GEOLOGY OF A PART OF THE SAN JOAQUIN HILLS

Thesis by

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In Partial Fulfillment of the Requirements
for the Degree of Master of Science,
California Institute of Technology,
Pasadena, California,
1932.

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GEOLOGY OF A PART OF THE SAN JOAQUIN HILLS

I. INTRODUCTION.

A. DISCUSSION OF THE PROBLEM.

The work on which the present report is based has been done by Mr. Francis D. Bode and the present writer. The problem was originally taken up as a thesis project for the degree of Bachelor of Science of the California Institute of Technology. Since that time, the author has spent all time available for research under the Institute curriculum for the Master's Degree on this problem. Mr. Bode has also spent a considerable amount of time on the area since the original theses were written. This study has been carried on under the direction of Dr. John P. Buwalda, chairman of the Division of Geology and Paleontology at the California Institute of Technology.

The ultimate object in view in this work is a detailed knowledge of the structure and stratigraphy, as well as of the fauna of the area. The immediate result desired in this thesis was a general account of the major structural features and a general knowledge of the stratigraphy and faunas. This last result is thought to have been accomplished. Details of structure in many parts of the area have yet to be worked out. In the region between Laguna and Abalone Point Canyon near the coast, particularly, the structure shown on the map here presented is subject to revision. It is apparently complicated; and our present conclusions may be considerably altered in detail with further work.

Likewise, the general stratigraphic column is thought to be satisfactorily known. Finer subdivisions can be made and mapped; but it was not possible to do so for the present report. There is a great deal of paleontologic material to be found in the Hills. Collections thus far made are probably representative but not complete. The paleontologic determinations here presented are tentative; further work will, however, probably not alter the general conclusions drawn from the paleontolgic evidence. It is hoped by Mr. Bode and myself that, in the course of work to be pursued for the Doctor's Degree, we shall be able to complete a detailed study of the Hills. Mr. Bode proposes to continue work on the structure; and I hope to make detailed studies of the petrology and faunas of the Vaqueros and Temblor formations.

B. GEOGRAPHY.

The San Joaquin Hills (also known as the Laguna Hills) are located on the Coast of Southern California, 9 miles south and slightly east of the city of Santa Ana, Orange County, California; and 27 miles southeast, along the coast, from the city of San Pedro, Los Angeles County. The Hills are bordered on the West and North by the flood plain of the Santa Ana River and tributaries. On the South they are bordered by the Pacific Ocean, and on the East by Laguna Canyon. The town of Laguna lies in the southeast corner of the area. Immediately to the West of the Hills, on the coast, are the beach towns of Newport and Balboa.

The area mapped extends to the East of Laguna Canyon a short distance. It is bordered on the West by a north-south line paralleling Laguna Canyon and about 4 1/2 miles west of it. On the North it is bordered by the alluvium of the valley and on the South by the sea.

C. MAPS.

In the earlier stages of the work, the map used was the Santa Ana Quadrangle Sheet of the United States Geological Survey (scale 1:62500, contour interval: 25 feet). This map is extremely unsatisfactory. The representation of topographic features is glaringly inaccurate. Later, a complete set of airplane maps was obtained from Continental Air Map Company. They are excellent maps. All mappable data are recorded upon them.

D. RECORDING OF DATA.

In recording attitudes of bedding on the map, several degrees of accuracy have been indicated. An attitude with the degree of dip given indicates that all the data shown were determined. The Greek alpha has been used to indicate cases in which the general direction of dip was known and the strike and degree of dip were approximately determinable. A question mark has been used in cases in which the strike and dip appeared to be determinable but the validity of which was questioned. Many attitudes have been recorded in which the strike was determinable and the direction of dip generally known, but for which quantitative determination of dip was not possible. In such cases no figure was recorded for dip. In other situations, the dip being known within limits, such limits were recorded.

Many of the contact lines are dashed. The significance of the dashed lines is that the contact is thought quite certainly to exist, but that its position is not exactly known. In case the existence of a contact is definitely uncertain, it has been qualified by the use of question marks. The profiles used in constructing structure sections were taken directly from the airplane mosaic. Elevations were obtained by the comparison of topographic forms on the mosaic with those on the Santa Ana Quadrangle Sheet. This method has proved to be fairly satisfactory, in the absence of any better practicable method.

E. FIELD METHODS.

Field methods were those of ordinary usage. Bearings and determinations of bedding attitudes were made with the Brunton compass. The use of airplane contact sheets was found to be an ideal procedure, except for the absence of elevations.

II. PREVIOUS LITERATURE.

R. P. McLaughlin and C. A. Waring (1914), and Lawrence Vander Leck (1921) make mention of the San Joaquin Hills; but no significant work dealing with the area has been published except that of A. O. Woodford (1925).

Woodford makes frequent mention of the San Joaquin Hills. He gives a sketch map including this area. In most of the area designated in this map as Vaqueros, we have found a Temblor fauna. There also appears to be a considerably greater areal extent of sediments of the San Onofre facies than the map suggests.

In this report we shall use Woodford's terms: Eastern Bedrock Complex, and Western Bedrock Complex. He defines the Eastern Bedrock Complex as the " The plutonic and metamorphic complex, perhaps entirely of Mesozoic age, which bounds the narrow coastal strip of sediments on the East". The plutonics are granites and related but more basic rocks. The metamorphics are metamorphosed Triassic slates and schists. There are also acid to intermediate volcanics.

The Western Bedrock Complex is found on Catalina Island and in a small area on San Pedro Hill, both of which are west of the Tertiary belt. It is characterised by its peculiar metamorphic facies, in which are found such minerals as crossite, lawsonite, and glaucophane. No rocks of a similar nature occur in the Eastern Bedrock Complex.

The distinctions drawn by Woodford between sediments composed of minerals from these two different sources have been of great value in establishing the field relations in this area. Distinctive minerals (especially glaucophane) from the Western Bedrock Complex are readily distinguished in the field if large enough to be seen with a hand lens.

III. PHYSICAL ASPECTS OF THE AREA.

The San Joaquin Hills constitute the westward extremity of a belt,of similar hills which trend along the coast toward the East and South until, a few miles to the East of Laguna Canyon, they merge with the Santa Ana Mountains on the North. Signal Peak (which is not named on the U.S.G.S. maps) is the highest point in the Hills, with an elevation of 1185 feet. It is centrally located in the area. The alluviated country to the North and West of the Hills nowhere has an elevation of more than 200 feet. Drainage heads at the main crest trending eastward from Signal Peak, and runs in a general northerly direction toward the valley on the one hand and in a southerly direction toward the sea on the other. At the eastern and western ends of this crest, drainage radiates normally into Laguna Canyon and the Inner Lake (an arm of Newport Bay occupying an old channel of the Santa Ana River) respectively. Laguna Canyon drains a relatively small portion of the area, although its head lies near the northern edge of the Hills, from which region it runs southward between the San Joaquin Hills and those on the East, opening into the sea. Remnants of old sea terraces are evident at many different altitudes from sea level well up toward the highest point. The concordant elevations of many of the long, level ridges reaching seaward from the main crest of the Hills, and their abrupt terminations near, but not at, the shoreline must inescapably be interpreted as remnants of old terraces.

In most cases the terrace deposits have been removed from the higher levels; but a few cases remain where the covering is still present.

The climate is that which is normal to neighboring coastal regions. It is more humid than that of coastal ranges farther inland. For this reason and for the further reason that the elevations are slight, a soil mantle is found covering a great deal of the area. Vegetation, which is also normal, is continuous over much of the area; although brush is not unusually heavy. The prevalence of soil mantle and vegetation, and consequent lack of exposures of the country rock, constitute a great hindrance to progress in the field.

IV. STRATIGRAPHY, LITHOLOGY AND FAUNA.

A. GENERAL.

Stratigraphic measurements were computed from the mapped data. Thus they are approximations, and are useful as such. Eventually, the sections will be measured by means of plane-table traverses. Lithologic data are taken from field observations. The faunas h ave been tentatively determined on the basis of their more common forms. Further work may change details, but probably will not alter greatly age determinations.

No Basement Complex rocks are exposed in the San Joaquin Hills. The rocks found here are all of Miocene and later ages. The sediments within the mapped area are all of undoubted Miocene age except the Quaternary Marine Terraces; with also the possible exception of a series of sandstones underlying the Vaqueros conglomerates, whcich will be discussed later.

The sediments of the San Joaquin Hills are considered as a seaward extension of those of the Santa Ana Mountains. There appears no reason for suspecting that they were not laid down in the same basin of deposition, which shall be here designated the Los Angeles-Santa Ana Basin.

The question of nomenclature of California Miocene sediments is an open one. Louderback (1913) proposes the term "Monterey Series" to include the sediments known under the designations Vaqueros, Temblor and Monterey. He considers these groups as representatives of an essentially continuous period of deposition. Vaqueros and Temblor would be used by him to designate the Turritella inezana and T. ocoyana zones respectively; and Monterey would designate shale formations of the type found at Monterey, which might be in part contemporaneous with the Vaqueros and Temblor zones or be of later age. The data of some authors agree with this general idea, and of others disagree. Kew (1924) considers that the Topanga (equals ? Temblor) overlies the Vaqueros unconformably and that the Topanga is overlain in turn unconformably by the Modelo (equals ? Monterey). English (1926) states that the Topanga overlies the Vaqueros with conformity but that the Puente shales (equals ? Monterey) overlie the Topanga unconformably. Hoots (1931) says that the Vaqueros (?) is apparently conformably overlain by the Topanga and that there is a striking unconformity between the Topanga and the overlying Modelo. Woodford (1925) finds the Temblor in depositional contact with the Vaqueros at certain localities and with the Tejon at others, indicating extensive overlap and probable unconformity. He considers the San Onofre (upper Temblor) to be interbedded in its upper portions with the overlying Monterey shales, indicating a gradational, transitional contact. B. N. Moore (1930) finds, in the Santa Ana Mountains, a disconformable relation between the Vaqueros and Topanga and unconformity between the Topanga and the Puente shales.

In the San Joaquin Hills, the only locality in which the Temblor appears in depositional contact with the Vaqueros is in the vicinity of Abalone Point Canyon, 1 1/2 miles from its mouth. The beds in this vicinity constitute a long fault sliver in which the strike of the beds is in general at right angles to the elongation of the block. Here, in a series of shales and fine sandstones with coarser sandstone beds intercalated, is found a Temblor fauna overlying a Vaqueros fauna, the two being separated by about 300 (?) feet of shales with their associated sandstone beds. No sharp and sustained lithologic break is found between the two faunas; and none occurs for some distance stratigraphically above the Temblor fauna and below the Vaqueros fauna. No angular discordance has been observed; and, considering the contimuity of the lithology, this is hardly to be expected. These facts are here interpreted to indicate continuous deposition between the time of existence of the Vaqueros fauna and that of the Temblor fauna, in this area.

Little evidence has been found regarding the nature of the depositional contact between Temblor sediments and Monterey shales. Within the area mapped the relation between these two formations is largely one of faulting; probably more so than is indicated on the map. Woodford (1925) has discussed this relation to some extent, as found in and around the San Joaquin Hills. His conclusion has been mentioned above: that the relation is a transitional one, with interbedding of the material of the two formations. One bit of evidence found in the present investigation is suggestive. In the vicinity of Emerald Bay, shales of the typical Monterey aspect are found overlying conformably beds of the San Onofre facies of the Temblor formation. The relation of this occurrence to the other sediments of the neighborhood is not well known; but this local condition seems to corroborate Woodford's conception, which we shall accept in this paper.

The conclusion drawn by the writer from consideration of data of investigators in surrounding regions and that found in the San Joaquin Hills is that Louderback's conception of the Monterey Series is essentially correct. The three formations appear to represent a period of more or less continuous deposition. The existence of unconformities between the formations in certain regions and not in others is conceived to be the outcome of diastrophic activity which brought the edges of the basins of deposition into the zone of erosion at various times, while the deeper and more seaward portions of the basins underwent continuous deposition. In general, it appears that the three formations, Vaqueros, Temblor and Monterey, were successive in time; altho the Monterey shales, or similar facies, may have been in part laid down contemporaneously with parts of the lower sediments. It is considered therefore that the Vaqueros, Temblor and Monterey formations are valid as such; and not merely as zones or facies.

As for the propriety of these names, Vaqueros is a name in good standing. The name Temblor has been discarded by some authors in favor of Topanga. The two are essentially equivalent, according to the literature; and since Temblor has the rights of priority, and apparently no serious faults, we shall use this name. Monterey is an old name. Faunal correlation with the Monterey type section is as feasible as with type Modelo or Puente; therefore, we shall use the name Monterey, in preference to Modelo or Puente.

As more and more detailed work is done in the different Miocene basins of deposition of California the correlation between deposits in different regions will undoubtedly become more and more exact. If, then, the equivalence of sections represented by later names with those represented by earlier names is disproved, the later names may legitimately be used. In the meantime, since the general equivalence of the sediments in the San Joaquin Hills to those in early recognized sections is fairly certain, we shall use the old names as stated above.

B. VAQUEROS FORMATION, LOWER MIOCENE.

1. General.

The Vaqueros formation outcrops chiefly in the northern and northeastern parts of the area. The top of the section is not exposed here, but is found in the vicinity of Abalone Point Canyon, as mentioned above, where it underlies Temblor sediments. The total estimated thickness of Vaqueros exposed in the area is 4100 feet. This figure was obtained by computing the thickness of the series along cross-section line A-A' and adding to that figure the estimated thickness of the section found in and near Abalone Point Canyon. Probably this leaves an unknown amount of the complete section unrepresented; because it is thought that the lowest sediments exposed in Abalone Point Canyon are higher than the highest beds exposed along the line A-A'.

Throughout, the Vaqueros sediments have been derived from the Eastern Bedrock Complex. They are considered to be entirely of marine origin, altho some of the red beds may indicate very shallow water and estuarine conditions during part of the time of deposition. Four divisions are recognizable, altho time was not sufficient for mapping them separately. These are, from bottom to top: (1) a series of sandstones, (2) conglomerates and sandstones, (3) fine, buff sandstones, (4) blue-gray shales with interbedded sandstones and sandy shales.

2. Lower sandstones.

The oldest beds, consisting of a series of sandstones, are found immediately to the West of the farther west dike of the two paralleling Laguna Canyon in the northeastern part of the area. The dike represents a fault along which intrusion has taken place. This group of beds is bounded on the West by a fault which brings them up against the Temblor. The base of the series is not exposed, due to the fact that it terminates downward in the section against the intrusive mass. The computed thickness of the series is 1400 feet. It is assigned to the Vaqueros because the beds underlie, with no apparent depositional break, the conglomerates which in turn conformably underlie beds bearing a Vaqueros fauna. No fossils have been found in them. They conform in general character and stratigraphic position to similar beds found by B. N. Moore (1930) in the Santa Ana Mountains. Altho they may be pre-Vaqueros in age, no evidence except their consistent lithologic difference from the section above has been found to substantiate this possibility. Upon encountering a heavy conglomerate series, one is entitled, in California Tertiary problems, to suspect a basal position for them. This does not seem to be the case here.

The sandstones are coarse-grained and arkosic. They are well and massively bedded. The heavy, coarse beds are separated by beds of finer-grained sands and sandy shale in some places. Toward the top of the section is found a peculiar white-weathering bed, which has been mapped for some distance. It appears to be a bed of conglomeratic sandstone which contains a certain amount of whitish material which may be ash or limey material or both. At one time it was thought that this bed represented a non-conformity. There appeared to be boulders of sandstone similar to the underlying (and overlying) sandstones in it. Finally it was decided that these blocks were the result of weathering, and that conformity existed thru the bed.

Overlying the sandstone series, between these beds and the Vaqueros-Temblor fault, apparently conformably, are the Vaqueros conglomerates.

3. Conglomerates and sandstones.

In addition to the above-mentioned occurrence of the basal beds, the conglomerates are exposed between and to the East of the two dikes paralleling the northern reaches of Laguna Canyon. They are here bounded on the South by the Vaqueros-Temblor fault, and extend a considerable distance to the North of the fault, disappearing toward the North because of faulting along the lines of the dikes and because of folding. The computed thickness of the conglomerates is 1600 feet. B. N. Moore (1930) states, regarding this series of conglomerates, that "In Santiago Canyon it is about 150 feet thick, to the West in the front of the range it is about 300 feet thick, and in the San Joaquin Hills it is considerably thicker". Our computations bear out this statement emphatically.

The constituents of the conglomerate series are definitely derivatives of the Eastern Bedrock Complex. No trace of the peculiar metamorphic facies of the Western Bedrock Complex was found in them. The aspects of these conglomerates and those of Santiago Canyon are seen in Plate 1, Figures 1 and 2. The pebbles and cobbles vary up to about 6 inches in maximum diameter. They are composed of fine-grained igneous rock (rather acidic porphyries, mostly), some coarser acidic intrusive rock, quartzites, and some schists and other metamorphics. They are well rounded and bedded. The matrix is a coarse arkosic sandstone, apparently fairly well washed. The conglomerate beds frequently weather out in thick reefs. They are usually well indurated, bearing a calcareous cement. In many places, particularly in the vicinity of Laguna Canyon immediately to the North of the Vaqueros-Temblor fault, these conglomerates weather out with a very distinctly red color. There are coarse sandstone beds intercalated with the conglomerates. The conglomeratic material appears to come into the section gradationally at the base and to grade out at the top.

In the northern part of Laguna Canyon are found outcrops of white, arkosic, very biotitic sandstones, interbedded with red muddy clay material (Plate 1, Fig. 3.). These are here included with the underlying conglomerate series. It is thought that these beds and the reddish color of some of the conglomerates may indicate shallow water during deposition. Perhaps the depth of the basin fluctuated between truly marine depths and those of estuarine or marshy conditions. Low humidity might account for lack of organic debris in shallow-water deposits in this case.

4. Fine-grained sandstones and shales.

Lying above the conglomerates, apparently conformably, is a computed thickness of 700 feet of fine-grained, massive-bedded (for the most part), light yellow-buff colored sandstones (Plate 1, Figure 4). These are exposed in the northern and northeastern parts of the area mapped. The series is well bedded, altho sometimes massive. The beds are fairly well indurated and bear a limonitic and calcareous cement. Quartz is the predominant mineral present; there are considerable amounts of feldspar and little of micaceous minerals. Intercalated with the sandstones are very limey, concretionary beds. Both the sandstones and the limey beds frequently bear fossils.

In the vicinity of Abalone Point Canyon, about 1 1/2 miles from its mouth, occurring as part of a fault block or sliver trending northwest-southeast, is found a series of fine-grained buff colored sandstones, mostly massive-bedded, overlain by coarser sandstones bearing a Turritella inezana fauna. These last are interbedded with blue-gray shales, which constitute the major proportion of the sediments higher in the section. They contain interbedded thin sandstones (up to 5 feet thick). Above the shales lies a hard, coarse sandstone bed (10 feet ? thick) bearing a Turritella ocoyana fauna. Above this bed are found

PLATE 1.

Figure 1. Outcrop of middle Vaqueros conglomerates in the northern part of Laguna Canyon. (Page 17)

Figure 2. Vaqueros conglomerates in Santiago Canyon, Santa Ana Mountains. (Page 17)

Figure 3. Red clays and white arkosic, biotitic beds of the Vaqueros of Laguna Canyon (Page 17)

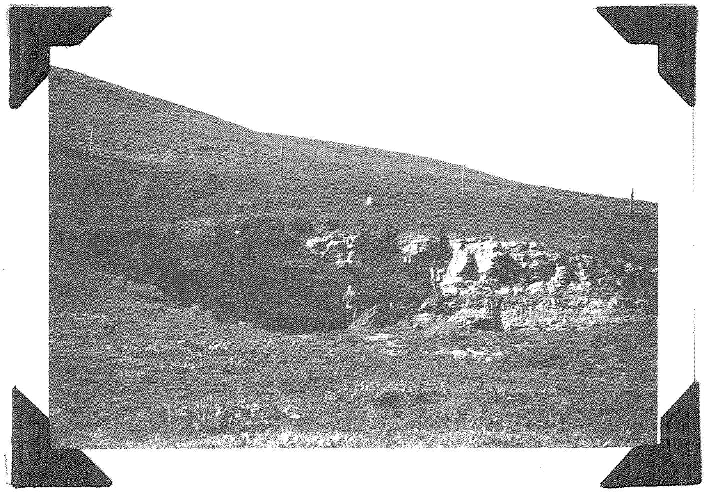


Figure 4. Fine-grained, buff Vaqueros sandstones exposed west of highway in the northern part of Laguna Canyon. (Page 18)

more blue-gray shales, very similar to the material below the fossil bed. The whole series appears to be conformable. The base of the T. ocoyana fossil bed is taken as the base of the Temblor formation and the top of the Vaqueros. The estimated thickness of the section from the lowest beds exposed (terminated by faulting) to the base of the T. ocoyana bed is 400 feet. Since the lowest sediments here exposed, fine-grained massive-bedded, buff sandstones, are very similar to the highest beds of the Vaqueros section exposed in the northeast part of the area, and since this section seems to be continuaous upward to the base of the Temblor, it is considered that this section lies wholly above the sediments measured in the other region. Possibly there is a small thickness of the section in common between the two localities; but it is thought more probable that a portion of the complete section is not represented in either locality. We have taken the sum of the thicknesses in two different localities to represent the exposed thickness of the formation in the mapped area. No direct evidence as to whether the shales and sandstones lying between the T. inezana fauna below and the T. ocoyana fauna above should be called Vaqueros or Temblor has been found. Indications point to continuous deposition, with no sharp lithologic break in the sediments. No mixing of the two faunas has been detected. The intervening shales have not been found to contain any fossils. Under the conditions, the name to be applied to the shales has been looked upon as largely an arbitrary matter. It seems logical to call the sediments Vaqueros until the appearance of the Temblor fauna; and this has been done.

The composition of the fine-grained buff sandstones in this locality is, as has been mentioned, very similar to that of the highest member described in the northeast part of the Hills. They are very quartzitic, fairly well indurated and contain a limey cement. They are easily weathered, except for the fossil beds, which contain more cement. The sandstone beds in which the Turritella inzana fauna occurs (overlying the fine-grained buff sandstones) are somewhat coarser and perhaps of a darker, more grayish color in the outcrop. These are similar to the thinner sandstone beds intercalated with the shales higher in the section. The shales are interbedded with the T. inezana-bearing sandstones, and become more prevalent upward in the section. They are blue-gray in color, fine-grained, sometimes sandy, are well bedded, have distinct shale-parting, and are often very well indurated by reason of limey cement. Intercalated with the shales are hard, calcareous, concretionary beds which form prominent outcrops.

C. TEMBLOR FORMATION, MIDDLE MIOCENE.

1. General.

As stated above, the base of the Temblor formation has been recognized only in the fault block trending northwest-southeast, traversed by Abalone Point Canyon about 1 1/2 miles from its mouth. The strike of the beds in this block is in general at right angles to the elongation of the block. Upper Vaqueros beds are exposed in Abalone Point Canyon. Toward the Northwest, higher and higher beds are exposed, including uppermost Vaqueros, lowermost Temblor, and continuously higher Temblor beds for some distance upward in the section/

The stratigraphic level taken as the base of the Temblor is the base of a hard, calcareous, rather coarse-grained, massive sandstone bed about 10(?) feet thick. This bed is apparently conformable with the Vaqueros series below. It contains a distinctive Turritella fauna composed of several varieties of the T. ocoyana group. About 200 - 300 feet stratigraphically below this level, occurs a T. inezana fauna,, as discussed above. No mixing of the two Turritella faunas has been found anywhere in the area.

Mr. W. H. Corey and Mr. Wayne Loel have done a great deal of work on the Vaqueros and Temblor formations and faunas. A publication by these two men on this subject is now in press at the University of California.

Some of the contentions set forth in their paper have been stated by Corey in papers and remarks given before meetings

of geological organizations within the last two or three years. Mr. Bode and the writer have also briefly discussed the subject of Vaqueros and Temblor faunas with Mr. Corey. One of the most interesting and pertinent conclusions reached by these two authors is that there was a period of time in the present Southern California region during which the faunas previously supposed to be respectively characteristic of the Vaqueros and Temblor formations lived together in the same basins of marine deposition. Turritella inezana and other forms had previously been supposed to be distinctive of the Vaqueros formation. T. ocoyana and its associates had been considered diagnostic forms for the Temblor. Corey reports that in several localities T. inezana and T. ocoyana or their varieties have both been found throughout certain sedimentary sections. A characteristic fauna or assemblage, called a "transition fauna", has been found associated with the simultaneous occurrence of the two species of Turritellas.
Mr. Corey stated to Mr. Bode and the writer, about 3 years ago, that in his investigations he had found what he considered the Vaqueros-Temblor transition fauna in the San Joaquin Hills. However, he stated also that he could not say definitely that he had found a mixture, or overlap in the time ranges of the two Turritellas (T. inezana and T. ocoyana) in this area.

During the investigations upon which this report is based, many fossil localities have been found in which Turritellas formed a large percentage of the fauna. They are the most abundant genus found in the sediments of the area; and they are widely scattered throughout the area and the section. In no case have we found any evidence to the effect that T. inezana or any of its varieties occurs simultaneously with or stratigraphically higher than T. ocoyana or its varieties.

Consequently, it has been considered during the course of this work that T. inezana is distinctive of the Vaqueros and T. ocoyana of the Temblor of the San Joaquin Hills. Further study on more complete fossil collections from the area and consideration of the data presented in the paper by Loel and Corey, when it is made available to the public, will bring out more details regarding the faunal problems of the region.

The term Temblor formation as here used includes all sediments bearing Turritella ocoyana and its associated fauna. The San Onofre breccia and its associated beds are included within the Temblor formation, as a facies, after Woodford. The limitations of Woodford's definition of the facies are not thoroughly understood. Apparently he used the term for the more breccia-like phases of the glaucamphibole-bearing sediments. In the absence of complete definition, and since the boundary between sediments which bear glaucamphibole constituents and those which do not is apparently more sharp than that between breccia and non-breccia phases, we have used the term San Onofre facies to include all sediments bearing Western Bedrock Complex minerals. This group of sediments has such distinctive characters, field and laboratory, that it would seem to be worthy of the status of a formation; but we shall not depart from Woodford's usage.

The San Onofre facies appears to be entirely conformable over the lower Temblor sediments, derived from the Eastern Bedrock Complex. Altho little evidence regarding the depositional contact between the San Onofre facies and the overlying Monterey shales has been derived from this investigation, Woodford's conclusion that the contact is gradational is borne out by this evidence.

The total thickness of the pre-San Onofre section of the Temblor is computed to be 6400 feet. This figure is approximately the same whether computed on the west flank of the general arch of the Hills or on the East flank, using in the latter case Woodford's base of the Temblor, which he defines as "the base of a pebble bed with glaucamphibole schists, beneath which no blue schist grains were observed". This contact was not traced during the present study; but the corresponding contact on the west flank of the arch was traced in detail.

The thickness of the San Onofre facies has not been computed. There is no unfaulted sequence of this member within the limits of the area mapped. It is safe to say that there is a thickness of something over 1000 feet exposed; but this figure means little since it is estimated from the base to no particular point in the section.

2. Pre-San Onofre Temblor.

The pre-San Onofre Temblor sediments make up the main central and east central part of the Hills.

Above the basal Temblor sandstone bed, previously discussed, are found about 300 feet of shales with intercalated thin sandstone beds about 5 feet in maximum thickness. The shales are very similar to those below the basal bed. They are blue-gray in color, fine-grained, sometimes sandy, have distinct shale parting, are regularly bedded, calcareous, often well indurated, but do not weather prominently except in the case of certain limey concretionary beds of slight thickness. The intercalated sandstones are medium-coarse-grained and well-bedded. They also are similar to the sandstone beds found in the shale series below the Temblor contact. Overlying this series are massive, fossiliferous sandstones.

In Abalone Point Canyon, about 1 mile from its mouth, is found a series of shales overlain toward the East by sandstones. These are apparently low in the Temblor section and are correlated with the shales and overlying sandstones mentioned above.

Overlying the shales conformably is a computed thickness of 6100 feet of sandstones, which are in turn overlain conformably by the sediments of the San Onofre facies. These sandstones are mostly massive and well bedded. They vary in texture from coarse to fine-grain, the former predominating. Quartz is the most abundant mineral present. There are considerable amounts of feldspars. Femic minerals are not abundant; they are limited largely to micaceous minerals, probably mostly biotite. The cement is in general calcareous, altho some limonitic material is present. The grains are fairly well rounded, and well sorted. Especially in the higher parts of the section, beds of pebble conglomerates are found. These are usually well defined, ranging up to 6 feet in thickness (Plate 2, Figure 1). The pebbles are composed of Eastern Bedrock Complex rocks. Acid to intermediate volcanics are frequent. More coarsely crystalline rocks are also found, of roughly granitic composition. Quartzites, schists and slates are also found, but not in large numbers. The average maximum longest diameter of the pebbles is under three inches. They are well rounded. Good sorting is the rule. The matrix is similar to the adjacent sandstones. Fine-grained sandstones are present, but form a minor percentage of the section. These are generally massively bedded and present a punky appearance. They look very much like the fine-grained sandstones in the upper portion of the Vaqueros section. The Temblor sandstones are generally well indurated; the fine sandstones less so than the coarse-grained beds. Typical weathering forms are seen in Laguna Canyon. Prominent reef beds with cavernous openings are of frequent occurrense. The dominant color of the series varies from gray to buff. This section is intermittently fossiliferous throughout. The fossiliferous beds are usually better indurated than those barren of fossils.

3. San Onofre facies.

The San Onofre facies of the Temblor formation is found within the area mapped in its greatest areal extent in the northwestern part of the area. In the extreme northwesterly region it conformably overlies the lower sandstone unit of the Temblor, dipping westward on the west flank of the general arch of the Hills. From the southeastern portion of this area of San Onofre sediments, they extend as a long, narrow fault block for some distance in a southeasterly direction toward the town of Laguna. To the north of Signal Peak and to the East and North of the area described immediately above, lies a northerly-trending graben of San Onofre sediments. This extends as far north as the valley alluvium bordering the mapped area. Again, in the vicinity of the town of Laguna, in the extreme southeastern part of the area, the San Onofre occupies a considerable area. This facies also occupies a large area to the East of the region here studied.

As previously mentioned, no thickness has been computed for the San Onofre facies, because no unfaulted sequence exists within the area mapped. Probably over 1000 feet of these sediments are exposed here. Woodford gives a thickness of 2600 feet for the San Onofre facies. Also due to the absence of any unfaulted sequence of considerable extent, no stratigraphic succession has been established within this unit.

Few fossils have been found in the San Onofre sediments. No collections from this series have been made; but at one locality (114) immediately north of the western part of the town of Laguna, Turritella ocoyana was recognized in the field.

The base of the San Onofre sediments is best seen at the contact with the lower Temblor sediments in the western portion of the area. It is also exposed in the vicinity of Laguna, north of the town. The description here given is taken from the former locality. The contact appears to be one of conformity and gradation. The highest beds of the sandstone series below are massive, coarse-grained, quartzitic, calcareously cemented sandstones. These are overlain by similar sandstones interbedded with shales. The contact was mapped at the lowest horizon in which glaucamphibole particles were consistently found. This horizon lies within the series of sandstones and shales, a short distance stratigraphically above the more boldly weathering sandstone reefs of the lower unit of Temblor sediments. Accompanying the glaucamphibole particles in the lower San Onofre sediments is found a large percentage of Eastern Bedrock Complex minerals. Some beds appear to be made up almost entirely of the latter. Biotite, which is relatively scarce in the more characteristic San Onofre sediments, is often present in these basal beds in considerably quanity. Apparently, drainage from the West began bringing into this area small quantities of Western Bedrock Complex minerals, from a newly emergent block, while deposition of detritus from the Eastern Bedrock Complex was still actively taking place. The sandstones of these basal beds are rather massive and are well bedded. Sometimes crossbedding is very prominent, within the larger bedding units. They vary in grain-size from medium ~~and~~ to coarse. In color, they are usually grayish to buff. They are in general much more poorly indurated than the sandstones of the underlying series of Temblor beds. They weather much more easily. A marked topographic break along the contact may be observed. The shales interbedded in this part of the section are dark gray or brownish gray in color. They are well confined to beds between the sandstones, but lamination within the shales is not so prominent as, for instance, in the lowermost Temblor shales described above. No calcareous lenses were found intercalated with these basal shales of the San Onofre. A rather characteristic feature of the sandstone beds of this part of the section is the frequent presence of particles or pebbles of shale near the bottom of the bed, but definitely within the sandstone, above the contact with underlying shales. These particles may have any orientation of cleavage. When this phenomenon was first observed, it was thought that nonconformity was indicated. Further observation disclosed that the feature was a rather common one in this part of the section, too general in beds at different stratigraphic levels to indicate nonconformity. It is thought that these particles of shale represent reworked bits of the material over which the sandstones were laid down. They may or may not have developed their shales cleavage before reworking.

They may quite conceivably have developed their shale cleavage in their present positions with respect to enclosing sandstone beds, during induration and diastrophism.

Proceeding upward in the section from the lowest consistent occurrence of glaucamphibole particles, the content of Western Bedrock Complex minerals increases. Shales become less frequent. Fine-bedded sandstones, medium- to fine-grained, are also to be found.

Included within the San Onofre section are breccias of very coarse, angular fragments (Plate 2, Figures 2 and 3). The largest of these breccia blocks observed in this area is about 10 feet in length. From this size, the constituent blocks and fragments may vary to microscopic particles. Little sorting is in evidence. Bedding is usually distinguishable. Sandstones are interbedded with the breccia. These, and the breccia matrix, are composed of finer angular fragments. All sizes of fragments are ordinarily derived from the Western Bedrock Complex; particularly the larger sizes are wholly of Western origin. Woodford (1925) has described these beds in minute detail.

Gray sandstones, usually massively bedded and medium- to coarse-grained are found associated with San Onofre sediments. The stratigraphic relation of these beds to the true San Onofre is not always determinable; but their general association with these sediments is evident. San Onofre minerals can not always be distinguished in these beds with a hand lens; laboratory methods would probably reveal their presence. Beds

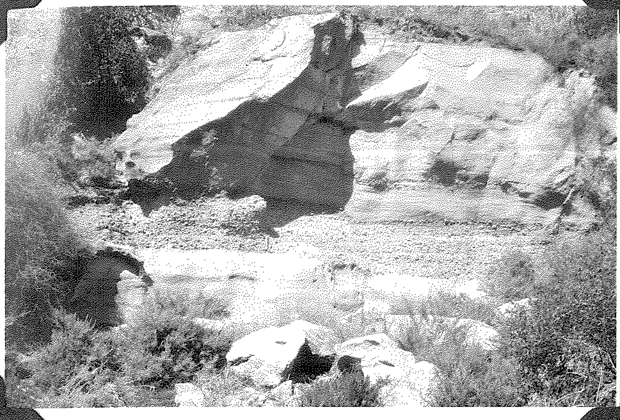


Figure 1. Pebble-conglomerate beds in the pre-San Onøfre Temblor. Outcrop in Laguna Canyon. (Page 26)

Figure 2. Block of glaucophane schist exposed in sea cliff west of Laguna. San Onofre facies of the Temblor formation. (Page 30)

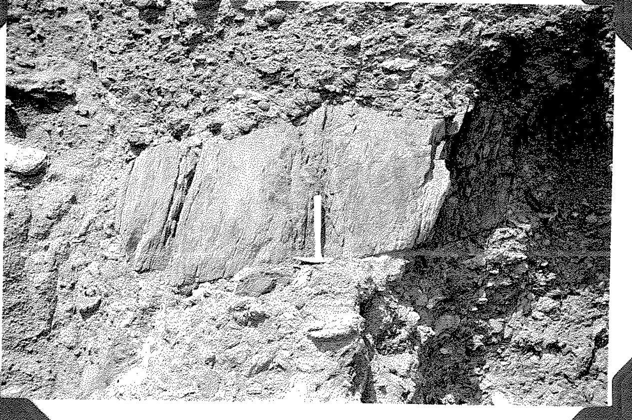


Figure 3. Large block of gnarled, metamorphosed sedimentary rock from Wester Bedrock Complex. San Onofre facies; west of Laguna in sea cliff. (Page 30)

of this description are found in the vicinity of Laguna town. Shales of a grayish, silty sort are sometimes associated with these beds. They also are found at Laguna.

D. MONTEREY FORMATION, UPPER MIOCENE.

White, siliceous shales occurring in the southwestern part of the area are referred to the Monterey formation. According to Woodford (1925), these shales lie probably conformably above the San Onofre facies of the Temblor formation. Practically no evidence is obtainable in the area mapped bearing upon the stratigraphic position of these beds. The occurrense at Emerald Bay in which white, siliceous shales of the Monterey type are seen to overlie with conformity beds of the San Onofre facies, has been mentioned above. The relation of these beds to others in the vicinity is not well known, but they appear to be interbedded with other San Onofre sediments. This bears out Woodford's conclusion that the two units are gradationally related. In the southwestern portion of the area, depositional contacts have been mapped between the San Onofre and the Monterey shales in two localities. These contacts do not throw any light on the stratigraphic relations between the two units. Structural relations in these localities are known to be complicated; and these contacts may be in part due to faulting. No fossils were found in this formation. The distinctive lithology of these beds is in definite accord with the conclusion that they are of Monterey age.

The top of the Monterey section is not exposed in this area. On account of this fact and that the section is hopelessly crumpled and distorted, as well as being poorly exposed, no measurement of the section has been attempted beyond a rough estimation of 2500 feet for its thickness.

The aspect of the Monterey formation in this area is similar to that of other correlatives of the type Monterey in Southern California. The cliff section along the shore from Abalone Point northwestward to Newport Beach constitutes an excellent exposure of these rocks. They consist mainly of white, siliceous shale. The texture is normally very fine. For the most part the shales are hard and flinty, but some beds are soft, punky and of low density. Concretionary beds are found, of very hard, dense limestone. Intercalated with the shales are occasional gray sandstone beds, a few feet in maximum thickness.

The Monterey formation is best studied in the area to the West of that here mapped, in the region of Newport Bay and the Inner Lake. In this locality occurs a gently folded anticline, in which the sequence of beds could be determined. It is hoped that this area may be studied in the future.

E. QUATERNARY MARINE TERRACE DEPOSITS.

Marine terrace deposits of Pleistocene age are found along the coastline of this area (Plate 3, Figures 1 and 2). They cover terraces reaching back from the sea cliffs. Their elevation above sea level is in the neighborhood of 75 feet. In one locality, immediately to the North of Laguna town and east of Laguna Canyon, a small, discontinuous area of these deposits has been mapped at an elevation of about 700 feet. To the West of the area mapped is found a situation similar to this last but of larger extent. There may be small patches of these sediments at other levels and other localities on the seaward slope of the Hills; but none have been definitely located and mapped.

These deposits have been assigned to the Pleistocene because of their undisturbed condition, except for elevation, and because they lie unconformably over all older sediments. North of Balboa, Mr. Everett Edwards of the California Institute reports a lower Pliocene or uppermost Miocene foraminifera fauna and an upper Pliocene fauna from silt beds overlain by terrace deposits which are evidently continuous with those of this area. An abundant marine molluscan fauna is found in certain of these terrace beds; but no paleontologic work has been done on them. The general aspect of the terraces and their deposits is very similar to that of such features in the vicinity of San Pedro.

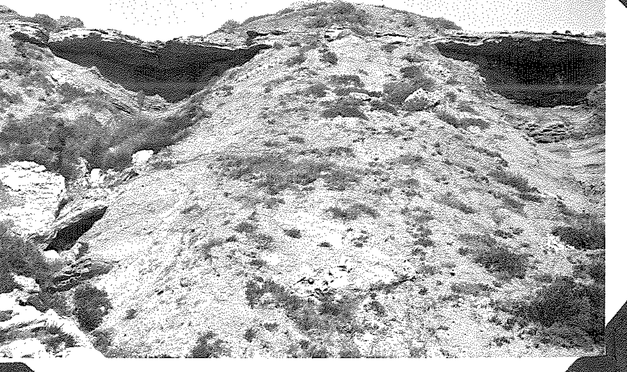
The major percentage of the terrace deposits consists of fine- to medium-grained sands. There are some conglomeratic beds, mainly basal. Some clay material is also found, in minor amounts. Constituent minerals may be from either the

Eastern or Western Bedrock Complex; but appear to be mainly from the East. They are probably almost entirely derived from the local Tertary sediments. The terrace deposits are very slightly indurated and easily weathered into bad-lands topography (on a small scale). Locally, cementation by limonitic and some calcareous material has progressed to a considerable degree, and certain beds are consequently well indurated. The typical aspects of these terrace deposits are shown in Plate 3, Figures 1, 2, and 3.

The maximum thickness of these deposits is probably 100 feet. The normal thickness is much less than 100 feet; but at certain points the deposits fill depressions in the pre-Pleistocene topography, and are therefore above average thickness.

Unfortunately these terraces mask areas near Laguna which are strategic in the unravelling of the Tertiary geology of that region.

Figure 1. Basal shell-conglomerate bed of Quaternary Marine Terrace deposits unconformably overlying Monterey shales. Cliff along coast southeast of Balboa. (Page 34)



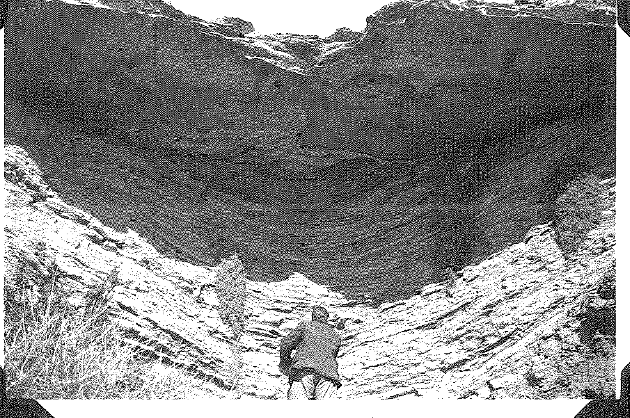


Figure 2. Closer view of locality of figure 1, above. Monterey shales truncated by basal Pleistocene bed. (Page 34)

Figure 3. Quaternary Marine Terrace deposits exposed north of State Highway, west of Abalone Point. (Page 35)

F. RECENT ALLUVIUM.

Recent alluvium is found in Laguna Canyon and in the beds of larger drainages in the northern part of the area. Its occurrence otherwise in the area has not been considered sufficiently important to warrant mapping. The northern edge of the Hills is bounded by the alluvium of the Santa Ana flood plain. Within the northern part of the area, the alluvium attains a considerable thickness (50 ? feet maximum). Some of these deposits may be of marine origin, continuous with the Pleistocene sediments in the southern part of the area. But since no marine shells or other definite evidence of marine deposition have been found, these are considered to be of terrestrial origin, and have been so mapped. Alluvial deposits are indicated on the map by uncolored areas.

Much of the alluvium found in the northern region is rather fine-grained sand and silt. Pebble beds and coarser detritus are also found. The alluvium found in Laguna Canyon is typical river gravel.

G. IGNEOUS ROCKS.

Outcrops of igneous rock are scattered throughout the area. The region between Signal Peak on the West and the Vaqueros-Temblor fault on the East is relatively free from these occurrences; also the area immediately south of this region.

The igneous rocks of the area are readily divided into two groups: those of intrusive origin and those of extrusive origin. The extrusive rocks are limited areally to the region along the coast from Laguna to Abalone Point.

The intrusive rocks occur as dikes and pipes which have evidently been intruded along zones of weakness, either faults or fracture zones. The chief area of outcrop of these rocks is along a north-south line paralleling the course of Laguna Canyon, a short distance to the West of the Canyon. In this region is found an interrupted series of dikes extending from near the northern limit of the area to the north edge of the marine terrace deposits in the town of Laguna. These dikes are essentially vertical. They are most prominent and have the widest outcrop in the northern region, where they occur in two long, continuous, roughly parallel outcrops, terminated on the South by the Vaqueros-Temblor fault. South of this fault they become less continuous and display a branching effect in the mapping pattern. Plate 4, Figure 1 shows one of the dikes south of the fault. The general elongation of this zone of intrusion is parallel to the direction of strike on the east flank of the general arch of the Hills, on which it is found.

PLATE 4.

Figure 1. Intrusive dike. West of Laguna Canyon and south of main Vaqueros-Temblor fault in north-eastern part of area. (Page 37)

Figure 2. View of west dike, west of northern part of Laguna Canyon. Showing abnormal in-duration of sediments near intrusive contact. (Page 38)

Figure 3. Typical aspect of dike; west of Laguna Canyon in its northern part. East main dike. Differential weathering of sediments and lava is evident. (Page 39)

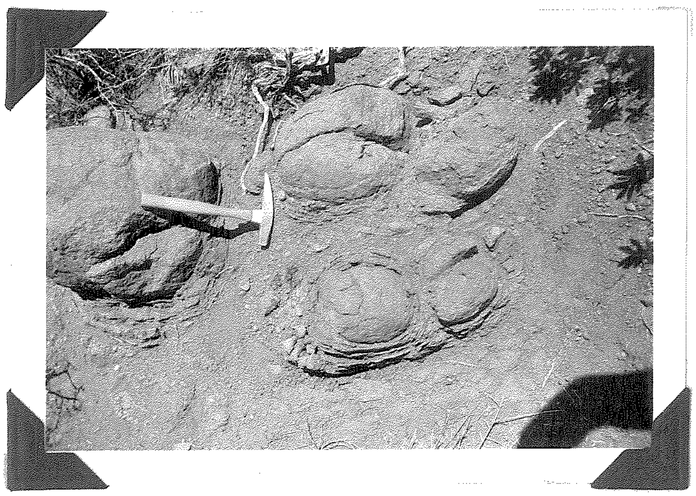


Figure 4. Spherical weathering forms exhibited by dike rocks in various localities. (Page 40)

The contacts of the dike rocks with the sediments intruded appears to be almost invariably intrusive. A possible exception to the rule is the case in which the trend of the dikes is off-set by a fault trending in a general east-west direction west of the small lakes in the northern part of Laguna Canyon. The dikes are here mapped as being offset by faulting subsequent to intrusion. Further study of this situation may reveal that the faulting took place previous to intrusion, and that the fractures or faults along which intrusion took place were displaced rather than the dike itself. In this case the contacts here would be intrusive instead of fault contacts, and thus conform to the conditions found elsewhere in the area. A rather slight baking effect is the only apparent result of a metamorphic nature of the intrusions on the intruded sediments. This is displayed only immediately at the contact. A pronounced increase in the degree of induration of sediments near intrusive contacts is frequently seen. This is apparently due to absorption of silica and calcite from the solutions emanating from the intruding body. Induration of this nature is seen in a striking fashion along the contacts of the more western of the two strong dikes to the West of Laguna Canyon in its northern reaches (Plate 4, Figure 2).

Occurrences of dikes and pipes other than those included in the prominent zone described above are too numerous to be discussed here. Not all of these outcrops have been mapped. Some are very minor in areal extent. They display the same general characters described above for the more significant occurrences. In the northwestern portion of the area are found two large outcrops of igneous rock. These have not been studied carefully; they are thought to be intrusive masses, the classification of which is not clear. They are of the same general composition and texture as other dike rocks of the area. But they do not have the mapping pattern of dikes; they may be modified sills.

As a rule, the intrusive rocks weather much more readily than the surrounding sediments (Plate 4, Figure 3). For this reason few localities have produced samples of sufficient freshness for laboratory study. Some exceptions to this rule are found. However, lack of time has forbidden thin-section examination of any of the igneous rocks. The usual texture is that of a rather fine-grained porphyry, with aphanitic groundmass. Both the phenocrysts and ground mass may vary considerably in coarseness. The texture of certain specimens taken from the more eastern of the two main dikes in the northern part of the area is much coarser than that of the usual dike rock of the area, and is not porphyritic but is of a uniform, medium phaneric nature. The acidity of these rocks varies. The usual case is one of rather higher than medium acidity. Striated feldspars are abundant. Orthoclase is rare. Quartz is ordinarily lacking; the specimens mentioned above from the east dike being an exception in this respect also. Femic minerals are not usually found as phenocrysts. In the uniform-grained specimens biotite is present. Other than this, dark minerals are indistinguishable. Some rocks from the intrusions in the northwestern part of the area appear to be more basic than the usual dike rock. These are also finer-grained porphyries than the usual type. At various points peculiar spherical weathering forms are found (Plate 4, Figure 4). These may be due to magmatic segregation or to concretionary action.

Calcite is very frequently associated with intrusive masses. It occurs along the contacts and in fractured portions of the surrounding rocks. The calcite probably crystalized out from liquids derived from the intruding mass, during and after intrusion. Shrinking of the intruding body may have left cavities in which the calcite was deposited along the contact. The mineral is often found in large, well developed crystals, in masses up to about 1 foot in diameter.

The extrusive rocks are scattered along the coast from Laguna to Abalone Point. (See Plate 5, Figures 1 and 2). Contacts are ordinarily not well exposed. At Abalone Point, on its northwest side, the contact of the lava with the underlying Monterey shale appears to consist of an agglomerate. It is partially covered by landslide material, and is not very satisfactorily exposed. But from what can be seen, the agglomerate, composed of fragments of various sorts from the underlying sediments and the overlying lavas, seems to give definite indication of extrusive conditions. Columnar structure is well displayed at Abalone Point and in the road cuts of the State Highway a short distance west of the center of Laguna town. This joint structure, the attitude of the contact at Abalone Point, and the general areal pattern of the lavas all indicate that the general dip of the flows is toward the sea.

These extrusive lavas are ordinarily very fine-grained and aphanitic. They are rather basic in composition. Mr. Engel states, orally, that some of the lavas contain a large amount of analcite. The general composition of the extrusive rocks is considered to be near that of basalts.

The question of the age of these igneous rocks is a difficult one. All evidence in the area tends to indicate that the intrusions were post-structure, or possibly in part contemporaneous with development of structure. The structure is obviously post-Tembler, since Temblor sediments are intimately involved in the structural features. Furthermore, accepting Woodford's conclusion that deposition was continuous and undisturbed in this region from San Onofre time through Capistrano time, the structure must be post-Capistrano. As mentioned above, Mr. Edwards has found lower (?) and upper Pliocene foraminifera faunas in beds to the North of Balboa; and these are rather confidently correlated with the Capistrano formation of Woodford (1925) on the opposite (east) side of the San Joaquin Hills. Woodford's evidence for conformity throughout the time interval

Figure 1. Extrusive lavas at Abalone Point. Columnar cooling structure is seen on the right. (Page 40)

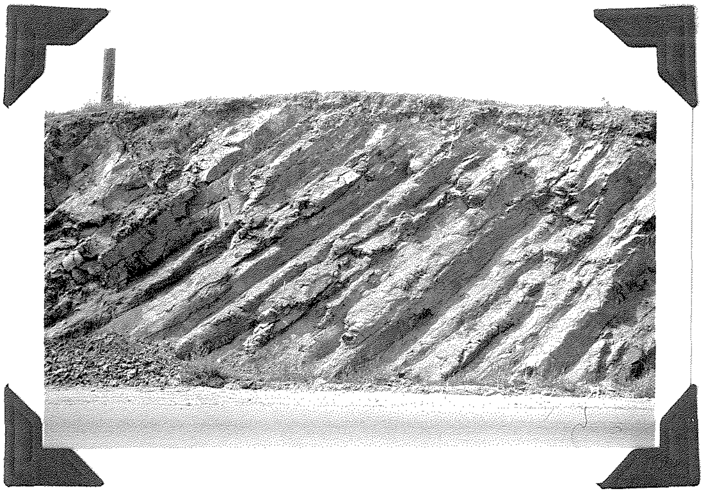


Figure 2. Extrusive lavas exposed in road cut of State Highway; town of Laguna, between Laguna Canyon and Emerald Bay. Columnar structure is evident. (Page 40)

stated appears to be valid. We have no evidence to the contrary. Also, the structure of the Hills is obviously older than the Pleistocene terraces. This would place the structure and intrusions in the Pleistocene; presumably in the lower half.

The extrusive igneous rocks of the area are older than the terrace deposits. That they are younger than the main period of development of the Hills is evident from the fact that they were extruded upon a surface in which the structural relations were essentially as they are today. It is probable, however, that the lavas were not originally laid down with their present dip toward the sea. Therefore, it is concluded that they were extruded during the earlier part of Pleistocene time, while the structure of the Hills was still in the process of development, or at approximately the same time as that of the intrusions.

This age assignment for the igneous rocks of this area is strikingly different from the age of similar igneous rocks in other regions surrounding the Los Angeles-Santa Ana Tertiary basin. The period of maximum volcanic activity in the Santa Monica Mountains and in the Puente Hills, for instance, is found to be largely confined to Temblor and pre-Monterey time.

If the Monterey formation were unconformable over the San Onofre facies in this region, the structure of the San Joaquin Hills could have been developed in the time interval represented. The present investigation has not brought forth evidence to this effect. Until such evidence has been produced, we must accept Woodford's conclusions, and deduce therfrom the age of the igneous rocks of this area as lying within the earlier half of Pleistocene time. It is recognized that this is discordant with the geologic history of neighboring regions; and that further investigation may prove that an unconformity exists within the post-Temblor Tertiary sedimentary section, allowing this age assignment to be changed.

V. STRUCTURE.

A. INTRODUCTORY REMARKS.

It is believed that the major structural features of the San Joaquin Hills have been discovered during the present investigation. Further work will, however, probably alter present conceptions of the mechanism of certain lines of faulting, and will add other details not now known regarding folding and faulting in the area. For instance, it is possible that the fault which brings the Vaqueros in the northeastern part of the area up against the Temblor will be found to consist of two intersecting faults instead of one continuous feature as here mapped.

In the following discussion, faults are believed to be vertical unless otherwise stated.

Also, it is convenient for purposes of discussion to consider the existing portion of the original arch of the Hills as the stable block, and to refer to minor blocks as having been dropped down or brought up with reference to it. This may or may not be literally true; but the conception will here be used as a convention.

B. DOMINANT FEATURES OF STRUCTURE.

Fundamentally, the San Joaquin Hills constitute a broad arch, plunging toward the North, which has been altered to an extreme degree by faulting. This arch, in its unfaulted state, would expose no sediments older than early Temblor, assuming the existing relations between the remaining portion of the arch and sea level to hold true. Faulting has brought Vaqueros sediments, well down in the section, into the zone of erosion in the southwestern and northeastern portions of the area.

The trend of the arch is generally north-south. This is indicated by the approximately north-south strike of the beds exposed on its flanks, at some distance from the axis. The arch is assymetrical. Dips in the unfaulted portion of its west flank range around 25 - 30 degrees toward the West. The axis trends generally northward in its southern part, swinging toward northwest until cut off by faulting. To the East of the axis dips range from 10 to 20 degrees north and northeast for some distance, after which they swing gradually to the East and increase to about 25 degrees again on the East flank. From a hasty glance at the map, the conclusion might be reached that the section on the west flank was much thinner than that on the east flank. This aspect is due to the assymetry of the arch, and is deceptive, since computations place the thickness of beds on the two flanks at approximately the same figure: about 4450 feet.

The major lines of faulting trend north of northwest. In a general northwest-southeast direction through the central part of the area from one limit to the other, extends a zone uncut by major faulting. To the Southwest and Northeast of this zone faulting has played havoc with the structural continuity of the beds.

C. STRUCTURE IN THE SOUTHWESTERN HALF OF THE AREA.

The unfaulted body of Temblor sediments in the zone mentioned immediately above strikes generally southward, toward sediments of Vaqueros, San Onofre, and Monterey ages, as well as blocks of sediments of the same stratigraphic unit as themselves. This zone or belt of rocks of various ages is separated by a continuous but irregular and branching series of faults from the main unfaulted block. This system of faults is a very complex one.

About one mile inland from Laguna and Arch Beach is found a fault trending in a general northwestward direction, which drops sediments of the San Onofre facies and upper pre-San Onofre Temblor sediments down against Temblor sediments lower in the section. The fault appears to dip toward the Southwest at an angle of probably 75 degrees. It is complicated by a parallel fault to the North, which joins the main fault at both ends. The area between the two faults includes Temblor sediments which are considerably disturbed, but whihhrespect probably not displaced to any large extent, with respect to the main mass of sediments to the North. Displacement along the main fault is estimated at 1000 feet. It extends eastward beyond the limits of the mapped area. Toward the Northwest it probably trends into a branch of the dike which outcrops uninterruptedly for about 2 1/2 miles north from Laguna, west of Laguna Canyon. Probably preintrusion faulting took place along this dike (or the zone along which intrusion took place later), since the sedimentary section measured at right angles to the dike is thinner than should normally be expected. The faulting along the line of this dike has interrupted and off set another fault striking into it, north of Laguna and west of Laguna Canyon, from the Northwest. East of the d dike, this fault appears to continue in the same general direction, but with lessened displacement. This fault also has brought the San Onofre down against lower Temblor sediments. The depositional contact between the San Onofre and the underlying facies of the Temblor parallels Laguna Canyon on its east wall, and is cut off on the South by the fault described immediately above and on the North by the first fault described.

The fault described immediately above, which is offset at the north-south dike (not by reason of faulting along the line of the dike, but by reason of the existence of the pre-intrusion fracture at the time of faulting along the offset structure), dies out less than a mile to the West along its strike. The displacement occurring along it is taken up by another fault trending into it from the Southwest. This in turn dies out and the displacement is taken up by still another fault trending west of North, which terminates, toward the North, two parallel faults coming in from the Northwest. The result of this whole continuous system of faults, along which movement is thought to have occurred simultaneously, has been to drop higher sediments on the

Figure 1. View of region traversed by north-dipping fault; west of Abalone Point Canyon, about 1 1/2 miles from coast. Vaqueros sediments in foreground, Temblor in background. (Page 48)

Figure 2. Exposure of main Vaqueros-Temblor fault, about 1 1/2 miles east of Signal Peak. Locality 42. Temblor fossiliferous sandstones on left and Vaqueros red conglomerates on right. (Page 54)

South and Southwest down against lower sediments on the North.

Between the two parallel faults mentioned immediately above occurs a block of San Onofre sediments. The more southerly of the two has been mapped as dying out toward the Northwest, after cutting off the Monterey-San Onofre depositional contact, which extends northward and westward from its point of termination against the fault. This contact, mapped as depositional, is probably further disturbed by faulting of an unknown character. The more northerly of the two parallel faults extends continuously for 2 or 3 miles toward the North and Northwest, before dying out, dropping the San Onofre sediments down in turn against lower Temblor sediments, Vaqueros sediments, again lower Temblor beds, upper Temblor rocks of the pre-San Onofre facies, and finally lower San Onofre sediments.

Branching off toward the East from the fault described immediately above are two others, one branching near its southeast end and the other near its northwest end, which, by intersecting with others to form a system, finally pinch together toward the Southeast, thereby enclosing a block composed of Vaqueros and lower Temblor sediments. This block is traversed in its eastern part by Abalone Point Canyon. It is bounded on the South-west by San Onofre sediments, and otherwise by non-San Onofre Temblor rocks ranging from the lower to upper parts of that section. The northeastern boundary of the block is a fault about 2 1/2 miles in length. Plate 6, Figure 1 shows the aspect of this boundary. This fault dips, abnormally for this area, at a minimum angle of probably 60 degrees. If all the curvature of the trace as mapped were due to dip, the angle would be much less than 60 degrees. In the more extremely curved portions, some of the curvature is thought to be due to actual curvature in the fault surface. Since the dip of the fault is toward the younger sediments, it is a normal fault. The maximum stratigraphic displacement along this fault is estimated to be in the neighborhood of 3000 feet. This displacement is believed to have had no horizontal component except that necessitated by dip. The stratigraphic displacement of the southwestern edge of the block, relative to the San Onofre sediments against which it is faulted, is much greater than that shown on the northern edge, estimated above, being about 7000 feet.

Other faults of a minor nature are present in the southwestern half of the area mapped, within the block discussed immediately above and elsewhere. These will not be discussed further.

An interesting feature of the structure of this part of the area is the presence of several well-defined, persistent lines of fracturing. Three of these fracture zones are present. The most easterly of the three is cut off on the South by the north-dipping fault between Temblor sediments on the North and Vaqueros sediments on the South, at a point on the west wall of Abalone Point Canyon, about 1 3/4 miles from the Canyon mouth. From this point,it trends west of North, swinging to almost due North. The next such zone branches off from the west side of the first, a short distance from its termination at the fault. Likewise, the third zone branches off from the second at a point not far from the juncture of the latter with the first zone. The two more westerly zones begin with trends west of North, the western-most trending more toward the West than either of the other two. These last two also swing toward the North during their courses. As a group, they form a radiating pattern, the angles between them being small. At Signal Peak, the two eastern-most of the three zones become faults between which a graben of San Onofre sediments has been dropped down in contact with pre-San Onofre Temblor sediments. The westernmost zone of the three continues as a fracture zone as far toward the Northwest as the depositional contact between the San Onofre facies and underlying Temblor sediments. There it appears to die out. Possibly the reason for the dying out of this fracture here is that the less indurated San Onofre sediments were capable of absorbing the stresses which caused the fractures without the development of definite planes of fracture.

In good exposures these zones are seen to be sharply delimited by well-defined discontinuity in the beds which they traverse. The width of the band of fractured, brecciated rock varies from a few feet to over 100 feet. The material within the zone is made up of fragments and blocks derived from the beds outcropping in the immediate vicinity. These blocks may be of any size, up to the width of the zone. In outcrops where the zone is wide the bounding surfaces may be seen at times to traverse the bedding as separate fractures, while the intervening material may consist of a relatively undisturbed

Figure 1. Frac ture zone south of Signal Peak. The two separate fractures here represent bounding surfaces of one main feature. The intervening region properly constitues the whole zone. (Page 51)

Figure 2. A condition similar to that of figure 1, along the same zone of fracture. (Page 51)

Figure 3. Fracture zone south of Signal Peak. The same bed is seen to extend away from the fracture from corresponding points on opposite sides, without change of position or attitude. (Page 51)

portion of the surrounding beds, continuous with the latter except for the breaks due to the limiting planes of the fracture. (See Plate 7, Figures 1 and 2). The rule is that there has been no net displacement along these zones. Beds exposed in continuous outcrop up to one limit of the fracture zones are frequently to be seen extending away from the corresponding point on the opposite side of the zone with the same attitude (see Plate 7, Figure 3). Locally, near faulted regions or intersection of fractures, the beds traversed are seen to have different attitudes on opposite sides of the zone; altho no net displacement can be distinguished. Exceptionally a small displacement has taken place along certain portions of a zone. These fractures traverse bedding irrespective of its attitude.

These phenomena are rather exceptional, at least within the experience of the writer. Altho no certain explanation of the origin of these observed facts is forthcoming, various ideas regarded as probable may be set forth. It may be that these zones represent incipient faults. This idea is borne out by the fact that two of them actually become faults of considerable displacement along their trend. They may represent planes or surfaces along which vibrational movements have taken place. If major displacement had taken place along them, the beds on either side would surely not have finally returned to their original relative positions. In any case they may be regarded as incipient faults in the sense that stress applied to the region in its present condition would undoubtedly be relieved, at least in part, by movement along these surfaces. They may have originally been formed either by shear stresses or tensional stresses in the portions of the original arch of the Hills having greater than average radius of curvature. Or they may be the result of a combination of these two types of stress and of others. It would seem strange that no displacement should result if the stresses were purely in the nature of shear. Perhaps clean, rectilinear breaks of this nature could not, on the other hand, be expected from purely tensional forces.

Infrequently, intrusive lavas are found along these zones. From this fact and the further observation that the mapping pattern of the dikes in the eastern part of the area is strikingly similar in general aspect to that of the fracture zones, it is deduced that these structures on which the dikes were intruded which were not faults were probably of the same nature as the fracture zones.

D. STRUCTURE IN THE NORTHEASTERN HALF OF THE AREA.

Structure to the Northeast of the northwest-southeasterly-trending area of unfaulted beds extending through the central part of the area from one limit to the other is very much more simple than the structure to the Southwest of this unfaulted zone.

The most significant structural feature in this northeastern half of the area is the Vaqueros-Temblor fault. This feature brings the sediments of the former formation up against those of the latter series for a distance of about six miles. The fault trends northwestwardly through the area from the limit of the map east of the confluence of Toro Canyon and Laguna Canyon to the alluvium of the Santa Ana flood plain in the northwest part of the map.

This fault was mapped late in the progress of field work. Throughout a great deal of its extent, it is not readily observable in the field. As field work progressed, evidence of faulting in different parts of the present mapped extent of the fault was more and more frequently encountered. Eventually, concurrence of the data made necessary the existence of a fault such as that mapped, or if not a single continuous fault, then a series of intersecting faults. Bearing in mind the demand of data already accumulated for the existence of the fault, a detailed field examination of the regions indicated by the data was made. Good evidence was found at frequent intervals along the trace of the feature for its existence. There are of course areas in which in which its existence can not be demonstrated.

In the neighborhood of Toro and Laguna Canyons and as far west as the western dike in this region, Vaqueros conglomerates strike into the fault from the North with the same trend as the much less conglomeratic Temblor sandstones and pebble-conglomerates strike into it from the South. In the earlier part of the investigation this change from heavily conglomeratic material to pebble-conglomeratic sandstones was thought possibly to be the result of lateral variation. But the transition along the strike of beds is found to occur abruptly at the fault.

Definite discontinuity of the dike series parallel to Laguna Canyon and west of the Canyon is observed along the trace of the fault. Intrusions along the fault are found to occupy a considerable proportion of its length in this vicinity. The trend of the dike series appears to be offset by this fault.

In the region west of the dikes, Vaqueros conglomerates dip and strike into the fault from the East and North, while on the West, Temblor sandstones strike into the fault. (See Plate 6, Figure 2). About 1 1/2 miles northeast of Signal Peak occurs a small block of fine-grained Vaqueros sandstone, west of the main trace of the fault. It is isolated by two short intersecting faults which cut off the northwest angle between the main fault and one terminating against it from the West. This small block bears a Turritella inezana fauna. It must have suffered its major displacement along the faults separating it from the Temblor sediments; its displacement relative to the Vaqueros conglomerates in contact along the main fault is estimated at roughly 1000 feet.

In addition to paleontologic evidence from the small block described immediately above (Locality 110), fossils are found at other points (Localities 92, 111 and 42), tending to substantiate the presence of the fault. At locality 92, Turritella inezana is found in a hard, concretionary, limestone bed. At locality 111, T. ocoyana and several of its varieties are found in fine-grained sandstones with limey concretions, these beds are very deceptively similar to those in the immediately adjacent small fault block of Vaqueros sediments (Locality 110). When T. ocoyana was found at locality 111, it was thought that the beds in which it occurs were members of the same series as those in the adjacent Vaqueros locality 110, bearing T. inezana. The beds at both localities were examined carefully, and not a species or variety was found in common. Another locality (42), about 1/2 mile southeast of the small Vaqueros fault block, immediately adjacent to the fault, has furnished a fauna of decided Temblor aspects.

The estimated maximum displacement on this fault is roughly 8000 feet. This figure is large, but inescapable. It is computed from the region in the northwestern part of the area, where intersection of a fault from the South with the main fault has brought the San Onofre sediments in contact with those of the middle Vaqueros.

East of the major fault described above, pre-intrusion faulting has taken place along the line of the west lava dike. Basal Vaqueros sandstones dip westerly to the West of this fault.

East of the fault, Vaqueros conglomerates belonging above these sandstones stratigraphically dip toward the East and Northeast.

Similarly, pre-intrusion faulting has probably taken place along the northern part of the east lava dike. East of this dike minor folding is exhibited in the upper Vaqueros sediments. Little is known of the details of this folding.

West of the small lakes in the northern portion of Laguna Canyon is found a westerly-trending fault which offsets the courses of the two dikes of this vicinity. As mapped, this fault indicates fault contacts with the igneous rock. Hence it would be of post-intrusive date, in contrast to the rule for other faults in the area associated with intrusions. More detailed examination may reveal that this fault, in common with the others, displaced not the dike itself but the lines of weakness along which intrusion took place.

North of Signal Peak occurs a north-south trending graben of San Onofre sediments, dropped down into contact with pre-San Onofre Temblor sediments; this has been mentioned above. The fault bounding the graben on the East terminates against the main Vaqueros-Temblor fault. The western bounding fault dips toward the East, toward the younger sediments, at a probable angle of 65 degrees. It is therefore a normal fault. Dip cannot be distinguished in the northern extent of this fault.

Many examples of intra-formational faulting, of a minor character, are found in this northeast half of the mapped area. They are usually intimately related with the major faulting. These will not be discussed further, in this report.

E. CONCLUSIONS REGARDING STRUCTURE AND ITS ORIGIN.

One conclusion reached on the basis of a general consideration of the structural features found in the San Joaquin Hills is that the general arch of the Hills was formed previously to the faulting. The faults are relatively local affairs as compared to the anticlinal arch. Blocks segregated from that portion of the original arch which still exists as such conform in a general way to the structure of the arch. As an example, in the vicinity of Laguna and in the northeastern part of the area, blocks thus segregated by major faulting still show a general northerly strike and easterly dip, comparable to that found in the undisturbed east flank of the arch situated between these two localities. Portions of the northeastern block, it is true, are at variance with this general condition; but they do not invalidate the essential truth of the above statement. If the faulting had occurred previously to the folding, this condition would probably not be found, since there would undoubtedly be differential stresses in the different blocks. It is not believed that any great length of time elapsed between arching and faulting. Rather, the faulting is regarded as an expression of a gradationally later phase of diastrophism than the folding. It is conceived that the development of the structure in the area began with gentle arching. This developed into pronounced arching. With continued activity of the deforming stresses, the upper portions of the arch, with radii of curvature greater than ~~the~~ average for the fold, were subjected to strains which resulted first in the fracturing and then in the faulting now exhibited. Undoubtedly the problem involves complicated details not stated above; but the general conception is not thereby invalidated. Judging from the computed magnitude of movement on the lines of faulting, and assuming that the faulting is due to stresses in the upper part of the fold, the rocks must have been affected by this diastrophism to a very great depth.

On most of the faults of the area, no dip is distinguishable. This is due, in some cases to inadequate exposure, and in others to the fact that they are actually vertical. In the cases of three major faults previously discussed, dip (not vertical) is measurable. In all three cases the dip is toward the younger sediments; hence all three are normal faults. Curvature in the main Vaqueros-Temblor fault in the Northeastern part of the area may be due to dip also. If so, this fault, having the largest displacement of any in the area, is also a normal fault. These facts are considered as good evidence that tensional stresses occupied a prominent place among those present in the upper portion of the arch of this area during the period of development of faulting. Other stressed were undoubtedly present.

Since it is probable from the preceding discussion that tensional stresses were present in a major degree during faulting, it is a logical conclusion that the fracture zones in the vicinity of Signal Peak and southward resulted in large measure from such stresses. Probably shear stresses were also present; but it is more difficult to understand how fracture zones generally showing no movement could have been formed from strains largely of shear than it is to understand their origin from largely tensional strains.

Horizontal movement along lines of faulting appears to have been very small in amount. Movement seems to have been almost wholly vertical, or, in the case of non-vertical faults in the direction of dip. The offset observable in the trend of the dike series west of and parrallel to Laguna Canyon at the Vaqueros-Temblor fault may be due to horizontal movement or to slightly non-vertical dip of the zones of intrusion. The stratigraphic displacement along the fault in this vicinity is very large compared to the offset in the dikes. If the dikes are dipping at a high angle to the horizontal, no horizontal movement is necessary to account for the offset; if they are essentially vertical, the vertical component of movement along the fault is very great as compared to the horizontal component. From this example and the general aspect of the structure of the area, it would appear that horizontal shear stresses were of minor importance in the development of the structure.

From the fact that a broad arch is the dominant structural feature of the Hills, it is evident that the fundamental external forces acting upon the region to produce the structure were of a compressional nature, unless arching was due directly to some such cause as the rise of a batholith, which is considered unlikely. This principal force must have acted in a general east-west direction, to produce the observed northward-plunging arch. The fact that the faulting, which is assumed to be subsequent to the folding, trends in directions varying from north-south toward northwest-southeast, would indicate that the direction of application of external deforming forces to the region changed progressively after the beginning of faulting from east-west toward northeast-southwest. This conclusion is borne out by the fact that in general, where lines of faulting and fracture intersect, the supposedly later northwest-southeast faults have cut the presumably older north-south faults and fractures.

VI. GEOLOGIC HISTORY.

A. PRE-MIOCENE TIME.

Assuming, as previously concluded, that the oldest beds exposed in the San Joaquin Hills are lower Vaqueros in age, no evidence regarding the geologic history of the region previous to lower Miocene time is to be derived from the area itself.

According to the literature, fluctuations in the distribution of land and sea occurred many times during Paleozoic and Mesozoic time, over the region of present California and the adjacent continental shelf, indiscriminately.

During Cretaceous and pre-Vaqueros Tertiary time, a land mass composed of the Eastern Bedrock Complex existed, with varying elevations, to the East of the Los Angeles-Santa Ana Basin. There is no evidence for a land mass to the west of the Basin during this time. The strand line flustuated during this period; causing alternate erosion and deposition in the Basin, at least marginally.

B. MIOCENE TIME.

1. Vaqueros Time (Lower Miocene).

As previosly mentioned, the history of earliest Vaqueros time is not revealed in the present area. The earliest (lower Vaqueros) sediments indicate for this region a shallow sea in which sands were being laid down, from sources composed of the Eastern Bedrock Complex. This condition prevailed during the deposition of about 1400 feet of such sediments. Probably the basin was continually subsiding; otherwise sediments of this nature would probably not have been continuously deposited to such a depth.

After deposition of these sandstones, conglomeratic material began to come into the basin. This change in character of the sediments may have been due to changes in climate, drainage or topography, or a combination of these. From the coarseness of these conglomerates and their color and the presence of red beds overlying them, it is concluded that the sea was very shallow, and that fluctuations of depth may have caused lagunary rather than frankly marine conditions at various times. Subsidence must have continued to take place in order to allow the deposition of 1600 feet of these conglomerates.

At this time the the basin began to subside more rapidly than the sediments came in, and truly marine conditions came to exist. The character of the sediments changed to predominantly fine sands. With these were deposited remains of the marine fauna, known as the Vaqueros or Turritella inezana fauna.

The character of the sediments again changed, and possibly a further deepening of the basin took place. Clays and sands were laid down alternately and with some mixing.

After about 400 feet of these sediments had been deposited, emergence of the marginal portions of the basin occurred. Erosion took place there and the beds just laid down were in some places deformed. During this diastrophic activity, ocean currents and other oceanographic conditions must have changed, for a new fauna appeared; and the old fauna disappeared from this part of the basin. Deposition was continuous throughout, in the region of the present San Joaquin Hills.

2. TEMBLOR TIME. (Middle Miocene).

a. Pre-San Onofre Time.

The beginning of Temblor time is dated from the appearance of this new fauna, called the Turritella ocoyana fauna. Its earliest remains were buried in medium - to coarse-grained sands, which later became well indurated with calcareous cement.

Alternating sands and clays, the latter predominating, similar to those deposited previously to the appearance of the T. ocoyana fauna, were laid down to a thickness of some 300 feet.

After this came a period during which 6100 feet of coarse- to medium-grained sands and pebble-conglomerate material was deposited. Some fine-grained sands were intercalated with these. During this time the basin must again have been undergoing subsidence. The materials are very similar throughout the whole thickness of these deposits. Remains of the Turritella ocoyana fauna were buried more or less continuously throughout this period, with the detritus from land. The sources of these sediments were to the East, as in the case of the Vaqueros deposits.

b. San Onofre Time.

At some time during Vaqueros or pre-San Onofre Temblor time,,a land mass arose to the West of the San Joaquin Hills area. It was composed of the Western Bedrock Complex, with a covering probably of Cretaceous or early Tertiary sediments or both. This cover was eroded, and after the deposition of 5100 feet of Temblor sediments drainage from this western land began to bring in detrius from the Western Bedrock Complex. At first these materials came in small amounts, and were mixed with material from the covering sediments (originally having been derived from the Eastern Bedrock Complex), and with material derived directly from the Eastern Bedrock Complex.

The percentage of Western Bedrock Complex detritus being deposited increased rapidly, until the sediments were almost if not wholly composed of this material. The western land mass must have been very close to the present coast line; since much of the material of the San Onofre facies is a very coarse, unsorted breccia, containing massive blocks with very angular edges. This land was probably continually emerging, and possibly the land mass to the East was subsiding, the combined final effect being to furnish the basin with sediments very largely derived from the West.

After deposition of several hundred feet (about 2600 feet according to Woodford) the western land ceased to furnish detrital sediments, as did also the eastern land. This effect was probably due to a combination of subsidence and erosion. In the absence of detrital sediments, and probably under the influence of constructive factors not well known, white, siliceous clay or mud began to be deposited. This material was intercalated with the last of the San Onofre sediments.

In the marginal portions of the basin, diastrophic activity produced distortion and erosion previous to the advent of the siliceous sediments. In the present area, continual deposition took place.

3. Monterey Time. (Upper Miocene).

A thickness of 2000 to 2500 (?) feet of deposits of the Monterey facies was laid down. During this time also, continuous subsidence of the basin is assumed. However, with this type of sediments subsidense is not so necessarily involved as with the previous beds discussed. Some sands were infrequently intercalated with the siliceous clays.

Peculiar physical conditions must have existed in this region in order to effect such a thickness of siliceous, white, organic clays. Many theories have been advanced in the literature to explain the origin of these sediments. It seems probable that a combination of low-lying bordering land masses, extreme aridity, and an abundant supply of ash from volcanic activity constitutes a large factor in this problem. That the contributing conditions were general is shown by the wide distribution in the California Coastal Belt of very similar sediments of the same age.

C. PLIOCENE TIME.

Deposition continued uninteruptedly from Monterey time into Pliocene time. The character of the sediments changed; the Capistrano sediments were mainly rather fine-grained sands and silts. Remains of the foraminifera fauna of the basin were deposited with detritus from land. In the basal beds fragments from the still emergent western land mass were deposited.

D. PLEISTOCENE TIME.

At some time during the earlier half of Pleistocene time the structure of the San Joaquin Hills was developed. This activity began with external forces acting in an east-west direction. The direction of application of these forces swung around to a northeast-southwest direction as diastrophism progressed. Thus were formed successively the dominant north-plunging arch, the north-south-trending faults and fractures, and finally the northwest-southeast-trending faults.

After the structure had been completely or nearly completely formed, intrusion of the dike rocks took place along lines of faulting and zones of fracture. At about this time also extrusions occurred, the remains of which are found along the coast northwest of Laguna town. Subsequently, a relatively small amount of diastrophic activity took place, tilting the extrusive lavas.

The western land mass probably subsided at about this time.

During the time of this diastrophic activity, the San Joaquin Hills had emerged into the zone of erosion. After erosion had proceeded sufficiently far to establish drainage, submergence of the whole area took place. Possibly a portion of the higher ground remained as an island.

From this state, the area emerged again, by intermittent stages. Terraces were cut by wave action; and subsequent deposition of upper Pleistocene sands and gravels took place on each of the terraces so cut. It has been estimated that about 10 of these terraces were formed, at intervals of elevation of 100 to 150 feet.

E. RECENT TIME.

During recent time, erosion has removed most of the Pleistocene terrace material from the higher elevations. The lower terraces still bear a great deal of their original burden of sediments. (See Plate 8, Figures 1 and 2.). Many of the higher terraces are still recognizable in the topographic forms presented.

At various places scattered throughout the area, alluviation of drainages with subsequent cutting down of streams to bedrock is observed (see Plate 9, Figure 1). This condition is interpreted as being due to slight elevation of the area, after normal alluviation, in relatively recent times. It is possible, however, that climatic changes or the effects of farming and grazing in the area may have produced this result.

In the northern portion of Laguna Canyon are found two small lakes (Plate 9, Figures 2 and 3) which at first glance appear to be anomalous occurrences. On further consideration it is seen that they are due to very recent damming effects of two large drainages entering Laguna Canyon from the West.

At the present time erosion is reducing the topography as rapidly as may be in hills whose greatest elevation is under 1200 feet. Cliff recession along the coast is taking place very actively. Probably a terrace of the same sort as those now found above sea level is being formed.

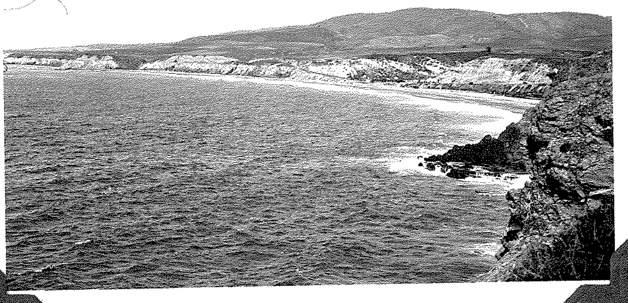
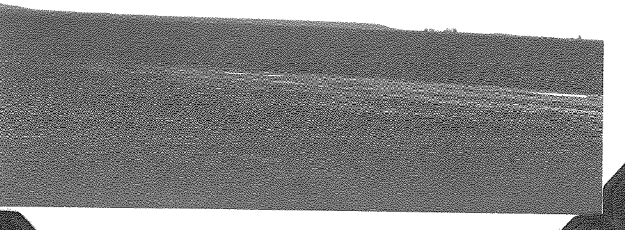


Figure 1. Pleistocene terraces, largely undissected. Seen from Abalone Point, looking northwestward. (Page 69)

Figure 2. Slightly dissected terraces in western portion of San Joaquin Hills, North of Balboa.



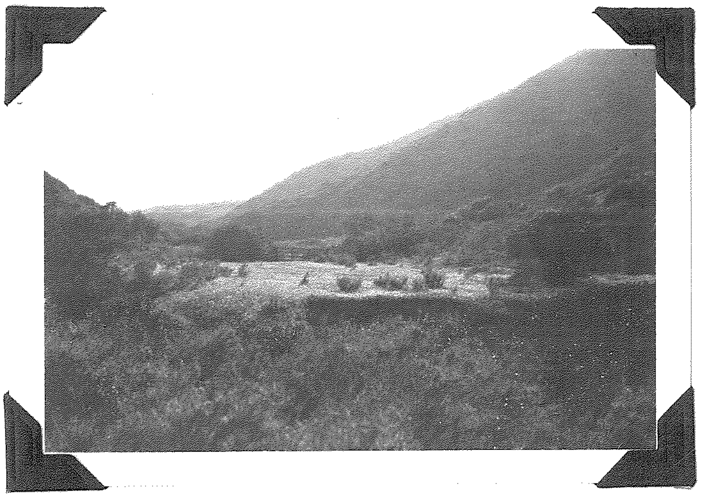


Figure 1. Dissected recent stream terrace in southern part of area. (Page 69)

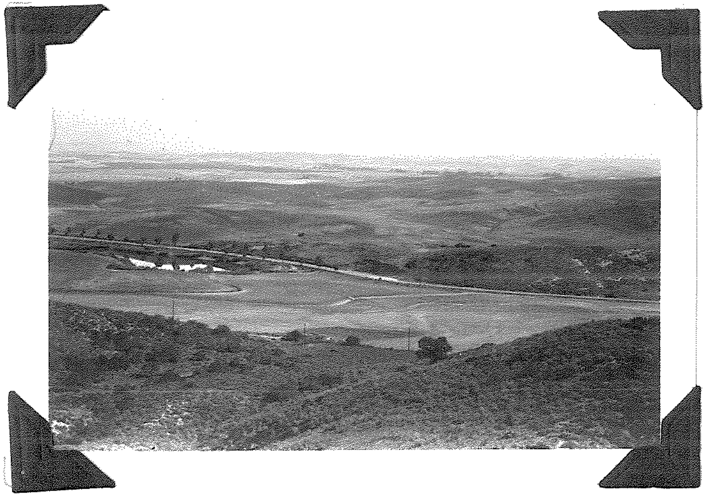


Figure 2. Small lake in northern reaches of Laguna Canyon, formed by damming effect of alluvium from large tributary drainages. (Page 69)

Figure 3. Second small lake of same nature as that of figure 2. Immediately south (to right) of figure 2. (Page 69)

VII. ECONOMIC POSSIBILITIES.

The only apparent possibility of economic deposits in the area is that of petroleum. The presence of much intrusive igneous rock would seem to indicate small probability of economically valuable amounts of oil. However, the infrequent occurrence of oil seeps along the cliff sections on the coast demonstrates that petroleum is present in the sediments. It is possible that detailed work would establish the desirability of drilling a test well near the axis of the main arch of the Hills to the North of the north-dipping fault which crosses Abalone Point Canyon about 1 3/4 miles from its mouth. No igneous rock has been observed in this vicinity.

VIII. SUMMARY AND CONCLUSIONS.

The sediments of the San Joaquin Hills, within the mapped area, are Miocene in age, belonging to the Vaqueros, Temblor and Monterey formations. These are overlain unconformably by Pleistocene marine terrace deposits. From original data it is concluded that continuous deposition took place from lower Vaqueros time through Temblor time. From Woodford's data (1925) it is concluded that deposition was further continuous through Pliocene time.

The structure of the area, consisting of a broad north-south-trending arch plunging northward, cut by north-south faults and fractures and then by northwest-southeast faults, was developed in the earlier half of Pleistocene time. Immediately following development of structure, intrusions of dike rocks along zones of weakness and extrusion of flows took place.

The age given for the intrusions is widely at variance with the Temblor-Monterey age assigned by investigators in other parts of the basin to similar rocks. From the present investigation nothing can be said further than that these intrusions came after structure in post-Temblor time. Woodford's data and conclusions (1925) are interpreted to mean that deposition was practically continuous from Temblor through Pliocene time, which places the post-structure intrusives in the Pleistocene. His is the only published work having a significant bearing on the present area. Woodford probably did not know the extent of these intrusions in the San Joaquin Hills. It is thought probable that future investigation will demonstrate discontinuity in the depositional sequence of this region during middle or late

Miocene time, and that the intrusions will be found to have occurred at that time. In the meantime, the only available published data has been accepted, and the structure and intrusions have been tentatively assigned a Pleistocene age.

IX. LITERATURE CITED.

English, Walter A.

1926. Geology and Oil Resources of the Puente Hills Region, Southern California.
U. S. Geological Survey, Bulletin 768.

Hoots, H. W.

1931. Geology of the Eastern Part of the Santa Monica Mountains, Los Angeles County, California.
U. S. Geological Survey, Professional Paper 165-C.
Shorter contributions to General Geology, 1930 (Pages 83-134).

Kew, W. S. W.

1924. Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California.
U. S. Geological Survey, Bulletin 753.

Louderback, G. D.

1913. The Monterey Series in California.
Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 177-241.

McLaughlin, R. P., and Waring, C. A.

1914. Petroleum Industry of California.
Calif. State Min. Bur., Bull. 69, 519 pp., with folio of geologic maps, etc.

Moore, B. N.

1930. Geology of the Southern Santa Ana Mountains, Orange County, California.
Unpublished thesis for the degree of Doctor of Philosophy, California Institute of Technology, Pasadena, California.

Vander Leck, Lawrence

1921. Petroleum Resources of California, with Special Reference to Unproved Areas.
Calif. State Min. Bur., Bull. 89, 186 pp., 12 figs., 6 pls.

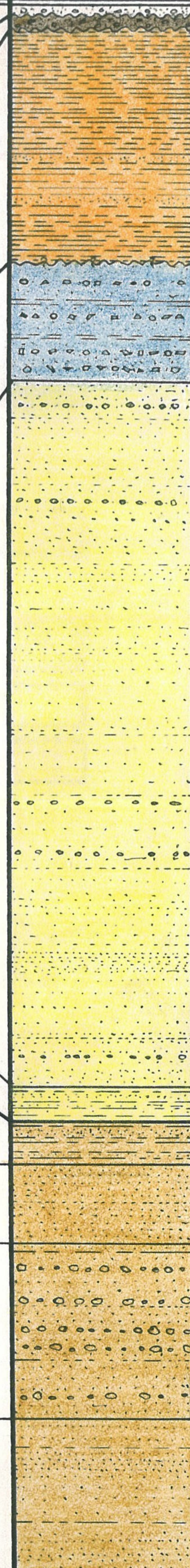
Woodford, A. O.

1925. The San Onofre Breccia, Its Nature and Origin.
University of California Publications, Bulletin of the Department of Geological Sciences, Vol. 15, No. 7, pp. 159-280, plates 23-35, figures 1-11.

COLUMNAR SECTION FOR SEDIMENTS OF THE SAN JOAQUIN HILLS

AGE	FORMATION AND CHARACTER	THICK-NESS
RECENT	QUATERNARY ALLUVIUM: Sands, gravels, etc.	50'
	Unconformity	
PLEISTOCENE	QUATERNARY MARINE TERRACE DEPOSITS: Sands, gravels, etc.	100'
	Unconformity	
UPPER MIOCENE	MONTEREY FORMATION: White, siliceous shales. Cherts. Spongy shales. Some sandstone.	2000'?
	Unconformity?	
MIDDLE MIOCENE	TEMBLOR FORMATION: San Onofre facies: Breccia, gray sandstones, gray shales.	1000'?
	Sandstones, coarse - to fine-grain. Pebble-conglomerates. Buff to gray color. Weathering in reefs with cavernous openings.	6100'
	Blue-gray shales, some sandstones.	300'
LOWER MIOCENE	VAQUEROS FORMATION: Blue-gray shales, some sandstones.	400'
	Fine-grained sandstones. Buff color.	700'
	Very coarse, red conglomerates with interbedded sandstones. Some red clays and white, arkosic sandstones, near top.	1600'
	Massive-bedded, coarse- to medium-grained sandstones. Some fine, shaley sandstones.	1400'

SCALE



L E G E N D

SEDIMENTARY ROCKS

RECENT

Quaternary Alluvium	QAL

PLEISTOCENE

Quaternary Marine Terrace Deposits	QMT

MIOCENE

Monterey Formation	TM
Temblor Formation	
San Onofre Facies	TTSO
Pre-San Onofre Facies	TT
Vaqueros Formation	TV

IGNEOUS ROCKS

PLEISTOCENE

Quaternary Extrusive Lava	QEL
Quaternary Intrusive Lava	QIL

CERTAIN UNCERTAIN CONCEALED

Fault or Breccia Zone

Depositional or Igneous Contact

Anticline

Syncline

Cross-section Line