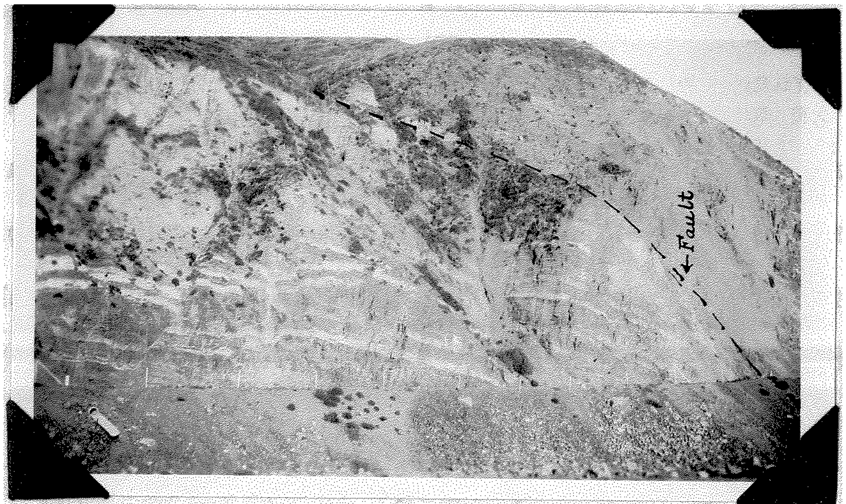

Fig. 32 Diabase sill near the mouth of Sycamore Canyon. Note step-faulting shown in the floor of the sill.

Fig. 33 View looking to the west from the end of the range with the marshy flats of the Oxnard Plain in the foreground and the Santa Barbara Islands in the distance.

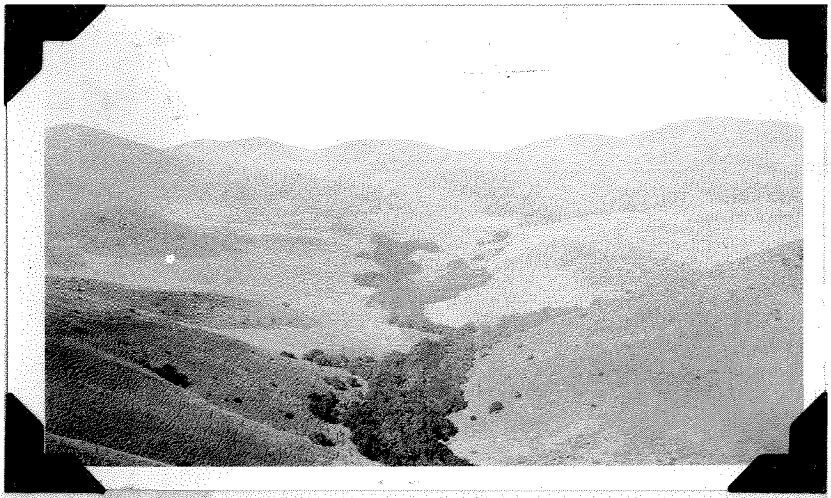

Fig. 34 View of La Joya Flat with the La Joya hogback ridge in background. Note the rounded character of the topography.

Fig. 35 View looking southeast from Laguna Peak with Mugu Peak at the right and the La Joya sand dune in the distance.

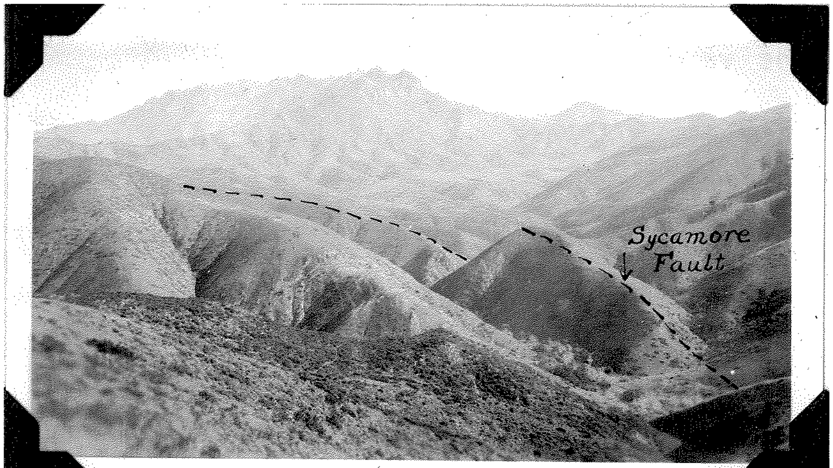

Fig. 36 View looking east across Sycamore Canyon at the branch of Serrano Creek. Serrano Flat and Boney Mountain in the distance.

PHYSIOGRAPHY

Relief - The relief of the western end of the mountains, roughly within the Hueneme quadrangle, is subdued as compared to the more rugged, higher region to the east, but is sharply contrasted to the flat Oxnard plain to the west. (See Fig. 33) This, however, is not due to separate erosion cycles but rather to difference in rock character and position in the end of the range. The highest summits of this lower area are close to 1500 feet altitude and are rounded or knob-like. (See Figs. 34 and 35) Several small upland flats are hemmed in by ridges and peaks. The La Joya flat (See Fig. 34) comprises some 750 acres of tillable land and stands at an intermediate elevation between the summits of the ridges and sea level. Serrano flat (See Fig. 36) is similar in character with a richer volcanic soil. Both of these flats are the result of normal erosive forces acting upon weaker belts of rock.

The main drainage divide lies much nearer the northern edge of the range. The cause of this is partly due to the character of the rocks, but of more importance in the difference in altitude between the graded valleys and plains to the north and the sea level to the south. Due to the greater distances to sea level via the northward drainage, the gradients must necessarily be less and hence their cutting power less.

Along the south side of the range there are a few accordant levels along the tops of the seaward trending ridges. At first these give the impression of being earlier

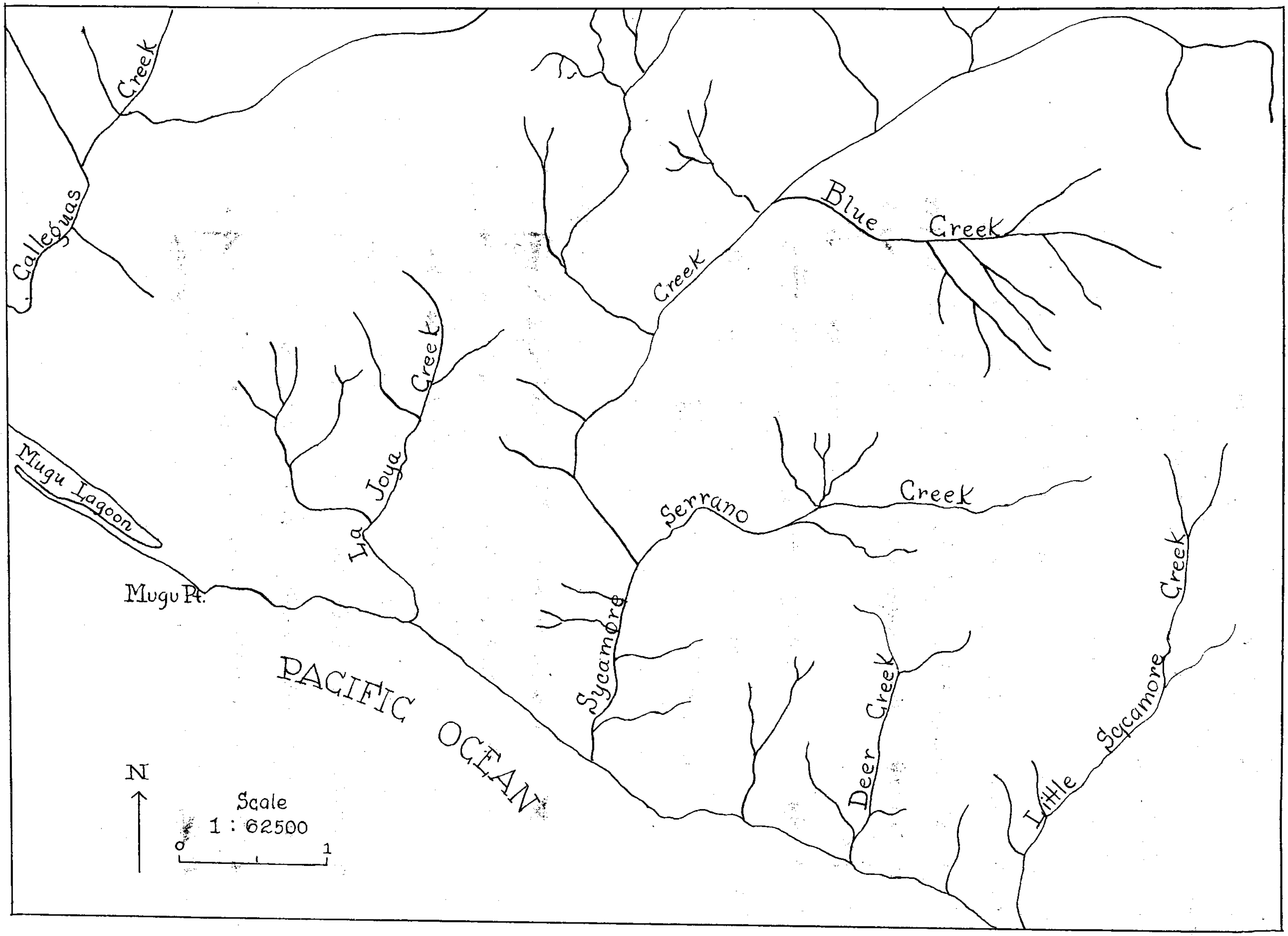

Fig. 37 Drainage pattern of the area mapped.

profiles of equilibrium. However, these levels are probably the result of present forces acting in part upon belts of homogeneous rock and upon flat-lying beds along the top of the broad anticline.

Rising abruptly back of the level of the seaward trending spurs and east of the subdued western area is Boney Mountain whose rocky crags and precipitous cliffs stand as conspicuous landmarks above the surrounding landscape. (See Figs. 36 and 38) The highest point on Boney Mountain is 3,059 feet, nearly twice that of the mountainous sector to the south and west. As intimated previously its height is due to the well indurated, massive character of the rocks.

On the whole the relief of the region is indicative of a mature stage of erosion. (See Fig. 36)

<u>Drainage</u> - The drainage pattern is shown by Figure 38, which emphasizes the preponderance of the mountainous area reached by Sycamore Creek and its tributaries. The western border is drained by Calleguas Creek which runs close to the mountain edge across the Oxnard plain and into the Mugu Lagoon. Debris is fed to branches of this creek during storm intervals and is carried down on to the tidal marshes of the plain. Where the creek in its lower stretch closely borders the mountains, several small alluvial fans have built out from the canyons to the creek margin.

The remainder of the area is drained directly to the sea through rather deep, narrow canyons, formed by headward erosion, along subsequent controls of structure and rock type.

Fig. 38 View to the north showing the precipitous cliffs in the Boney Mountain agglomerate.

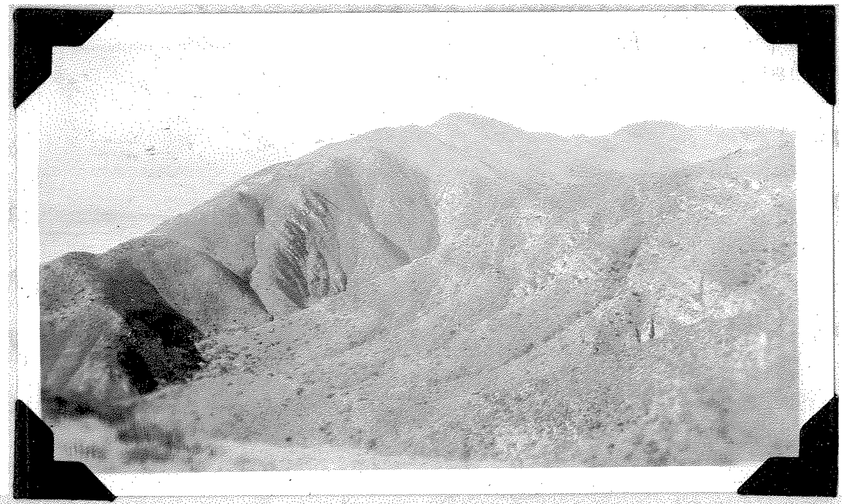

Fig. 39 La Joya Canyon near its mouth. Note the prominent outcropping of the Vaqueros massive sandstone member.

La Joya, Deer, and Little Sycamore Creeks may be dismissed as the work of, as yet, small subsequent streams without graded lower courses.

Sycamore Creek is the major stream of the area and has the longest graded lower course of any stream emptying directly into the ocean in the Santa Monica Mountains. The lower course is seven miles long and has a fall of only 60 feet per mile. The course of this stream for the most part is the result of rock weakness produced by the Sycamore fault with which the stream coincides along most of its lower course. This stream completely transects the Santa Monica Mountains and heads southward on the north slopes of Boney Mountain. Some of its branches are progressively cutting into the inter-mountain valleys to the northwest of the main mountain mass. The Malibu Creek which empties into the ocean 17 miles east, also transects the range, and its western branch heads only a fraction of a mile from the source of Sycamore Creek. In a sense, these two streams have carved out a large section of the range to themselves.

Sycamore canyon is one of the most beautiful canyons in the whole range. Its flat alluvial floor moderately strewn with live oak and magnificent sycamore trees, winds like a broad ribbon through faceted mountain spurs and narrow side canyons. It is but a few hours, even after continued storms, before the surface drainage disappear beneath the thick gravel mantel of the lower course.

<u>Development of the Shoreline</u> - Several distinct marine

Fig. 40 Soil creep on the back of La Joya Peak, greatly facilitated by the dip slope.

terraces occur along the mountainous coast and are best developed and preserved in the upper Miocene shales at Dume Point which is about twelve miles east of Sycamore Canyon. W. M. Davis [1] has described and named these terraces in an abstract of a paper presented before the Geological Society of America. He has called the oldest, highest terrace, the Malibu, and the next youngest, the Dume. The Malibu platform is only definitely known to be preserved back of Dume Point. Eastward and westward it has presumably been undercut by later marine denudation. The Dume platform being younger is better preserved along its coastal extent but in many places it also has been undercut by the present marine action.

The Dume shoreline at its type locality is about 100 feet above sea level, but declines westward until it drops beneath the present sea level near Deer Canyon. This tilting of the old shoreline may have been due to (1) a differential emergence of the land, (2) an even emergence of the land and a differential subsidence later. An even or regular emergence of the land may involve (a) actual movement of the land mass by diastrophic forces, (b) sinking of the ocean bottom to cause lowering of the water's surface, (3) lowering the sea level during a glacial epoch due to the enormous accumulation of water on the land in the form of ice. However, the question of what emergence of the land involves will not be considered. The results would be practically the same, except under the glacial postulate, wherein the sea would be expected to return

[1] Pan Am. Geol. vol. 54, No. 2 p. 154, 1930

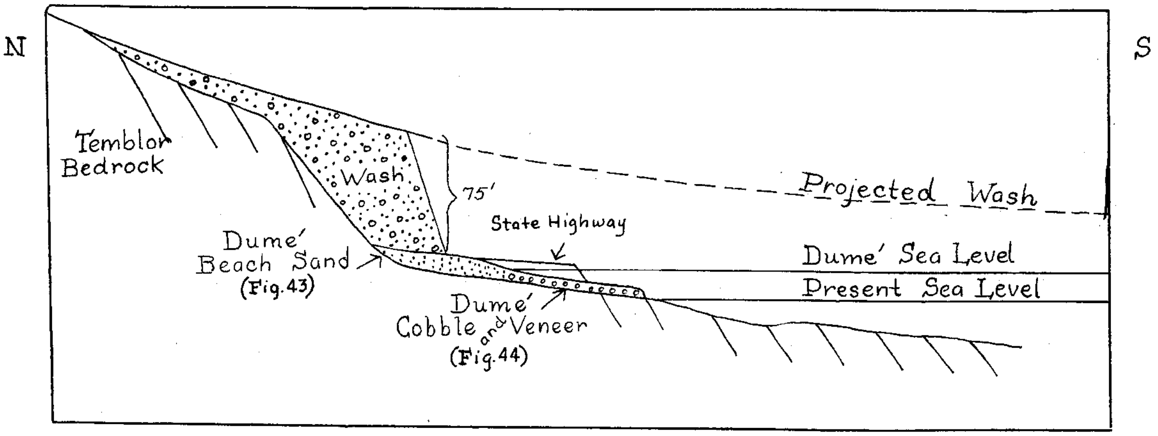

Fig. 41 Section showing the relations between the Dume platform, the overlying terrestial outwash, and the present sea level.

Fig. 42 Dume (Pleistocene) beach sand overlain by wash from the Dume cliffs. (See figure 41)

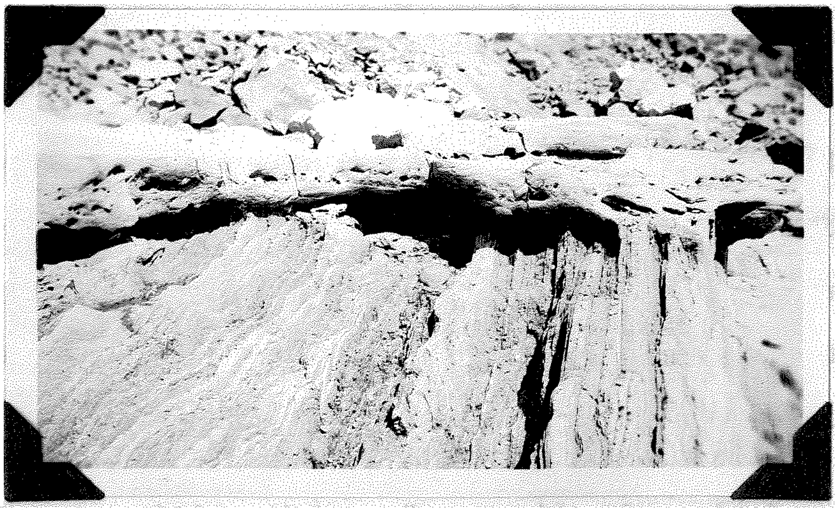

Fig. 43 Hardened Dume cobbles and sand cemented across truncated Temblor strata. (See Fig. 41)

in an interglacial epoch, other things remaining constant. The important point to be demonstrated in the region under consideration is that the land has submerged since the initial withdrawal of the sea from the Dume shoreline. The evidence is remarkably exposed along the present sea-cliff between Little Sycamore and Deer Canyons. The diagram in Fig. 41 and the accompanying photographs are meant to show that the maximum retreat of the shoreline, after the cutting of the Dume shelf, must have been a considerable distance (one or two miles is estimated by projection to scale) to allow for the accumulation of (75-100 feet) alluvial fan material. The altitude of the crude bedded fan deposits, near the cliff from which they were derived, is hardly over ten or fifteen degrees and this should lessen slightly seaward. Now, had the sea retreated even one mile or half of a mile from the Dume shore, its level, upon cutting the cliffs back to their present position, would have been much lower than it now is, provided present offshore slopes can be used as any criterion at all. The present shoreline is about 15 feet below the old Dume shoreline at the point of the section. At present, depths of 15 or 20 feet of water are usually found at distances not over one or two hundred yards off shore. Of course the offshore slopes may have been much less than at present, but if so, upon the return of the shoreline the waves would have to cut back across this shallow shelf and a similar if not identical slope ought to be recut. Figure 44 shows a general view of the alluvial terraces being mentioned. The section shown in Figure 41 is taken on a line with the beach groin seen in the middle distance. Figure 45 shows a contact between terrace

Fig. 44 Alluvial terrace formed from the alluvial outwash which covered the Dume platform. The beach groin at the right marks the line of the section in figure 42.

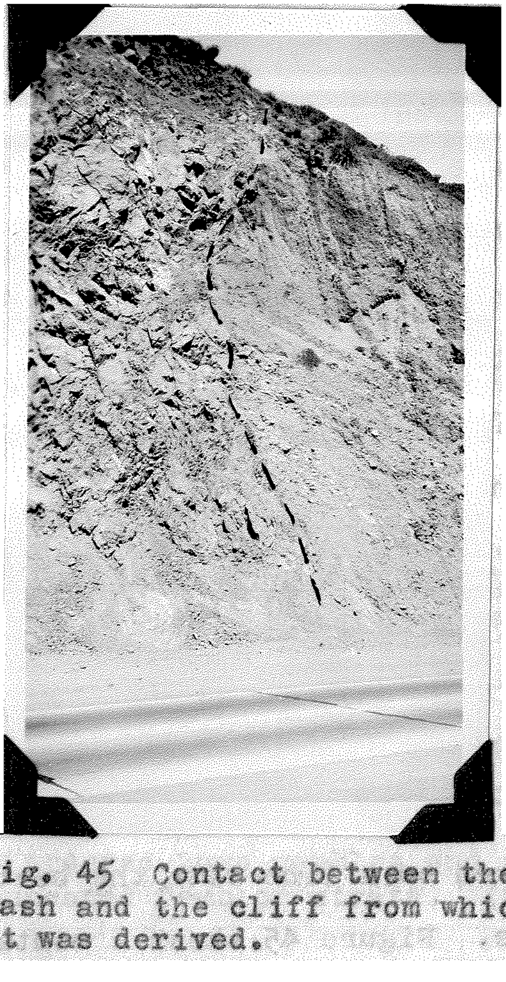

Fig. 45 Contact between the wash and the cliff from which it was derived.

alluvium and the cliff from which it was derived.

The veneer of cobbles and sand overlying the bedrock of the platform contains Pleistocene fossils and Hoots[1] says of the outwash plain covering the continuation of this platform to the east: "the age of the plain is definitely late Pleistocene because the strata of which it is composed locally rest directly upon a slight thickness of horizontal fossiliferous marine upper Pleistocene deposits."

The present shoreline is quite straight except for a few bites into the soft rocks and the normal hard rock promontories. In fact it is so regular that most observers contend that it could not be a shoreline of submergence as shown above. There are two factors which might have prevented the formation of the so-called normal irregularities of submerged coast-lines. First, the plain over which the returning sea has so far advanced has been a comparatively level outwash plain without pronounced irregularities and these being in soft rock have been rapidly removed; second, the return of the sea was slow enough to allow the streams to aggrade and maintain their mouths without indentation. The wide, deep, alluvial floor and lengthened lower course of Sycamore Canyon is in support of this. Both of these factors may have entered in together with the possibility that the submergence has lately ceased.

The present attack of the sea has nearly everywhere advanced to a stage where the hard rock is well exposed beneath the softer mantel of wash. Thus the shoreline is properly classified as contraposed according to D. W. Johnson.[2]

[1] U. S. G. S. Prof. Paper 165-c, p. 130, 1930

[2] D. W. Johnson-Shore Processes and Shore Development p. 401

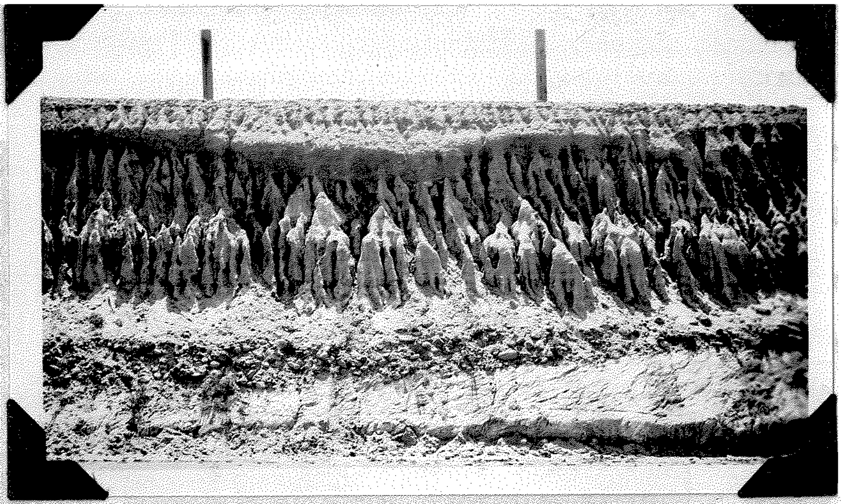

Fig. 46 Dume platform showing the usual succession upward of cobbles, sand, and wash.

Fig. 47 La Joya sand dune formed against the cliff back of the beach. Note the basalt dikes cutting the Vaqueros strata back of the dune.

The development of such minor features as stacks, caves, and reefs of harder rock at the immediate shoreline, has been greatly modified by the construction of the highway. An enormous amount of debris has been blasted and dumped into the sea. More recently, miles of seawall have been constructed and groins built into the sea, thus altering the normal transportation and deposition of debris.

Of more ordinary interest is the large sand dune developed against the cliff back of La Joya beach. Figures 47 and 48 are of this dune and its surroundings. It is quite obvious that the dune has formed as a result of full exposure to the wind with an abundant supply of sand from the broad beach and the pocket formed by the curving sea cliff. But why should the wind be so capable at this particular point? Additional observation has revealed that Sycamore Canyon produces a "draft" through which the onshore wind is concentrated with greater force and constancy. Plate I shows the relation of the dune to the canyon and the narrow intervening ridge.

Fig. 48 La Joya sand dune in the foreground and Mugu Point in the distance. Note the double row of sand dunes on the beach.

GEOLOGIC HISTORY

The base of the Vaqueros is not exposed in this area but the evidence from surrounding areas would seem to point to a greater restriction of true marine conditions just prior to the true Vaqueros. During the Vaqueros time the sea floor and shoreline conditions probably varied some, but in general an east-west embayment was maintained with practically continuous deposition largely supplied from the north or non-metamorphic areas. The Temblor age was ushered in without any apparent break in the sedimentation, although the source soon changed from north to south or from non-metamorphic areas to the Catalina metamorphic area. The southern land mass became very formidable during the early Temblor as shown by the clasticity of the sediments. In general the same embayment existed but somewhat expanded in size.

Near the end of the Temblor age vulcanism began first upon the sea floor and later under subaerial conditions. Locally the activity was quite violent and steady resulting in enormous accumulations of lavas and pyroclastic material. Injection into the lower Miocene sediments must necessarily have begun with the vulcanism and continued even after surface outbursts ceased.

Following the igneous activity, and during it to some extent, enormous vertical stresses were applied to the accumulations resulting in great displacements and some arching of the strata. It is believed that arching was not brought about entirely at one time, but was accentuated by post faulting injection and more recent vertical forces so evidently applied to the surrounding region.

Upper Miocene shales may have once covered the entire arch as is thought in the eastern end of the range. If this was so practically all trace has since been removed. The region has most like been suffering erosion at least since the close of the Miocene. Just what the relief was and how it was modified between then and the Pleistocene is impossible to say. It is perhaps enough that the relief and time since exposure has been sufficient to truncate the broad fold to its present form.

The several Pleistocene terraces indicate uplift for the most part since that time so that the present relief is probably as great if not somewhat greater than during Pleistocene time.

ECONOMIC GEOLOGY

The western end of the Santa Monica Mountains has been mapped and considered for oil. The large anticline has most likely been rejected as a possibility because of the faulting and fracturing along the crest and the enormous amount of intrusive rock. The formations involved contain excellent source rocks in the form of black organic shales and at least one oil seepage is known, that reported at the mouth of Deer Canyon and now covered by alluvium. It is thought by some that drilling of the anticline would reveal an igneous plug at relatively shallow depths.

Just to the north of the area mapped is the Conejo oil field at the foot of the Conejo grade. It is one of the most unusual in California as the oil is obtained from basalt agglomerate, sheared basalt, or the alluvium overlying these rocks. The oil is encountered at 60-250 feet in a simple monoclinal structure with dips from 20-28 degrees. It is thought that the oil may have migrated into these rocks along a fault. The total production is only a few barrels per day.

Within the last year the Hansen Petroleum Company sank a hole west of Potrero Valley and about one mile north east of the head of Sycamore Canyon. The well was located on the horst between the Sycamore and Blue faults. It was advised with the hope that the two bounding faults might trap the oil. The structure is monoclinal and the faults may as well afford avenues of escape for the oil. For some unknown reason the well was abandoned at about 1500 feet.

LITERATURE CONSULTED

Daly, R. A.
1914 Igneous Rocks and Their Origin. Chap. 5

Davis, W. M., Putnam, W. C. and Richards, G. L.
1930 Elevated Shore-lines of Santa Monica Mountains. Pan-Am. Geol., vol. 54 #2, p. 154

Goldman, M. I.
1924 "Black Shale" Formation In and About Chesapeake Bay. Am. Assoc. Pet. Geol., Bull., vol. 8, p. 195-201

Harker, A.
1923 Petrology For Students

Hoots, H. W.
1930 Geology of the Eastern Part of the Santa Monica Mountains, Los Angeles County, California. U. S. Geol. Surv. Prof. Paper 165-c

Johnson, D. W.
1919 Shore Processes and Shoreline Development

Kew, W. S. W.
1924 Geology and Oil Resources of a part of Los Angeles and Ventura Counties, California U. S. Geol. Surv. vol. 753, p. 1-202

Kew, W. S. W.
1927 Geologic Sketch of Santa Rosa Island, Santa Barbara County, California. Geol. Soc. Am. Bull., vol. 38, p. 645-654

Lahee, F. H.
1923 Field Geology

Lawson, A. C.
1893 The Post-Pliocene Diastrophism of the Coast of Southern California. Univ. Calif. Pub. Bull. Dept. Geol., vol. 1, p. 115-160

Lilley, E. R.
1928 The Geology of Petroleum and Natural Gas, Chap. 4

Reed, R. D.
1927 Researches in Sedimentation in 1926-27, Report of the Committee on Sedimentation, National Research Council Washington, D. C. p. 77

Ridgway, J. L.
1920 The Preparation of Illustrations for reports of the U. S. Geol. Surv.

Rubey, W. W.
1930 Lithologic Studies of Fine-Grained Upper Cretaceous Sedimentary Rocks of the Black Hills Region. U. S. Geol. Surv., Prof. Paper 165-A

Taliaferro, N. L.
1924 The Oil Fields of Ventura County, California. Am. Assoc. Pet. Geol. Bull., vol. 8, p. 789-810

Trask, P. D.
1931 Sedimentation in the Channel Islands Region, California, Econ. Geol., vol. 26, p. 24-43

Twenhofel, W. H.
1915 Notes on Black Shale in the Making. Am. Jour. Sc., 4th series, vol. 40 p. 272-280

Twenhofel, W. H.
Treatise on Sedimentation

Tyrrell, G. W.
1926 Principles of Petrology

Wiedey, L. W.
1928 Notes on the Vaqueros and Temblor Formations of the California Miocene With Descriptions of New Species. Trans. San Diego Soc. Nat. His., vol. 5 no. 10, p. 95-182

Willis, B., and Willis, R.
1929 Geologic Structures

Wilmarth, M. G.
1931 Names and Definitions of the Geologic Units of California, U. S. Geol. Surv., Bull. 826

Woodford, A. O.
1925 The San Onofre Breccia. Univ. Calif. Pub. Bull. Dept. Geol., vol. 15, p 159-280

Woodford, A. O. and Bailey, T. L.
1928 Northwestern Continuation of the San Onofre Breccia. Univ. Calif. Pub. Bull. Dept. Geol., vol. 17, p. 187-191.