Geology of the Southern Santa Ana Mountains,

Orange County, California

Thesis by

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Abstract

The area studied lies on the southwestern slope of the Santa Ana Mountains in the southeastern quarter of the Corona Quadrangle.

The oldest rocks are a series of slates and sandstones with some lenses of limestone and intruded by andesite porphyry dikes. Unconformably overlying the slates is a coarse conglomerate and in part of the area a series of basic lavas and tuffs. All these rocks have been metamorphosed by andesite granodiorite and diabase intrusions. Triassic fossils have been reported from the slates. The rocks overlying the "basement complex" constitute a westward dipping homocline, including upper Cretaceous. Paleocene, and middle Eocene formations, the Vaqueros and Topanga formations, the Puente shales, and the Capistrano formation, each of which is bounded by an unconformity or disconformity.

The structure is unusual in that, while the sediments are those typical of the Coast Ranges, the mountains are a tilted fault block, uplift taking place along the Elsinore fault system. The detailed structure consists of a few folds and faults not aligned with the Elsinore system.

The physiographic history shows a long series of repeated uplifts. Some of the lower terraces are marine. In the evolution of the present topography the resistance of the rocks has played a large part.

Summary of Thesis

The area studied and described in this thesis is located in the southeastern quarter of the Corona Quadrangle, California. In mapping this area which lies on the southwest slope of the Santa Ana Mountains two summers were spent were spent in the field as well as the week ends and holidays of the past four years.

The country may be described as a tilted fault block which has been warped up by movement along the Elsinore fault system. On the southern face of this block a wide range of formations is exposed. The stratigraphy embraces two distinct sets of rocks, one a complex of old metamorphic and igneous formations, the other, a group of Cretaceous and Tertiary sediments.

In this report the pre-Cretaceous rocks of the Santa Ana Mountains have been separated for the first time. The oldest formations are metamorphic rocks and consist of slates, sandstones, and conglomerates. The oldest of these is a group of slates and sandstones which have been named the Silverado formation. They amount in thickness to at least 17,000 feet. In Silverado Canyon, which is the type section of this formation, another old series is found. This is the Hough formation and is composed of a coarse basal conglomerate with overlying beds of sandstones and slates. This lies on the Silverado with a marked angular unconformity but due to erosion is exposed at only one place, that in Silverado and Ladd Canyons. It totals some 250 feet in thickness. The age of these two formations is Triassic.

There are exposed in San Juan Hot Springs Canyon a series of three lavas and tuffs which have been metamorphosed.

These are known as the San Juan Hot Springs formation. They are the expression of volcanic activity by stocks like that represented by Sierra Peak. The age of this material is dated as probably late Triassic or early Jurassic.

Intrusive into the preceeding rocks are a series of more or less closely related andesitic bosses, stocks, and dikes. These rocks are named the Modjeska series. They are intensively altered but are fresh enough to allow of mineralogical determinations. In some places diabases occur as much later intrusions. Intrusive into these andesites is a large mass of granodiorite. In the area studied only small tongues of this material are mapped. They are the irregular edge of the large and extensive batholith underlying the whole Peninsular Range.

The metamorphism of the old rocks is due to the action of the granodiorite batholith. This material is fresh, but the older rocks, especially the tuffs and andesites show the effects of hydrothermal alteration. The andesites are altered to a green rock with chloritized ferromagnesian and calcitized felspathic constituents. It is believed that the greater part of the metamorphism of the slates is due to contact rather than to regional metamorphism.

Associated with the crystalline rocks is a series of diabase intrusions. These have been mapped as Miocene in age from their striking resemblance to material in the Puente oil fields. They show the effects of autometamorphism in the uralitization of the pyroxene.

The sediments of the Santa Ana Mountains form a westward dipping homocline. The oldest rocks are Cretaceous in age.

The red basal conglomerate, called the Trabuco formation, is clearly only a basal conglomerate and of less formational value than some of the other lithologic zones of the Cretaceous which have here been mapped. The age of the Cretaceous of the Santa Ana Mountains is not definitely settled, but is regarded as upper rather than lower Cretaceous. Overlying the Cretaceous unconformably is a large thickness of Martinez sediments, areally more important than has been hitherto realized. The upper part of the Eocene is represented by beds belonging to the Domengine. The Miocene is separted from the Eocene by a distinct nonconformity. It is divided into the Vaqueros, the Topanga, and the Puente formations. The Topanga rests on the Vaqueros with a distinct disconformity. The later formations consist of Capistrano beds, Pliocene sands and gravels, and terrace deposits. The terrace gravels and Quaternary allutium form only thin veneers and are of little importanse except for their areal extent.

The sedimentary series is noteworthy for the predominance of clean well sorted marine sands, sandy shales, and conglomerates. Except for the basal portion of the Martinez of lacustrine origin, the series is marine. The Trabuco formation and the Vaqueros red beds are the result of alteration of arkosic sands after deposition and are not continental deposits as has been stated. The clays and coals are restricted to the lacustrine deposits of the lower parts of the Martinez. As is usual in the Californian region the sediments are without exception arkosic.

The unusual feature of the Santa Ana Mountains is the association of such a complete section of Tertiary formations. with a block type of structure. The region is noteworthy for the absence of strong folding so characteristic of the Coast Ranges. The Santa Ana Mountains, which grade without structural break into the southern continuation of the Peninsular Range, form the northern tip of a long rugged range which terminates in the Los Angeles Basin. Study has revealed in the small area covered by this thesis that the oldest rocks as well as the youngest show little folding. Unconformities are apparently the result of the tilting of the block and the rise and fall of the shore in the various basins of deposition. In the period following the development of the Perris peneplain the present range was formed. The formation of the small structural features such as the faults, normal and thrust, is believed to be the response to small local stresses in the block, in part due to the forces raising the block, and in part due to the intrusion of the diabase. Whatever has formed these small structures, it is certain that they are not related to the Elsinore system of faulting directly. It is believed that the present Santa Ana Mountains are a fault block which has been formed by the raising of the part along the Elsinore side and theconsequent warping of the western side along the region stretching from Tustin to the coast below Oceanside.

The development of this block has taken place in a series of movements which have left as a record a large series of stream terraces. Later dissection has developed many features controlled by structure. The most interesting physiographic feature is the anomalous position of Santiago Creek which is believed to represent an inherited drainage pattern.

The history of the region covers a long and eventful space of time. The deposition of the Silverado slates from a western land mass, folding and intrusion, and then the deposition of the Hough were the first events. Further diastrophism took place, then the volcanic outbreak which gave rise to the San Juan Hot Springs formation. This was followed by intrusion of the Modjeska andesite bodies. The intrusion of granodiorite, presumably of the same period as the Sierran intrusion, resulted in the metamorphism of the older rocks. The first succeeding event is recorded in the advance of the Cretaceous sea over a rough land surface of metamorphic and igneous rocks. The Cretaceous was followed by the Martinez which at its base represents deposition in a huge series of swamps and marshes. After deposition of the clay and coal marine deposition was resumed. The deposition of the Domengine, Vaqueros, Topanga, Puente, and Capistrano is a long record of uplift, erosion, and subsidence.

There is little of economic value in the Santa Ana Mountains save for the Martinez clays. These extend throughout the Elsinore depression and occur on the west side of the range from Santa Ana Canyon to Oceanside. Some coal associated withe the clays has been mined but it is too lignitic, full of sand, and too lenticular for cheap mining. There are some low grade lead-zinc-silver deposits connected with the andesite intrusions. Due to their small size they are not of economic importance. Nowhere in the area mapped is there indication of a future oil field.due to the lack of satisfactory structure. At the head of Rabbit Canyon the lower shales of the Puente contain considerable oil.

Apologia

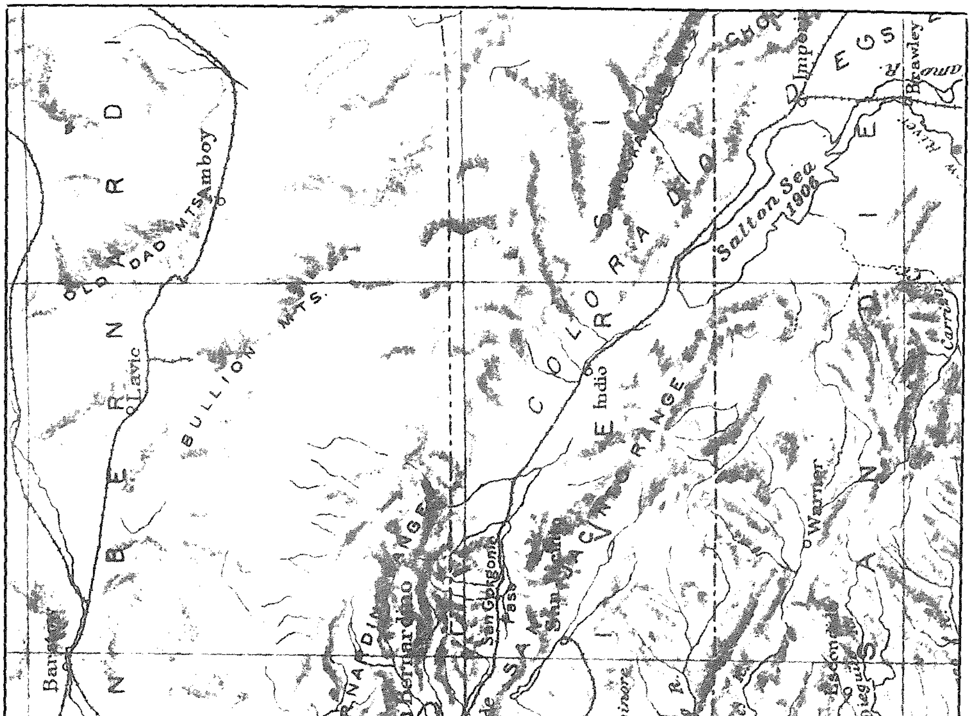
The Santa Ana Mountains of Southern California represent one of those regions so common in California which are at the same time known and yet unknown. In the past The Santa Ana Mountains have been ignored largely because they were presumably typical examples of "Coast Range" geology, a term used to indicate complex folded and faulted ranges of the Coast Ranges. This is the first investigation which has had for its aim the deciphering of the history of this region. Work was commenced in 1926 in the belief that complexly folded and faulted sediments would be met with. It was expected also that the range would differ in no marked respect from those to the north- the Santa Ynez and others.

Work in this region has revealed an extremely interesting case of a block mountain range which owes much of its apparent complexity to the development of a peculiar topography. The relation of this block to the Los Angeles basin and the country to the north is particularly interesting because of the contrast between this rigid block and the deformed blocks to the north.

The investigation of this region has also resulted in the mapping of the basement complex over a limited area and the separation of these rocks, so commonly relegated to an insignificant position, into their constituent formations. In this paper six formations are described, all new to Southern California Geology. The deciphering of the history of this "basement complex" has proved to be one of the most fascinating parts of the work inasmuch as a new chapter was being added to the geological history in a period about which we as yet know very little. Work on the later formations, particularly those of the Eocene, has revealed new facts. The mapping of the coals and clays as Martinez is a new idea though field work shows its correctness. The Martinez was found to have a much greater extent than formerly supposed. The overlying Eocene has been mapped as Domengine. Careful work has shown that the red beds of the Vaqueros and the "Trabuco" formations are in reality altered marine deposits rather than continental beds.

While it is acknowledged that future work in this country will undoubtedly produce new ideas it is stated with some confidence that the major parts of this work will be little modified by subsequent investigation. This region which in the past has been considered to be rather barren of interest has to my mind furnished a very interesting addition to the geology of the Coast Ranges. The association of sediments in such a complete column with a block type of range and a semi-arid climate has resulted in some very interesting modifications of Coast Range structure and Basin Range physiography.

Plate II Index Map



Introduction

The Santa Ana Mountains form the northern tip of the Peninsular Range. The location of the area mapped is shown on the map on Plate II. It lies for the most part on the southwestern slope of the range though one corner, the northeast extends nearly to the base of the eastern scarp. It is only a short distance from Los Angeles and is connected with the rest of Southern California by good roads.

The area mapped amounts to some 150 square miles. It is located between the region to the north mapped by English in U.S.G.S.Bull.768 and the region to the south mapped by A.O.Woodford in Pubs.Univ.Cal.Geol., Vol.15. The field work was done on an enlargement of a portion of the Corona Quadrangle of the U.S.G.S. Considering the period at which this area was mapped the base is fairly good, though there are some very bad mistakes in the topography. The structure was simple enough to be uninfluenced in appearance on the areal map.

The time spent in the field includes two summers, those of 1928 and 1929, as well as the week ends and holidays of the last four years. During this time theories of the geology of the region were rapidly formed and abandoned. The ideas presented in these pages are believed to represent an unpredjudiced view.

The Santa Ana Mountains in climate and vegetation are much like the other ranges of the region. They are heavily brushed due to the burning off of the original stands of timber. This brush is particularly thick and trying in the higher country. The lower country is grassy, an unfortunate fact, for the sod prevents adequate exposure of the underlying rocks. The country during years of normal rainfall is adequately watered, though the last few years have seen serious shortages during the summer months. The region is delightful to work in since fogs are common during the summer, the nights are usually cool, and the temperature during the day rarely rises above 100° for more than a week at a time.

The work carried out was done on Forest lands and the property of private companies and individuals. The author owes his sincere acknowledgements of help and cooperation to the U.S.Forest Service, the Irvine Company, the Santa Margarita Rancho, and the Whiting Ranch. Also to the following individuals: Messrs. Holz, Myers, Schultz, Pleasant, Fortune, Serrano, Harris, Hunter, Moles, Molton, and to numerous other land owners in the region. The author wishes here to acknowledge help in the field from Mr.B.A.Otis of the General Petroleum Company with respect to the diabase of Coldwater Canyon, to Mr.Clark Sutherland of the Pacific Clay Products Company for suggestions on the clays of the Martinez, Dr. W.P.Woodring of the Institute for help on the Miocene, and Dr.A.O.Woodford for numerous suggestions as to the general geology. He also wishes to acknowledge the kind help of the Institute staff including Dr.J.P.Buwalda, Dr.L.F.Ransome, Mr.R.Engel, and Dr.C.Stock.

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General Considerations

The rocks of the Santa Ana Mountains fall into two cdasses-a metamorphic and igneous group commonly referred to as the "basement complex" and a series of considerably younger sediments. In this study the "basement complex" has been separated as far as possiblà into its elements. The later sedimentaries have been divided into the same formations as are found in the neighboring regions.

The oldest rocks are a series of slates, sandstones, and limestones which are mapped as a new unit, the Silverado Formation. This is Triassic in age and comprises some 17,000 feet of strata. It is intruded by dikes of andesite porphyry and unconformably overlain by the Hough Formation, another new unit. This is probably Triassic in age. It is represented by only 250 feet of conglomerate, sandstones, and slate. Intrusive into the preceeding formations is a series of dacite porphyries. These are genetically connected with the San Juan Hot Springs Formation, a series of metamorphosed lavas and tuffs amounting to 1900 feet in thickness, and of uncertain age. The series of slates, conglomerates, and tuffs is intrudėd by andesites of the Modjeska Formation. These are porphyrytic in nature, occur in irregular dike and stocklike masses, and in places show evidence of having absorbed considerable of the country rock. Intrusive into the whole of the preceeding group is a coarse white granodiorite, part of the batholithic mass of the Peninsular Range. Intrusion of this rock has resulted in the metamorphism of the igneous as well as of the older sedimentaries.

The overlying sediments have as their base a coarse red conglomerate, the Trabuco Formation. This is grouped the rest of the Cretaceous of which it is properly only the basal conglomerate.

The Cretaceous is of marine origin and consists of a lower conglomerate, a sandstone, a thick middle shale member, and an upper conglomerate, sandstone, and shale member. Its thickness in Silverado Canyon is close to 2500 feet. Overlying it with a marked unconformity are the Paleocene beds of the Martinez Formation. This is 2700 feet thick in the vicinity of Trabuco Creek. The lower part is lacustrine and the upper portion marine. Overlying it with a marked unconformity occur the beds formerly mapped as Tejon but which are clearly Domengine. They attain a maximum thickness of 700 feet. Overlying the Eocene is a series of Miocene sediments. These include some 2500 feet of Vaqueros which is separated from the overlying Topanga by a disconformity. The Topanga amounts to only 300 feet in maximum thickness. It is unconformably overlain by the Puente which here attains a thickness of 1900 feet. The Pliocene is represented by the Capistrano Formation whichoccupies an analogous position to the Fernando of the Puente Hills. The overlying terrace deposits and recent alluvium are thin veneers of material which, while extensive, are of no great importance.

In general the deposits are noteworthy for their excellent sorting. The sedimentary series from the Cretaceous to the Capistrano is made up of clean, well graded material. This makes the recognition of contacts on the basis of lithology a difficult matter unless the formations are well known to the worker. The sediments are dominantly marine and are made up of the products of weathering of an old land mass to the east. The exceptions are the Martinez, in part freshwater, and the Topanga which contains schist material derived from the west. The conditions of deposition have varied greatly. The Trabuco is a deposit formed by an advancing sea. The overlying beds of the Cretaceous are marine and of shallow water origin. The base of the Martinez is fresh

fresh water and contains widely distributed clay and coal beds. The Vaqueros, contrary to the views od some workers, is a well sorted marine sandstone, characterized in its upper portions by its excellent sorting. The Topanga consists of material derived from both eastern and western land masses. In places these two types of sediments interfinger. Usually the Topanga is less well sorted than the Vaqueros. The Puente Shales are of marine origin and represent a shallow water deposit. The Capistrano formation is likewise a marine formation and exhibits excellent sorting.

The stratigraphic column is noteworthy for its great thickness as well as for the number of formations represented. The total number of feet, 30,500, may seem incredible. It must be rembered, however, that this includes less than the maximum thickness of several formations. On comparison it will be seen that while this is a great thickness, it is not unusual in the the Coast Ranges.

Metamorphic Rocks

Introduction

The oldest rocks in the Santa Ana Mountains are a series of metamorphosed sandstones, slates, conglomerates, and limestones. These form the core of the northern part of the range occupying a roughly triangular area which tapers from a width of about ten miles i in the vicinity of San Juan Canyon to a point near Santa Ana Canyon. To the south of San Juan Canyon these rocks are replaced by the intrusives of the batholith of the Peninsular Range.

The age of these rocks has been assigned to different periods by different observers. Dr.Whitney believed them to be metamorphosed Cretaceous Strata;

> "This portion of the Santa Anna Range (that is, around Santiago Peak) is chiefly made up of granitic, trappean, and metamorphic rocks... ..... At the mouth of Agua Fria Canon (now Coldwater Canyon) granite is seen, and next above it, a a striped jaspery rock, which is a metamorphic slate, such[1] as has often been seen among the altered Cretaceous strata."

H.W.Fairbanks in 1893 described the rocks as Carboniferous,[2] a statement based on the determination of a pelycopod from the limestone of Ladd Canyon as Carboniferous by the National Museum.

W.C.Mendenhall in 1912[3] described the slates as Triassic on the basis of fossils from the sandstones of Ladd and Bedford Canyons.

J.P.Smith in 1914 described the fossil found by Fairbanks as Daonella sanctaeanae Smith, and placed the beds in the Middle Triassic.[4]

[1] Geology, Calif.State Geol.Surv., Vol.1,p.173,1865.

[2] Cal.State Min.Bur., 11thAnn.Rep't for 1891-1892,p.116,1893.

[3] In B.Willis, U.S.G.S.P.P.71,pp505-506,1912.

[4] J.P.Smith, Middle Triassic Faunas, U.S.G.S.P.P.83,p.145,1914.

The writer of the present paper has made diligent efforts to obtain fossils from these rocks. However, due to the metamorphic character no localities have as yet yielded determinable material. The limestones are fetid and show dim outlines of of organic remains, but recrystallisation has obliterated any definite outline. The sandstones and slates have been subjected to such metamorphism that they too are in all cases seen unfossiliferous.

In this paper the metamorphic rocks are divided into three series on the basis of lithology and stratigraphic relations. These are:

San Juan Hot Springs Formation-	Lavas and tuffs-	1900 feet.
Hough Conglomerate-	Conglomerate, sandstone, slate-	250 feet
Silverado Formation-	Sandstones, slates, limestones-	17,300 feet.

The igneous rocks of the basement complex are later than the above and will be described under a separate heading.

The Silverado Formation

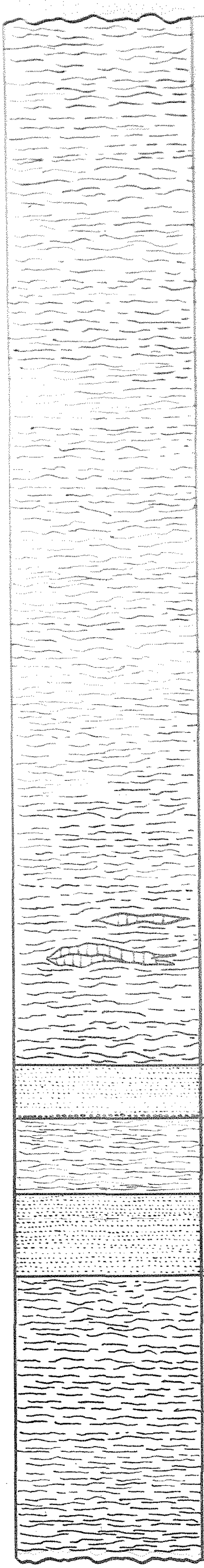
The Silverado formation is the oldest series of Rocks exposed in the Santa Ana Mountains. It is made up dominantly of slates with some sandstone, conglomerate, and limestone. It is recognized in the field by its slatey nature, by the hardness of its sandstones, and the silicification of the conglomerates. The slatey material weathers to a rusty red on steep outcrops. On gentler slopes white soil may be formed. While outcrops are ragged no jagged pinnacles such as are found among the andesites are to be seen. The formation may be distinguished from the igneous rocks at a distance by its regular bedding as opposed to irregular jointing.

In the area mapped in detail the Silverado formation is seen to be intruded by igneous bodies which have metamorphosed it to a greater or lesser degree. This metamorphism is particularly marked in the upper part of Holy Jim Canyon where the sandstones near the diabase change to a banded quartzite. In Trabuco Canyon the series is badly crushed, though no folding is noticeable. In Harding Canyon the slates are badly intruded and the section is far from complete.

The most complete section of the formation is to be found along the course of Silverado Creek. This is the type locality for the Silverado formation. The section given in Plate IV was taken from the field map along a line running from the fault above the Hough Conglomerate in Silverado Canyon to the main divide at the point where the ridge north of Coldwater Creek joins the divide. The Silverado Formation represents here the western limb of a syncline which has been beveled off and covered to the west by the Hough Conglomerate. Consequently the complete column is not known. The section in this locality is the most complete one in the Santa Ana Mountains, however, and is therefore

COLUMNAR SECTION
SILVERADO FORMATION
AS EXPOSED IN SILVERADO CANYON. SANTA ANA MOUNTAINS, ORANGE CO. CALIF

SCALE 1:20,000
or 1" = 1600 feet



Thickness	Description
11,700'	Blue black slates interbedded with thin beds of blue black calcareous sandstone, the whole being crushed and in places baked by intrusive rocks. In the lower portion irregular lenses of a fetid black crystalline limestone occur
600'	Thick bedded sandstone with about 25 ft of brown silicified conglomerate at base.
850'	Blue black slate with thin beds of fine sandstone
950'	Fine grained, coarse bedded, blue black sandstone with slaty beds
3,200'	Blue black slates with minor amounts of thin bedded dark sandstones.

taken as the type section.

Description of Section in Silverado Canyon

Starting at the fault in Silverado Canyon east of the contact with the Hough Conglomerate one encounters a series of eastward dipping beds. These have been divided as follows:

1. 3200 feet of interbedded slates and sandstones. These form the lowest part of the Silverado section known. The sandstones interbedded with the slates are in general thin bedded and form a minor amount of the total thickness. They may range up to a foot or more in thickness but are generally only a few inches thick. The slate and sandstone are both blue black. The slates show a rather imperfect slatey cleavage developed nearly parallel to the bedding plane. This cleavage is not apparent in the sandier material or in the interbedded sandstone. It is obscured ordinarily by the development of a joint system at an angle to it which causes it to break into small blocks rather than cleave. The slates and sandstones are blue black but weather to a rusty color on outcrops. The slate weathers easily to form soil and except on the steep canyon walls and in the stream beds outcrops are rare.

2. 950 feet of sandstone with interbedded slate. This part of the column is made up largely of sandstone with a lesser amount of slate. The sandstone is a fine to medium dark blue material made up largely of quartz grains. The cementing material seems to be quartz rather than calcite, although small veins of calcite are not uncommon. The beds are usually massive and are separated by partings of slate or by a thickness of slate and fine sandstone beds. The line of demarcation between this and the beds above and below is purely arbitrary, being taken at the points where there is a noticeable change in the amount of the sandstone with respect to that of the slate.

3. 850 feet of slate with some interbedded sandstone. This part of the section resembles the lowermost 3200 feet very much. It is a series of dark blue black slates with numerous small beds of a x hard dark sandstone. In appearance it resembles the Mariposa slates.

4. 600 feet of conglomerate and sandstone. Above the preceeding slates occurs about 25 feet of a brown silicified conglomerate. This is made up of pebbles of quartzites, slates and other metamorphic rocks. The maximum size range is up to an inch, but the usual range is around the size of a pea. The pebbles and sandgrains are in most places well silicified and the rock breaks with a conchoidal fracture. In places material will be found not so well silicified in which after fracture the surfaces of the constituent particles may be observed. The pebbles are round and apparently were well polished. The conglomerate is a light brown on weathered surfaces due to the oxidation of the iron compounds to limonite. It is a distinctive rock and its presence in the float of a stream may be taken to mean that there is an outcrop of this horizon in the vicinity.

The sudden transition from slate to conglomerate implies a hiatus of some kind. In the absence of fossil evidence it is impossible to tell what the time value of the disconformity is. It may represent no more of a break in the sequence of the strata than is represented by the conglomerate lenses in some of the Tertiary formations. In view of the thickness of the formation and its shallow waterorigin it probably represents the latter rather than an extensive disconformity.

5. 11,700 feet of slates with some interbedded saandstone and limestone. Above the conglomerate sandstone division

rests a huge thickness of slates with more or less interbedded sandstone. The sandstones and slates are the same as those in the lower divisions as far as external appearances go. They differ, however, in the fact that at about 1000 feet above their basenumerous lenses of a fetid,black limestone occur. This limestone is in the process of recrystallization. It is coarsely crystalline for the main part and is seamed with white veins of calcite. There are traces of organic remains but no determinable fossils have been found by the author. In places the material may form lenses several hundred feet thick as in Ladd Canyon. These lenses have small lateral exeènt and are limited to small areas. A few small limestone lenses occur in Silverado Canyon on the south slope, and also in Trabuco Canyon a few hundred feet above the stream on the north wall above the Ranger Station. In places the limestone forms an autoclastic breccia, particles of slate and sandstone being imbedded in a groundmass of the limestone.

The slates above the limestone horizon are not distinguishable in the field from those lower in the section. They form an unbroken sucession of eastward dipping beds to the divide. Here they change their attitude and the slates on the east face of the range all dip to the west. This transition from one limb of the syncline to the other is best seen in Ladd Canyon where h there are fewer dikes to confuse the observer.

Age

Due to the metamorphosed condition of the Silverado formation fossils are quite rare. I have been unable to find any in the field although they have been reported in the literature. It is evident, however, that careful searching over a considerable number of outcrops might reveal some localities.

The fossils found by H.W.Fairbanks occurred in the limestones in the upper part of Ladd Canyon. These have been described by J.P.Smith as upper Middle Triassic in age. They include an undetermined Rhynconellid and a new species of Daonella, D. sanctae-anae Smith. Since Daonella is a characteristic genus of the middle Triassic and its species are used as zone fossils it is certain that the assigning of this portion of the series to the middle Triassic is based on sound grounds.

The fossils found by Mendenhall and reported on by Dr.Stanton come from a horizon lowerethan the limestones. In Ladd Canyon the collection was made by Dr.Mendenhall just above the junction of the west fork (oral communication). This corresponds to a position above the conglomerate but below the limestone. This is the same horizon as the locality in Bedford Canyon according to Dr.Stanton. The fauna consisted of Rhynconella sp., Spiriferina sp.,Terebratula sp., and crinoid fragments. This assemblage was regarded as Triassic and probably of the upper Triassic rather than lower.

From the two references cited it seems clear that the Silverado formation is clearly middle Triassic in age. Since the fossils come from close to the middle of the section, the exact age of the material above and below is uncertain. From the lithology it appears that the material was deposited rapidly in a shallow basin. It may be that the formation represents a part of middle Triassic time instead of a longer space as the thickness suggests.

The Silverado Formation in Other Localities

Harding Canyon- The Silverado formation as exposed in Harding Canyon resembles that of Silverado greatly. No contortion of individual beds is to be noticed, though the dip varies from 45°east to nearly vertical. There is no change in attitude as igneous bodies are approached. There is a narrow band ofslate and sandstone bordering the quartz diabase in Harding Canyon. At the contact the sandstone and slate have been recrystallised to form a dark crystalline rock. The remainder of the band is well silicified but shows no such intense baking. Some contortion of the slate is to be noted at the andesite contact on Modjeska Peak. This is restricted to a zone a few feet wide and is rather an unusual feature.

In Santiago Canyon the same independence of dip with regard to intrusives exists. The slates are well baked but show no contortion.

In Trabuco Canyon the Silverado formation presents a different aspect. Crushing of the slate and sandstone has resulted not in intense deformation of the beds but in the development of numerous small fractures along which movement has taken place. The santones interbedded with the slates have been fractured and the fissures filled with quartz and calcite. The slates have been crushed so that when an attempt is made to break out a hand sample the material invariably cleaves into a lens shaped mass with smooth slickensided surfaces. As a result of the compression this condition is prevalent throufhout the lower part of Trabuco canyon. The slates are consequently slippery and slides are frequent in tunnels and in road cuts.

To the south of Trabuco Canyon the slates are not so badly crushed and resemble those of Silverado Canyon to a greater

Character and Origin of the Sediments

From the description of the section it is evident that the rocks of the Silverado formation are dominantly sandy slates with a considerable amount on intercalated sandstones. The exact nature of the sediments is not apparent megascopically but is seen only on microscopic examination. The rocks described in the following section are believed to be typical of the section. The major constituents are much the same throughout the series though the heavy minerals vary considerably as might be expected in such a thicknessof beds.

Description of thin sections

Section 53. (Plate V, Fig.1) This is a section of a fine grained blue sandstone taken from the Silverado formation just below the contact with the Hough formation in Silverado Canyon. The sandstone is hard and resistant to erosion and forms smooth polished surfaces in the stream bed.

Under the microscope it is seen to be made up dominantly of quartz grains with a small amount of felspar. The heavy minerals consist of abundant sillimanite grains, ilmenite and leucoxene, apatite, and muscovite. The quartz grains vary from angular particles to subangular grains and are embedded in a dark altered groundmass of the finer particles in which minute quartz grains may be distinguished. The quartz shows a slightly undulatory extinction in most grains. Associated with it are oc occasional rectangular or square grains of felspar, usually oligoclase. Associated with the quartz are long latheshaped grains with a high index and high birefringence. They are apparently sillimanite. This mineral, while abundant, is apparently only a local concentrate and is not universally found.

Plate V

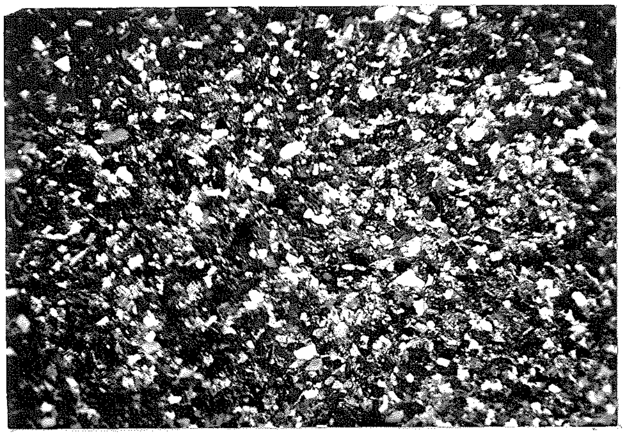


Fig. 1 Sandstone of the Silverado Formation, Silverado Canyon.

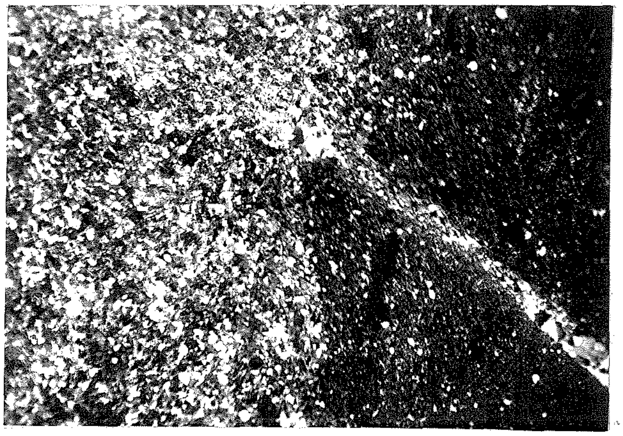


Fig. 2 Sandstone and slate, Silverado Formation, Silverado Canyon.

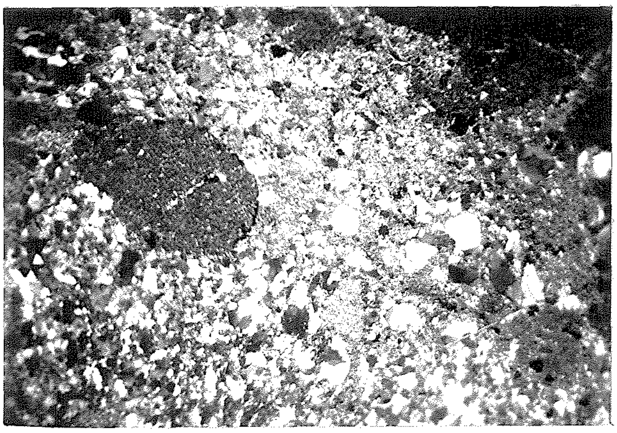


Fig. 3 Quartzite, Silverado Formation, upper Holy Jim Canyon.

Irregular dark grains of ilmenite are present as well as grains of leucoxene. The leucoxene is in places intergrown with the ilmenite which would indicate that the leucoxene is an alteration product. The sillimanite is related to the quartz, some of the larger quartz grains having inclusions of this mineral. Minor amounts of apatite and muscovite also occur.

Section 54- This is a section of the arenaceous slate from the same locality as the preceeding sandstone. As may be seen from Fig.2, Plate V, the section shows the contact of the slate with one of the intercalated sandstone beds. It will be noticed that the slate is cracked and that the fissure is filled with sand grains. This is an original structure and was formed during deposition of the sediments. The slate is composed of occasional grains of quartz and sillimanite embedded in a matrix of an undetermined clay mineral which has numerous small particles of quartz, sillimanite, apatite, ilmenite, and leucoxene scattered through it. In this particular rock there is an alternation of layers of more or less arenaceous character. This is apparently due to seasonal variation. These bands vary in width from a few millimeters up to a centimeter or more in thickness.

Section 34. This is a quartzite from the upper part of Holy Jim Canyon. The original material has been altered from a dark blue conglomeratic sandstone to a dense white material which shows only faintly its sedimentary origin megascopically. As shown in Fig.3 Plate V, it is made up largely of angular to subangular quartz grains with numerous larger particles of quartzites. No felspar was noted. Ilmenite and leucoxene are present as well as large well rounded zircons. Some calcite occurs as large irregular masses and veinlets. It is apparently segregated from the rest of the rock and does not act as a cement. Masses of dark argillaceous matter, probably remnants of old slate particles occur scattered irregularly throughout the section.

Section 51. Fig.1 Plate VI, shows a photomicrograph of a section of the mineralized country rock from the Blue Light Mine in Silverado Canyon. This material is a hard smooth light grayrrock with a conchoidal fracture. In the hand specimen it resembles a chert with a considerable amount of metallic sulfides disseminated in it. In the section it appears to be a badly altered sandstone. The quartz grains show the usual undulatory extinction and are the only recognizable material present. The remainder of the rock is made up of a groundmass that is apparently isotropic. The alteration is most likely due to the ore bearing solutions.

From the description given of the above typical sections it appears that the source of the sediments was probably some mass of metamorphic rather than igneous rocks. Minerals such as sillimanite, especially in abundance, indicate derivation from either metamorphics or from older sediments. The undulatory extinction of the quartz suggests derivation from metamorphics since there is no evidence of any great dynamic metamorphism of the Silverado formation itself. The presence of a small amount of plagioclase felspars suggests that the rest of the minerals were derived directly from the metamorphic rock rather than through an intermediary sedimentary one since the weathering in the latter case would probably remove all traces of the calcic felspar. That there has been derivation of some

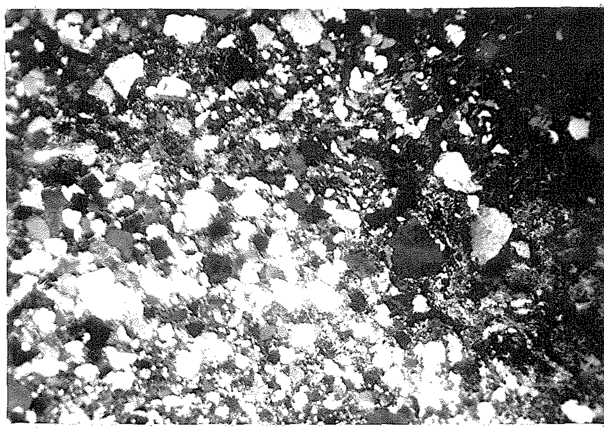


Fig. 1 Silverado Formation, Blue Light Mine, Silverado Canyo.

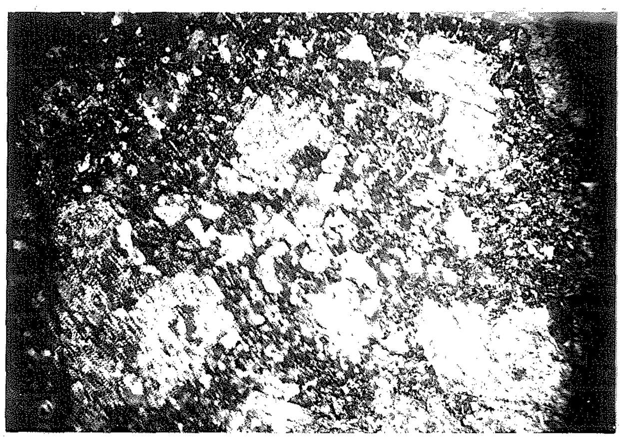


Fig. 2 Dike in Silverado Formation just below contact with Hough in Silverado Canyon.

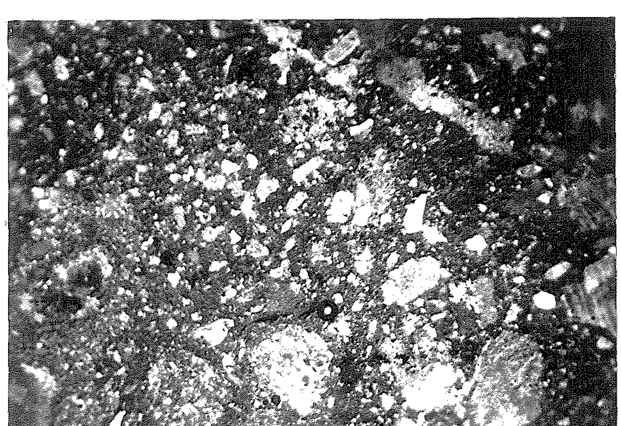


Fig. 3 Hough conglomerate, contact with Silverado in Silverado Canyòn.

of the sediments from older sedimentary formations is shown in the presence of the extremely well rounded zircons in some of the conglomeratic beds. The type of metamorphics that furnished the material for the Silverado series was evidently not a single one. While the undulatory quartz, sillimanite, and felspar are suggestive of a schist series, the well rounded zircons and the slate and quartzite pebbles of the conglomerate band were probably derived from a sedimentary series metamorphosed toa much less extent. The size of a land mass necessary to furnish detrirus for more than 17,000 feet of strata can not be expected to have been very uniform in lithology, however, and considerable differences might be expected on detailed study of the minerals of the slate series.

The conditions under which the material was laid down were much like those of the later sedimentaries in some ways and quite dissimilar in others. Judging from the composition of the sediments the detritus was subjected to sufficient weathering to remove the ferromagnesian elements as well as most of the felspars. In this respect it stands in great contrast to the dominant arkosic nature of the Cretaceous and Teriary sediments. The alternation of slate and sandstone is suggestive of deposition in a shallow basin. The coarseness of the sandstone indicates deposition at no great distance from share. In general appearance the formation resembles the younger, though unmetamorphosed, series of shale and sandstone of the Cretaceous.

From the preceeding considerations it seems that the Silverado formation was deposited under conditions favoring solution of non-resistant minerals in a shallow but constantly sinking basin. The coarseness of sandstone indicates deposition at no great distance from shore. The nature of the section probably indicates a rather rapid deposition. From these two considerations may be deduced the idea that the source of sediments was either a low lying mountain range close to the shore, or if at some distance may have been of considerable altitude. For wherever the source was there must have been oportunity for a considerable amount of weathering as indicated by the non-arkosic nature of the deposits.

The forgoing summary of the type of material, its source rocks, and its mode of deposition place a distinct limitation on the location of the source of the sediments. The distance from the present Santa Ana Mountains cannot have been very great, probably not over fifty miles. Examination of the surrounding country shows no areas of rocks older than the Triassic except to the east in the San Gabriel and San Bernardino Ranges. Unfortunately they have been so much disturbed by later igneous intrusions that it is unlikely that had they been the source of the sediments it would be possible to determine it.

There is, however, another line of evidence throwing light on the source of the rocks. From a study of the pattern of the various Triassic sediments in California and Nevada Dr.J. P.Smith believes that there existed throughout Triassic time a long gulf of the ocean extending up through the present Great Ba sin country which was gradually filled and finally disappeared towards the close of the period. Under this consideration the derivation of the sediments from the west rather than the east is favored. If an eastward origin could be shown, it probably would be found to be an island mass in this arm of the Triassic ocean. This phase of the history is dim, however, and only speculation.

Effect of Intrusives

From a study of the slates one comes to the conclusion that although they have been subjected to pressure they show no evidence of dynamic metamorphism. Baking and cementation caused by intrusives is, however, quite evident. The slates are noticeably harder and more flinty near the contacts with the later igneous rocks. This is not so marked in the case of the hypabyssal rocks of the Modjeska series as in the case of later granodioite and diabase. In the case of the granodiorite the effect was widespread. The size of the batholith and its magmatic exhalations played a vast part in the metamorphism not only of the Silverado Formation but also of the Modjeska series which show the effects of hydrothermal alteration to quite a degree. The effect in the case of the Miocene diabase is also marked. In Coldwater Canyon and more especially in Holy Jim Canyon intrusions of the diabase have greatly altered the sandstones producing in some cases white quartzites. This pronounced effect may be due to the fact that the alteration performed by the granodiorite was great enough to allow these smaller bodies to carry the process to a marked position.

The least affected slate bodies are those in Ladd and Silverado Canyons, that is, farthest from intrusions. These are much less changed than the smaller areas to the south. From a consideration of the different outcrops one concludes the metamorphism is contact rather than dynamic. The preservation of sedimentary structures such as bedding, texture, color, and the absence of crumpling point to freedom from any great compressive stresses. The absence of dynamic metamorphism in beds of this age in this region is interesting in view of the great orogenic activity of the Tertiary period.

Post-Silverado Pre-Hough Igneous Rocks (Undifferentiated)

Intrusive into the Silverado formation are a few dikes of andesite porphyry. These are not abundant and are not mapped on the areal geology sheet, although they throw considerable light on the relation of the Silverado to the overlying Hough beds. Two of these dikes are known to the writer. One occurs in Ladd Canyon about one eigth mile above its juncture with the west fork. The other occurs in Silverado Canyon just at the contact with the Hough formation. These dikes resemble one another in their extreme alteration and in their composition as far as the latter may be determined.

Fig.1 Plate VII shows the dike in Silverado Canyon intruding the slates of the Silverado formation. It is cut off along the contact with the Hough and boulders of the same material incorporated in the Hough. The age of the dike is thus well established as post-Silverado pre-Hough.

The dike consists of a light grey porphyritis rock with phenocrysts of an opaque white felspar. This is badly altered and the outlines are fuzzy. Despite alteration the material is extremely tough. On examination in thin section (PlateVI Fig.2) the rock is seen to consist of a ground mass of altered felspar with some quartz grains, their shape suggesting derivation from the surrounding sandstones. In this ground mass are patches of calcite and large phenocrysts of an andesine felspar in all stages of alteration to calcite. There is no unaltered femic mineral.

These dikes are not related to any other known rock bodies. They are the oldest igneous rocks known in the district and probably record an ancient volcanic activity.

The Hough Formation

In Silverado Canyon about a fifth of a mile above its junction with Ladd Canyon occurs a coarse westwardly dipping conglomerate. This conglomerate is made up of very coarse material and due to its hardness stands out as a distinct bed. The first person to note this conglomerate prior to the study recorded in these pages was H.W.Fairbanks.[1] In a description of the Cretaceous in Silverado Canyon he states:

> " Between the two beds is a conglomerate stratum carrying boulders different from any seen in the Santa Ana Mountains."

To the formation of which this bed is the basal conglomerate it is proposed to give the name, Hough formation.

The type locality of the Hough formation is on the western end of the Hough property in Silverado Canyon and about a fifth of a mile above the junction with Ladd Canyon.

The formation consists of a basal conglomerate which grades into sandstones and slates. The conglomerate is made up at its base of subangular to round boulders which vary in size up to several feet in diameter. The interstices are filled with some finer pebbles and sand. As one rises in the section the conglomerate becomes finer and in a thickness of about 25 feet grades completely into a coarse blue sandstone which resembles that of the Silverado Formation greatly. In the upper part of the 250 feet of strata exposed at the type section, slates predominate much as is the case in the Silverado Formation.

The conglomerate is coarse but well consolidated. The boulders, especially the larger ones are derived to a considerable extent from the andesite Dike in the lower Silverado formation.

[1] Cal.State.Min.Bur.,11th Ann.Rept.,1891-1892, p.116, 1893.

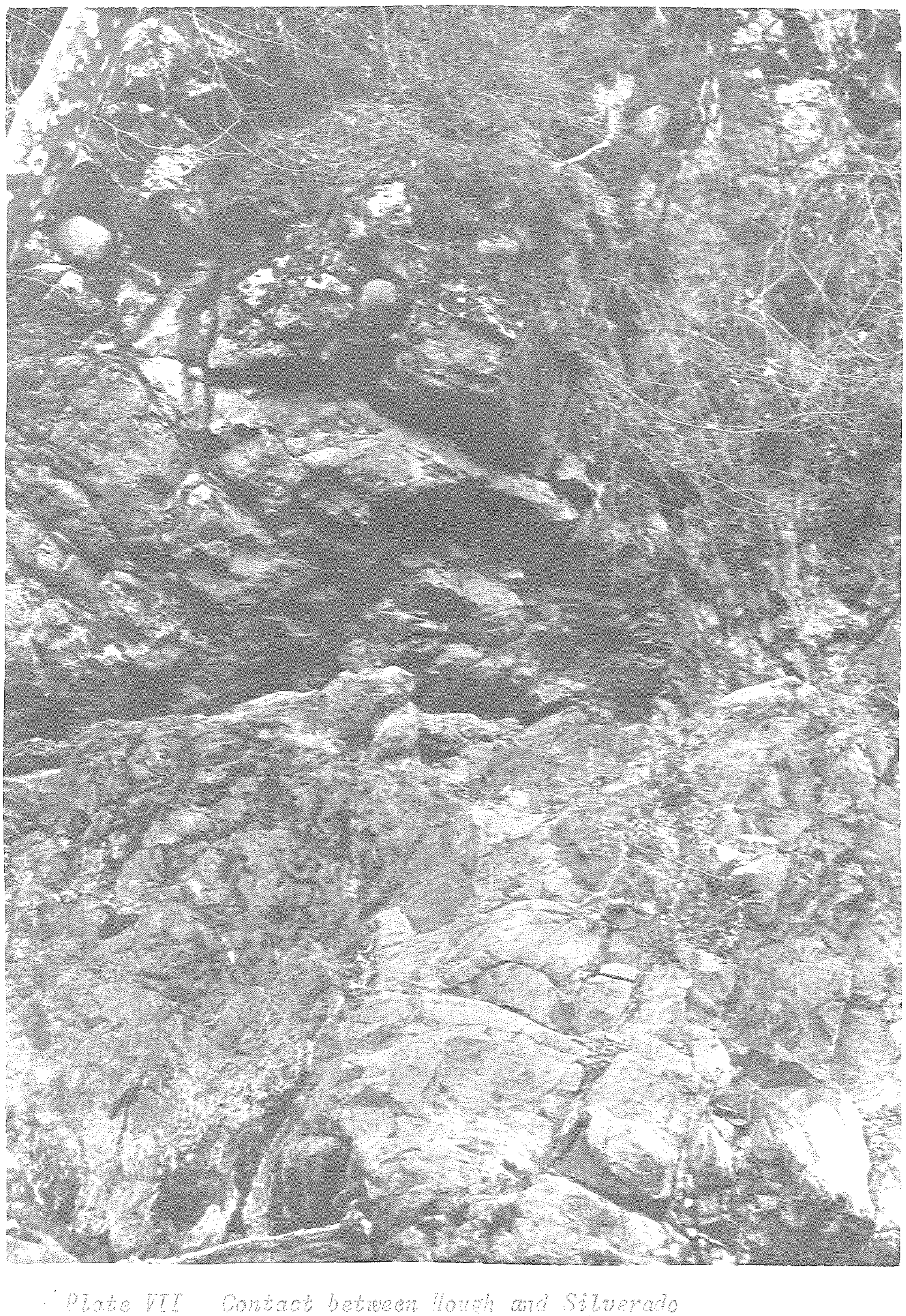


Plate VII   Contact between Hough and Silverado

The conglomerate with the exception of the boulders of andesite has been so silicified that pebbles break cleanly and in many cases may be seen in conchoidal fractures, their shape affecting fracture not a bit. In color the conglomerate is a dark blue grey on freshly fractured surfaces but weathers to rusty tints. The sandstones and slates are so similar to those of the Silverado that separation is impossible on megascopic appearance.

The relations of the Hough to the Silverado are clearly those of unconformity. The conglomerate is clearly a basal one and in itself is indicative of such relations. Further the Conglomerate has incorporated in it material from the underlying Silverado formation. Dikes in the Silverado formation have also been truncated by erosion prior to the deposition of the conglomerate. The most striking feature, however, is the angular discordance. The Silverado formation at the contact has the attitude 35°E N45°W, while the conglomerate is 15°W N60°W. The relation of these two formations at the contact are very clear as shown in the views in Plates VII and VIII. Plate VII shows the Silverado slates intruded by the dike and overlain by the Hough formation. Plate VIII is a view of the Hough formation showing the character of its conglomerate.

Unlike the Silverado the Hough has a small areal distribution. The maximum thickness in Silverado Canyon amounts to only 250 feet The only outcrops so far known are those in Silverado and Ladd Canyons. In Silverado Canyon the formation is cut off to the west by dikes and covered by the Cretaceous. In Ladd Canyon the formation exhibits a very interesting phenomenon. Here a large series of andesite porphyry dikes of the Modjeska series have intruded the conglomerate forming a striking intrusive breccia. Large well polished boulders of the conglomerate are

Plate VIII   Basal Conglomerate of Hough embedded in a crystalline groundmass of red and green andesite. This material outcrops along the stream for a distance of a thousnd feet furnishing a series of showy outcrops, striking because of the obviously sedimentary cobbles embedded in as obvious dike rock.

The exact time relations of the Hough to the underlying Silverado is unknown. Fossils from the Hough are lacking, and unlike the case of the Silverado, there seems to be no chance of obtaining any to judge from the metamorphism of the farmation. Consequently there is no possibilty of comparison on the basis of paleontologic evidence. The extent of the erosion interval and the diastrophism represented by the unconformity is hard to judge. The Hough is obviously post middle Triassic since that is the age of the Silverado and considerably younger than the igneous rocks of the Jurassic. It is probable that it represents the upper Triassic or earliest Jurassic.

The Hough Formation and the Silverado are consolidated to the same extent. The consolidation and silicification are due undoubtedly to the later granodiorite intrusion, hence little can be said as to age on that score. A thin section of the conglomerate (PlateVI,Fig.3) shows it to be made of rock fragments and sand . The fragments may be easily distinguished under plane polarized light, but under crossed nichols the boundaries between grains vanishes, This is apparently due to the silicification which has not only acted to cement the particles but also to silicify them. Earge patches of calcite may be seen around the altered felspars. Heavy minerals were not noted except in the fragments derived from the Silverado. The pebbles comprise slates, sandstones, quartzites, and andesite porphyries, the latter from the dikes nearby.

San Juan Hot Springs Formation

In the vicinity of San Juan Hot Springs in San Juan Canyon there is an interesting series of old lavas and tuffs which have, strangely enough, never before been described. These rocks are outside of the area mapped in detail but their significance in the geologic history of the Santa Ana Mountains is such as to warrant a detailed description.

The type locality of the San Juan Hot Springs formation is in San Juan Canyon just below the Hot Springs. Here is exposed the following section (thicknesses estimated):

Upper tuff	200 feet plus
Upper flow (dacite)	50 feet
Middle tuff	300-400 feet
Middle andesite	75 feet
Lower tuff	1000 feet
Lower andesite	100 feet

This section consists of material dipping south at an angle of close to 30°. It runs from a point just below the Hot Springs along the creek, through the gorge and ends at the contact with the overlying Cretaceous, which may hide further beds in the series. Due to this unconformable contact the complete section is not exposed. There may be additional material hidden by the Cretaceous, or the upper part of the series may have been removed by the extensive pre-Cretaceous erosion.

Description of the Formation

The lowermost flow exposed is a dense black andesite about 200 feet thick and resting on the granodiorite at San Juan Hot Springs. The apparent relations here are not the actual ones, however, since the contact between the lava and the granodiorite is an intrusive contact and not a depositional one. To the east the lava series rests on patches of slates which have likewise been intruded by the granodiorite.

Lower Andesite

The lower andesite is a dark black rock with a greenish tinge on thin edges. It weathers to a red soil. In texture it is porphyritic, numerous dark felspar phenocrysts several millimeters long being set in a fine grained ground mass. To the eye the material is quite fresh and would be termed a basalt in the field. Jointing is complex, the earliest jointing being horizontal rather than columnar. Later joints have been superposed on this system resulting in a much fractured rock. A hand sample of this rock is shown in Fig.1, PlateXI.

Examination of the thin section under the microscope (fig.1, Plate IX) shows the material to be porphyritic with phenocrysts amounting to about half the total mass of the rock, or sempatic. The phenocrysts are composed of andesine showing albite twinning. There are also phenocrysts of a pyroxene, altered to uralite and chlorites. Magnetite as an alteration product of the pyroxenes is common. The phenocrysts of felspar show an incipient alteration to calcite. The groundmass is made up of a network of small andesine laths with a considerable amount of badly altered pyroxene. Secondary minerals such as calcite, chlorite, and magnetite are common throughout the section.

From the above description the rock is an altered andesite porphyry, although in the field one would be tempted to call it a basalt.

Lower Tuff

The lower andesite is overlain by nearly a thousand feet

Plate IX

Fig. 1 First Flow below Hot Springs, San Juan Canyon.

Fig. 2 Second Flow below Hot Springs, San Juan Canyon

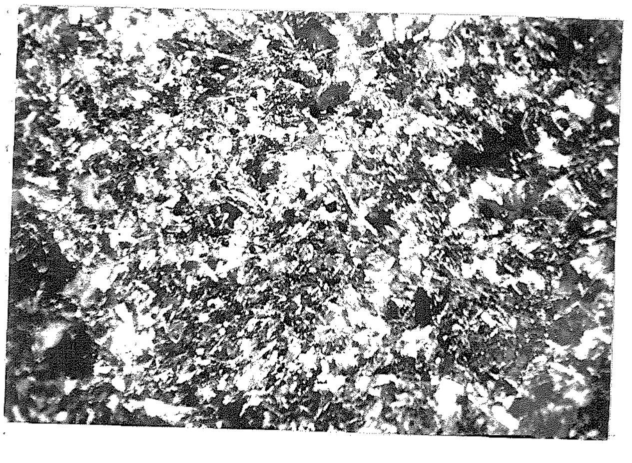


Fig. 3 Third Flow below Hot Springs San Juan Canyon

Plate XI

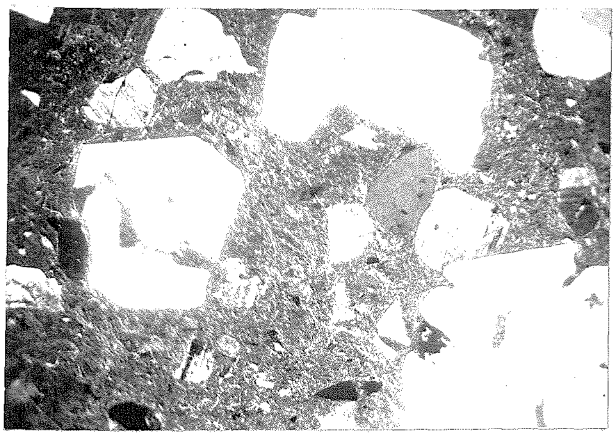


Fig. 1 First Tuff below San Juan Hot Springs, San Juan Canyon.

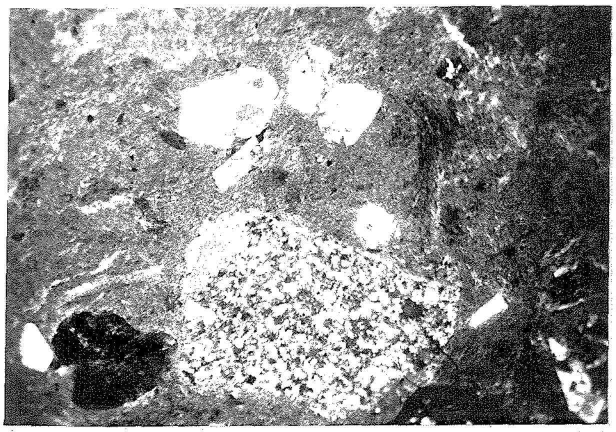


Fig. 2 Second Tuff below San Juan Hot Springs, San Juan Canyon.

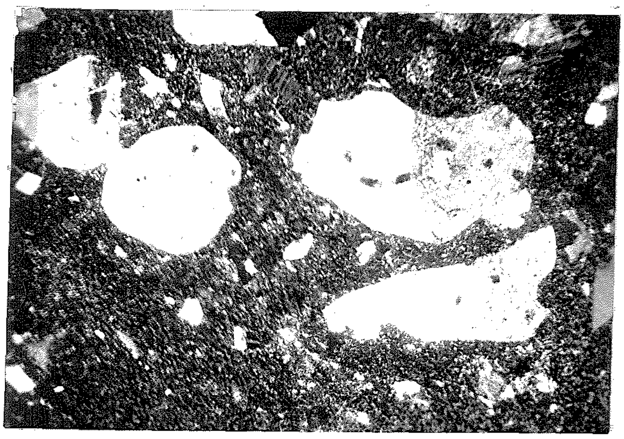


Fig. 3 Third Tuff below San Juan Hot Springs, San Juan Canyon.

Plate XII

Fig. 1 First Lava Flow, San Juan Hot Springs Formation, San Juan Canyon

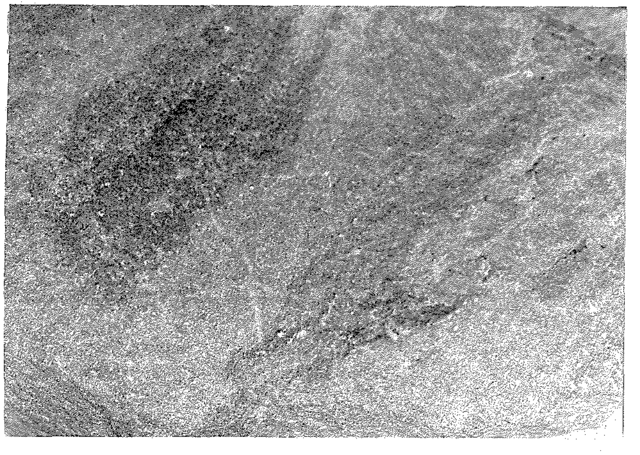


Fig. 2 Second Lava Flow, San Juan Hot Springs Formation, San Juan Canyon

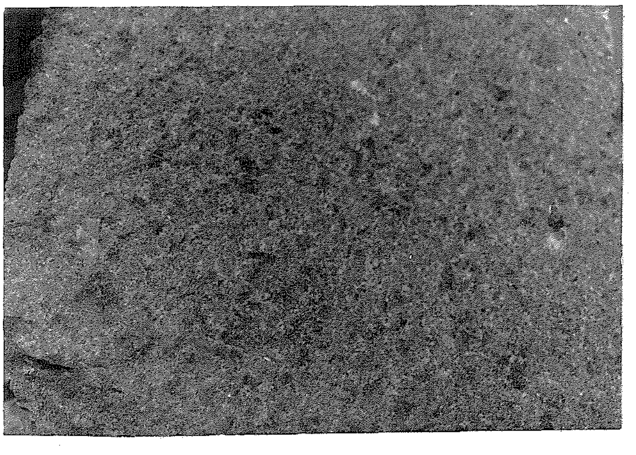


Fig. 3 Third Lava Flow, San Juan Hot Springs Formation, San Juan Canyon

Plate XII

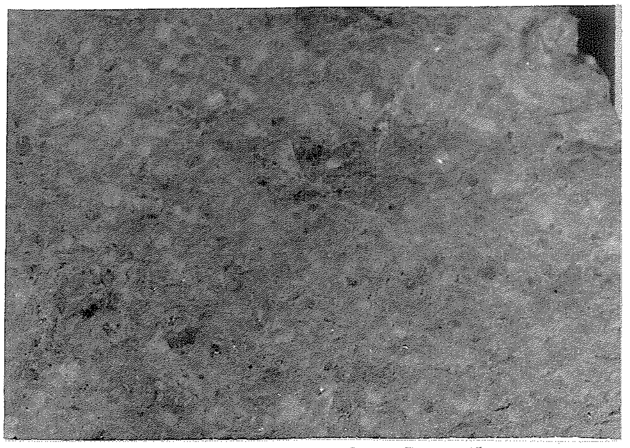


Fig. 1 Lower Tuff, San Juan Hot
Hot Springs Formation, San Juan Canyon

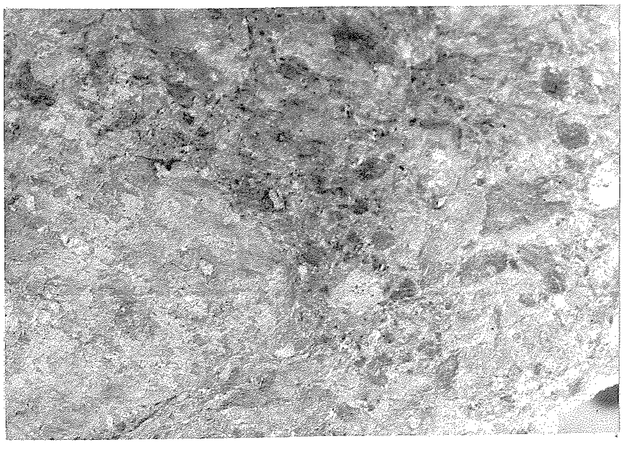


Fig. 2 Middle Tuff, San Juan Hot
Springs Formation, San Juan Canyon

Fig. 3 Upper Tuff, San Juan Hot
Springs Formation, San Juan Canyon

of a peculiar looking rock, dark green to greenish white in color, soapy in general appearance, and containing grains of a brilliant transparent quartz as well as masses of serpentine like material. This material in places is streaked with green fibrous material which gives it a bedded appearance(Plate XII, fig.1). It is massively jointed and weathers to a red soil. On first encounter with this rock one is tempted to call it an altered andesite. The contrast with the undoubted andesites, its relations to the andesites, its bedded character, the occurence of altered sedimentary material as pebbles and grains, all suggest its clastic nature. However there is also a suggestion of igneous origin in the quartz and felspar grains which are in many cases nearly euhedral. An examination under the microscope quickly confirms its pyroclastic origin and places it as a tuff.

Examination under the microscope (Fig.1,Plate X) shows in an altered ground mass of calcitic and talcose material large corroded quartz grains with some smaller felspar grains and particles of slates and sandstones. Some of the quartz has attached to it particles of fine grained volcanic rocks. There are also particles of quartz shaped in triangular, rectangular, elliptical, and concavo-convex forms. These peculiarly shaped particles resemble pyroclastics rather than clastics. Smooth concavo-convex forms are highly diagnostic of an explosive origin. In the development of angular clastics irregular particles are formed but their boundaries are ~~no~~ not the smooth boundaries here found, but hackly ones. The present of quartz grains showing large embayments and other corrosion features also suggests pyroclastic origin, for weathering of a quartz porphyry would reduce these forms to smaller and stronger grains.

While the shape of the particles clearly indicates a pyroclastic origin as opposed to either an igneous or a clastic, their composition also furnishes some additional information. A large part of the green material that resembles serpentine is altered slate. This combined with the fact that there is also some sandstone and quartzite suggests that the material is not a pure ash but is the result of the incorporation of both clastic and pyroclastic materials. In this respect it would resemble the extensive tuffs of the Great Basin which while dominantly volcanic are nevertheless partly laid down by water. In view of the thickness of the material and the absence of any noticeable agglomerate beds it would appear that it was laid down slowly enough to permit the incorporation of clastics which would have been deposited alone under normal conditions.

Unfortunately the tuff is so badly altered that the relative amounts of clastic and purely pyroclastic material cannot be determined. The ground mass is indeterminable and any glass that may have once existed is too altered for detection.

Middle Andesite

The preceeding tuff is followed by a flow of an andesite (PlateIX Fig.2, Plate XI Fig.2) about 75 feet thick. In appearance this rock is fine grained, dark green in color, and mottled with faint squarish black phenocrysts. It is jointed massively and forms a distict outcrop on the hill slopes due to its relatively great hardness.

In thin section this rock is seen to be holocrystalline though fine grained, perpatic with phenocrysts of andesine felspar set in a ground mass of small felspar laths. The andesine phenocrysts are more or less calcitized. There were at one time phenocrysts of pyroxene but these have been too badly altered for any determination. The ground mass of small more or less calcitized felspar laths contains some chlorite and uralite, as well as pyrite, magnetite, calcite, and other alteration products and secondary minerals. This alteration is not due to meteoric waters but to hydrothermal alteration.

Middle Tuff

Overlying the middle andesite occurs 300-400 feet of another tuff(Fig.2 Pl.X, Fig.2 Plate XII). In general appearance this material resembles the lower tuff. It has the same soapy green color and contains dark green patches of altered pebbles. Under the microscope it is seen to resemble the first tuff fairly closely. It will be observed that while in this tuff there are corroded quartz grains, the preponderance of material is on the side of the clastics rather than of the pyroclastics. The amount of altered slate and sandstone fragments is certainly greater than in the lower bed.

Upper Andesite (dacite)

Above the middle tuff occurs a flow about fifty feet thick of a light greenish rock, finer grained than either of the preceeding and with few phenocrysts. This differs from the other flows magascopically in no important respect(Plate XI Fig.3) but when observed under the microscope(Plate IX Fig.3) it may be seen to have a certain amount of quartz in its composition. This rock is holocrystalline and perpatic. The ground mass consists of small felspar grains which are squarish rather than lath shaped. In the interstices is a small amount of an altered femic mineral. Calcite is also common as an alteration product.

The interesting occurrence in this rock is the quartz. It occurs as small irregular grains showing undulatory extinction and possessing an outline similar to that of the quartz of clastics.

Masses of these quartz grains occur up to one centimeter in diameter. The latter resemble greatly particles of quartzites. The apparent lack of relations of the quartz grains to any of the minerals of the rock suggest that they are of clastic origin and have been introduced from the country rock during the passage of the lava through its vent. This occurrence of clastic quartz in hypabyssal and surface rocks is not confined solely to these flows. The andesites of the later Modjeska series exhibit the same type of unassimilated quartz grains derived in all probability from the sides of the chambers through which they passed.

Upper Tuff

Overlying the upper andesite is the third tuff, which is in all essential respects like the other two. It contains somewhat less clastic material than the second tuff and somewhat less in the way of pyroclastic quartz than the first. Plates X and XII, Figs.3, show this material in both megascopic and microscopic view. In thickness it amounts to at least 200 feet. The original thickness has been modified by the pre-Cretaceous erosion.

Illustrations of this and the other tuffs cannot do justice to their beauty. The soapy green color with the brilliant quartz grains furnishes a rock that is extremely easy to recognize in the field.

From the above description of the San Juan Hot Spring series it is evident that volcanic activity is responsible for by far the major portion of material. The occurence of flows associated with interbedded clastics carrying volcanic materials is clearly a characteristic of pyroclastic deposits.

From the stratigraphic relations of the formation it is evident that the age is greater than that of the granodiorite but that it is younger than the Silverado formation. Like the latter it has been considerably metamorphosed. The calcitization of the feldspars and the uralitization of the pyroxenes is due not to weathering, but to deep seated alteration. The intrusion of of the granodiorite is believed to be responsible for this alteration inasmuch as it is not altered itself but all the preceeding formations are. The gases and vapors given off during the intrusion and cooling of these later rocks has caused profound alterations in these earlier formations. There is no evidence for ground water leaching since no oxidation of the material is noticed. Further the alteration is everywhere as intense showing no relation to a possible old land surface. Also the type of alteration is such that many minerals containing ferrous iron have been formed, a condition implying reducing conditions. Had dynamic metamorphism acted on the tuffs cleavage and shear planes would have been developed, and the tuffs would have in all probability been transformed into talcose schists. A consideration of the factors forces one to conclude that hydrothermal alteration has been responsible for the change of the tuffs and lavas.

The Age of the San Juan Hot Springs Formation

From a consideration of the conditions existing at the type locality of the formation no definite age can be assigned to the tuffs other than one of post-Silverado pre-granodiorite time. In this region there are no younger or older rocks than those mentioned which are beveled by either the bottom or top of the formation. In the vicinity of San Juan Canyon there are no intrusive bodies connected with these flows as far as the writer is aware. However in the spring of 1930 I found rocks in the vicinity of Sierra Peak which throw much light on the age of the lavas and tuffs as well as on some other intrusive bodies.

The rocks to be described are from three localities.

The first locality is Sierra Peak, the most northern peak of the Santa Ana Mountains, and the northern extension of the crystalline "basement complex". The second locality is a dike in Silverado Canyon near the contact of the Hough and Silverado formations, while the third is on the hill back of the Blue Light mine in Silverado Canyon.

In Silverado Canyon on Hill 3506 back of the Blue Light mine there is an outcrop of a dazzling white rock, slightly rusty in spots with numerous large quartz grains several millimeters in diameter. This forms a roughly elliptical stock about two hundred feet long in a north south direction and about a hundred feet in an east west direction. Under the microscope (Plate XIII Fig.3) this rock is seen to be very badly altered. It is composed of a few quartz phenocrysts in a ground mass of calctized felspars and quartz. Little can be said of the rock other than that it is an altered quartz porphyry. However, the shape of the quartz phenocrysts should be kept in mind. Their size, degree of corrosion, and general appearance are believed to be of value in the following correlations.

In Silverado Canyon another dike occurs several hundred feet west of the Silverado Hough contact. This strikes across the stream in a north-south direction and reaches a height of several hundred feet on each of the canyon walls. This material is pale green to white in color and resembles the material on Hill3506 in every way except the degree of alteration. It is apparent from the hand specimen that further alteration would result in the formation of a rock in every way similar to that of Hill3506. Besides the quartz grains there are traces of femic minerals and streaks of altered slates. Under the microscope (Plate XIII Fig.2) it appears to be a badly altered dacite with a ground mass composed of numerous andesine laths and altered femic minerals. The andesine is extensively altered to calcite. The rock is porphyrĕtic and appears to be holocrystalline. It is perpatic, the phenocrysts consisting of large calcitized felspars and deeply embayed quartz crystals. The rock is extensively altered but not nearly as much as the preceeding one. Here also the badly corroded but euhedral quartz is a striking character of the rock.

The most interesting of these dacites is that of Sierra Peak. In accanyon leading south from the peak excellent outcrops of what is an apparently coarse grained rock may be found. This rock (PlateXIV Fig.1) does not lend itself to a correct determination megascopically. Under the microscope the impression of a granitic rock is at once dispelled. The material consists of a small amount of fine grained ground mass in which are embedded large extensively corroded quartz phenocrysts with smaller crystals of andesine and a few crystals of a biotite of very small optic angle. In the photomicrograph (Plate XIII Fig.1) a quartz phenocryst may be seen which has been deeply corroded. The embayments are filled with groundmass. The crystal has been split and a small lath of andesine forced between the two pieces. Other phenocrysts appear to be almost perfect basal sections of euhedral crystals, while there are others that instead of exhibiting faces are bounded by concave and convex fracture surfaces. These are clastic shapes. The rock is of course a dacite porphyry and from thea consideration of the bent and fractured crystals was evidently subjected to considerable force in the viscous state. This raises the suggestion that the material is the filling of an old plug. Certainly the eruption of such material would be in the nature of an explosive fashion rather than of a quiet type.

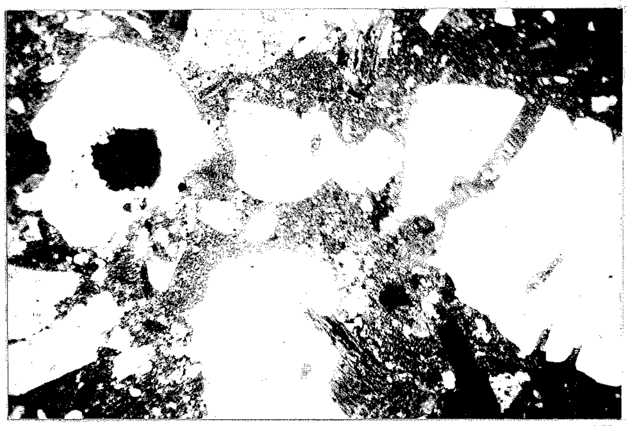


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Fig. 1 Dacite, Sierra Peak

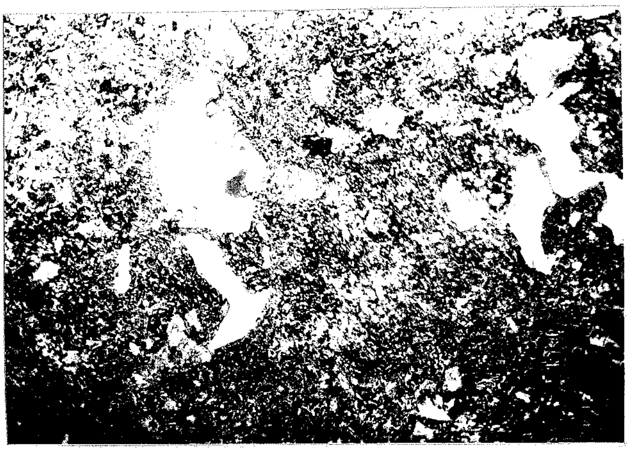

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Fig. 2 Altered Dacite, Silverado Canyon

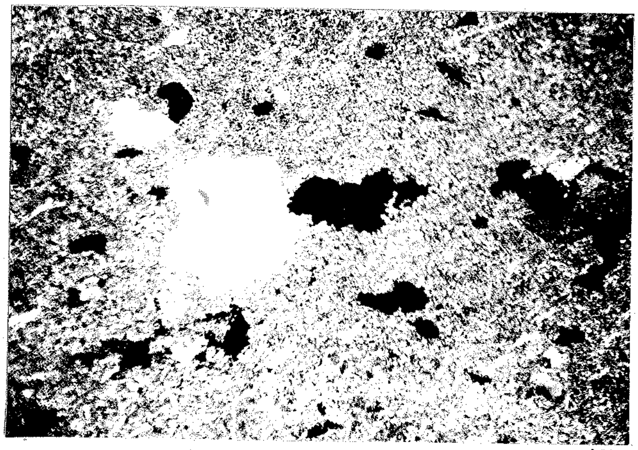

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Fig. 3 Altered Dacite, Hill 3506, Silverado Harding Divide.

A consideration of these three rocks leads one to the conclusion that if they are not representatives of the same magma, they are at least closely related. The phenocrysts in each are almost identical in shape size, and habit. Little can be told from the other minerals since they are badly weathered in some cases. The occurrence of rocks so similar in such a small area is strong evidence of consanguinity and contemporaneity as well.

If one compares the illustration of the thin section of the Sierra Peak dacite with that of the lower tuff from San Juan Canyon, he must be struck by the strong resemblance between the quartz phenocrysts. These are apparently closely related not only because of their shape and appearance, but because ofthe occurrence of similar inclusions. They contain slender needles of apatite and very long needles of an unidentified mineral. This similarity of the quartz is more than a mere coincidence, especially since no other source of similar material is known. The dacite of Sierra Peak is considered, therefore, to represent the old stock from which the material forming the pyroclastics of San Juan Canyon was derived. There may have been other vents contributing similar material but their location is not known.

Correlation of these various formations fixes the age of the San Juan Hot Springs rather closely. The dike of dacite in Silverado Canyon cuts the Hough and is in turn cut by a dike of the Modjeska andesites. Thus the age of the tuffs and lavas is fixed as post-Hough pre-Modjeska. Considering the granodiorite as upper Jurassic, the Modjeska series as middle Jurassic, and the Hough as upper Triassic or very early Jurassic, this would place the San Juan Hot Springs Formation in the lower Jurassic. In the absence of fossil evidence this is as close a determination as can be hoped for.

Igneous Rocks

The metamorphic rocks described in the previous section are intruded by a series of igneous rocks of Jurassic age. The combined metamorphic and igneous rocks of pre-Cretaceous age are referred to collectively as the "basement complex". In this paper the igneous rocks have been separated as well as the metamorphic ones and it has been found that the socalled "basement complex" contains two distinct ages of intrusives, one Jurassic and made up of a series of andesite dikes and a granodiorite intrusion, and the other, a diabase intrusion of Miocene age.

Modjeska Series

The Modjeska series includes a group of genetically related andesitic rocks which intrude the three earlier metamorphic formations. This series is subdivided into three types of rock. The first is an andesite porphyry, the second is an andesite porphyry which contains more or less unassimilated quartz derived from the sandstone of the Silverado formation, while the third is a diabase porphyry intrusive into the earlier andesite of the series. These rocks will be first described from a geographical point of view and then their relations will be discussed.

Silverado Canyon near Junction with Ladd Canyon

In Silverado Canyon about 100 yar ds abovethe junction with Ladd Canyon there occurs an intrusive body of andesite porphyry. This material is exposed under an overlapping blanket of Cretaceous sediments and widens considerably to the north in Ladd Canyon. To the south it may be followed to the Williams Harding divide.

In appearance this rock is at first confusing to the person in the field so various are its modifications. In certain zones, irregularly spaced, the material has the characteristics of an agglomerate while at others it appears to be a normal dike rock. The parts resembling agglomerates contain numerous angular fragments of dark red and purple andesitic material embedded in a dark green crystalline matrix, while the normal dikes are solid colors, usually dark green to black.

Under the microscope (Plate XV, Fig.1) the normal andesite porphyry is found to be a porphyritic, dopatic, and holocrystalline rock. The ground mass is badly altered and much of it is not resolvable. There are a few grains of unaltered labradorite with much magnetite and some calcite. Embedded in this are numerous large phenocrysts of partially calcitized labradorite and an altered femic mineral. This rock is apparently an andesite porphyry. No quartz was found in the sections.

The more altered material resembling a breccia was not sectioned, experience having shown that similar material from other localities is too badly altered for microscopic determination.

The structure of this mass of rock appears to be a series of dikes which are oriented in a north south direction. The whole might be thought of as a composite dike. The portions which suggest a pyroclastic origin are regarded as intusive breccias for the following reasons:

1. The material is all of the same type. No fragments can be found which suggest an explosive origin nor is any of the ground mass tuffaceous or scoriaceous. The fragments are blocks of andesite porphyry embedded in andesite porphyry which save for its color (due probably to differences in alteration) is very much the same.

2. The angular shape of the included material precludes its origin as schlieren as does also its strong resemblance to the

groundmass. They are clearly fragments of a rock very similar to the groudmass.

On consideration of various types of breccias this one is found to be most closely related to an intrusion breccia. The injection of a series of dikes under pressure has resulted in the incorporation of material from the older dikes in the younger. This mechanical nature of the inclusions is best demonstrated by the occurrence in Ladd Canyon. Here (Plate XVI)there is a very extensive outcrop of the andesite breccia which includes not only fragments of earlier dikes but boulders from the Hough formation. This was noted by H.W.Fairbanks[1] in his reconnaissance of San Diego, Orange, and San Bernardino Counties. The obviously sedimentary boulders of polished slates and quartzites embedded in a matrix of a green crystalline rock furnishes a striking sight. Due to alteration of some of the outcrops the material might be confused in places with an agglomerate. However an examination of fresh surfaces shows that it is in reality an intrusive breccia.

The variation in character of the andesite porphyry is explained by the fact that it is made up of a series of dikes, all related, but at the same time, of slightly different age. Hence the intrusions represent different phases of the magma, and in different dikes there may be present different assimilated matter.

Andesites of Upper Silverado Canyon

In upper Silverado Canyon there are numerous small dikes of andesite porphyry and of diabase that reach the surface. These all occur to the east of the area mapped. They may be recognized by their green color and general similarity to the other areas of the Modjeska series.

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[1]Fairbanks, Calif.State Min.Bur., 14th Ann.Rept.,p.115-116,1893.

Rocks of the Modjeska Peak Region

On referring to the areal map a large region of andesitic rocks may be noted about Modjeska Peak. These form a roughly rectangular area trending somewhat west of north. This is the type locality of the Modjeska series. Along a line running west from Santiago Peak and down the Modjeska fire trail may be found rocks illustrating most of the types making up this interesting group.

The first rock to be described occurs on the summit of Santiago Peak. It occurs not so far from the contact with the later intrusive diabase. It is a dark green rock, apparently fresh, and very hard and tough. Under the microscope it is found to be composed of some altered femic phenocrysts set in an altered ground mass which shows relics of old flow lines. Alteration has been so extensive that no determination is possible other than that it was a felsite porphyry. The intense alteration is perhaps due to its proximity to the granodiorite and diabase intrusives.

As one approaches the saddle between Santiago and Modjeska Peaks a series of red and green intrusive breccias may be noted. This material exists here on a much grander scale than in Silverado Canyon. The upper part of Santiago Creek follows for several miles this zone. The material consists of clean angular chunks of red and purple andesite porphyry set irregularly in a ground mass of a green andesite porphyry. Here as elsewhere the absence of any tuffaceous or scoriaceous material may be noted. The materials throughout are solid fine grained igneous rocks with no interstices or cavities. Thin sections show that the rocks are badly altered and were probably an andesite porphyry. Altered andesine phenocrysts with some altered pyroxenes occur set in a very badly altered groundmass. It is to be noted that most of the fine grained green rocks met with in the field are badly altered no matter how tough they may be. The combination of toughness and extensive alteration is one evidence for hydrothermal rather than groundwater alteration.

The intrusive breccia some hundred yards west of the saddle gives place to a dark green rock of uniform texture.This appears under the microscope as a badly altered andesite porphyry in the ground mass of which one can distinguish a few quartz grains. These look very much like the clastic grains associated with sandstones. Their irregularity is neither that of fragmental grains associated with pyroclastics, the corroded type associated with quartz porphyries, nor interstitial fillings. Among the phenocrysts of andesine felspar and badly altered femic minerals occur some large masses of quartz grains. The individual particles show an undulatory extinction and taken together form a typical fragment of quartzite. No cement other than a possible one of silica has been noted but the relation of the grains and the absence of other minerals among such an aggregate is strong evidence that it is quartzite. This and the individual grains scattered through the rock suggest that considerable stoping has taken place but that assimilation of the parts stoped has not been complete. The forceful intrusion of the andesite porphyry as shown by the formation of the intrusion breccia would be expected to remove parts of the wall rock and incorporate them in itself. In this way large quantities of material of sedimentary origin might be included in a strictly igneous rock.

As one approaches the contact with the slates to the west the andesite becomes finer grained. At the contact it appears as a very fine grained green rock with a few small phenocryst of felspar. This on microscopic examination turns out to be badly altered, but a few large andesine crystals can be made out in a ground mass of minute felspar laths and glass. There are also remnants of a femic mineral. The fine grain of this selvage zone is what would be expected on the basis of an intrusion. This material and that from Santiago Peak mark the extreme limits of this intrusive body. Intrusion was forceful from the first as is shown by the crumpled slates along the western contact. After the first intrusion occurred there were subsequent injections of material through the center of the dike. These resulted in the development of the intrusive breccia. The number of dikes which make up this composite structure is not known, but it is certainly large to judge from the variation of the rocks.

On the ridge running south from Modjeska Peak another very distinct variety of igneous rock occurs. On fresh surfaces this is a light green porphyritic rock with distinctive aggregates of ferromagnesian minerals. Large phenocrysts of felspar can also be discerned. On weathering the ground mass turns a light pink, but the aggregates of femic minerals are always preserved and lend a very characteristic appearance to the rock by which it may be easily recognized in the field. In thin section (Plate XVII, Fig.1) the rock is found to be an andesite porphyry. The phenocrysts are composed of more or less calcitized andesine felspars of lath shape. The femic mineral is not determinable. The ground mass is a badly altered mixture of small felspar laths, femic material, and glass. Associated with the phenocrysts are irregular aggregates of quartz grains which are apperently non-assimilated particles from the sandstones.

To the west beyond a small band of slates there occurs a large stock like mass of another rock of the Modjeska Series. This is called the Modjeska diabase. It forms the mass of Hill 4460 and extends on the east to the slate contact. On the other boundaries, however, it is in contact with a more or less narrow zone of the ordinary green andesite porphyry.

On fresh surfaces the rock is dark green in color with numerous black lath shaped crystals of hornblende as phenocrysts. It weathers to alight greenish white on outcrops and gives rise to smooth rounded land forms covered with soft sandy material. These white outcrops may be seen from a distance and can easily be confused with limestone outcrops.

Thin sections of the fresher unweathered material (Plate XV, fig.3) show little alteration o the felspars, but quite a noticeable amount in the case of the ferromagnesian elements. The phenocrysts consist of hornblende and occasional rounded altered grains of olivine. There are a few masses of quartz which are evidently of foreign origin. The ground mass consists almost entirely of felspar laths with some interstitial hornblende. Where the latter occurs in abundance small laths of felspar may be found entirely surrounded by it. Magnetite also occurs, as well as secondary sulfides and oxides. The texture is quite plainly a diabasic intersertal type.

This hornblende diabase porphyry is best represented on Hill4460, but there are other occurrences of the highly distinctive rock. These are in dikes in the heads of Ladd and Silverado Canyons. There is also an interesting occurrence in the small tongue of the Modjeska series on the North Colwater fire trail. Here the same diabase, somewhat finer in texture, occurs as a dike some hundred feet wide intrusive along the center of the older andesite porphyry dikes. It is evidently part of the series of dikes in

Plate

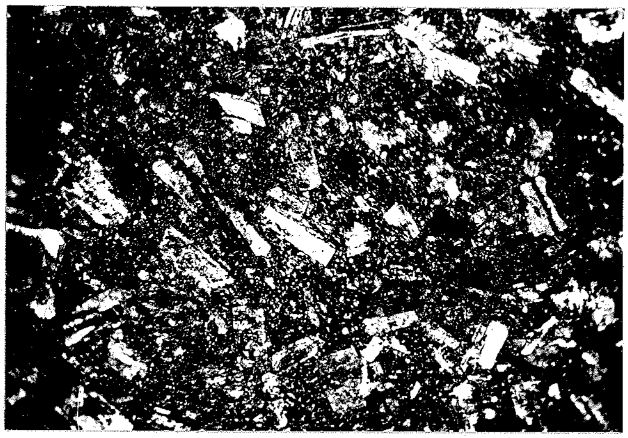

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Fig. 1 Andesite Porphyry, near junction of Silvetado and Ladd Canyons

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Fig. 2 Dacite Porphyry, Silverado Harding Divide

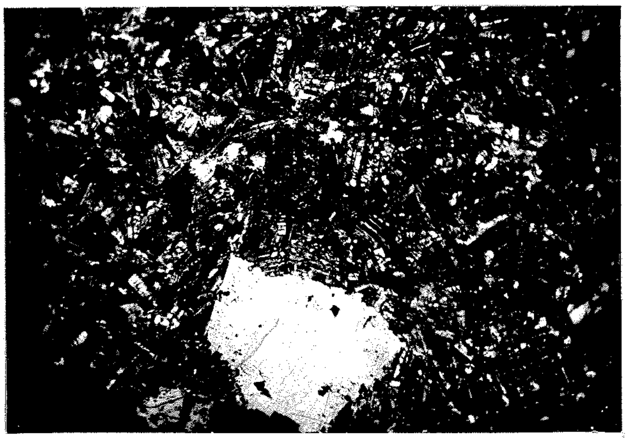

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Fig. 3 Hornblende Diabase Porphyry, Santiago Harding Divide

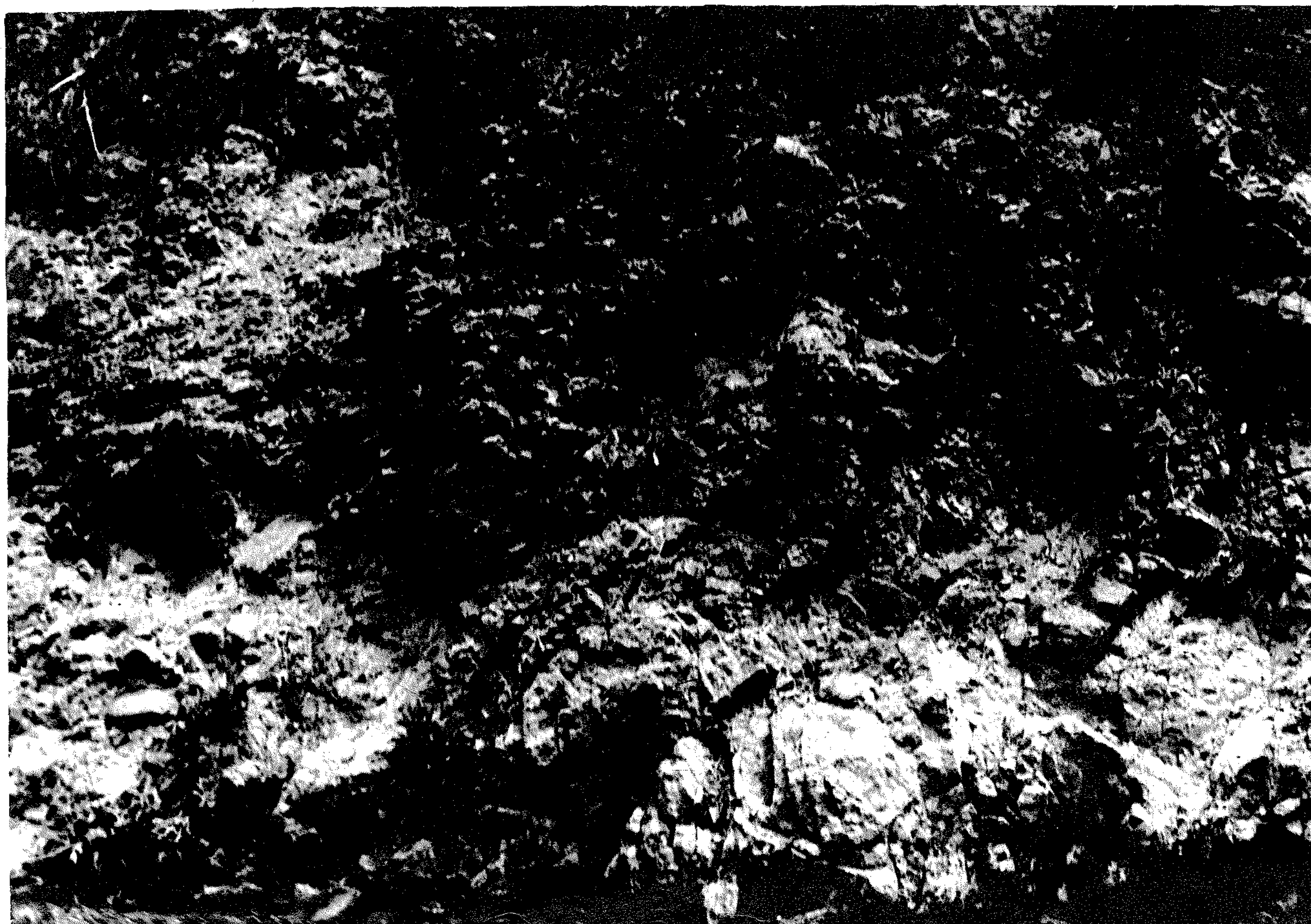

Plate XVI   Intrusion Breccia of Modjeska Andesite, Wadd Canyon

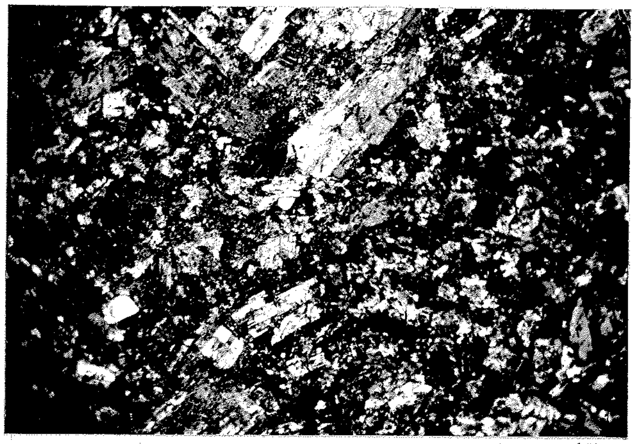

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Fig. 1 Andesite Porphyry, Modjeska Peak

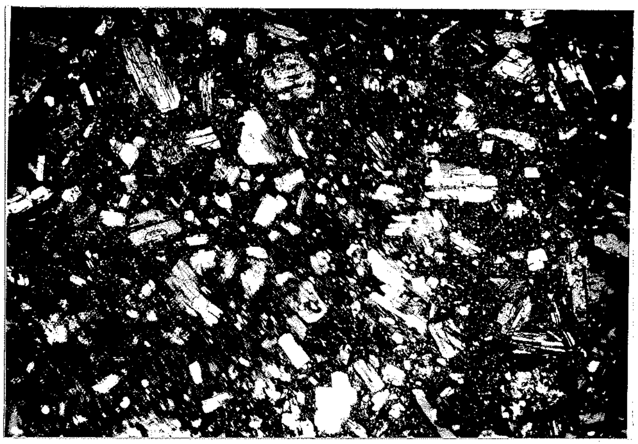

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Fig. 2 Andesite Porphyry, Trabuco Canyon

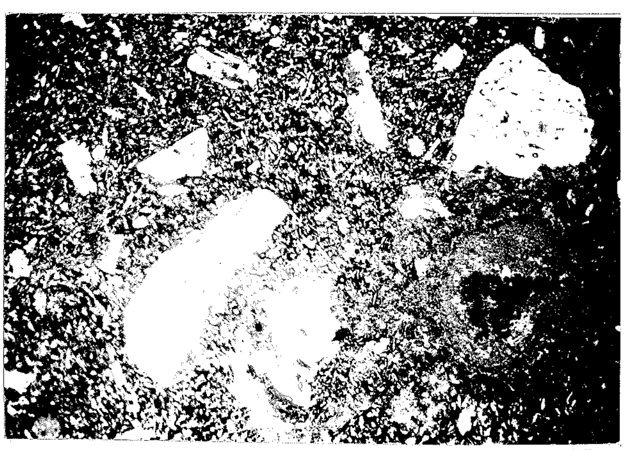

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Fig. 3 Andesite Porphyry, Trabuco Bell Divide this locality.

The diabase in the above mentioned occurrences is believed to represent a later intrusion rather than a differentiation in place. This is shown in several ways. In the case of the large stock on Hill4460 it will be noted that the surrounding andesite porphyry is missing on the east boundary. Yet this is an intrusive contact of diabase and slate. Due to alteration and weathering it is not possible to tell whether the diabase is intrusive at other places in this particular locality, but it is believed that intrusion into the slate is ample evidence of its origin at some other point, rather than as a local differentiate. The dikes mentioned above also cut the earlier andesites and slates. The occurrence on the North Coldwater fire line shows clearly the intrusive contact of the diabase and andesite.

The association of the diabase with the andesite intrusions rather than with areas of weaker rocks leads one to believe that it possesses a genetic relation to the rest of the Modjeska series. This relation is particular impressive to the worker in the field who has seen some of the other facies of the series which look like types transitional between the diabase and andesite. While the diabase might be mapped as part of a different series, it would raise the serious question of the status of the intermediate rock types. Mapping of distinct intrusive bodies would be rather in the nature of subdivision of the series and would show greater evidence for relationship than for dissimilarity.

To the south there are other occurrences of the andesites of this series. The area that starts in the neighborhood of Modjeska Peak extends south in an irregular and devious fashion across Trabuco Creek. The material north of Trabuco Creek rsembles that of the upper parts of Santiago Creek. It possesses the same green color and shows the same variation from occasional fresher dark material to the andesite breccia. The latter in some of the badly weatherd zones resembles a volcanic agglomerate rather than an intrusive hypabyssal rock. This material extends across Trabuco Creek, but to the south a different phacies is found.

A thin section of andesite porphyry from the Boundary fire line just north of Trabuco Creek shows the same type of alteration common to the other occurrences. The section (Plate XVII Fig.2) shows the rock as made up of more or less calcitized labradorite and uralitized pyroxene phenocrysts set in a ground mass of badly altered fine felspar and femic elements. There is some primary magnetite and apatite. Calcite and chloritic minerals are abundant.

The material outcropping between Trabuco and Bell Canyons is a dark porphyritic rock which occurs in an area surround by an andesite porphyry similar to that of the north. While this rock is apparently quite fresh in the hand specimens thin sections (Plate XVII,Fig.3) show it to be badly altered. It consists essentially of large labradorite phenocrysts in a ground mass of andesine laths and altered ferromagnesian elements. Occasional femic phenocrysts occur as seen in the illustration but these are more than ordinarily badly altered. Calcitization of the felspars has progressed to the point where they appear in some cases to have anomalous colors.

Summary

The Modjeska series is a group of closely related andesitic rocks. The type section is Modjeska Peak. The group shows considerable variation but it is found that the similarity of the various facies is sufficiently great to permit of considerable ease in the mapping of the unit.

In general the rocks are green in color and porphyritic. Some cases of other colors exist. In general they form irregular dike like masses which may be complicated by repeated intrusions. This intrusion has taken place under considerable pressure as may be seen from the incorporation of materials from the walls of the intu intruded formations. In this way have arisen the striking intrusive breccias made up of andesite particles in a groundmass of a crystalline felsite or of sedimentary materials in a similar groundmass. This has also resulted in the incorporation of considerable foreign material, particularly quartz. This is visible under the microscope and where care is not used might lead to the classification of these rocks as dacites.

In composition the rocks range from andesite porphyries whose felspars are basic andesines through andesite porphyries with acid labradorites. Diabases also occur. Though the composition be somewhat variable field work has shown that the series is a closely related one.

Dacite of the Silverado-Harding Divide

Extending from Hill 3300 (West of Hill 3305) on the Silverado-Harding divide to the Cretaceous contact in Williams Canyon is a large body of dacite. This material is decidedly different from from the andesites of the Modjeska series. It weathers to rusty colors but on fresh fractures is a dark gray speckled with numerous phenocrysts. It is fresh and has suffered comparatively little alteration.

Under the microscope (Plate XV, Fig.2) this rock appears to be a dacite porphyry. There are a few large phenocrysts of felspar and quartz which amount to less than 5% of the rock. Hence it is perpatic. The groundmass is composed of quartz and altered felspar and femic elemnnts. The quartz grains which amount to about about 40% of the rock are about one tenth to one half a millimater in size. These resemble euhedral crystals which have been badly corroded and cracked but which still show portions of the original faces. Surrounding these is an altered mass of oligoclase felspar. In this groundmass of quartz and felspar occur large phenocrysts of oligoclase, uralite, and alteration products of femic minerals.

From the above description the rock is easily seen to be decidedly different from both the Modjeska series and the earlier dacites of the metamorphic series. It differs decidedly in the occurence of quartz in the ground mass and also in the occurrence of such an acid felspar as oligoclase. For this reason it has been separated as a distinct unit. Its age is later than that of the Modjeska series and probably corresponds to other dacites found outside of this particular area.

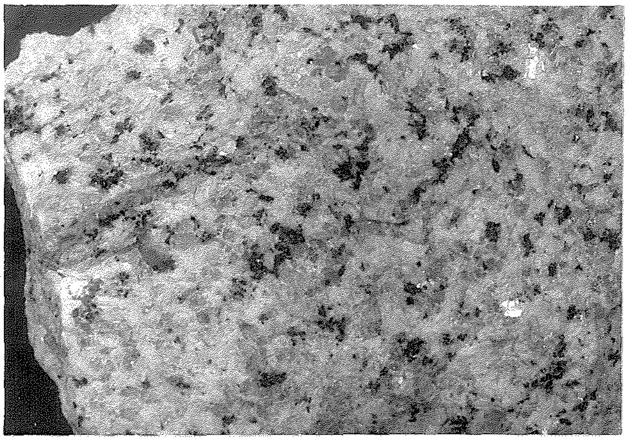

Fig. 1 Granodiorite, Main Divide
East of Santiago Peak

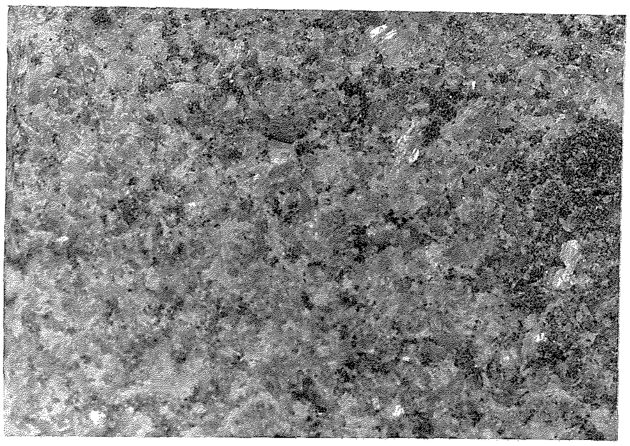

Fig. 2 Granodiorite, Ranger Station
Hot Springs Canyon

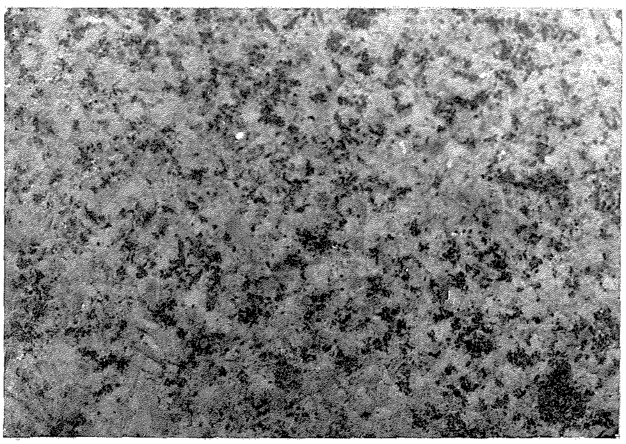

Fig. 3 Granodiorite, Junction of
San Juan and Hot Springs Canyons

Plate XIX

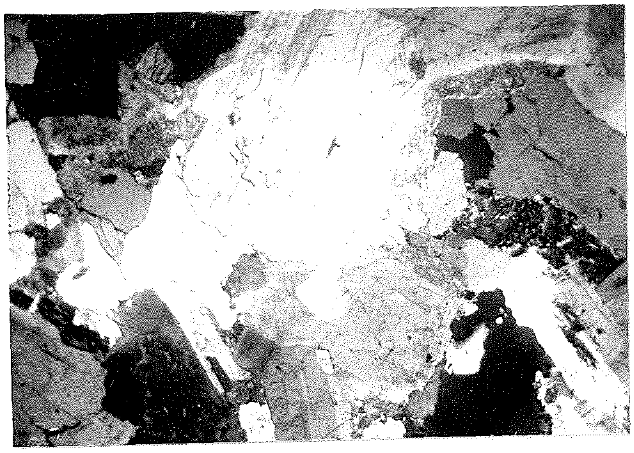

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Fig. 1 Granodiorite, Main Divide east of Santiago Peak

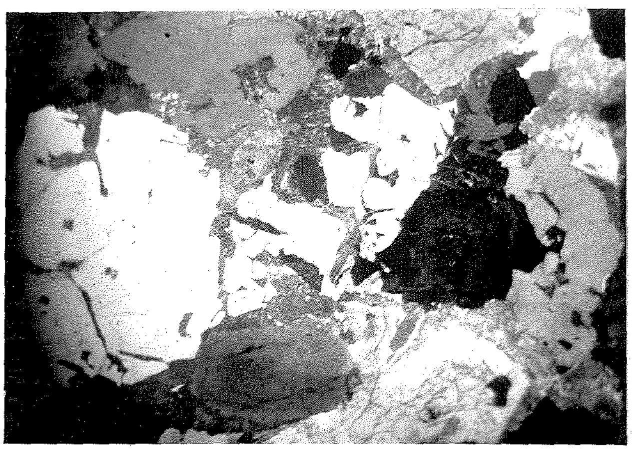

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Fig. 2 Granodiorite, Ranger Station Hot Springs Canyon

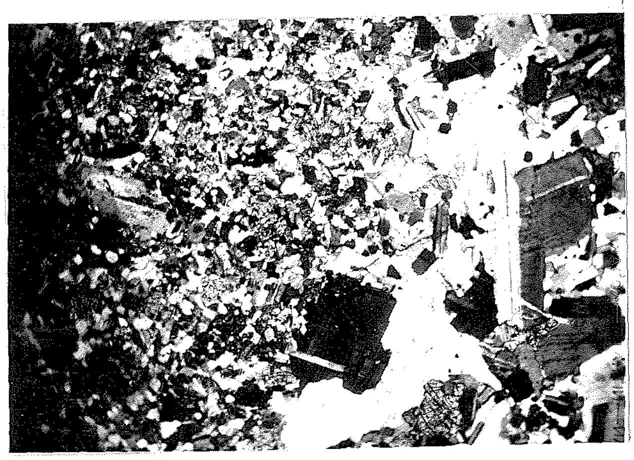

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Fig. 3 Section showing contact of Slate and Granodiorite, San Juan Canyon

Granodiorite

There are mapped in the region studied two areas of granodiorite. One occurs to the northeast of Santiago Peak and the other in the lower southeast corner of the map. While the granodiorite has been mapped as a single unit there are certain variations in texture and composition which if mapped would undoubtedly show it to be not a single type of rock but a series of rocks of rather close relationships.

The granodiorite of the northeastern corner of the area is a rock which is characteristic of much of the country of the Peninsular Range and the region to the east. This is a very coarse grained white rock which weathers on exposures to daazling white sandy outcrops. The rock is white with numerous black specks of biotite and hornblende. The light minerals consist of quartz and plagioclase felspar. As seen from the hand sample the rock appears fresh. Fig.1 Plate XVIII gives a fair idea of the appearance of this rock.

A section of this same rock (Plate XIX, Fig.1) from the main divide east of Santiago Peak shows it to be composed essentially of acid plagioclase and quartz. The texture is holocrystalline, seriate porphyroid, The constituents are oligoclase (50%), quartz (30%), perthite (15%), Biotite, green hornblende, and magnetite 5%. This is evidently a granodiorite.

The rock from the ranger station in Hot Springs Canyon resembles the latter in being a holocrystalline rock, but it is much finer grained, and is considerably darker in color, though no more basic. Fig.2 PlateXVIII is an illustration of a hand speciman of this rock. It is a greasy grey in appearance and weathers to a dirty sandy soil instead of the white gravelly material of the coarser facies. Under the microscope (Plate XIX Fig.2) it is seen to be made up of about 55% oligoclase, 40% quartz, and 5% biotite, green hornblende, and magnetite. Some calcite and chlorite occur in this rock as alteration products. The dark color of the plagioclase in the hand sample appear to be due to small alterations which affect its transmission of light.

Another granodiorite from near the slate contact in San Juan Canyon shows an entirely different appearance. It is a light rock (Plate XVIII Fig.3) and is white in color with numerous specks of biotite and green hornblende. It resembles the material from the Main Divide rather closely in appearance except for its finer texture. A thin section (Plate XIX, Fig.3) shows that it is composed of oligoclase, quartz, and green horneblende and biotite. The quartz is less in amount than in the preceeding rock and there is a larger amount of biotite and hornblende. Despite this lesser acidity it is nearly white as compared with the grey of the other rock.

Age

The granodiorite of the Santa Ana Mountains is closely connected with the other granodiorites of the Southern Californian batholith. This has been considered to be upper Jurassic in age and to represent about the same age of intrusion as the great Sierran batholith. As far as the age of the material goes from the relations existing in this area, it may be expressed as pre-upper Cretaceous, post Modjeska. An upper Jurassic age would. however,fit well into into the series of events in this region.

The relation of the granodiorite to the Cretaceous is plainly that of unconformity. The Cretaceous not only rests on the intrusives but has incorporated in its conglomerates fragments of them. Further a study of its sediments shows them to be derived from a granodiorite land mass. Under these conditions a sufficient lapse of time must have occurred in pre-Cretaceous time to allow the batholith to cool, to have its thick cover of metamorphics stripped off, and to cause one part to sink and another part in h the east to rise and form a land mass which might contribute sediments. This chain of events suggests independantly an upper Jurassic or very early Cretaceous age as far as this area is concerned.

One of the most interesting relations the granodiorite possesses is that with regard to metamorphism of the earlier rocks. These have been undoubtedly subjected to heat and solutions. The fact that the granodiorite is the only rock representative of a very large mass is evidence in favor of it as the cause. Further, the fact that the granodiorite is apparently not affected by hydrothermal alteration is another strong bit of evidence. An elimination of the other igneous rocks may be easily effected, and as aresult the granodiorite is left as the only rock potent enough to effect such wide and extensive alteration.

Igneous Rocks Younger than the Pre-Cretaceous "Basement Complex"

In the Santa Ana Mountains there occurs a rock of considerably younger age than the pre-Cretaceous complex. This is so intimately associated with the older rocks that were it not for its relations to similar rocks in nearby regions, it would have been mapped as pre-Cretaceous. For many of the suggestions as to the age and relations of this rock the author is indebted to Mr.B.A.Otis of the General Petroleum Company of California, who informed him of the occurence of similar material in the Puente Hills.

This rock, which is a diabase,occurs in three distinct patches in the area mapped. These include the mouth of Coldwater Canyon, the upper part of Holy Jim Canyon, and a narrow strip along the bottom of Harding Canyon. There are some differences in the material from these different areas but they are explained as the results of local factors influencing assimilation of foreign material and the rate of cooling.

The type section of the diabase is taken as the occurrence in Colwater Canyon on the eastern face of the scarp just above the Glen Ivy Hot Springs. Since the name Coldwater is preoccupied the term Glen Ivy Diabase is proposed as a name for the formation.

The occurrence of the Glen Ivy Diabase at the type locality is in the nature of a large dike-like mass which runs nearly parallel to the east scarp along its base. To the east the body is bounded by the Elsinore fault, while to the west it is intrusive into the slates of the Silverado formation. In this body occur frequent xenoliths of slates which are baked to a cherty rock. One of these may be noted in Coldwater Canyon. It is some 200 feet in width and of undetermined length.

In the hand speciman (Plate XX Fig.1) the rock might be mistaken for a dark medium grained granitic rock. A close examination, however, shows the felspars to be lath shaped and surrounded by the femic minerals. Thus it is evidently a diabase. The minerals making up the rock are labradorite and a dark fibrous hornblende with a minor amout of magnetite and pyrite. The labradorite is easily recognizable megascopically by its typical blue interference color. The hornblende is fibrous and rather soft. The felspars are only slightly altered but the ferromagnesian element is evidently a considerably altered mineral.

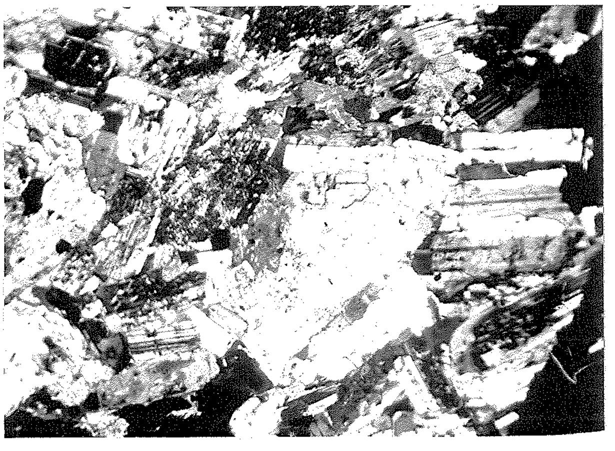
A thin section (Plate XXI Fig.2) shows at once the nature of the rock. The felspar which makes up nearly half its bulk consists of labradorite in lath shaped crystals. These are surrounded by uralite and other alteration products of augite. The section shows the rock to be holocrystalline and ophitic in texture. Besides the labradorite and uralite there is a small variable amount of quartz. For reasons to be cited later this is considered as probably due to assimilation of material from the surrounding Silverado formation. Zircon and apatite occur as accessory minerals in the felspar grains. The zircon occurs as crystals with slightly rounded faces. The apatite is in the form of long acicular crystals. The dark opaque material consists of pyrrhotite and magnetite.

There is an occurrence of a similar rock in along narrow dike-like body in the bottom of Harding Canyon. This is intrusive into the slates which form a zone between it and the adjacent andesite porphyry bodies. In appearance it differs slightly from the Glen Ivy material since it includes a coarser grained facies (Plate XX Fig.2). This grades into finer grained rocks which resembles that of Coldwater Canyon. In

Plate XXI

×15

Fig.1 Quartz Diabase, Harding Canyon

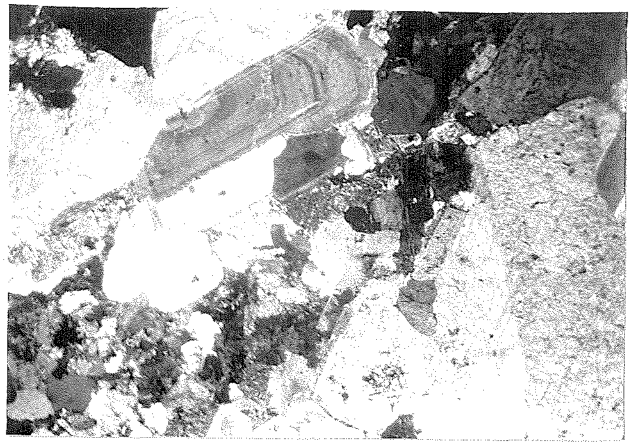


×15

Fig.2 Quartz Diabase, Coldwater Canyon

Fig.3 Quartz Diabase, Holy Jim Canyon

Plate XXII

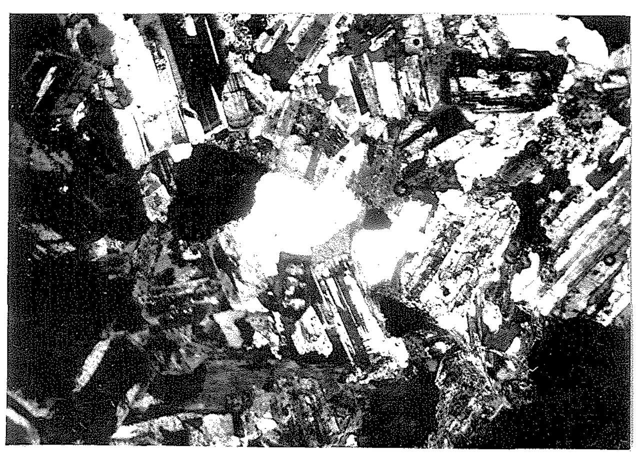


×15

Fig. 1 Quartz Diabase from Spring on
Hily Jim Santiago Peak Trail

×15

Fig. 2 Diabase from contact zone,
Santiago Peak



×15

Fig. 3 Quartz Diabase, dike near
Yaeger's Mine, Trabuco Canyon

composition this rock is made up of equal amounts of labradorite and hornblende.

Thin sections (Plate XXI Fig.1) show the rock made up of labradorite laths surrounded by an intergrowth of uralite and chloritic material. There is also some quartz which is considered in this case also as due to assimilation of the country rock. The quartz is surrounded by the uralite and chlorite. The texture is holocrystalline ophitic. Some apatite and zircon is present as accesory minerals included in the felspars. There is much magnetite in the uralite, probably of secondary origin.

The material in the area mapped on the east slope of Santiago Peak and in the upper part of Holy Jim Canyon is a rather light greenish gray rock of medium grain. There is considerable variation in this material from the contact zone to the center of the body.

A typical rock from Holy Jim Canyon (Plate XX Fig.3) is a rather uniformly medium grained, light greenish gray in appearance. On the hand specimen it appears to be made up of lath shaped felspar crystals and fibrous hornblende. The rock appears fresh and tough and is quite resistant. A thin section (Plate XXI Fig.3)shows the texture to be an intersertal type rather than ophitic due to the samller amount of uralite. The larger portion of the rock is made up of rather basic andesine laths (60%). Next is an abundant micropegmatite or granophyre forming nearly 10%. Quartz is abundant forming nearly 15% of the total bulk. The ferromagnesian elements are uralite and chlorites, with a small amount of biotite. Apatite in long acicular crystals is abundant in the felspars. Theresis a small amount of Zircon. Magnetite and pyrhhotite are also present.

This rock is evidently a quartz diabase. If one traces the western slate diabase contact to the Main Divide he will follow a fine grained dark rock which represents the chilled part of the intrusion. This presents quite a different appearance under the microscope. As seen in Fig.2 Plate XXII it is made up of lath shaped labradorite crystals (60%) and uralite. Quartz is absent. The felspars contain much acicular apatite and some zircon. Some magnetite and pyrite are also present. This rock is a decided contrast to the other occurences both in texture and composition. The felspars are rather uniform in size, are constant in composition, and are quite basic. There is no quartz or micropegmatite.

Sections of other localities show some other variations. That from the spring on the Holy Jim Santiago Peak trail (Plate XXII Fig.1) is interesting because of its variation in texture. It is composed of andesine, micropegmatite, quartz, and uralite. At this locality float from close to the contact is found which is very fine grained, in appearance resembling a vitrophyre. Material from a dike in Trabuco Canyon just below Yaeger's mine (Plate XXII Fig.3) resembles that from the main divide in many respects. It contains, however, a small amount of quartz.

The preceeding rocks are undoubtedly all variations of the same parent magma. The most important differences in composition, the presence of quartz and micropegmatite, is assigned to assimilation of country rock for the reason that wherever a chilled border zone occurs, very little of this material is found. Further the more acid phacies occur in the larger intrusions, those which are capable of digesting the included rocks and incorporating them in their subsequently formed minerals. The power of the intusions to assimilate foreign bodies is shown by the alteration of the sandstones and conglomerates in Holy Jim Canyon at the diabase contact. Here the Silverado formation has been converted into a white quartzite by the heat and gases of the solidifying rock. This has been accompanied by the exertion of no great pressure.

The age of the diabase is of the greatest interest. In the Santa Ana Mountains it is unfortunately intrusive into all the rocks with which it is found in contact. Hence from these occurrences the only date that can be assigned is post-granodiorite. Recently there have been discovered rocks which are so similar in composition, texture, and occurence that no doubt exists as to their relation to the Glen Ivy diabase.

In the Puente Hills intrusive into the Puente formation is found a large sill of diabase which is identical with the Glen Ivy rock. It is composed of labradorite and uralite with the same textural relations and the same accessory minerals. Thin sections of the two rocks may be easily confused when working on them due to the resemblance of the rocks. In the hills around El Modena there is a dark basalt, feldspathic in composition, which has also been investigated. Chemical analyses of this basalt, diabase from the Puente Hills, and the Glen Ivy material have been made by the General Petroleum Company. These are so close that it is certain that the rocks are of the same origin.

In view of the fact that similar material occurs in the Santa Monica Mountains in Topanga Canyon and to the south in the La Jolla Quadrangle, the existence of a large Miocene batholith amy be postulated which has given rise in the Los Angeles Basin to many of the later Tertiary Lavas. If this be the case the Glen Ivy diabase has added a very interesting and hitherto unknown chapter to the history of the Los Angeles Basim. Due to the recency of this discovery I have been unable to investigate the relations of the diabase less thoroughly than they deserve.

Sedimentary Rocks

Cretaceous

The Cretaceous of the Santa Ana Mountains consists of a thick series of beds overlying the basement rocks unconformably. In the area studied these constitute a westward dipping homocline. To the north in the vicinity of Santa Ana Canyon they occupy a more extensive area and are gently folded and faulted. To the south the dips become smaller and as result the pattern of the outcrop becomes wider.

The rocks consist of a series of conglomerates, sandstones, and shales some 2500 feet thick in the neighborhood of Silverado Canyon. This is divided into several lithologic units for the convenience of Mapping. These are as follows:

Upper conglomerate, sandstone, and shale series.
------- Disconformity------
Middle shales, with lenses of sandstones and conglomerates
------- Gradational contact--
Lower conglomerate and sandstone
------- Gradational contact--
Basal conglomerate, altered to a red color. (This is also known as the Trabuco Formation)

In this paper it will be noted that the so-called Trabuco formation is mapped as the basal conglomerate of the Cretaceous. The Cretaceous above this unit is mapped as upper Cretaceous rather than Chico because of the fact that it embraces beds which differ from "type Chico". Due to the lack of adequate knowledge both of the "type Chico" and the fauna of the Santa Ana Cretaceous it was felt that any correlation with the northern formation might prove more of a hindrance in future work than an aid.

In the field the section resembles other sections of Cretaceous strata both in the black shales and in the olive tones of the sandstones. A view of the section in Santiago Canyon is shown in Plate XXIII. Here the relation of the different units is well shown, with the exception of the basal red conglomerate. The relation of the lower cliff forming conglomerate to the middle shale can easily be seen . The Upper series forms the dip slopes in Santiago Canyon.

Trabuco Formation

At the base of the Cretaceous north of Trabuco Creek is a coarse red conglomerate which has been named the Trabuco formation by Packard[1]. The basis for the naming of this formation was its striking apparent lithologic difference from the remainder of the section and its apparently non-gradational contact. Due to its deep brick red color, its softness, and its unsorted nature a continental origin was assigned to it.

Careful examination of the basal conglomerate in the field shows it to be a typical sandy and arkosic material resembling to a great extent in texture some of the sandy Tertiary conglomerates. There are thick beds of boulders up to several feet in diameter. These are lens-like and alternate with finer conglomerates and sands. The fineness of the bedding varies greatly being massive in the case of the very coarse material and fine, i.e. less than an inch, in the case of the sandy layers. This is well illustrated in Plate XXIV. The color of the conglomerate is dominantly red though there are locally irregular patches a light green in color. The material of which the conglomerate is made is subangular to rounded . The larger boulders are usually well rounded, suggesting considerable water action. They are made up of metamorphics, volcanics, and a coarse grained granodiorite. The metamorphics are usually slates though some quartzites and cherts may be found. The volcanics form fewer of the boulders. The granodiorite in others resembles that of

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[1] Packard, Univ.Calif.Pubs.Geol., Vol.9, No.12, p.140, 1916.

the Elsinore region, a coarse grained white rock. The most interesting fact with regard to these boulders is that wherever they are embedded in the red matrix they are universally so badly altered that they fall to pieces under a sharp blow. In view of the size of the material and its degree of rounding the present state of alteration must be due to leaching or some similar process. The finer material is likewise altered and in general appearance would appear to be muddy and earthy. A comparison with the material from the irregular green patches reveals an interesting fact. The sands and pebbles in this material are, while altered, still fresh enough to appear in their true relations. In appearance the sands resemble ordinary coarse arkoses. Sorting is not good but bedding may easily be distinguished. From examination of the relations of the unaltered material one must conclude that the surrounding red material is an alteration.

Careful examination of the relations of the two differently colored rocks of the formation will confirm the idea that the red color is a later than the deposition of the sediments. Also under further investigation the true nature of the red sandstone appears. Thin sections show that the apparent presence of muddy material is due to alteration of the grains. A comparison of the two differently colored rocks indicates that the difference in color is not associated with textural differences but with greater degrees of alteration.

A full consideration of the available evidence leads me to believe that the red color and the apparent continental nature of the deposit are due, not to a different and non-marine mode of deposition, but to alteration of a coarse porous arkosic material. The mechanism of the alteration is unknown. Whatever type it was it is certain, because of the evident oxidation of the iron, that oxygen bearing meteoric waters were involved. In the process of alteration the more porous parts were most easily oxidized. Some parts were evidently so slightly porous as to prevent much alteration.

Relations to the Lower Conglomerate.

The relation of the red beds to the overlying members of the series is clearly that of a basal conglomerate. In the field there is no discontinuity between the red material and the grey overlying beds. The contact is gradational and in places there is an alternation of beds, red and grey. This is well shown by the locality on the Santiago-Trabuco divide. Here the red beds are interbedded with the lower conglomerate, the alternation producing a very confusing aspect. The tracing of the contact between the two sediments under such conditions is quite trying, but it serves to illustrate the gradational nature of the contact.

There is, however, an evident difference in the composition of the two types of material. The basal beds are definitely arkosic and represent rapidly deposited sediments while the overlying conglomerates and sands appear to have been much more thoroughly worked over. It is believed that the differnce in color is due to the large amounts of easily oxidizable iron minerals in the original arkosic sediments of the basal beds.

Due to the absence of fossils in the Trabuco no age can be assigned to it. It is not much younger than the lower conglomerate. In view of the close relationship of this basal series to the overlying Cretaceous it is believed that it has no status as a distinct formation. The persistence of the name as a formational name will doubtless persist despite the fact that it merely designates the basal beds of the "Chico" formation of the same region. However, it furnishes a good name for a very strikig and characteristic bed of the Cretaceous.

Beds above the Red Basal Conglomerate

The formation above the basal conglomerate is a thick series of conglomerates, sandstones, and shales. These are fossiliferous and furnish an excellent opportunity for the study of Cretaceous faunas. This part of the Cretaceous is made up of three easily distinguishable members, a lower conglomerate-sandstone series a thick section of shale, and an upper series of conglomerate, sandstone, and shale. In general appearance the rocks resemble those of the Cretaceous elsewhere. The conglomerates are light olive in color and are well cemented. The sandstones have an olive tint. The shales are a deep blue black and in places have intercalated sandstone members.

The superior hardness of the lower conglomerate as compared with that of the Trabuco has led to a beautiful topographic expression of the basal part of the Cretaceous. From considerable distances one can follow the lower conglomerate which stands out as a great bluff facing the old rocks to the east. The longitudinal valleys along this cliff are of course the result of the ease of weathering of the red beds. Much of the steepness of the conglomerate cliffs is also due to this same weakness of the Trabuco which allows the process of sapping to continue. The whole of the conglomerate, sandstone and shale section is more resistant than the Tertiary beds, and as a result most of the area occupied by the Cretaceous is higher in elevation than that of the Tertiary sediments.

The lower conglomerate rests as we have already noted, on the Trabuco with a gradational contact. This conglomerate is formed of pebble beds of variable thickness which towards the top of the 350 feet are replaced by sandstone beds. Throughout its thickness it presents a sandy appearance suggesting shallow water deposition. The pebble beds possess a definite lens like structure and grade laterally into pebbly sandstones. This suggests old channels which have been scoured and filled. In color the material is a light buff to gray on outcrops, although fresh cuts show it to have a dark blue color much like that of the Silverado. The olive color associated with the outcropping of the formation appears to be due to the prsence of much chloritic material. The pebbles are usually well rounded, some specimens being nearly perfect flattened spheres. Polish is not at all uncommon. The size is from that of coarse sand up to half a foot in diameter, although the greatest number is between one and two inches. In composition these pebbles are composed dominantly of slates and quartzites, derived, presumably from areas of basement rocks. Pebbles of felsites are less abundant, while ones of coarse grained rocks like granodiorite are not found at all. In general it might be said that while this part of the Cretaceous is coarse and a shallow water deposit, considerable working over of the material making up the sediments has taken place.

Overlying the sandstones and conglomerates is a thick section of black shales, some 1500 feet thick in Silverado Canyon. These lie conformably on the sandstones though the transition is abrupt. For the most part they are made up of a sandy shale, deep black in color, and weathering to light blues and grays. In this shale occur occasional fossiliferous beds of sandstones and conglomerates. The interbedd sandstones so common at other Cretaceous localities do not occur in this section. The color of these shales is sufficient to distinguish them from any other shales of the sedimentary column. From the occurance of sandstone and conglomerates throughout the section one is forced to the conclusion that the size range of the sediments was determined to a large degree by diastrophic movements affecting the source of the sediments rather than by the depth of the basin in which they were deposited.

Above the shale section is a series embracing a conglomerate, sandstones, and shales. The occurrence of conglomerate immediately on top of shales suggests a disconformity, and on looking one was found. The beds above and below this disconformity are separated by a slight angle measured by a vertical distance of 40 feet in three miles. The conglomerate is made up of well rounded pebbles and grades into sandstone in the space of 25 feet. Above this bed is a series of thin shale and sandstone beds which alternate with each other. This series, like the others, is obviously a shallow water deposi

The above description gives a general outline of the lithology of the formation. The units mapped in the field are of course lithologic ones. Collecting, however, has revealed the presence of a number of distinct fossiliferous horizons. These are shown in the sketch columnar section of Plate XXV. This is roughly 250bfeet to the inch. The section, which is represented as having a total thickness of 2500 feet, is taken from an accurate measured section in Silverado Canyon on which have been imposed facts gathered from other localities.

Due to the fact that preservation of material in the Cretaceous is dependant on protection of the fossil from leaching by ground waters, only those occurring in a hard limey matrix have been adequately preserved. Where this type of material is weathered to the right degree excellent collections may be obtained. In the larger number of cases the matrix is too limey or weathering has progressed too far to allow of the collection of adequate faunas. As a result only the more common species are obtained and the rarer typesescape. Since much of the zoning depends on the appearance and disappearance of these less common species differences between zones may not be noticed.

The colle ctions from the localities in the area mapped are believed to be fuller than others hitherto made. These have not been completely worked up but there are some interesting facts brought out in connection with the zones aside from the purely paleontologic ones.

As may be seen from the section there are thirteen distinct fossil beds in the Cretaceous in the vicinity of Silverado and Santiago Canyons. Nowhere else in the Santa Ana Mountains is there so complete a fossiliferous section exposed. These zones are as follows.

1. The lowermost fossiliferous beds occur some 100 feet above the base of the lower conglomerate. The fauna of these beds ranges through the conglomerates and into the sandstones. It is a shallow water fauna and most of the fossils represent heavy shelled animals adapted to life in pebbly sand. There is no apparent vertcal change in this fauna throughout the 250 feet in which it occurs.It is characterized by the abundance of Trigonarca species. Liopistha anaana (Anderson), Limopsis silveradoensis Packard, Volutoderma californica Dall are also common species.

2. At the top of the lower sandstone occurs a thin zone which contains numerous individuals of Astarte sulcata Packard. This highly characteristic species appears confined to this zone.

3. About 25 feet above the base of the shale occurs a thin bed of sandstone carrying a fauna much like the preceeding ones but chharacterized by the occurrence of Acteonella oviformis Gabb. The relations of this zone to that of Astarte sulcata is best seen on the Santiago-Trabuco divide. Here about five feet of shale separate the A.oviformis fauna from the A.sulcata fauna.

4. Some distance above the Acteonella bed occurs a 2 foot bed of sandstone literally filled with a Cucullaea comparable to Cucullaea inermis Gabb.

5. Separated from the last bed by a thickness of shale

is another sandstone bed which carries a fauna distinguished by a small opis, O. triangulata (Cooper).

6. Above the Opis bed and separated by a thickness of shale amounting to about 25 feet occurs another sanstone bed carrying a large number of aporrhaids, nautiloids, ammonites, and a new species of Gervilliopsis. There are also some characteristic gastropods.

7. The shales lying above these beds containsa large Inoceramus which attains a length of four feet. Most of the fauna associated with this species has been destroyed although occasional ammonites may be found.

8. At some distance from the base of the section in Harding Canyon there occurs interbedded in the shales a conglomerate-sandstone bed which is about 15 feet thick. This bed contains a fauna similar to that of the lower conglomerate but with the addition of numerous rudistids.

9. At quite a distance above the Rudistid bed occurs another conglomerate bed. This is only about a foot thick and is quite extensive. It is characterized by abundant specimens of a large Opis, Nemodon vancouverensis (Meek), Crasatella lomana Cooper, and several other fossils.

10. The next zone has been found only in Santiago Canyon. It is characterized by a large species of Gryphaea, numerous specimens of V. californica Dall, and a Cucullaea. The interesting part of this zone is the lithology. The conglomerate is made up of boulders of granodiorite ranging around a foot and a half in diameter. The fossils occur between these huge boulders in a very coarse sandstone. The outcrop exposes a section 25 feet thick and a hundred yards long.

11. The next zone is one about 75 feet below the contact

with the upper conglomerate. It is a thin sandstone bed carrying Astarte lapidis Packard and Nemodon vancouverensis (Meek) in great numbers.

12. Above the last zone and at a variable distance below the upper conglomerate (due to the disconformity) is a ten foot bed filled with a large fauna. The most striking species from a standpoint of numbers are Turritella chicoensis Gabb and Crasatella lomana Cooper.

13. The upper conglomerate is not fossiliferous but the shales and sandstones above carry a fauna that has a vertical range of several hundred feet. This contains large volutes such as Volutoderma magna Packard, Volutoderma santana Packard, Turritella chicoensis Gabb, numerous tellinids and spisulids, and several ammonites.

From the faunas already collected the great differences to be found are in the number of individuals of each common species rather in the species. A check of fossils collected from the different localities shows the impossibility of zoning the section on the basis of common species. Since the rarer species are not always present in the collections due to difficulties in collecting this introduces some uncertainty in the zoning.

The zones described above represent definite fossiliferous horizons. It is interesting to note that the majority of them are in the shale section and that in each case they occur in either an interbedded sandstone or conglomerate stratum. These throw an interesting light on the deposition of the shales. The assumption that the shales were deposited in a basin which gradually became shallower[1] by the filling action of sediments is evidently not warranted. The occurrence of the numerous sandstone and conglomerate

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[1] Packard, Univ.Cal.Pubs.Geol.,Vol.9,No.12, p.143, 1916.

beds in the shale series points to the occurrence of either diastrophic or climatic changes in the land mass contributing the sediments. The repetition of sandstones in the lower part of the section suggests that the basin was rather shallow at the time. The conglomeratic zone of the rudistid fauna points to shallow water deposition as well as the succeeding conglomeratic beds.

The occurrence of conglomerates in a shale section such as this is highly suggestive of disconformities, and even unconformities. Examination of the section will convince one that all the evidence for these is present. However in most cases the break in faunas accompanying these hiatuses is so slight as to be unrecognizable. The contact with the upper conglomerate and sandstone is quite extensive and may be traced throughout the mountains. Although elements of each fauna are present in the other, the upper series has a distinctly different fauna as far as the preponderance of pelycopods of the genera Tellina and Spisula are concerned.

It is believed that in general the formations in this district which exhibit this variation in lithology were deposited under similar diastrophic conditions, that is, in a shallow basin in which the dominant movement was one of subsidence, but in which there were frequent fluctuations. These fluctuations would result in the formation of disconformable relations between beds. Diastrophism in nearby sources of sediments governed the steepness of slope, and other factors controlling the character of sediments contributed to the basin. Under such conditions the Cretaceous sediments were laid down. The later Tertiary sediments possess many points in common although they represent deposits from more arid land masses.

Cretaceous South of Trabuco Creek

To the south of Trabuco Creek the Cretaceous beds present a somewhat different appearance than in the northern region. Due to the faulting in the vicinity of Trabuco Creek the formation is effectively hidden for a distance of some four miles. In this space it changes character greatly.

The red basal conglomerate so conspicuous to the north is missing but it is represented by a very similar formation differing mainly in its normal buff color. Overlying this basal conglomerate is a thick conglomerate and sandstone series containing a fauna in places which resembles that of the lower conglomerate in Santiago Canyon. Above this is a shale series unfossiliferous for the most part. It is unconformably overlain by the Martinez. The most northern extension of this part of the Cretaceous is a coarse sandstone lens which carries a fauna consisting mainly of small fossils. Ammonites are abundant. Some of the tortecone ammonites resemble those found in the lower shales in Silverado Canyon. Fossils are much scarcer in this region than to the north but it is believed they show the two areas to be part of the same series of Cretaceous rocks. Differences may be ascribed to lensing of the different beds. This feature, well exhibited by the rudistid bed in Santiago Canyon, probably accounts for the differences displayed in the formation south of Trabuco Creek.

Cretaceous North of Area.

The Cretaceous may be traced to Santa Ana Canyon. In the vicinity of Sierra Canyon the section is much less fossiliferous than in Silverado Canyon. The important lithologic differences are the change of the red basal conglomerate to a buff conglomerate, and the the greater development of the upper conglomerate. The latter consists of close to a thousand feet of conglomeratic sandstone instead of the thin bedded sandstones and shales of Santiago Canyon.

A consideration of the numerous facts presented in these last few pages leads one to consider that the Cretaceous is a formation that shows considerable lateral variation. The deep red color of the Trabuco in Silverado and Harding Canyons changes to a buff color at the head of Tin Mine Canyon to the north and in San Juan Canyon to the south. Although the red color is plainly a result of alteration, the material furnishing the alteration products has evidently been deposited over only a short distance. The change of the overlying conglomerate from a very fossiliferous rock in the region of Silverado Canyon to one carrying few fossils to the north and to the south to one with a different fauna shows considerable lateral variation. The conglomerate above the shales is perhaps the most striking case of the variation. To the north in Santa Ana Canyon it is a thick conglomeratic, unfossiliferous formation. In Santiago Canyon it is thin, shaley, and fossiliferous, while to the south in San Juan Canyon it is again thick, conglomeratic, and carries few fossils. It is evident from such facts that the deposition of sediments in unstable basins took place in the Cretaceous as well as in Tertiary times. Further study of the formation in a monographic manner will well repay any student.

Eocene

The Eocene of the Santa Ana Mountains occupies a long, though somewhat broken, strip along the western slope. It is divided into two formations, the Paleocene Martinez, and the middle Eocene Domengine, which are unconformable with respect to each other. The unconformity with the Cretaceous is sharp and distinctly marked at all the localities while that with the overlying Vaqueros, though distinct in the region north of Trabuco Creek, becomes hard to follow south of that region due to the similarity of attitude and lithology of the deposits.

Past work in the region has been largely of a rough reconnaissance type and as a result the maps available are inaccurate, especially so with regard to the areal distribution of the Martinez and Domengine. It is stated confidently that the importance of the Martinez as an areal unit has never been recognized though it underlies most of the Elsinore Valley and occupies a strip along the western side from Santa Ana Canyon to Oceanside.

In this report it will be noticed that all the clay and coal deposits are mapped as Martinez instead of Domengine, Martinez, and Cretaceous. This is a result of detailed study of the localities and the formations, not of any preconceived ideas. It is regrettable that in early reconnaissance work this fact was overlooked. As a result areas have been mapped as Domengine and Cretaceous that have been Martinez. These deposits are characteristic of the Martinez and may be used as marker beds. Prospecting for clay and coal may likewise be prosecuted to advantage by examining the beds in the various areas of Martinez sediments, rather than looking in other barren formations.

Martinez

To the north of the area described in detail the Martinez forms isolated areas of rather small extent and irregular distribution due to the fact that it is flat lying and that its base is above the level of the stream beds. In the series of westward dipping beds exposed from Silverado Canyon to the south it forms a long continuous strip increasing towards the south to a width of as much as two miles.

The Martinez is composed of two types of sediments, marine and fresh water. The basal part is in most localities dominantly freshwater in origin, though in places there are intercalated brackish water members carrying fossils as at Alber Hill. The upper part is everywhere of marine origin and like the Vaqueros and other overlying formations it is very well sorted.

In the field the Martinez is most easily recognized by its clay and coal beds. These, together with the fact that the sandstones and conglomerates are lacustrine, form an easily recognized horizon. The thickness of these beds shows a distinct variation over short distances. The appended table shows in a graphic manner the variation in character of the Martinez in this area.

Detailed Lithology (Plate XXVI)

The section exposed in Silverado Canyon is typical of the Martinez in the Northern part of the range. It is as follows:

Domengine conglomerate

-- Unconformity--

Martinez;

Coarse to medium grained sandstone	240'
Shaley sandstone	62'
Coarse to medium grained sandstone	94'
Concretionary sandstone	27'
Coarse white quartzose sandstone	153'
Fine greenish micaceous sandstone	93'
Shale and sandstone	85'
Coarse white quartzose sandstone	23'

Brown sandstone	36'
White quartzose sandstone	6'
Brown sandstone	86'
Coarse buff sandstone and conglomerate	43'
Lignitic shale	2'
Coarse brown sandstone with micaceous beds and tan clay shale	14'
White quartzose conglomerate	18'
Conglomerate	197'
Total	1176'

The above section was taped off along the ridge west of the Martinez-Cretaceous contact on the north side of Silverado Canyon. The following section is one taped off along the Santiago-Aliso divide:

Vaqueros conglomerate

--Unconformity--

Martinez:

Buff sandstone	63'
Greenish white sandstone	26'
Coarse buff sandstone	72'
Fine greenish sandstone	86'
Coarse pebbly sandstone	108'
Thin bedded green sandstone	83'
White sandstone	42'
Light buff sandstone (Serrano Clay near base of this member)	120'
Coarse pebbly sandstone	3'
Lignitic shale	1'
Shaley sandstone	3'
Conglomeratic sandstone	86'
Sandstone with large amount of chlorite	7'
Black clay shale	2'
Tan clay shale	3'
Dark green sandstone weathering red (mica and chlorite)	6'
Conglomerate	25'
Total ...	736'

A section in Trabuco Canyon scaled from the map gives the following result:

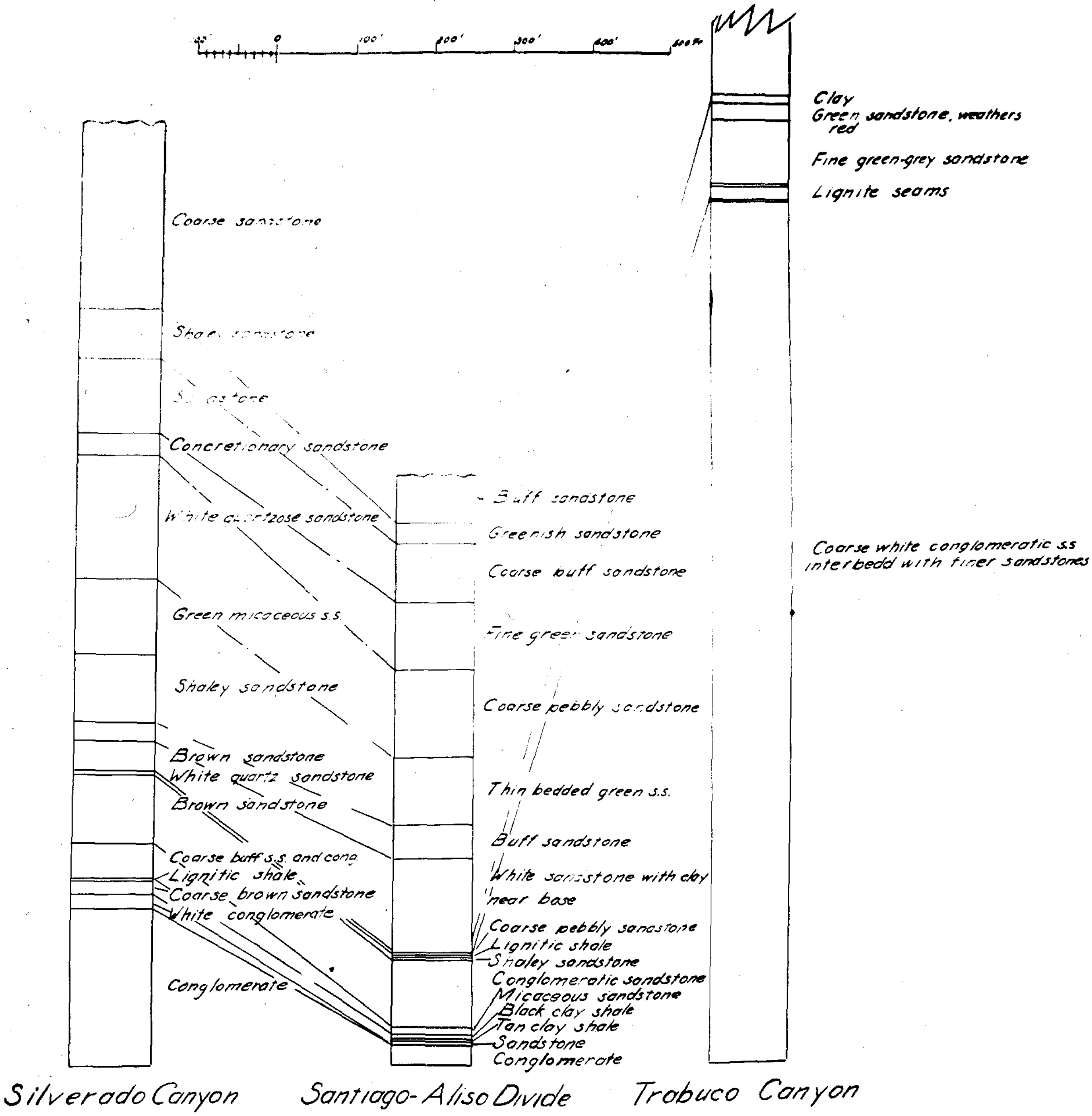
Vaqueros

--Unconformity--

Martinez:

Alternating massively bedded sandstone members and greenish shales	1700'-
Serrano Clay	10'
Dark green chloritic sandstone, weathers red	20'
Greenish fine bedded sandstone	80'
Lignitic shale	1'
White sandstone	20'
Lignitic shale	1'
Massively bedded coarse white sandstone	1080'
Total	2900'

Sections in Martinez of Santa Ana Mts



The section exposed in Silverado Canyon is typical of the Martinez in the northern part of the range. The basal conglomerate is 197' thick. It weathers to a tan color and is made up of interfingering lenses of sandstone and cobbles, a fact suggesting deposition in shallow water. The color of this bed is a distinctive greenish yellow due largely to the weathering of the chloritic minerals to limonite on the outcrops. Fresh fractures show a green color. The cobbles making up the conglomerate vary in size from that of a pea up to six inches in diameter, the mean size being about two inches. These are made up of well rounded and polished slate, chert, and quartzite cobbles derived from the Cretaceous conglomerates, also some felsite pebbles from the same source, and large numbers of angular fragments of Cretaceous sandstones and shales. The lenses of sandstone are coarse grained but are well sorted.

When traced north this conglomerate retains its olive yellow color, but to the south it changes. On the Santiago@Aliso divide it is represented by about 25 feet of material similar in all respects save increased coarseness, more angular particles, and poorer sorting. On Trabuco Creek, however, the basal conglomerate is represented by more than 1000' of a different type of sediment. This is a white to light buff conglomeratic sandstone. It is pebbly at the base and grades upward into massively bedded coarse sandstones. The rock is a dazzling white on weathered outcrops. Examination of the sands shows them to be made chiefly of quartz and felspar with very little in the way of ferromagnesian elements. The cobbles are made of quartzites, slates, and felsites.

In San Juan Canyon the basal conglomerate is a thick well sorted formation of large well rounded cobbles. It is here faulted against the Cretaceous.

Overlying the basal part of the formation is a series of beds amounting to less than 200 feet in thickness which show great variation from one locality to the next. It is this part of the section that carries the coal and clay deposits.

In Silverado Canyon the basal conglomerate is followed by about 18 feet of a coarse white sandstone made up of quartz and rotted feldspar grains. The thickness of the bed varies greatly in short distances. It is well indurated and forms a prominent white reef on cliff faces. Overlying this is a coarse brown sandstone which is extremely rich in muscovite. The flakes of mica average close to a quarter of an inch in diameter and give the sandstone the appearance of a rotted schist. Fresh samples of the sandstone are dark green in color. The brown or reddish color is due to alteration of the chlorite which makes up a large part of the brown sandstones of the Martinez.

Overlying the micaceous sandstone is a bed of bauxitic clay shale, tan in color and pisolitic in texture. This clay shale is a characteristic feature of the basal Martinez. It is found in deposits throughout the Elsinore trough and the Santa Ana Mountains. There is considerable variation in texture but it is always easily recognized in the field. At the Goat Ranch of the Gladding McBean Co.,south of the Santa Ana River, it is decidedly bauxitic and gibbsitic. The outcrops resemble piles of small peas due to the weathering out of the pisolites. In some places it is massive with only traces of pisolitic structure, while in other places it is sandy. It is always distinguished by its olive brown color, its conchoidal fracture, and its bauxitic appearance. In almost all cases some trace of pisolitic structure can be observed. Wherever this clay is found it serves as a definite marker for this horizon of the Martinez.

In Silverado Canyon the white clay shale that occurs above this material is missing and the tan bauxitic clay is overlain by several feet of lignitic shale. This is in turn overlain by a series of coarse buff sandstones of a micaceous and chloritic composition, then by finer concretionary and shaley sandstones.

The lignites and lignitic shales of the Santa Ana Mountains are as good markers of the Martinez as is the clay shale. It is obvious that the occurrence of these two types of rocks is limited to lacustrine deposits so that no occurrence is to be expected in marine formations. No other series in the Santa Ana Mountains is known to contain these materials or to have been deposited under conditions favorable to their formation.

On the Santiago-Aliso divide we find a modified section. Here the thinner basal conglomerate is followed by about five feet of a dark olive sandstone weathering red. This is a very heavy rock and is characterized by a large amount of chloritic material and also biotite. In places it resembles the sandstone in Silverado Canyon in the amount of muscovite that it contains. Overlying this is about three feet of tan clay shale showing mmassive bedding, conchoidal fracture, and bauxitix structure. It is covered by several feet of a black clay shale. The latter is colored by carbonaceous matter. This is followed by another micaceous sandstone which grades up into a coarse brown rock. It is followed by about 86 feet of white arkosic sandstone which contains badly weathered pebbles and boulders of granodiorite up to several feet in diamter. Over this is a three foot bed of shale followed by a one foot bed of lignitic shale. This is overlain by a white pebbly sandstone and then by a bed of sandy clay of variable thickness. Above this is a series of sandstones of coarse and fine texture with some pebbly beds. They are all well sorted and possess a clean appearance. The finer material is green in color and contains much biotite and chlorite while the coarser is dominantly quartz and felspar.

The clay bed mentioned is best seen a little east of the divide at Serrano's clay pit. Here the clay has been faulted up against the upper green sandstones of the Martinez. This clay is quite unlike that of the lower horizon. In appearance it resembles a coarse sandstone, dazzling white in color, and massively bedded. In places the outcrops are vividly colored by red and purple stains. At first sight one is disinclined to believe that the rock is a clay but kneading the material with water produces a plastic mass. This sandy clay is a distinctive lithologic zone of the Martinez. It may be traced to Vista, south of Oceanside, a distance of nearly 50 miles. Along its outcrops it presents the same characters, variation being confined to the ratio of quartz and clay.

The nature of this material is best shown at the pit on Mr. Moles property on the south side of Trabuco Creek. Here the clay is interbedded with massive sandstones which differ little in general appearance. An examination of the pit shows that the clay bed, some ten feet thick, grades laterally into coarser stuff and in places into a conglomerate. These conglomerates are made up of pebbles of felsites and metamorphic rocks in a clayey groundmass. Inspection of of the pebbles and boulders, which range up to a foot in diameter, shows that they are badly decomposed. A single blow of the hammer suffices to shatter what appears to be a hard felsite cobble, while the impure quartzites crumble as easily. In places these boulders are so badly altered as to be nearly indistinguishable from the ground mass.

The variation of the clay from a coarse sandstone to a coarse conglomerate shows that the clay is not of sedimentary origin. No sorting of the finer and coarser material into separate layers has been observed. The clay invariable occurs as the matrix in which the grains of quartz are set. The relation of the clay to the quartz is that of an alteration product of the original felspar grains of the arkose. In the conglomeratic facies the clay is contained in the sandy matrix which resembles the coarse sandy clay beds. This textural relation of the kaolin to the quartz is the same over long distances. In no place does it occur as beds separated from the quartz. Since normal sedimentary processes are not able to form such a rock it is believed that the clay originated in the alteration of an arkosic sandstone which in places was conglomeratic.

The existence of a bed as widespread as is the clay demands leaching over a considerable area. It is believed that the leaching took place over an extensive flat surface covered with swamps. Only a little distance below the Serrano clayis lignitic shale, and indication of further swamp deposits in the bauxitic beds. The recurrence of such conditions is not improbable. Occasional plant impressions are found in the sandy clay, another indication of freshwater deposition. Under the action of the water and humic acids furnished by the vegetable matter conditions were favorable for thorough alteration of the felspars and ferro-magnesian minerals. The leaching was very thorough. Analyses of the clay direct from the pit and the washed material shows that the two dominant constituents are quartz and kaolin. No unaltered felspar is present. The clay is kaolin with the addition of a slight amount of iron, calcium and magnesium, and traces of alkalies. The amounts of these impurities are constant before and after washing, showing that the coarse material is exclusively quartz.

Alteration of widely different materials might produce similar types of residual clays. The complete alteration of a felsitic ash and a fine arkose might both produce similar clays. Under such conditions it is difficult to tell just what the original material was from which the clay was derived. The appearance of the quartz grains suggests a coarse arkose derived from a granodiorite. With this may have been mixed other sediments such as ash, but of these no trace is left. All that ban be stated is that in the localities seen the clay appears as made up of glassy quartz grains surrounded by kaolin, in appearance an altered arkose.

The section on Trabuco Creek is quite different from that on the Santiago-Aliso divide. Due to the thrust faulting in Trabuco Canyon some of the basal portion is obscured. What is shown is a white sandy conglomerate which grades up into a massively bedded white sandstone. There is exposed some 1100 feet of white sandstones and pebbly sandstones, on which lignitic shales rest wihh no apparent break. These shales are about a footh thick and are separated by a coarse white sandstone. Above the shales is a thickness of a light green well sorted sandstone followed by a few feet of a dark green micaceous sandstone weathering rusty red. Just above the latter occurs the Serrano clay. The green sandstone mentioned contains some tan clay shale. The upper part of the section is formed of thick beds of well sorted medium to fine sandstones.

Overlying the clays in all the sections are a series of beds ranging from pebbly sandstones to shales. A general idea of the alternation of the fine and coarse beds is given in Plate XXVI. The lateral variation, however, is not so clearly presented. There is a decided change from north to south. To the north buff sands with large amounts of chlorite predominate. The shales are dark and the general appearance points to a less well sorted condition than to the south. The change from the heavy dark rocks of the north cemented with iron compounds to the light green, excellently

Plate XXVII   Martinez Overlapping Cretaceous, Silverado Canyon sorted, nearly incoherent sands of the south is remarkable. The difference in lithology is so great that were it not for detailed work the Eocene to the south might easily be mistaken for Vaqueros.

Age of Formation

The beds that have been mapped as Martinez are correlated with that formation on the basis of the faunal evidence of several localities. The age of the clays at Alber Hill in the Elsinore Valley was determined for the first time by Mr. Clark Sutherland whoc collected Turritella pachecoensis Stanton from a sandstone member above the clays. These beds had previously been considered to be Pliocene or Miocene lake beds.

R. Engel found T. pachecoensis near Lee Lake in 1927 and thus determined the age of these beds as Martinez before Sutherland started his work in the area.

The author has collected T.pachecoensis from sandstones associated with the clays in Tin Mine Canyon at the McKnight Ranch on the northeastern slope of the range.

From the shale in the upper part of Sierra Canyon the following fauna was collected (Calif.Inst.Coll.Invt.Pal.):

Venericardia sp.
Meretrix stantoni Dickerson

Euspira nuciformis (Gabb)
"Fusus aratus Gabb" Dickerson 1915
Priscoficus caudatus (Gabb)
Turritella pachecoensis Stanton

This is clearly a fauna of the Martinez or Paleocene. The most characteristic element of the faunas is T.pachecoensis which not only occurs at most fossil localities, but is also the most diagnostic form.

At this point it might be advisable to note the fact that many areas mapped as Martinez by previous workers are Domengine and also many areas of Martinez have been mapped as Cretaceous. In the field it should be remembered that no conglomerates occur in the section above the clay horizons.

The relations of the Martinez to the Cretaceous are unconformable. One of the best localities to study these relations is in Silverado Canypn. Here as may seen from the map the lower conglomerate of the Martinez laps over the Cretaceous shale. The thick bed of Turritella Chicoensis is missing and most of the Opis zone is covered. Plate XXVII is a view taken from the south side of Silverado Canyon looking across at the contact. Perhaps the most spectacular proof of the nonconformity is furnished by the high bluff back of the Holz Ranch. Here the lower Cretaceous conglomerate is apparently thickened by some three hundred feet. There is something puzzling about the relation of the conglomerates to the shales even to the passer by. Closer examination shows that this additional thickness is due not faulting of the Creta eous but to the overlap of the basal Martinez conglomerate over the Cretaceous. The conglomerate is separated from the rest of the formation by a strip of Cretaceous along the saddles cut through the Martinez.

The reworking of the Cretaceous conglomerates and sandstones and the incorporation of Cretaceous sandstones, shales, and cobbles from the conglomerates in the basal conglomerate is another striking evidence of unconformity.

While the angular discordance of the Martinez is rarely as great as 10° there is always a distinct unconformity shown where vegetation is not too dense. The mapping of the formation on the basis of the relations to the other formations shows that the clay and coal beds are distinctive markers of this formation. They may be relied on as a means of correlation as implicitly as are the fossils.

Domengine

Lying unconformably upon the Martinez is a series of strata which, together with the Martinez, are truncated by the pre-Vaqueros erosion surface. These beds make up the Domengine horizon of the Santa Ana Mountains. Included in the Domengine are the beds formerly mapped as Tejon and some mapped as Martinez.

The only appearance of the Domengine in the area mapped in detail is in the vicinity of the mouth of Silverado Canyon. Here is found a series of beds which strike in the same general direction as those of the Martinez and Vaqueros and dip gently off to the west. The most complete section extends from a point about one half mile up Silverado Canyon to the west side of Santiago Creek opposite Baker Canyon. The base consists of a conglomerate about 25 feet thick overlying the Martinez sandstones with a slight angular discordance. Other evidences of unconformity such as irregular contact and reworked material may be found. The conglomerate is made up largely of well rounded pebbles which are as much as six inches in diameter. Bedding is present and is well shown by the sandy lenses occuring between the thin pebble bands. Above the conglomerate is a series of thick bedded buff sandstones, pebbly sandstones, and concretionary sandy shales. In some localities these latter are fossiliferous. Near the contact with the Vaqueros the material is a fine grained sandstone and carries some plant material. The sandstones of this formation are marine and differ from the Martinez, especially the lower part of the Martinez, in their better sorting, their freedom from limonitic cement, and their color.

Outside of the area mapped in detail the Domengine outcrops in several patches considerably smaller than the extensive Martinez formation. On San Onofre Creek fine grained soft green sandstones resembling the Vaqueros carry a fauna characterised by Nerita triangulata Gabb and other forms associated with the fauna of La Jolla. North of the area there is a fossiliferous occurence near the old coal mine back of Irvine Park (B.M.610 Corona Quad.) Here the Domengine occurs lying concordantly on the Martinez. It is separated by an unconformity, however, which is at the base of a thick conglomerate. In Bulletin 768 of the U.S.Geological Survey this unconformity was not recognized and the whole thickness was mapped as Martinez. In the shales near the fault contact with the Cretaceous occurs a typical Domengine fauna (California Institute Invertebrate Locality 608):

Cardium brewerii Gabb(?)
Pitaria aequilateralis (Gabb)
Solen novacula Anderson and Hanna

Amaurellina (Euspirocrommium) clarki Stewart
Cerithium dumblei (Dickerson)
Conus remondi Gabb
Ectinochilus canalifer (Gabb)
Ficopsis remondii (Gabb)
Galeodea tuberculiformis (Hanna
Globularia hannibali (Dickerson)
Pseudoperissolax blakei (Conrad)
Sinum obliquum (Gabb)
Scaphander costatus (Gabb)
Turritella uvasana Conrad

Most of the above species are indicative of the Domengine age of the assemblage. In the area mapped an oyster bed has been found above the concretionary sandy shales but no other forms have been collected.

The relations of the Domengine to the Martinez are clearly unconformable. There is a slight difference in the attitudes of the beds on either side of the contact. Further the contact is an erosional one, the basal conglomerate of the Domengine being deposited upon an irregular surface of the Martinez. This contact surface was taken by Dickerson to be very rough and he cites in

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[1] Dickerson, Cal.Univ.Pubs.Geol., Vol.8,No.11, p.265.

support of this contention two sections taken a mile apart which show in one case more than a thousand feet of basal beds that are missing in the other section. Unfortunately the fact was overlooked that the thicker section was composed of both Martinez and Domengine, and that in consequence the basal beds below the unconformity were in reality Martinez. It is noted that in this unusual section of "Tejon" there is a conglomerate which is the basal conglomerate of the Domengine. In both Domengine and Martinez sections there are no known disconformities marked by a thick conglomerate. Throughout the Santa Ana Mountains the base of formations is marked by a basal conglomerate that may be easily recognised as such. The interbedded conglomerates show no disconformable relations.

The Domengine, like the Martinez, was deposited over a wide area. Its materials were derived from the eastern bedrock complex since none of the metamorphics of the western complex have been found. Deposition was rapid as indicated by crossbedding in some of the sandstone members, yet at the same time the sediments were excellently sorted. Some slight fluctuations in type of material are noted. Change from sandstones to sandy shales or pebbly sandstones probably are a result of changes at the source of sediments rather than differences in the depth of the basin. From what has been seen of the formation it would be characterized as shallow water in origin.

Vaqueros

Lying unconformably upon the Martinez and Domengine is a series of strata mapped as Vaqueros. This formation occupies the larger part of the area of Tertiary rocks in the Santa Ana Mountains. The main mass of the hills southwest of Santiago Creek are made of these rocks as is also the country in the region of Plano Trabuco and the San Joaquin Hills. The coastal plain for some little distance northwest of El Toro is made up of Vaqueros sediments covered by a thin layer of alluvium.

The Vaqueros of the Santa Ana Mountains is marine in origin. Throughout the section the sands or conglomerates show a clean, well washed, and well sorted appearance. The lowermost Vaqueros is variable in character along the strike due to the occurrence of a lens of conglomerate which has been mapped as a separate unit. In places along Santiago Creek this conglomerate represents the lowest part of the formation. It is a well consolidated rock, light brown on outcrops, and made up of well rounded polished pebbles. The pebbles are usually from two to three inches in diameter and are laid down along definite lines. Bedding is prominent. The cobbles are made up of felsitic material, quartzites, slates, and cherts. Granodiorite is very scarce. This lens extends from the northern edge of the area mapped to a point near Aliso Creek. To the south in the region of Plano Trabuco it does not appear. To the northwest it is found in a spot near the northwest corner of the map. Traced into the San Joaquin Hills it becomes a very thick and important member. 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. In Santiago Canyon near Modjeska's the conglomerate rests directly on the Martinez. Opposite the mouth of Baker Canyon, just north of the limits of the map, it rests upon several hundred feet of coarse red sandstone which resembles in every way that above the lens. These red beds lie unconformably upon the Domengine. The same beds may be seen on the western front of the range where they form a patch appearing through a window in the conglomerates. In the San Joaquin Hills a considerable thickness of beds is found under the conglomerates.

The conglomerate is a lens formed in a series of beds overlapping the older formations. It is conformable with the red beds above and below, the contacts being gradational rather than disconformities. It is believed that it represents a period of diastrophism in the land mass furnishing the sediments rather than any change in the basin.

The conglomerate is light colored and may easily be mistaken at a distance for the Topanga. Care must be taken in faulted areas such as exist in the San Joaquin Hills that this confusion does not arise. The difference in the composition of the pebbles allows an easy method of determination in the field.

Overlyin the conglomerate in the neighborhood of Santiago Creek is a succession of sandstones, pebbly at the base but becoming increasingly finer towards the top. These are strongly colored, reds predominating at the base, and greens towards the top. They are without exception well sorted and save for later alteration, well washed and clean with little cementing material. Plate XXVIII illustrates the results of a mechanical analysis performed on some typical material from Plano Trabuco. In the hand specimen it is a fine grained greenish sandstone weathering to buff. It consists largely of quartz, felspar, and chlorite grains. As seen from the figures it is remarkably well sorted. The cementing medium seems to be a slight film of limonite around the chlorite grains which are present in sufficient numbers to bond the other grains together.

Plate XXVIII

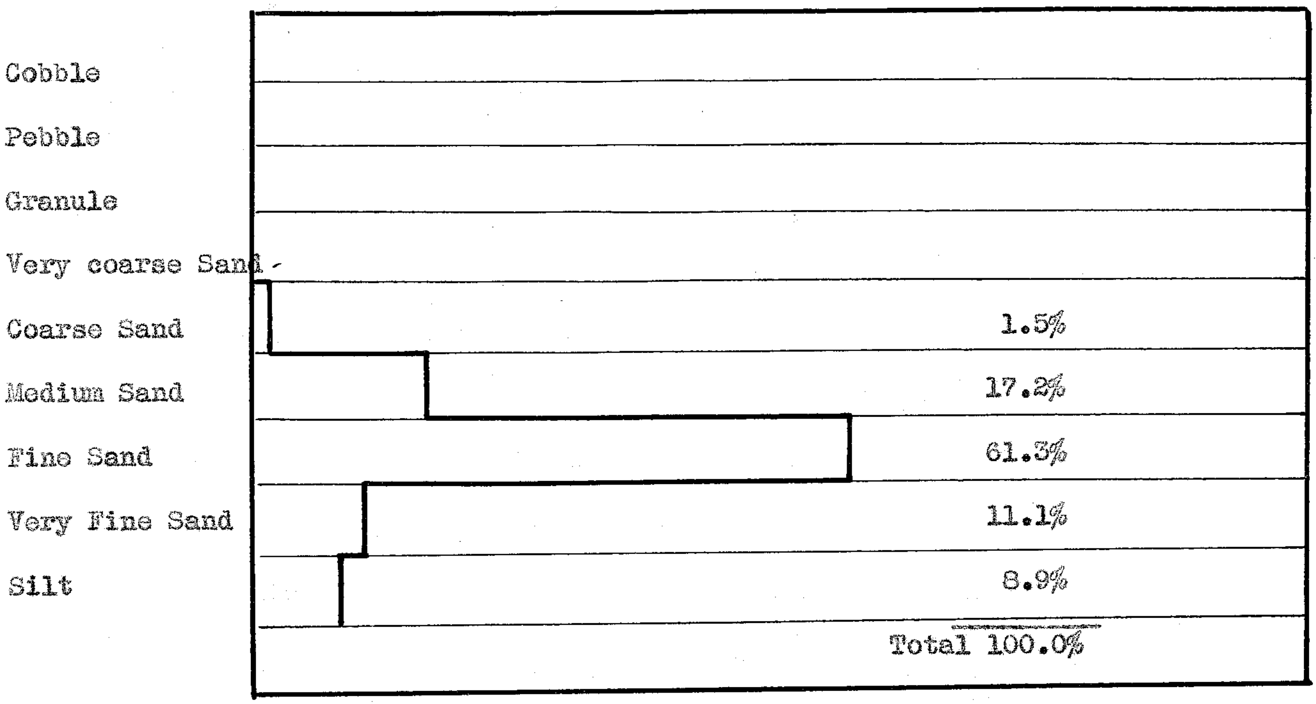

Fig.1 Sand from bed below contact with Topanga, Plano Trabuco

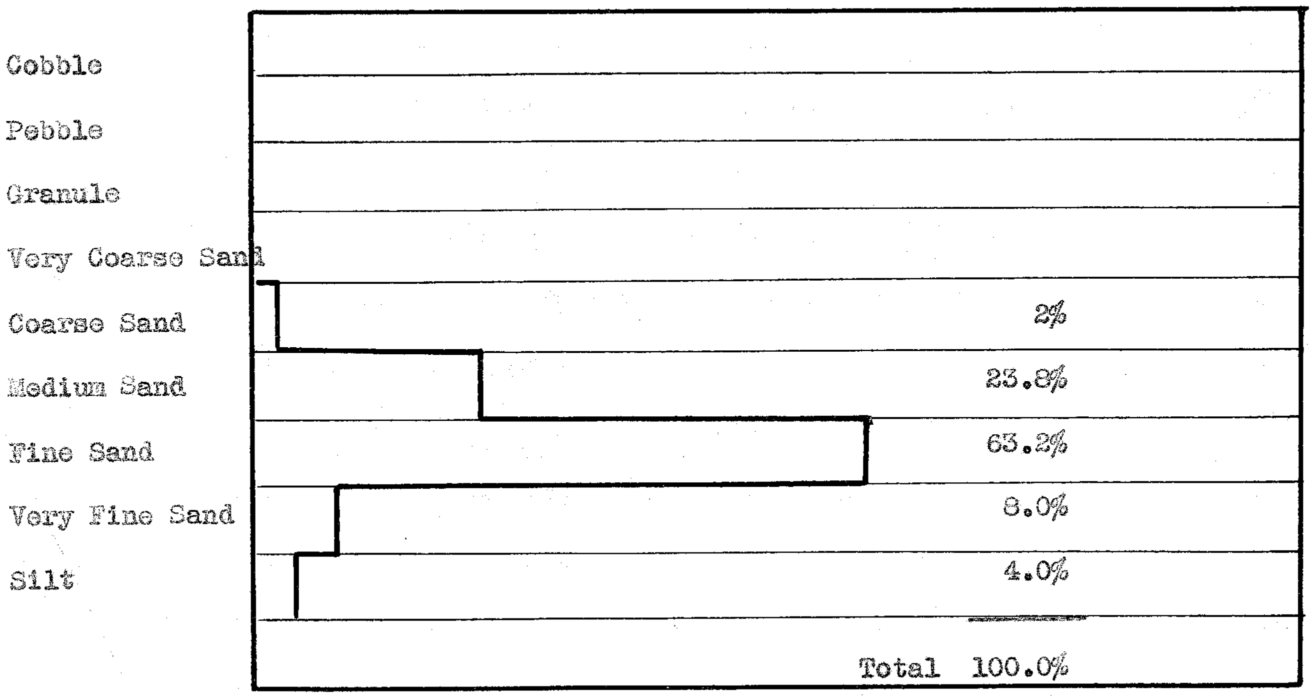

Fig.2 Sand from bed 50 feet below Topanga contact, Plano Trabuco

The red beds are made up of material ranging from a coarse sandstone to a fine sandstone. The material above the conglomerate lens is pebbly and appears to be gradational with respect to the conglomerate. It is coarse and crossbedded in massive beds ranging up to 15 feet thick. In some cases shale partings occur between these beds, but no clays, muds, or material resembling continental deposits has been seen anywhere in the area. Although the sands are pebbly, coarse grained, and frequently crossbedded they are regarded as marine in origin. The sorting of the material is good and the bedding, though massive, excellent. In general appearance they resemble closely the coarse members of other Tertiary formations of the Coast Ranges. The only suggestion of continental origin is in the red color.

The coarse red sandstones grade upward into very excellently sorted fine sediments. These upper red beds possess little sement and as a result are very soft. Weathering of the steep faces of outcrops results in the washing down of muds from the overlying soil mantles. Outside of these rain streaked outcrops no suggestion is found of clays or muds in this part of the series. The whole section is characterized by its clean well sorted material which is so well sorted as to demand a marine origin.

In general red beds are considered to be characteristic of the continental deposits of arid regions. The Santa Ana Vaqueros has been referred to the Sespe, a continental deposit, on the basis of this red color. The Sespe is a typical continental formation made up of conglomerates, sandstones, and mudstones. These are poorly sorted and show in the hand specimen large amounts of clay, gypsum, and other material associated with a size range of material corresponding to that from deposits of arid regions. The red color is a typical brick red to a deep purple and the bedd beds have a universally muddy appearance. The continental origin of the Sespe is confirmed by a varied fauna of vertebrate forms. In general appearance, fauna, and specific lithologic detail the Sespe and the Santa Ana Vaqueros cannot be compared. It is feared that past correlation has been on a hasty ill judged basis.

The Santa Ana Red Beds show some interesting deviations from the ordinary type of red beds in that they are marine and exhibit all the characters of marine sediments. The beds are arkosic and are made up of quartz and felspars derived from a land mass of granitic rocks. With the quartz and felspar is associated a variable amount of biotite in different stages of alteration. In the green beds there is much chlorite, which has probably been derived from dioritic rocks. It may be noticed that the red beds appear to contain little in the way of femic mineral grains outside the biotite. The green beds on the other hand contain large amounts of chloritic material. If the sandstone be examined under a microscope it will be seen that the red color is a stain covering the grains. This is much more intense close to the biotites than at some distance from them. In places the groups of biotite grains may be observed to have turned a brilliant red. Usually the thin edges of the grains are a decided carmine tint. Biotite is lacking in the green sandstones though numerous flakes of a dark green chlorite mineral occur. A green stain occurs in this case. In the cases of dead white material which is found scattered through the red beds the biotite is gone though small specks of what appear to be limonite are left. In both cases the color of the rock is due to the iron, in the case of the red beds formed by the alteration of biotite, in the case of the green beds from the abundance of green chlorite minerals.

The color of the red beds is not a constant nor a uniform shade. In places large greenish white patches may be found which suggest that the color was not formed until after deposition. At various seasons of the year the color varies. It is a vivid carmine in the spring but in the fall it fades to a light pink. This same change may be noted in hand samples. When collected they may be deeply colored but on storage their color fades to pink or even dirty white shades. The relation of the color of the formation to the degree of dessication shows that in all probability the coloring matter is a hydrous oxide of iron and possibly colloidal. The exact nature of this compound is not known since it is impractical to attempt to isolate it. Solution of the thin films of stain would be contaminated with decomposition products of the felspars.

It is evident that the color of the red beds is due to alteration of constituent grains rather than to the deposition of colored minerals, alteration before deposition, or deposition under arid conditions. The extent of this color with respect to depth. is not known. It is impossible to decipher any facts regarding color from the well logs, Cuttings would give only a faint idea on this point and no cores are available. The color is too extensive and uniform to be due to the leaching of the outcrops. It is more probably due to circulation of the underground water during the period represented by the Perris peneplane. At the present time wells on the Irvine ranch have tapped water layers at depths of a thousand feet. Circulation of water at this depth would suffice to oxidize the biotite which had already been weathered during transportation, to form the red color.

The derivation of the Vaqueros took place from a source of several different types of rocks. The material forming the cobbles may be in part reworked material of older conglomerate beds. The

Plate XXIX Unconformity between Martinez and Vaqueros, head of Borego Canyon.

abundance of felsite pebbles suggests that much of the material is fresh and not reworked since the Domengine, Martinez, and Cretaceous conglomerates do not carry such a large proportion of cobbles derived from acid volcanics. The red beds appear to have been derived from an area of granodiorite. The large quartz and felspar grains together with the biotite are suggestive of the granodiorite mapped in the basement series. The green sediments are plainly derived from a rock containing a large amount of hornblende. No rock of this type is known in the area mapped.

Deposition of the formation took place in shallow water. The thick beds of crossbedded sandstone at the base suggests that this was very rapid at times. From the change in nature of the sediments from the bottom to the top of the column it appears that the basin in which they were deposited was subsiding at a constantly decreasing rate which nearly kept pace with the change in rate of deposition as reflected in the increasingly finer texture of the rocks.

South of Trabuco Creek the Vaqueros differs in the absence of red beds. It resembles the more northerly outcrops, however, in the general appearance of sediments. The conglomerate lens is represented by a pebbly sandstone. As a result the break between the Vaqueros and Martinez is not easy to trace.

The age of the Vaqueros is determined by correlation with other formations in the state regarded as Vaqueros. The formation has strictly unconformable relations with the Eocene, overlapping the Domengine and the Martinez. Plate XXIX shows the unconformity existing between the Martinez and the Vaqueros west of the road summit on the Santiago-Aliso road. Here the base of the Vaqueros is represented by the conglomerate lens which has overlapped the red beds occurring in Santiago Canyon opposite the mouth of Baker Canyon.

The Vaqueros is fossiliferous, numerous fossil localities being scattered through the finer sands of the red and green beds. This fauna is characterized by a large number of typical Vaqueros forms and by its dissimilarity with the overlying Topanga fauna. In the cliff section of the Vaqueros opposite the southwestern end of Plano Trabuco the following forms have been collected:

Arca santana Loel and Corey
Tivela inezana Arnold

Crepidula diminutiva Loel and Corey
Olivella santana Loel and Corey
Polinices recluzianus (Petit)
Rapana vaquerosensis (Arnold)
Terebra santana Loel and Corey
Turritella inezana Conrad

Scutella fairbanksi Arnold var. santanensis Kew

There is no break exposed in the red beds. Mapping of part of the formation as Vaqueros and the rest as Sespe is not justified, stratigraphically or lithologically. Throughout the region the formation is a simple unit.

Topanga

Overlying the Vaqueros is a series of beds sepatated by several well defined characteristics. These form the Topanga, a formation described originally from the Santa Monica Mountains by W.S.W.Kew.[1] While it is not discordant with the Vaqueros, it is disconformable, and its distinctive fauna as well as its lithology separate it sharply from that formation.

The Topanga is distributed along a narrow zone between the Vaqueros and Puente. This is due to the pre-Puente erosion which removed great thicknesses of the formation in this particular region. Consequently the areal distribution resembles in plan long ribbon like masses of rock.

In the field the Topanga is distinguished from the Vaqueros by its poorer sorting, its coarser nature, and its dominant light buff color. The formation consists largely of sandstohes. These differ from the Vaqueros in being quartzose, and containing little or no femic material as grains. In places the sand is very coarse and even may be pebbly. It is usually well cemented, apparently by limonite to which is due the buff color. A comparison of a hand sample with some material from the upper Vaqueros at once demonstrates the lithologic differences. The Vaqueros is a fine clean sandstone, soft, and easily crumbled. The amount of ferromagnesian material is apparent to the naked eye. The sample ogfTopanga appears as a light buff, coarse, gritty rock. It is well cemented, has little in the way of ferromagnesian minerals, and is not well sorted. These differences are great enough to allow of considerable accuracy in mapping, even when the contact with the underlying formations is not exposed.

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[1] Kew, U.S.G.S.Bull.753, pp47-52.

In general green and red colors are restricted to the Vaqueros. If pebbles or coarser fragments than those of sands are found information as to whether schists, especially glaucophane schist, are present or not is of very great help. Schists from the western bed rock complex are diagnostic of Topanga since the Vaqueros was derived entirely from material of the eastern complex, a series of rocks carrying no schists similar to those of the west.

Sections of Topanga Strata

In the section along the crest of the foothills in the vicinity of Rabbit Canyon several hundred feet of Topanga is exposed. Here the gentle dips of the formation allow the basal contact on both sides of the hills to be studied. The basal beds of the Topanga are a series of very coarse to coarse sandstones resting concordantly upon the red sediments of the Vaqueros. In most cases the actual contact is not exposed. However from the exposures seen it appears to be a very smooth one. The chief evidence of disconformity lies in the sudden transition from the smooth soft sands of the red and green beds to the coarse gritty sand of the Topanga. The Topanga sand is quartzose in character and is colored a light buff. Scattered through it are occasional small pebbles of white quartzite and some schist. This material grades upwards into finer sandstones, all buff in color. At 200 feet above the base occurs a fossil bed containing typical Topanga fossils. This has been cited as a Vaqueros locality by English[1]. Both fauna and lithology show it to be in the Topanga. At some distance (100') below the contact Vaqueros fossils may be found.

As sharp a break may be found in the northeastern part of

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[1] English, U.S.G.S.Bull.768,pp.25 in table of section, 1926.

of the San Joaquin Hills. Here red beds, fine grained and well sorted are overlain by a coarse light colored sandstone carrying Turritella ocoyana. The contact is sharply defined. The red beds grade downwards into the conglomerate zone. The Topanga is evidently disconformable due to the sudden change in lithology. The actual contact was not seen due to vegetation. The lithologic change takes place within five feet. There is no evidence of a lithologic transition. The zones are as sharply differentiated as in Rabbit Canyon. The schists are restricted to the Topanga here as there.

Of all the sections showing the contact the most satisfactory is that on Trabuco Creek in the cliffs opposite the southwestern corner of Plano Trabuco. Downcutting of Trabuco Creek along the strike of the formations has resulted in the exposing of the Vaqueros and Topanga in a section some 300 feet high and extending several miles along the creek. This is shown in Plate XXX. Here the gently dipping beds may be seen as reefs and recesses depending on their hardness. The contact runs along the bottom of the middle ledge marked on the plate. The relations to the underlying formation may be made out from the irregular base exposed.

This section exposes a series of light green Vaqueros sandstones which are quite fossiliferous in certain beds. In places these beds are limey due to the large number of fossils contained. These are massively to finely bedded with frequent shale partings between beds. One bed contains so large a proportion of Olivella santana as to be a coquina. The prominent ledge outcropping along the middle of the cliff consists of a very well cemented conglomerate resting on light green sandstone.The conglomerate represents the base of the Topanga. The nature of the contact is apparent from a distance. The irregular surface, reworked material, and the presence of material derived from a different source are all evidence of disconformity. This contact may be traced for several miles to the north. Along its whole course it is irregular with little pockets extending into the lower sandstones. It is a typical erosion surface. In the sandstones associated with the conglomerate are numerous fossils, including Turritella ocoyana.

In this section the lowermost member of the Topanga is a conglomerate made up of angular blocks of schist up to a foot in length. This is about two feet thick. It is followed by a buff sandstone and then by material resembling the Vaqueros. Above this there is repeated two times the same type of conglomerate, buff sandstone, and green sandstones. Above the last conglomerate the normal buff sandstones are found. To the north the light green sandstones are found to grade into a coarse quartzose sandstone which appears to be the representative of the whole series of conglomerates and sandstones here exposed.

The occurrence of the Topanga in this section is of interest, especially with regard to the repetion of the conglomerates. The formation as a whole represents shallow water deposition. It is believed that the conglomerates correspond to changes in the land mass to the west which allowed a flood of coarse material to be spread out over a basin in which material was being deposited from the east. The lateral gradation towards Santiago Creek into a coarse quartzose sandstone suggests that the source of the finer sediments was being approached and that the source of the conglomerates was being increased in distance.

The Topanga formation of the Santa Monica has been described by W.S.W.Kew[1]. It is presumably the correlative of the

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[1] W.S.W.Kew, Bull. 753, U.S.G.S., p.50,1924.

"Temblor" formation of F.M.Anderson[1]. This formation was considered by its namer to be the same as the Vaqueros described by Hamlin[2]. Since the name Vaqueros enjoys a wide use for the lower Miocene beds characterized by the Turritella inezana fauna the use of the later name Temblor, proposed originally for the same beds, for the overlying series of the Turritella ocoyana beds is not justified. Due to this confusion of Nomenclature it has been deemed wise to follow the example of the United States Geological Survey and disregard the Temblor. In its place is used the local term Topanga formation proposed by Kew. This formation is considered by all as the equivalent of the Temblor, or what is called Temblor by California geologists.

The correlation of the Topanga of the Santa Ana Mountains with that of the Santa Monica Mountains is based up on stratigraphic relations to the underlying and overlying formations as well as upon faunal evidence. The relations to the Vaqueros are those of a disconformable series. The two formations, although they show no angular discordance, are separated by a definite erosion surface. There is a distinct difference in lithology between the Vaqueros and Topanga also. The relation to the overlying Puente shales is that of an unconformity. The shales lie upon both Vaqueros and Topanga, the small change in dip showing up well on the areal map. The surface below the Puente represents the result of erosion sufficient to have removed many feet of beds. This series of shales is related to the siliceous shales mapped as Modelo in the Ventura and Los Angeles Basins. From the relations of the

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1 Anderson, F.M., A Stratigraphic Study of the Mount Diablo Range of California, Cal.Ac.Sci.Proc., 3rd ser., Geology, vol.2, pp.156-250, 1905; A Further Study of the Mount Diablo Range of California: Cal.Ac.Sci. Proc., 4th ser., vol.3, pp.1-40, 1908.

2 Hamlin, Homer, Water Resources of the Salinas Valley, California: U.S.Geological Survey Water Supply Paper 89, 1904.

Puente formation and the Vaqueros the intervening beds might be correlated with the Topanga without faunal evidence.

The fauna of the Topanga of the Santa Ana Mountains shows distinct relations with that of the Santa Monica Mountains and also with the "Temblor" of the more northern Coast Ranges. The fauna includes the following forms:

Cerithium topangensis Arnold
Conus owenianus Anderson
Oliva californica Anderson .
Terebra?sp. resembling Kew's species from Topanga Canyon
Turritella ocoyana

Arca montereyana var.barkerianum Clark
Dosinia mathewsoni Gabb
Mytilus expansus Arnold
Phacoides sanctaecrucis Arnold
Clementia pertenuis (Gabb)

A more complete description of the faunas of both the Turritella ocoyana and the T.inezana faunas of the Santa Ana Mountains will be found in a manuscript paper by the author on the "Miocene of the Santa Ana Mountains".

Throughout the Santa Ana Mountains and the northern part of the San Joaquin Hills the Topanga and the Vaqueros bear the same disconformable relation to each other. The faunal break is as sharp as the very apparent lithologic break and is synchronised with it. In no case have the two Turitellas been found in the same bed in place, though considerable time was spent in the attempt to find such an occurrance.

Puente Formation

Overlying both the Vaqueros and the Topanga are beds of shales and sandstones which have been correlated on the basis of stratigraphic relations, lithology, and areal connection with the Puente formation of the Puente Hills. In general they correspond to the shales of the Monterey group in lithology and age. In the region mapped the formation forms a syncline with a roughly north-south axis which plunges to the south in the direction of El Toro. This area may be followed along the crest of the foothills north of the region mapped in detail. The Puente is fairly well restricted to the area mentioned for the reason that the outcrop of Topanga west of El Toro furnishes the western boundary of the formation as folded in the syncline. Wells drilled in the plain to the west encounter no shales of this formation but rather a series of beds highly suggestive of the Vaqueros. It is believed that the plain is a cut surface rather than an aggraded one and that this surface has cut beds older than the Puente.

In appearance the shales resemble those of similar formations elsewhere in California. The characteristic beds are the siliceous shales. In the Puente Hills the formation is divided into three distinct members, lower shale, middle sandstone, and upper shale. The lower shale there is a series of hard siliceous shales, dark in color, and heavy. There are numerous beds of massive sandstones. These are particularly frequent towards the bottom of the section. Above the lower shale is a series of sandstones which are buff in color and contain some biotite. The upper shales are much lighter than the lower shales, weather to light colors, and are commonly fluffy and light in weight.

The formation as exposed in the Santa Ana Mountains shows strong lateral variation within short distances. One of the most accessible sections exposed is that to the east of Borrego Canyon. Here the Puente lies upon the Vaqueros with a distinct angular unconformity. The basal bed of the Puente is a conglomerate about a foot thick. It is made up of coarse pebbles derived in part from old Vaqueros conglomerates. The bed is fossiliferous and contains a fair sized megafauna which will be mentioned later. Over this conglomerate occur a series of thin bedded hard siliceous shales with which are interbedded some large sandstone members. These beds of sandstone are not abundant on this ridge but to the west in Borego Canyon they are quite numerous and displace the shales. The thickest section of the Puente was scaled from the map at 1900 feet. The section in Borego Canyon is not quite this thick but it is typical of the material in the Santa Ana Mountains. The sandstones are usually fine grained buff arkosic sands. The shales are heavy hard siliceous shales with thin beds of sandstone scattered through them. In general appearance they resemble the lower shales of the Puente shales rather than the upper fluffy series.

A section in the Puente near the north of the area mapped differs markedly from the one in Borego Canyon. Here the lower 200 feet are a thin bedded hard siliceous shale. Above this is a bed of coarse massively bedded sandstone 100 feet thick. This is followed by more shale. This coarse sandstone which is here so prominent is not seen in Borego Canyon which is separated by a distance of only four miles. Near the head of Rabbit Canyon at the spring near the Tomato Spring Canyon divide there is an occurrence of a dark organic shale at the base of the Puente. This is the only known locality of such a shale. On distillation it gives about 30 gallons of oil to the ton. Since the Puente is regarded as the source of the oil in the Puente field this black shale probably represents the original appearance of much of the shale from which the oil has migrated.

Sections to the south in the vicinity of Osa Creek are quite different from the above. Here the section is dominantly thin bedded shale without frequent beds of sandstones. A section drawn from Plano Trabuco reveals a series of western dipping beds about 1900 feet thick.The lower part of the section is made up of shales, light in color, hard, and well cemented. In fields where outcrops are poor the presence of the Puente formation is recognized by the abundant fragments of silicified shale which have withstood the soil forming processes and have been plowed up. Near the middle of the section there is a lens of a coarse sandstone, rather quartzose which carries a few large oysters and shark teeth. At some distance above this on the western side of Osa Creek occurs a bed some 25 feet thick which represents a lens of medium grained sandstone. This is arkosic in nature and represents in composition the products of a weatherdd granite. These are present in such close relation to percentage values of the constituents of the original rock that the arkose, which is exceptionally well cemented with calcite, might easily be mistaken for a fine grained granite. Above this lens the formation is made up of the same siliceous shales.

In the San Joaquin Hills the Puente is composed almost altogether of shale. This is in some places a light fluffy material and attempts have been made to mine it. Here the greater part of the material is likewise a dark rock which weathers white. It is ordinarily well silicified and quite hard and tough.

A general comparison of the various sections of the Puente formation reveals the fact that lateral variation is exceedingly great. Massive beds of sandstone which may be quite prominent in one locality will be missing in one only a mile way. This is repeatedly born in on any one who attempts to do detailed work in this formation. The lack of lithologic units as well as megfaunas, and in most cases microfaunas, leads to much uncertainty in mapping large areas of the formation. While it is believed that the Puente of the Santa Ana Mountains represents the lower part of the Puente section exposed in the Puente Hills there is no definite evidence either way.

As a result of the lack of continuity of beds the formation was not subdivided in the mapping. There were mapped the thick sandstones exposed above the lowermost shales along the ridge of foothills. Further mapping showed the uselessness of this except inasmuch as it helped to show the lateral variation in the formation.

The most striking characteristic of the Puente of the Santa Ana Mountains is its freedom from crumpling and folding. Th usual outcrop throughout the basin of the Puente and similar incompetent formations shows much folding and crumpling on a small scale. In the region mapped the Puente is conspicuously free from minor deformation. This is due to the fact that the Santa Ana Mountains represent a rigid block which has had as a foundation a strong and competent series of basement rocks. Some gentle warping has resulted and some faulting but the forces acting on the block have not been sufficiently great to shorten the basement rocks in a direction so as to crumple the overlying sediments. The absence of crumpling ennables one to use dips and strikes measured directly upon the strata with considerable confidence.

Age of Puente Formation

The age of the Puente formation is determined by its stratigraphic relations to be upper Miocene. It overlies the Vaqueros and Topanga uncongormably. The Fernando overlies it in the same manner. Since the Topanga is considered to be middle Miocene and the "Fernando" lower Pliocene the Puente is assigned to the upper Miocene. No faunas have been reported from the Puente formation. The author has collected a small fauna from a locality in the basal conglomerate of the Puente to the east of Borego Canyon. This has yielded the following forms:

Chione diabloensis Clark
Dosinia merriami Clark
Panope generosa Gould
Paphia?sp.
Pecten raymondi Clark var. brionianus Trask
Solen sp.

Cast of gastropod cf. Neptunea cierboensis(Clark)
Cast of Trophon?sp.
Cast of large naticoid. Lunatia lewisii Gould?

While this assemblage is small it is suggestive of relation to the Briones fauna of the San Pablo group. In view of its lithologic similarity to the Modelo formation the faunal resemblances suggest that the two formations are probably the same age. In this case they would represent the same formation as exposed on the different sides of the Los Angeles Basin. It is hoped that in the future more definite faunal evidence will be secured to effect correlation of the Puente. From the present relations it is probably related to the Briones formation and locally to the Modelo.

Plate XXXI Capistrano Formation, Highway between El Toro and San Juan Capistrano

Capistrano

Overlying the Puente formation with unconformable relations is found a series of loosely consolidated sands, gravels and shaley sandstones. This formation is mapped as the Capistrano[1], a name applied to a similar series of sandy beds in the neighborhood of San Juan Capistrano by A.O.Woodford. The correlation of the two series of beds was effected by tracing out the boundaries.

The Capistrano beds occupy a roughly synclinal area extending from the country around San Juan Capistrano to El Toro and thence a few miles north. Due to their softness there are few outcrops and as a result detailed work in the formation is impossible. They are easily confused with terrace deposits except in fresh cuts along streams and roads.

The formation consists for the greater part of sandstones, light grey in color, loosely consolidated, and well sorted. The material is arkosic and carries numerous particles of biotite. Bedding is ordinarily massive in the sandstones. In certain localities, notably in the region around San Juan Capistrano the formation is made up to a large extent of soft finebedded shaley sandstones. Along the foot of the hills north east of El Toro the lower beds are quite conglomeratic. Here the beds are much coarser. The sandstones are coarse though fairly well sorted and are interbedded with thick conglomerate beds. The gradual increase of fineness of the sediments from the extreme northerly areas recorded on the map to the region around San Juan Capistrano is noticeable in the field. It is certain that in every case the formation is the same one since the contact is continuous and does not suggest the existence of more than one.

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[1] Woodford, Univ.Cal.Pubs.Geol.,Vol.15,p. , 1925

The Capistrano formation is a shallow water formation. The presence of lenses of conglomerate and their lateral gradation into coarse sandstones is reminiscent of the Fernando. The sandstones in the massively bedded coarse grained facies are cross bedded. The combination of crossbedding and lenticular bodies of conglomerates suggests that the formation was laid down rapidly in shallow water. Despite the conditions surrounding deposition the sands are well sorted. The coarse sands are not as well sorted as the fine material. The latter is as well sorted as the fine Vaqueros sediments.

The Capistrano is definitely unconformable upon the Puente. It laps over the Puente and onto the Vaqueros. It is folded with the other sediments as may be seen along the monoclinal flexure which passes through Tomato Springs Canyon. The relations of the formation to the present topography show that it is much older than any original surface the Santa Ana Mountain Block may have possessed. On the other hand the unconformity with the Puente indicates a sizeable period of time. In the region to the south Woodford reports the presence of a fossil locality from which Tieje identified Pliocene fossils. In the area mapped no fossils were found. From the relation of the beds to the Puente and its general lithologic appearance it resembles the Fernando of the Puente Hills very closely. It is separated from the outcrops of Fernando by a distance of some then miles. It was felt that in this report that correlation with the Fernando had best be put off until definite faunal evidence was found.

Terrace Deposits

The terrace deposits of the Santa Ana Mountains are of various ages. The relations of these deposits to one another are described under the section relating to geomorphogeny.

There are numerous samll patches of terraces as much as 1000 feet above the present level of the plain. The lower terraces such as those along Trabuco Creek, Bell Canyon, Aliso Creek, and the country west of El Toro are quite extensive. The material making up the terraces is much the same. It is composed of detritus derived from the present mountain block.

Some of the lower terraces around El Toro are in part marine, a fact which accounts for the clean white sands and conglomerates making up the deposits. These as well as the land laid terraces are merely thin veneers covering old erosion surfaces. In few cases do these deposits reach the thickness of 25 feet. The usual thickness is about 10 feet. They are of importance since they mask much of the underlying rock.

Quaternary Alluvium

Under the heading of Quaternary Alluvium are mapped many diverse deposits. In general there is little alluvium in the region save for the deposits along stream courses and on the plain around Irvine.

The alluvium found along the stream courses is the ordinary type of stream gravel. In places this is cemented into a conglomerate by the lime deposited from the streams. Tufas are common in some streams due to the limestone lenses in the older rocks. Usually the alluvium is thin and represents a veneer. There are places where it attains considerable thickness. The most interesting example of this is in the wash of Santiago Creek. From the head to a point a little north of Williams Canyon the alluvium is merely a veneer. From the latter point to the mouth of Sierra Canyon the alluvium is very thick, in places reaching thicknesses of over 100 feet. As a result of this depth of alluvium a natural resevoir has been formed which a water company makes use of. Unfortunately much is lost by seepage since the stream follows the strike of the rather porous Vaqueros beds.

The plain around Irvine is covered with a thin layer of alluvium as shown by well logs. This plain is not an alluviated feature but a cut surface on which is a thin film of alluvium. Here the alluvium is a soft sandy material due to its derivation from the soft Vaqueros sediments of the foothills.

Structure

The Santa Ana Mountains represent at the present time one of a series of structural modifications through which the country is ceaselessly passing. In the consideration of the structures found in this region an historical viewpoint will be taken. The structures formed in and recorded by the successive formations will be first considered, then the structures which define the mountain mass and the structures imposed on it, and finally the structure of the range as a whole and its relation to the structural features of Southern California.

Structural Features of the Crystalline Complex

The oldest part of the crystalline complex is made up of the Silverado Formation. The enormous thickness of these rocks, 17,300 feet, as exposed in Silverado Canyon, might well raise the question of whether isoclinal folding has taken place. The formation as may be seen from the columnar section, shows several distinct zones. The most characteristic of these is the brown conglomerate near the lower third of the section. The horizon furnishing the limestone beds is also a good marker. Neither of these units have been repeated anywhere in the section. These beds are, however, separated by a considerable thickness of slates and it might be argued that crumpling and resultant thickening of the section took place in Silverado Canyon. A close examination of the rocks in Silverado Canyon reveals a surprising absemce of crumpling in the slates and sandstones. Further, in Trabuco Canyon the Silverado formation possesses low dips near the mouth of the gorge, a fact that is impossible to reconcile with isoclinal folding. Thus it is seen that while the formation is ordinarily dipping steeply to the east there are places at which the formation dips so slightly that the presence of close folding is disproved.

The relations of the Silverado formation at the present time show a large syncline in the region of Silverado Canyon. The axis runs along the main divide This structure is best seen by following Silverado Canyon to the Blue Light Mine, then ascending the Silverado-Harding divide, and following the latter to the Main Divide. From the crest one may follow the North Coldwater fire trail eastwardly across the other limb of the structure. To the west of the divide the beds dip steadily to the east, the angle decreasing gradually towards the divide from 45° to 25°. At the divide the beds are disturbed by a dike of andesite. Descending the east slope of the range the westward dipping beds of the other limb are encountered. This structure is better illustrated in Ladd and Bedford canyons to the north since there no intrusions are encountered and the beds are undisturbed.

In Trabuco Canyon the slates form an eastward dipping monocline. Near the mouth of the gorge the dips are gentle and in places the strata lie flat. The beds further up the canyon dip consistently eastwards at angles varying from 40° to 50°. The gentle dips may possibly represent an anticlinal axis but no strong evidence is furnished by the field relations.

In other places the the slates are usually found dipping steeply to the east at angles faryinng from 40° to 70°.

The age of this folding is considerably older than the series of later igneous rocks. This is shown by the fact that the overlying Hough formation cuts across one limb of the syncline exposed in Silverado Canyon. If one calculates the dip existing at the time of the Hough the figure of 50° is reached. The existence of this fold in pre-Hough time is thus well established.

The remarkable uniformity of attitude of the Silverado formation leads to several conclusions. The first is that there has been comparatively little folding of the area now occupied by the crystalline complex after the deposition of the Hough. In the district no suggestion of the development of different directions of folding has been found. This may be due in part to the later hardening of the formations and their change to strong competent rocks. There,is, however, a complex series of joints which have been developed in response to later forces.

The rather uniform attitude of the Silverado slates is of interest with respect to the intrusion of the later igneous rocks. There is evidence that the intrusion of the bodies of igneous rocks of the Modjeska series was forceful. This is born out by the presence of intrusionbreccias in the andesite porphyries. However there was even in these rocks some assimilation as shown by the presence of quartz grains derived from sedimentary rocks in the material. These intrusions follow the strike of the slates in a rough way but show no relation to the dip. They may be considered to have followed fissures or else to have creted their own channels of intrusion. There is no evidence for the former in the presence of faults or fault systems connected with the intusive bodies. From the field relations it appears that whatever forces were exerted by these bodies was taken care of by compression of the surrounding sediments. Drag and other features commonly associated with intusives in sediments are not found.

The later intrusions of the granodiorite present a different problem. In this case a large batholith was intruded into already compacted sediments. Around the edges of this body no structures are found suggesting a forcible entry of the rock. The slates continue to the boundary with unchanged dips, and at the contact show no traces of drag. It is plain from the field relations that the intrusion of the granodiorite was a quiet affair. Assimilation rather than forceful intrusion played the major part, stoping removing the roof pendants of the slates and sandstones which were assimilated by the magma. The fact that the granodiorite is formed of smaller bodies of variable composition is in itself related to the process of assimilation and differentiation.

The structure of the individual igneous bodies has been described in detail under the heading of Stratigraphy. Hence there is no necessity of pointing out their shapes and modes of formation at this point. It is desired, however, to emphasize the fact that the larger part of the fine grained rocks of the Santa Ana Mountains represent stock and dike-like intrusions rather than lava flows as has been suggested.

Santiago Peak owes its origin to a core of hard and resistant material from which the covering formation has been stripped by erosion. It is the highest peak in the Santa Ana mountains, rising to an altitude of 5680 feet, and standing 4000 feet above Trabuco Canyon. The core is a composite body of igneous rocks surrounded by a belt of slates which extend from the Holy Jim fire line on the crest of the range across the upper part of Holy Jim Canyon, along the face of the mountain, across Falls Canyon and Santiago Canyon, and around the west face of Modjeska Peak. Small patches of slates and quartzites are found on the east face of Santiago Peak up to 500 feet of the summit. From the summit west to Modjeska Peak is a series of andesite porphyry dikes of the Modjeska Series, while to the east is a large intrusion of the quartz bearing phase of the Glen Ivy Diabase. To the north east is a tongue of the granodiorite batholith. In general appearance Santiago Peak resembles a large stock (Plate XXXII). In reality it is a mass made up of several different ages of igneous rocks which have formed a stock like mass from which the cover of slates has been eroded.

The overlying sedimentary rocks are exposed as a series of bands which follow in a general way the outlines of the igneous and metamorphic basement. They all exhibit unconformities with each other with the exception of the Vaqueros and Topanga which are disconformable. Structures imposed on these formations between the periods of sedimentation are not recognizable due, perhaps, to the slight exposure of the contacts. Jointing in the sandstones and the conglomerate consists of occasional surfaces normal to the planes of bedding. These are not pronounced in either abundance or development. The relation of the sandstones, conglomerates, and shales of a formation to one another is striking. The same dip and strike are found throughout the section regardless of the competency of the beds. No crumpling of the shales is noticed between the competent members. The Cretaceous shale, an incompetent rock, is apparently not crushed or deformed to any greater extent than the sandstone and conglomerate members which bound it. This absence from crumpling is particularly noticeable in the Puente shales which are usually thought of as occurring in outcrops showing badly distorted strata. In the Santa Ana Mountains they lie in beds so free from crumpling that dips measured from the strata are dependable in mapping. This lack of distortion is surprising to any one who has worked in the Los Angeles Basin.

While little of the older sedimentary formations is exposed to view, one concludes that while there has probably been some broad gentle folding in the past, deformation such as is common in the Coast Ranges to the north has played little part in the history of this region. The angular difference represented by the unconformities may in part be due to tilting of the block as well asto folding. The area has been close to the edges of the basin of deposition and hence unconformities would be recorded in more striking fashion than in the center of the basin. Also unconformities may exist at the edges of the basin which are represented in parts of contimuous sections in the basin.

Structures of the Santa Ana Mountains

There are a number of interesting structures present in the region studied. While these are not features of great magnitude such as to outline the block, nor apparently directly related to the forces which have resulted in the formation of the block, they are of considerable interest.

The foothills to the northeast of Irvine and El Toro have been regarded as forming a scarp bounding the Santa Ana Mountains as a southern boundary. This is due to their abrupt ascent from the plain, a feature that from a distance suggests the presence of a scarp. Close examination reveals no evidence for faulting, but much against it.

The front of the hills is very irregular. This is apparent when standing at their base or trying to find a spot which will allow a view along their front. The topographic map fails to bring out this irregularity of the front. There is no physiographic evidence of faulting such as fans, truncated spurs, alignment of spurs, displaced stream courses, sag ponds, or depressions. The appearance is rather that of a series of low spurs which rise from the plain in an irregular fashion. The ends of some may be as much as a mile out in the plain surrounded by fields. This irregularity is surprising to one who has seen the hills only from the highway. These low spurs rise abruptly some distance from the plain to form a series of rugged hills rising to an elevation of some 1700 feet. To the southwest the plain slopes to the ocean in a long concave surface. This is highly suggestive of a fan built up of sandier material than is commonly found in such features. Well logs of the Irvine Company show that the alluvium on this plain is very thin, a mere veneer of from a few feet or less to as much 50 feet in thickness. This surface is evidently not one of aggradation primarily but a cut surface like the terraces to the east.

Stratigraphically the evidence against faulting is stronger. The formations under the plains are Vaqueros to judge from the well logs, with the Cretaceous at no great depth. If faulting had taken place one would expect a great thickness of Puente shale and possibly considerable Capistrano. The results of the areal mapping indicate clearly the absence of such a fault in the fact that in the vicinity of Aliso and Borego Canyons no break is found in the Puente or Capistrano beds indicating the presence of a fault. The outlines of the western limb of the gentle syncline in the Puente near El Toro show no evidences of faulting. Were a fault of the magnitude indicated by the elevation of the hills, which would be at least 1000 feet displacement, present the areal pattern in the region around Aliso Creek would be totally different from the present one. Further the beds existing under the plains would be younger than those in the foothills rather than the age of the oldest represented there. As a result no fault was mapped but in view of the rumors assigning a fault to this particular locality it was deemed wise to spend some time discussing its possibilities.

There are a number of interesting faults and flexures in the Santa Ana Mountains. They appear to have no definite relation to the Elsinore Fault system nor to any direction of deformation of the block. They are doubtless due to the accumulation of strains caused by ~~faulting~~ external stresses and intrusion of the Miocene diabases. They may be considered as local phenomena which do not affect our concept of the block as a whole.

One of these folds is the one so well exposed in Tomato Springs Canyon. Here a monocline runs nearly northwest southeast at an angle to the front of the range. This structure may be traced from a point near the fault south of Hill 1700 tp a point near Bee Canyon where it dies out. The sudden change from flat lying beds to ones dipping 60° to the south west and then back to almost flat beds is well shown.in Tomato Springs Canyon. This fold involves the Vaqueros, Topanga, Puente, and Capistrano formations. The hard buff sandstones of the Topanga form the central part of the 400 feet of steeply dipping beds and the thin remnant of the Puente shale and some conglomerates of the Capistrano form the the southern part of the steep beds which flatten rapidly towards the plain. The age of this flexure is clearly post-Capistrano or upper Plioceneor Pleistocene. The fold is believed to represent an incipient fault or a fault in the basement series which is of only sufficient magnitude to flex the overlying sediments. The displacement of beds in this flexure is about 400 feet. It may be estimated from the relative positions of the Topanga sandstone on either side of the fault.

This flexure is of interest in comparison with one to the north which starts in the red beds near the head of Tomato Springs Canyon. This passes into a fault with a dispacement of several hundred feet in Borego Canyon which may be traced to Trabuco Canyon. This starts as has been stated in a monoclinal flexure. The red beds which are nearly flat are observed at one point to have a dip of nearly 45° to the west. This feature traced to the head of Tomato Springs Canyon becomes a fault. It is a normal one in Tomato Springs and Borego Canyons and at the head of the latter has a displacement of several hundred feet dropping Topanga to the southwest down against Vaqueros to the northeast. The exact dimensions of the movement are unknown due to the fact that it is impossible to recognize individual beds in the Vaqueros. To the east this fault passes into a reverse fault which is complicated by some horizontal movement. This has resulted in the Vaqueros beds on either side of the fault having different attitudes. South of the fault the beds have the same strike as the fault, while those to the north strike into the plane of the fault. This attitude of the beds suggests horizontal movement such that the eastern block moved north with respect to the western block dragging the sediments. The fault exposed in Serrano's clay pit shows definitely its reverse character. The plane dips 70° to the south or west and the western side has moved up with respect to the eastern. In this movement the Serrano clays have been faulted up against the green sandstones of the upper part of the Martinez section. The displacement here is about 200 feet as scaled from the map. The fault itself is displaced by some small north-south faults having a horizontal component of nearly 150 feet. These fractures were not visible on the surface but were seen in tunnels of the Pacific Clay Products Company through the courtesy of Mr. Clark Sutherland, geologist for the company. Further to the east the fault again resumes its normal character dropping Martinez down against the Cretaceous. In the vicinity of the old Joplin Place the fault assumes its most interesting aspect. Here it curves suddenly into the old rocks and runs into another fault which has just started to parallel its course. For half a mile or more the Cretaceous conglomerates between these two faults have been overturned

Plate XXXIV   Fault in Serrano Clay Pit.   Looking South

until they dip into the old rocks at angles of 60° to 70°. The basal red conglomerate is absent, having been faulted out. Plate XXIX shows the fault as it is exposed in Borego Canyon. Plate XXXIII shows the fault looking west from Serrano's clay pit. Plate XXXIV shows the fault lookigg east from Serrano's.

The explanation of the dying out of the above fault lies in the fact that it has run into a thrust fault which starts near its termination and swings in an arc to the southeast across Trabuco Creek. The word thrust for the Trabuco fault is used advisedly for both areal pattern and the actual exposure of the fault surface show it to be that. Examination of the areal map shows Cretaceous to the north and the south of Trabuco Creek apparently striking into andesite porphyries of the Modjeska series from both sides. The contact between the Martinez and the Cretaceous runs into the same andesite body. This wedge of andesite is so clearly out of place that the thrust nature of the material is apparent at once. Examination of the fault zone as exposed on the south side of Trabuco Creek gives confirmatory evidence. There is no simple surface on which all movement has taken place. A zone several hundred feet wide of layers of crushed andesite and gouge exists and may be studied just below the mouth of the gorge. At places in this zone faults may be found dipping towards the range at all angles. One large seam of gouge several feet thick dips into the range at an angle of 30° while anotherfollows a horizontal course for nearly fifty feet. There are numerous vertical seams of gouge also. Plate XXXV is a view of a small portion of the zone. Here the compressional nature of the forces producing the faulting are clearly shown. It is evident that the left side is the one which has been pushed over the right side.

Plate XXXV Part of Fault Zone in Trabuco Canyon

The fault has a displacement in a horizontal direction of at least 3000 feet. This is measured by projecting the contact of the Cretaceous and basement rocks across the tongue of andesite. The absence of recognizable horizons in the andesite makes an exact computation difficult. The fault extends in a north-south distance only three miles, dying out at both ends. It is evidently a response to forces acting on a very small area rather than to those involved in the Elsinore fault system.

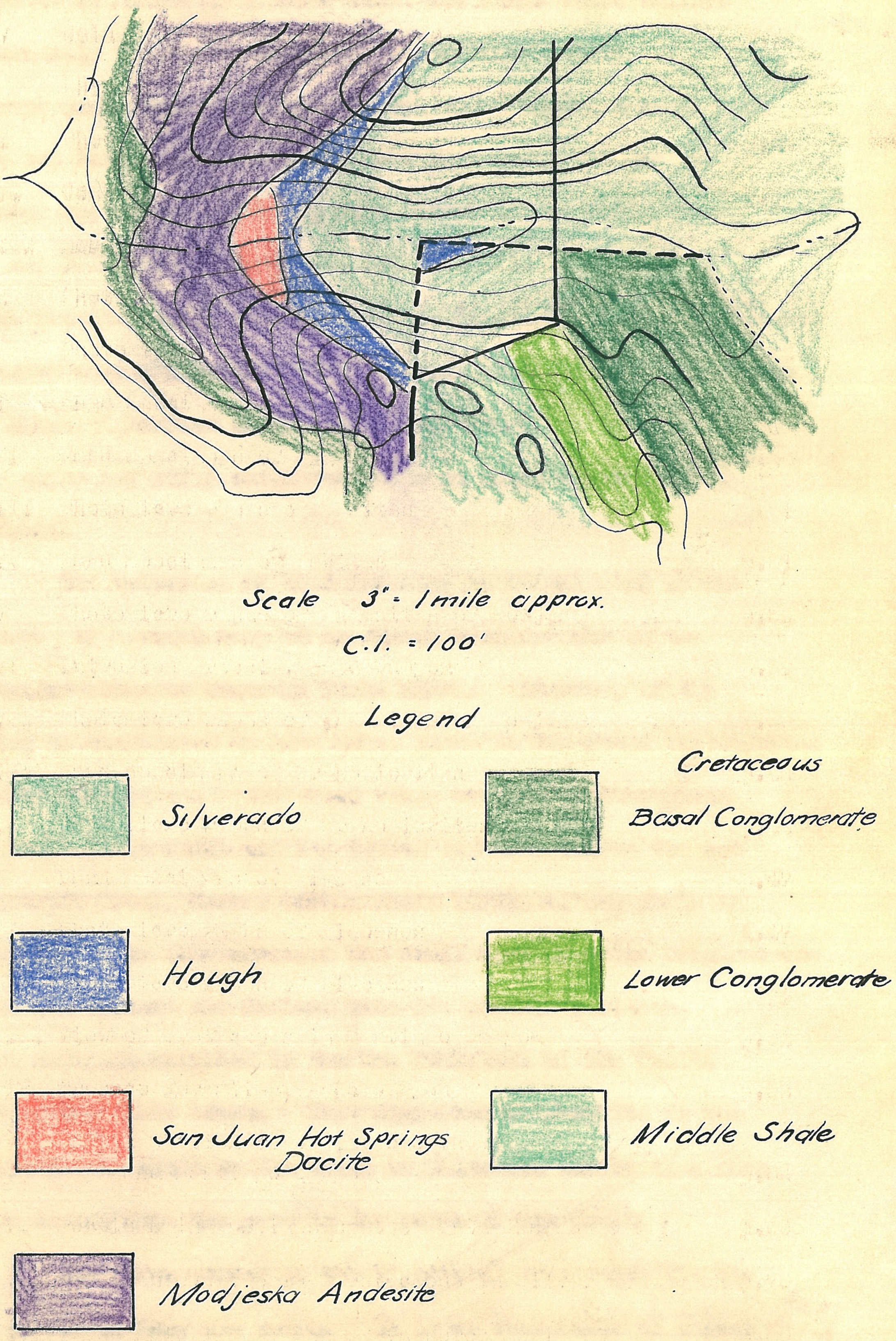
The small lateral extent of the thrust fault is comparable to that of a small normal fault running from Santiago Canyon to Silverado Canyon. In a distance of two miles this fault attains a measurable displacement of 3000 feet.

Starting in Santiago Canyon one ascends the Modjeska fire trail. Looking south there is seen a massive cliff section of the lower Cretaceous conglomerate. No faulting mars this face. On the fire trail, however, one encounters two patches of the red basal conglomerate of the Cretaceous separated from the main mass by slates. Inspection reveals that these two patches dip into the slates and at their western contacts show the effects of faulting. They represent two outliers of the basal beds separated not by erosion of an irregular contact surface but by faults. These two outcrops line up with two similar but larger ones on the Harding-Williams Divide.

The displacement on the western fault amounts to 200 feet and that on the eastern to 350 feet on the Modjeska trail. On the divide to the north this displacement has increased to 500 feet while the eastern fault has increased to 400 feet. North of the divide the eastern fault dies out and is not present in Silverado Canyon. The western fault continues with a rather sinuous pattern, dropping first the red conglomerate against the

Plate XXXVI

Sketch Map of Faulted Zone in Silverado Canyon



andesite, then the gray conglomerate, and in the fields of the old Sidley Place between Williams and Silverado, the middle shales. In Silverado Canyon the faulting is complicated by the fact that the fault does not cross the canyon but appears to be offset by a later east west fault which follows approximately the stream course. On the saddle north of Silverado Creek (not shown on the map) there occurs a small area of the red basal conglomerate faulted down among the the andesites and slates, while in Ladd Canyon to the north the fault may be observed inthe andesite intrusion breccias. It appears from the areal pattern that the material north of Silverado is faulted with a throw of 1000 feet less than the material on the south side.. Further on the south side there are two small faults which set off a small rectangle of slate against the Cretaceous.

The mechanism of this faulting is complicated by the existence of a small body of the Hough Conglomerate in the rectangular slice as shown in Plate XXXVI. However, if the faulting is considered to have taken place in two steps the solution is easily arrived at. The first stage consisted of movement along the western fault and its dotted continuation to the bed of Silverado Creek, thence east a short distance, and north to Ladd Canyon. In this movement the small area of Hough Conglomerate east of the contact was faulted into its present position. Further movement resulted in the the formation of the faults marked by the solid lines. This displacement resulted in the lowering of the block to the south of Silverado Canyon to a much greater extentthan the part to the north of the Creek.

The above scheme is one of several that might fit the facts as far as they are known. It is as reasonable to assume the first movement to have taken place on either system or that the movements took place during the same period and that the block of slates is a result of shearing the corner of the southern block.

The cause of the faulting discussed is not known. In none of the cases are the features aligned with the Elsinore system. Further they are not oriented in a direction suggesting relief of pressures developed by couples connected with the Elsinore system. They seem to be strictly local in each case. The flexure is probably the flexing of the surface beds over a depper seated fault. The faults in Trabuco Canyon and to the west are compressional features. The faults in the vicinity of Silverado Canyon are normal faults. It is believed that the cause of the faulting is due to adjustments within the block. The presence of such large quantities of diabase suggests that considerable movement of magma has taken place under the present block. Faults of small extent and large displacement are frequently connected with igneous activity. While the faults in this case are not numerous enough to form a mosaic, their lack of structural control by the surrounding regional features and their great displacements suggest a local origin due to readjustment following intrusion.

Folding in the Santa Ana Mountains is rare. There are several very gentle folds that must be noted, however, These may be observed in the lower part of the range in the vicinity of Rabbit Canyon. Due to the presence of a sandstone member close to the base of the Puente Shales these folds are easily observed in the field. They trend north and south and from this fact appear to be related to the stronger north south folds of the San Joaquin Hills. From their relations to the other structures they appear to be older than the monocline and faults.

One of the many folds of the San Joaquin Hills appears in the southeast corner of the map. This anticline is of interest in that it shows the greater amount of deformation that exists at ever increasing distances from the crystalline core of the range. The country between the San Joaquin Hills and the main mass of the Santa Ana Mountains has been considered to represent a graben. The nonexistence of this structure has been shown and in its place I wish to set up the idea that the lack of relief of the plain is due to the fact that it is the last of a series of cut terraces. I believe that the structure under the plain is a continuation of the anticlinorium of the San Joaquin Hills which stretches across the valley under the thin cover of alluvium. This is not susceptible of proof by undeniable outcrops of strata. The fact that the valley is a marine terrace as discussed under Geomorphogeny implies that structures on one side should be continuous with those on the other in the absence of intervening faults for which there seems to be no evidence in this case.

To the south of El Toro there is a syncline plunging at a low angle to the southeast. The part north of El Toro is obscured by alluvium but from well logs it appears to be underlain by Vaqueros sediments. The existence of this syncline as a complementary feature to the anticlinorium is what one woul expect. It is from the continuation of this structure in its unbroken fashion across the supposed graben that much of the evidence against faulting as the origin of the plain is derived as well as evidence for the continuation of the anticlinorium of the San Joaquin Hills.

Structure of the Santa Ana Mountains

The Santa Ana Mountains are a block which owes much of its present topography to erosion rather than structural features. It may be regarded as a typical block range warped up along the Elsinore fault system to the east. Its western slope has been sculptured to such an extent by erosional agencies that the simplicity of its structure is not apparent until considerable study has been done.

The Elsinore fault system along which the block was raised is not discussed in this paper. It is so striking that it is not necessary to put forth all the evidence for faulting along the eastern face. The Elsinore valley is a rift valley with numerous features such as sag ponds, lakes, hummocks, and longitudinal streams. The eastern scarp in some places, notably near Coldwater Canyon, appears to have been elevated on one fault. In other places step faulting has taken place.

The age of the Elsinore fault system is not known. The youngest marine sediments are Martinez beds. These were at one time continuous with those on the western flank of the range. If the Perris peneplain be represented in the Santa Anas the age of the present fault valley is certainly younger than that surface. Whatever its exact age is, it is known that during the periods of deposition in which the Vaqueros, Topanga, Puente, and Fernando were laid down there was a land mass to the east of the Elsinore trough contributing sediments to the region occupied by the present block.

The uplift of the block has taken place in an intermittent fashion as shown by the series of terraces through out the range. These are at uniform levels in the different drainage systems, a fact which shows that they are due regional uplift rather than local causes. During the uplift of the block it is believed the structures represented by the monocline in Tomato Springs Canyon and some of the faults were superposed on the north south structures originating in the San Joaquin Hills. A reconstruction of the movement of the Santa Ana Block must take into account the effect other blocks have exerted in its history. It is believed that the north-south structures of the San Joaquin Hills are the result of movement of the Santa Ana block northward with respect to to the seaward block. This is based on the assumption that the folds of the San Joaquin Hills which are at angles of 45° to the direction of faulting are the result of a couple along the fault. Occurring as they do in the soft thick sedimentary series along the southwestern edge of the block this origin seems to be the most probable one. Further the fact that they gradually die out towards the heart of the range is also very suggestive. Thus the block can be considered as rising, and during the rising being compressed between two fault zones. During this rise there was a couple moving the block north with respect to the one to the west which developed folds in the San Joaquin Hills. Relief of strains in the block later gave rise to some of the features in the foothills which are superposed upon the earlier San Joquin folds.

The peculiarity about the Santa Ana Mountains is the fact that the block is very rigid. It is aligned with the Coast Ranges of the north but while possessing a sedimentary column like theirs it resembles the Basin Ranges in structure. The determination of the Structure as block type is based in part upon the physiography, in part upon the condition of the sediments, and in part upon the detailed structure.

The detailed structure of the Santa Ana Mountains reveals the block as made up of a series of westwardly dipping sediments resting upon a core of old crystalline rocks. A cross section from the Elsinore Valley to the ocean would show first a series of old basement rocks then a series of sediments dipping more and more gently towards the plain around Irvine. The sediments might dip slightly to the east in the San Joaquin Hills but not markedly so. Towards the ocean the section would stop at the continuation of the Inglewood fault. As visualised the structure fits that of an upwarped block perfectly. The absence of structures formed in response to regional stresses is another striking evidence for the presence of a fairly rigid block. The block while rigid enough to prevent deformation of the sediments on the scale seen in the Puente Hills was still not proof against small warps, such as the syncline in the region of San Juan Capistrano. Further, where the block carries a thickness of sediments and is in a position to be affected by other blocks deformation takes place with a certain amount of folding as in the case of the San Joaquin Hills and the country immediately south of Santa Ana Canyon.

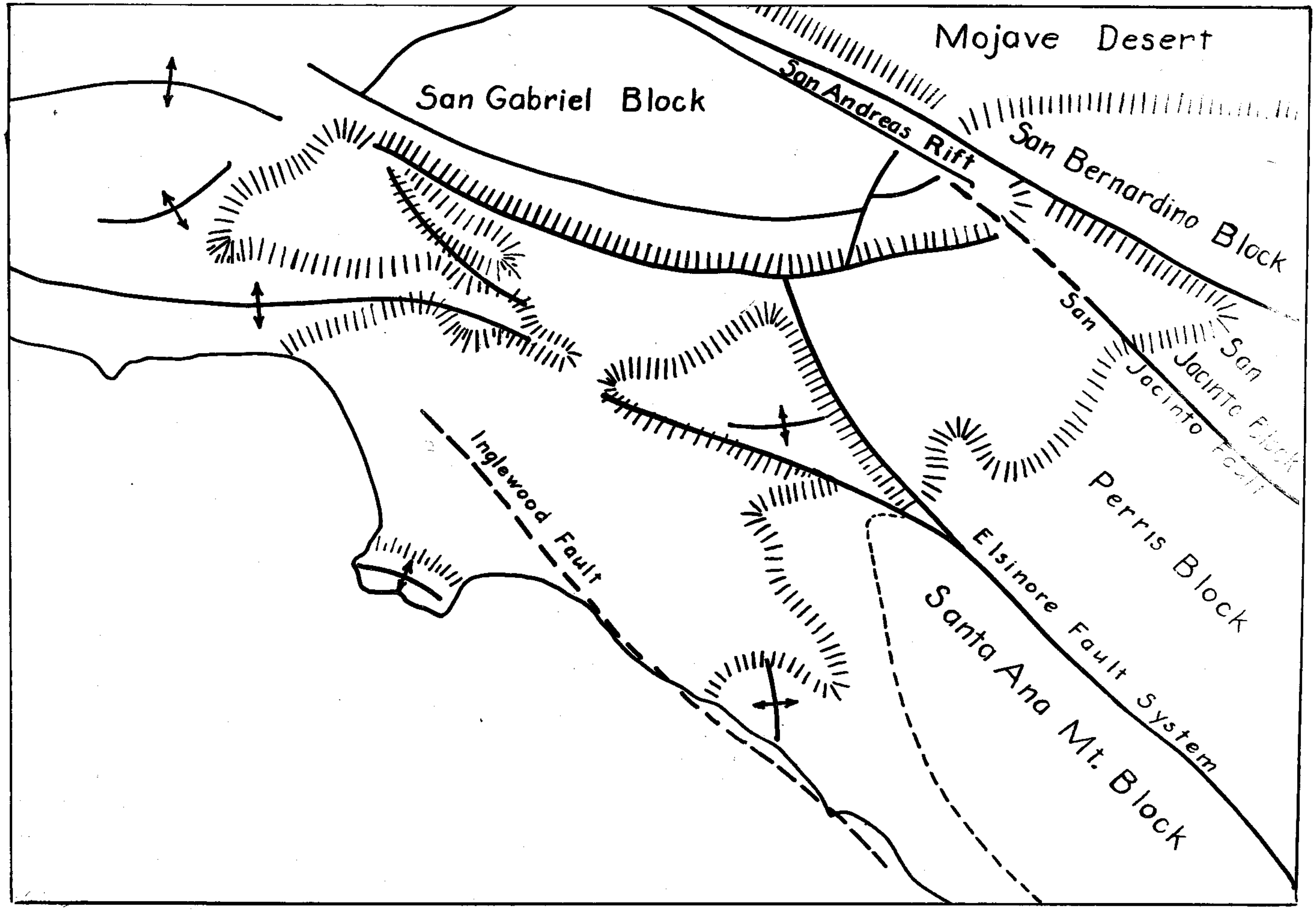


Plate XXXVII Sketch of Major features in Southern California Structure

Relation of the Santa Ana Mountains to the Surrounding Country

If we examine any map of Southern California we can discern several important blocks which form the outlines of Southern California geology. Extending from the Mexican border to the Los Angeles basin there is a long series of mountains known as the Peninsular Ranges. Different names have been assigned to different parts, but the structural unity of this mass, of which the Santa Ana Mountains form the northern tip, is quite apparent. To the east of this block another, the Perris block, is found which is a rather low flat block with gentler topography. Wedged between this block and the San Bernardino Block is the high block of the San Jacintos. To the northeast the Los Angeles basin is bounded by the complex San Gabriel Block.

These blocks form a distinct boundary for the Los Angeles basin as is shown in Plate XXXVII. The contrast in structure of these two divisions is as remarkable ad is their contrast in topography. The Los Angeles basin represents a great thickness of down warped sediments intensely folded and in places forming small mountains which resemble the folded Coast Ranges to the north. The transition from the folded structure of the basin which most assuredly represents a continuation of the valleys and mountains forming the Coast Ranges, to that of the high rugged ranges of the fault block type to the south suggests that one is passing from a structurally unstable area to one in which the strength of the rocks is an important factor. This is evident in a comparison of the Puente Hills with the Santa Ana Mountains. The Puente Hills are a wedge shaped block forced up between two reverse faults. The Santa Ana Mountains are faulted up along a compressional fault but show none of the intense folds which characterize the Puente Hills. To be sure sedimentation has taken place in this southern area but it has been more in the nature of thin deposits on the edges of the blocks than that of basin deposits.

The Peninsular Range is a long series of mountains separated only by local names into separate ranges. It represents a mass of crystalline rocks which have suffered little deformation due probably to their strength. To the east the Perris old age surface extends for great distances, little disturbed by faulting or folding. While the blocks to the east have suffered considerable elevation they still represent distinct units little affected by the forces which have acted on them.

Along the western margin of the Peninsular Ranges there is an extensive strip of sediments. Instead of being folded like the materials in the Coast Ranges to the north, these formations are without exception noteworthy for their freedom from folding, a fact that suggests that even the edges of the blocks have been little affected by folding where the sediments are thin.

Considering the problem in a broad way one is tempted to generalize. The Peninsular Range in its geographic position and orientation is certainly to be considered a part of the Coast Ranges, yet it has certain definite characters such as its freedom from folding and its block structure which set it aside from a typical northern range like the Santa Ynez. One is inclined to wonder to what extent the two parts of the Coast Ranges are related and to what extent removed in origin.

There is one concept which, while quite generalized, will give at least a suggestion as to the origin of this belt of mountains, at once related and yet diverse. In both cases there is a series of parallel ranges which occupy analogous positions with regard to a western edge of the continent and to an eastern massif of old rocks, the Sierras in the case of Coast Ranges and the Mojave and Colorado deserts in the case of the southern ranges. Between these two boundaries of the Continental shelf and an eastern massif the intervening rocks have been subjected to strong forces. The San Andreas Rift which runs through the whole series of ranges is the greatest expression of this force. Whether it is the result of Continetal creep or not the existence of strong forces in this belt is too evident to need discussion. On the assumption that the northern part represents an unstable sinking area which has received vast thicknesses of sediments or a geosyncline and that the country south of Los Angeles basin represents what would normally be a shield of hard rocks it is possible to obtain the present structures by the folding of the blocks of the geosyncline and the elevation of the blocks of the shield. Detailed study of the blocks involved is badly needed. In the case of the southern area it is believed that the San Andreas Rift represents merely the line of major horizontal movement and that much has taken place between the individual blocks. The combination of horizontal movements with reverse faults leads to underthrusting and elevation of different blocks. It is evident that isostasy alone has not determined the rise and fall of these blocks but that a more potent factor, possibly that of continental creep has been involved.

Geologic History

The geologic history of the Santa Ana Mountains embraces a long and eventful period dating from the Triassic to the present. It forms a remarkably complete record and throws considerable light on some of the little known events of Southern California, more particularly in the Triassic and Jurassic.

The earliest event of which we have a record is the deposition of the Silverado formation. This formation is middle Triassic in age. It represents a very thick section of sediments laid down in a subsiding basin which allowed of continuous shallow water conditions. The appearance of the formation resembles that of the thick sections of Cretaceous frequently seen in the Coast Ranges. The base of the section is unfortunately not exposed nor is the top. However the section is some 17,000 feet thick without these missing parts. This formation was deposited in the gulf which in Triassic time ran across Southern California and up into the Great Basin country. Deposition was from a land to the west, it is believed. The sediments were derived in part from old schists and in part from old sediments, the age of which is unknown. To judge from the coarse sandstones and the conglomerate band in the section, this land was at no great distance.

After the deposition of the Silverado there was a period of uplift and folding. During this period there were intruded some dikes of andesites. It is not known whether there was any volcanic activity during this period for no lavas or pyroclastics are preserved. How long this period of mountain building lasted is unknown for there is no fossil evidence dating the erosion period.

The next event is the submergence of the truncated Silverado formation and the advance of the ocean. During this advance material on the surface was reworked and formed into a coarse basal conglomerate. Material from the dikes in the slates is found as huge boulders at no great distance from their source. This formation was undoubtedly quite extensive at one time but erosion which took place after the next orogenic period resulted in the planing away of most of the beds. This formation known as the Hough was laid down under much the same sort of conditions as the Silverado.

The deposition of the two marine formations mentioned forms the first chapter in the history of the region. For a period ranging from the start of the erosion of the Hough to the start of the deposition of the basal beds of the Cretaceous the record is one of igneous activity. The first event was the intrusion of a series of dacites. The present Sierra Peak represents an old stock of the dacite porphyry which was expelled in an explosive fashion. The San Juan Hot Springs formation, a series of lavas and tuffs, is correlated with this series of vents.

After the vulcanism had ceased there was a period in which numerous andesite dikes, stocks, and bosses were intruded. These were forced into the older rocks under great pressure as is shown by the development of intrusive breccias. Any surface flows connected with the intrusive bodies of the Modjeska series were removed by subsequent erosion.

Following the andesite porphyries was a period of relative quiescence during which occasional intrusive bodies of dacite and andesite porphyries were formed. These are not of any great importance in the Santa Ana Mountains proper.

The intrusion of the granodiorite was the last event in the formation of the basement complex. This exists as tongues of a larger batholith to the south. It is supposed to represent the same period that the granodiorites of the Sierras represent. This intrusion was of the greatest importance to the Santa Ana Mountains for to it is traceable most of the metamorphism of the older rocks. This was obviously hydrothermal in nature rather than dynamic metamorphism.

After the intrusion of the granodiorite the region was raised and a period of erosion commenced. The igneous rocks were laid bare and planed off over a large area. It is during this period that most of the removal of the roof pendants of the metamorphics took place. On this surface in upper Cretaceous times the ocean advanced laying down a coarse basal conglomerate which due to the presence of much iron was later to weather to a deep red. These basal red beds were marine, not continental, in origin. The Cretaceous was deposited in shallow water near shore. In some horizons extensive scour channels are present, while in others there is a suggestion of estuarine conditions. There is strong lateral variation in the Cretaceous. Sections removed only a few miles from one another show striking differences. From the lack of uniformity it is plain that the deposits were formed along a coast and influenced by local sources of sediments.

After the deposition of the Cretaceous there was a period of uplift, warping, and erosion. Much of the Cretaceous was removed. During this period an extensive surface was developed at no great distance above sea level. On this surface were deposited the basal beds of the Paleocene Martinez. The initiation of deposition in the lakes and marshes on this flat plain was probably due to tectonic changes to the east which resulted in the formation of a steep mountain scarp. The first deposits were conglomeratic but later ones were finer and included clays and coals. Thesesdeposits were covered by m marine sediments due to the lowering of the land and the upper part of the section is a record of alternating coarse and fine marine deposits. The extent of the Martinez is very great. It occurs thoughout the Elsinore Valley and as far south as Oceanside. The surface on which these marshes and lakes of the basal series occurred were very extensive. The presence of such an extensive area of low lying marsh lands close to the ocean is totally unlike the country today.

After the deposition of the Martinez was dempleted a new period of uplift, warping, and erosion took place in which vast thicknesses of sediments were stripped off. At the end of this period subsidence again took place and the Domengine formation was laid down. This is marked by a basal conglomerate and then a series of alternating coarse and fine sandstones which are massivelky bedded. Cross bedding is common indicating rapid deposition. The sands of the Domengine as well as those of most of the sediments are well sorted showing that grading of the material was rather thorough.

The Domengine was followed by another period of uplift, warping, and erosion during which time most of the formation was removed in this region. The Vaqueros sediments which follow were laid down on an irregular surface as the overlap of sandstones and conglomerates shows. The Vaqueros sea was a shallow sea in which increasingly finer sediments were deposited. The top of the Vaqueros is marked by a break in deposition. The sediments stood close to sea level and were eroded by currents. Sinking of the basin resulted in renewed deposition but this time from the west. The schist blocks forming the basal conglomerate of the Topanga were derived from a land to the west made up of metamorphics of the Catalina facies. The overlying sandstones of the Topanga show deposition from both landmasses. The most interesting feature is the legth of time represented by the disconformity between the formations. While no angular discordance is recorded the faunas are so distinctly different that a considerable lapse of time is indicated.

After the deposition of the Topanga there was renewed diastrophic activity and erosion removed most of the Topanga sediments and much of the Vaqueros. On the surface formed the shales and sandstones of the Puente formation were laid down. Here again deposition took place in a subsiding area and as a result the formation represents shallow water deposits through quite a thickness of beds. During this period it is believed that the intrusion of the diabase sill in the Puente Hills took place as well as the diabase in the Santa Ana Mountains.

There was another period of erosion after the deposition of the Puente. The Capistrano beds overlying the Puente and Vaqueros beds is a series of loosely cemented sediments of shallow water origin. They probably are related to the Fernando of the Puente Hills.

The folds of the region were developed during the period following the deposition of the Capistrano. Their exact relation to the forces causing the elevation of the present mountains is unknown.

Geomorphogeny

The last chapter in the history of the Santa Ana Mountains is written in the present land forms. This range , which occupies a prominent position in Southern California, has had an interesting geomorphic history. Unlike the Coast Ranges of the north which are complexly folded and faulted, it is a tilted block much like the ranges of the Great Basin, although in geographic trend and position it corresponds to a continuation of the Coast Ranges. Due to the humidity it resembles the desert ranges little in topography, but rather one of the Coast Ranges proper.

The Santa Ana Mountains comprise a range running from the Santa Ana Canyon on the north to some distance below Trabuco Canyon where there is an insensible gradation into the Santa Margarita and Elsinore Mountains. They trend in a northwesterly direction, forming a high country between the low Perris Plain and the ocean. Their greatest altitude is 5680 feet and the maximum relief in the area mapped is about 5200 feet. The crest, which is only a few miles west of the eastern base, has an average elevation of from 4000 to 4500 feet and is rather even. The high country is narrow and equally rugged on either side of the divide. The distance by trail from Coldwater Canyon and from Holy Jim Canyon to Santiago Peak is the same as is also the vertical distance. In each case the rise in a direct line of two miles is close to 4200 feet.

From the east the range stands out as a bold scarp rising above the terraced Elsinore depression. From the west there is no indication of a smooth back slope. Rather it appears to be made up of a high country separated by a valley from a lower though equally rugged set of hills which are in turn set off from a series of lower terraces and the coastal plain in a very abrupt manner.

The evolution of the present topography shows very clearly the action of three major processes. The first of these is the dissection of the block consequent to the intermittent uplift along the eastern scarp. This is the controlling factor in much of the history and on it rest the other two processes which are unusual modifications of the cycle of erosion of block mountains. The second is the persistence of master streams, while the third is the action of the ocean along the western side of the block. As a result of these different processes the western slope presents a rather confusing aspect at first sight. Unlike the typical arid climate block range the streams do not follow the back slope to the base where they form fans. They drain instead into a master stream, Santiago Creek, which follows a course nearly parallel to the front. As a result of the downcutting of Santiago Creek there have come into existence two topographic units, the high country of the older rocks, and the foothills. These foothills instead of sloping gradually to the west are sharply cut off and rise abruptly from the plain forming what has been termed a fault scarp by some observers. Examination shows that here the block has been modified by marine erosion which has left low lying terraces in the neighborhood of El Toro and the San Joaquin Hills.

These three important synchronous processes can not be separated in the consideration of the development of the present land forms. Hence if the following descriptions appear disjointed it is because interdependent details are described by themselves.

The Eastern Scarp

It is certain from a study of the structure of the Santa Ana Mountains that they represent an upwarped portion of the earth's crust, the movement taking place alongthe Elsinore fault system. The existence of a fault or rather a fault system along the eastern face is so apparent from the physiography that little other than a casual examination is needed to establish the point. The eastern face is a steep rugged scarp comparatively straight, with a number of fans developed at the points where the streams debouche. The Elsinore trough is a complicated structure which is the result of the rifting movements of the region. Numerous enclosed depressions as well as sag ponds and hummocky ground are common features. Where there are branch faults in the face of the scarp offset of streams may be observed. Features such as truncated spurs and facets have been largely removed by erosion.

The eastern scarp is not an uncomplicated feature, In places such as Coldwater Canyon one fault seems to be responsible for the whole displacement. On the road in Tin Mine Canyon there may be observed several faults along all of which considerable displacement has taken place. Thus in places the scarp may be considered to be simple and in other places to represent step faulting. In this paper no great space is devoted to the eastern scarp since it is being more thoroughly investigated by another student of the department. Enough has been said to give a general idea of its appearance and its relations to the rest of the block. Plate XXXVIII is a view of the scarp from the east which shows it in its typical form.

Western Slope

The western slope of the Santa Ana Mountains represents the back slope of a warped block as may be seen from an inspection of the structure sections. The present topography shows no unmistakable traces of the oldest surface but there is one suggested in the rather even crest line , the long even ridges cut in rocks of varied hardness and attitude and the extent of weathering of some of the material along the crest.

In the country to the south there are large areas of a flat old age surface cut in the granitic rocks. This is correlated with the Perris Peneplain. In the Santa Ana Mountains proper there is none of this left. This is perhaps due to the fact that in the Elsinore Mountains elevations are not so great and the range is wider, both factors deaccelerating headward erosion. In view of the close relations of the different regions it is very probable that this surface was at one time continuous throughout the ranges.

The uplift of the western slope took place in an intermittent fashion the record of which lies in the extensive series of broad terraces. The relation of these terraces to regional movements rather than to differences in the local cycle is shown by the close similarity of the altitude of terraces in the different stream valleys. In all the drainage areas terraces have been developed and the more important of these may be correlated from one drainage to the next. The large remnant in the southeast, Plano Trabuco, seems to represent the same period that the terraces near the mouth of Silverado Creek represent. The terraces in this region are quite numerous and some time could be spent in mapping them. However, it was felt that such a detailed study would add no essential knowledge to the history of the region.

It is usual to think of uplift of a fault block resulting in the formation of consequent streams on both sides of the scarp. This is the usual case in the arid cycle where there are no well defined drainage systems. In the Santa Ana Mountains the back slope presents little of the appearance that one would expect. The upper crest is separated from the lower part by a stream valley and the base of the slope terminates in an erosional scarp. Since structurally there is no break an explanation must be sought in the history of erosion. A consideration of the drainage pattern of the Santa Ana Mountains leads one to the conclusion that there was a well developed stream system in existence before uplift took place. Instead of flowing down the slope of the range Santiago Creek follows a sinuous course along the face of the higher country until it strikes the plain near Santa Ana Canyon. The stream is clearly not connected with faulting nor is it the result of piracy for it itself is in imminent danger of capture by other streams at several points. The present course along with the well developed side drainage, particularly from the south, suggests the inheritance of the present pattern.

An examination of the course of Santiago Creek reveals the fact that the creek flows along contacts between

Plate XXXIX Santiago Creek as seen from Plano Trabuco. Santiago Creek starts in the notch in the center of the distant mountains, flows south, and turns west in a canyon just behind the first longitudinal ridge

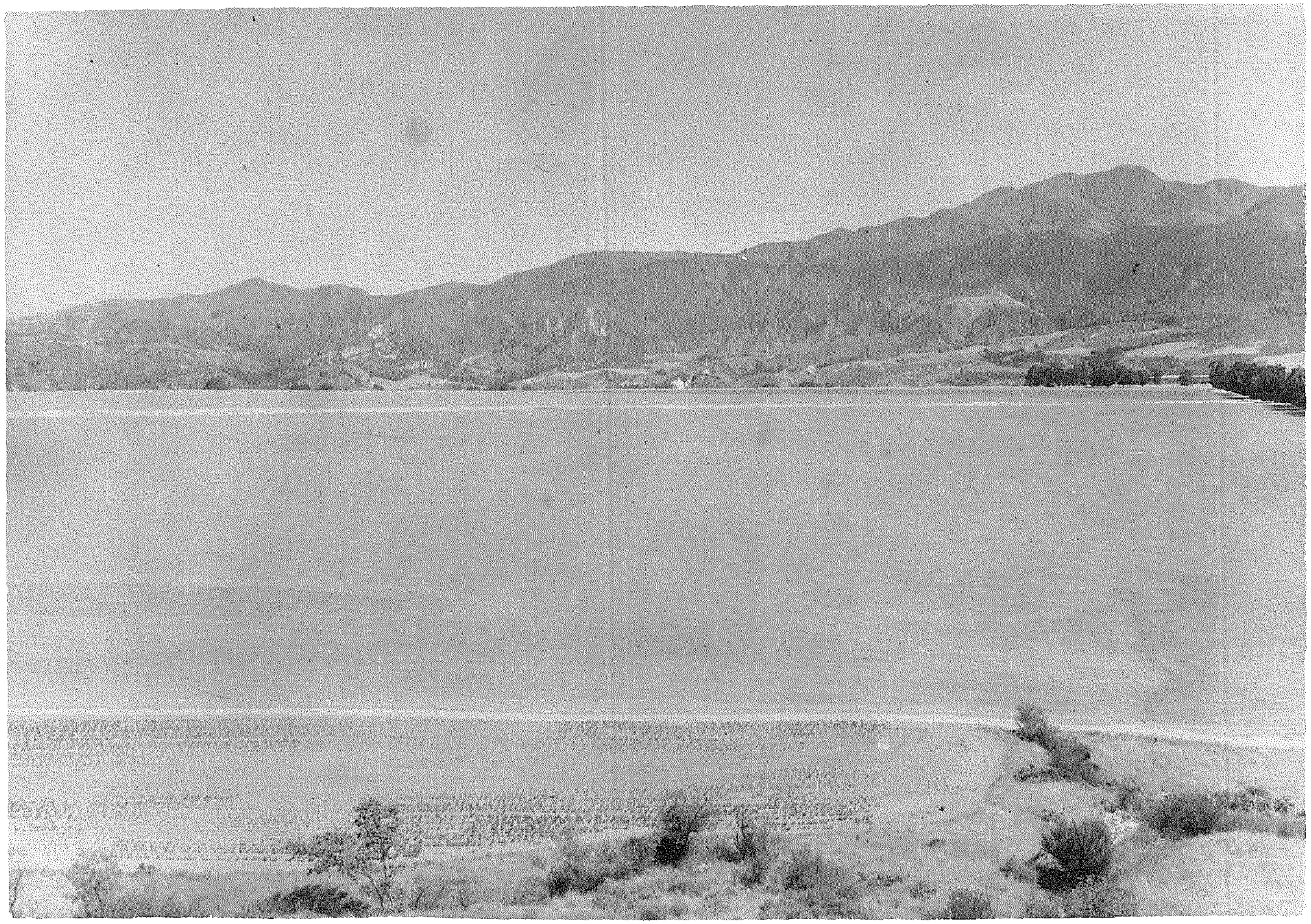


Plate XXXIX   Santiago Creek seen from Plano Trabuco.

the different formations or along the strike of these rocks. In its headwaters it is confined to a shallow ditch in the old rocks. Here little in the way of differential hardness is noted, but at the bend where the stream turns to the west it may be observed that an extension of the Cretaceous conglomerate would have served as an admirable canyon wall in the past. At a point several miles down stream conglomerate bluffs may be noted on one side and slates on the other. The westward course is broken below Modjeska's and the course of the creek changes to the northwest following the Martinez which is here a long ribbon of soft sandstones between the hard sandstones of the Cretaceous to the east and the hard Vaqueros conglomerates to the west. This northwesterly course is followed through the region with some minor turns. In general the course follows the strike of the rocks closely until it approaches Sierra Canyon when it cuts through Cretaceous and Vaqueros in its escape to the plains.

This pattern, comparable to a gutter along the roof of a building, is clearly an anomalous one and not due to any process of erosion as developed on the back slope of a fault block. Plate XXXIX shows the position of Santiago Creek as seen from Plano Trabuco. Near the turn Santiago Creek is only 75 feet below the divide and the vertical distance to the Trabuco drainage level at that point is 1500 feet. At this spot Santiago Creek is in imminent danger of capture by tributaries of the other drainage. The explanation of this course by the theory that it represents essentially the old course as developed on the old surface explains not only this feature but several related ones.

Under the above theory uplift of the block would produce renewed activity on the part of Santiago Creek and also promote lateral cutting on the down slope side of the creek. Throughout the course it is notable that the bluffs are invariably better developed on the down slope side and that the terraces are more extensive on the up slope side. The position of the terraces recalls the slip off terraces common on intrenched meanders. The downward cutting of Santiago Creek has been so great that canyons deep enough to hold it have been developed. Had lateral erosion played the greater part the stream would have been able to cut out to the plains at several places forming several smaller streams.

The importance of Santiago Creek in the northern part of the Santa Ana Mountains cannot be over emphasized. The peculiar topography - two divides on the same structural block-is due to the action of this stream. In the development of this topography we must visualize not only Santiago Creek but its tributaries. Santiago Creek flowed in a broad shallow valley and on uplift was intrenched. Plate XL shows the relation of the present topography to that of the old surface of the block. As may be seen from the plate uplift measured in feet was greater along the present crest than along the course of the creek due to the fact that it was farther from the line representing the pin of the hinge.. It is easily seen that the country to the northeast of the creek would suffer a great deal of erosion due to uplift while to the south there would be very little. Were it not for the rapid intrenchment of Santiago Creek aggrading of the northward flowing drainage would have taken place.

South of Santiago Canyon on the higher parts of the crest are patches of old gravels. Between these are remnants

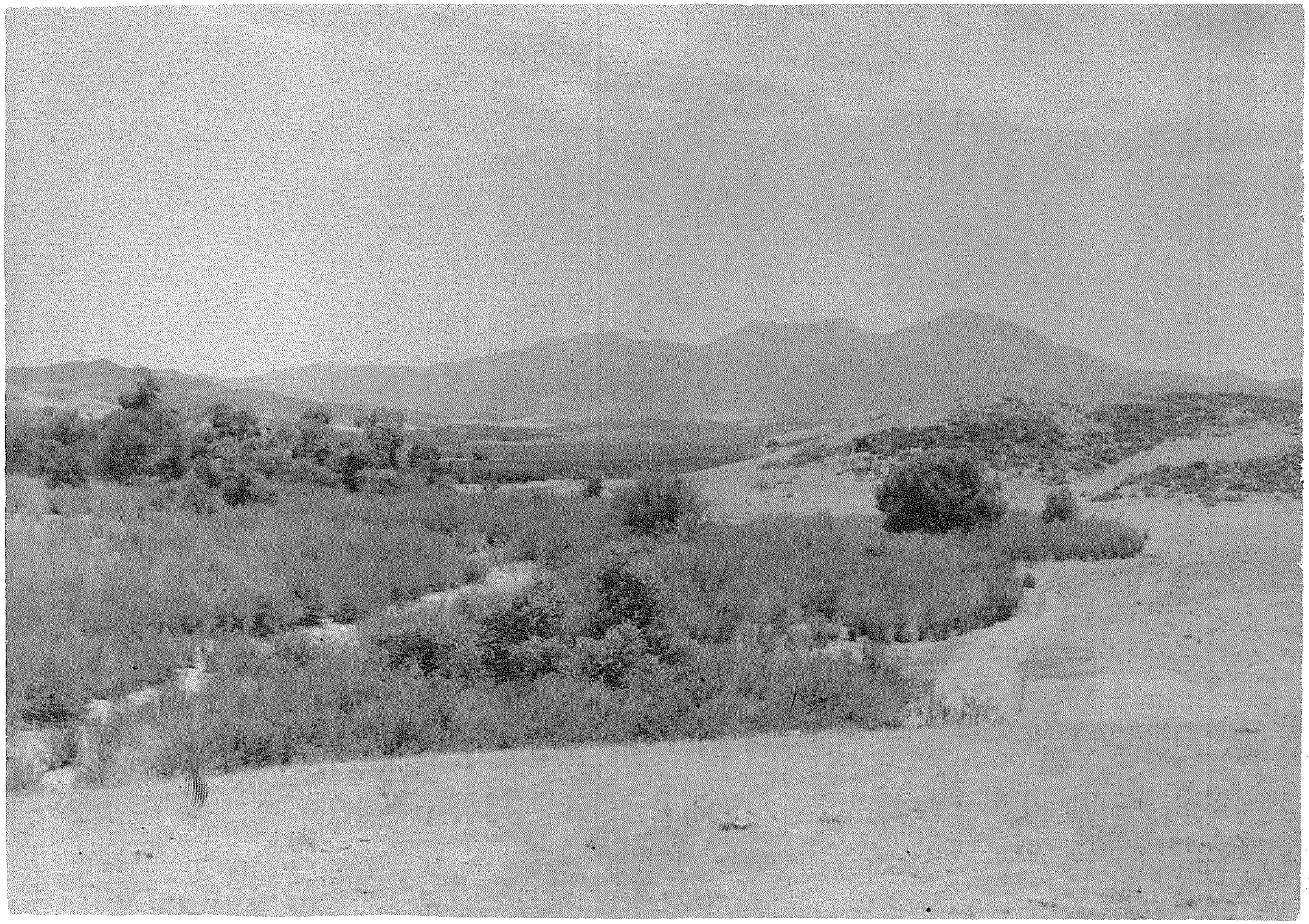


Plate XLI Looking North in Canada Gubernadora, a Canyon now Being widened of broad gentle stream valleys. The occurrence of these forms has always been something of a puzzle since they appear to demand the existence of a range of considerable height to the southwest or else were the old channels of streams like Black Star Creek and Sierra Creek. The structure of the block does not admit of a former elevated portion in the vicinity of the present plain around Irvine. The fact that Santiago Creek represents the old drainage pattern itself does away with the argument that they are the lower parts of courses of consequent streams which were captured by Santiago. Further, the topography of these features show that the original direction of their drainage was towards the north and not to the south. Under the theory outlined these features are shown to be normal and are easily explained. Tilting of the block would decrease the grade of northeasterly flowing streams and exercise a preservative influence on their courses. Until Santiago Creek had intrenched itself enough to change the base level for these streams it is evident that their valleys would either be aggraded or else balanced. Thus traces of the old features of the prosurface might well be preserved for considerably longer periods than topography located on southwest drainages near the summit. The features thus need represent nothing more than the shallow features found on old age surfaces. The necessity for a high land to the southwest is then removed.

That the old gravels found along the crest at an elevation of 1700 feet are part of the prosurface is suggested by the nature of the pebbles. Many of these are granodiorite, a rock that is not present in the Santiago drainage area and is very scarce in the old conglomerates due to its ease of weathering. The source of this material is across the present fault system bounding the block. The conclusion is that the gravels were derived from the Elsinore region and thus represent a pre-faulting date. In this case they would be connected with the prosurface or the Perris peneplain, providing that that is considered to be the equivalent of the original surface of the block.

In the period during which Santiago Creek was being modified by erosion numerous terraces were formed. These are for the most part to the north of the present stream. These have been reffered to as resembling slip off terraces. They extend through a vertical range of about 1000 feet above the stream. The higher ones are not well preserved due to their originally small size and the ruggedness of the topography. The lower ones are well developed and well preserved at the present time. These will not be discussed in detail for it is believed that such a discussion is not necessary. However, there is one that possesses considerable interest, and that is the one represented in the dissected divide between Santiago and Rabbit Canyons.

The divide between the streams in Rabbit Canyon and Santiago Canyon represents an old terrace developed by Santiago Creek and extensive over the present drainage of the two streams. After this flat valley represented by the terrace had been formed rejuvenation of the system took place and down-cutting of Santiago Creek took place. This resembled much the situation in Plano Trabuco where on the side opposite that of the intrenched course of Trabuco Creek a new drainage is developing to care for the runoff from the other side. Santiago Creek happened to intrench itself along the northern side of the valley and as the process went on the run off from the hills to the south formed Rabbit Creek. Intrenching of the streams and lateral cutting has resulted in the present topography.

At the present time Santiago is cutting down its bed. This may be due to rejuvenation by regional uplift or by burning off of the vegetation. From the numerous stream flats developed only a few feet above the present stream one would be tempted to say that degradation was going on. A consideration of the depth of gravel in the stream bed, however, which amounts to 100 feet in places, suggests that possibly some aggradation may have taken place fairly recently. The exact process taking place mow is uncertain, but it is certain that the trend has always been torwards cutting down rather than building up in the past.

The drainage system to the south od Santiago Creek is somewhat less complicated than that to the north. Trabuco Creek which forms one of the important streams is apparently a consequent stream modified in its lower reaches by structural control. Bell Creek shows an interesting bend where it emerges from the old rocks. San Juan River is a large important stream which receives the drainage of Trabuco and Bell Canyons. It is to all outward signs a consequent stream.

The streams mentioned above are interesting in that they all appear to be consequent in their upper courses. In the parts lying in the Tertiary rocks they are subsequent. This peculiarity has been brought about by the fact that the higher lying old rocks are resistant to erosion while the Tertiary sediments are easily removed. Consequently during uplift of the region the channel in the old rocks, being farther from

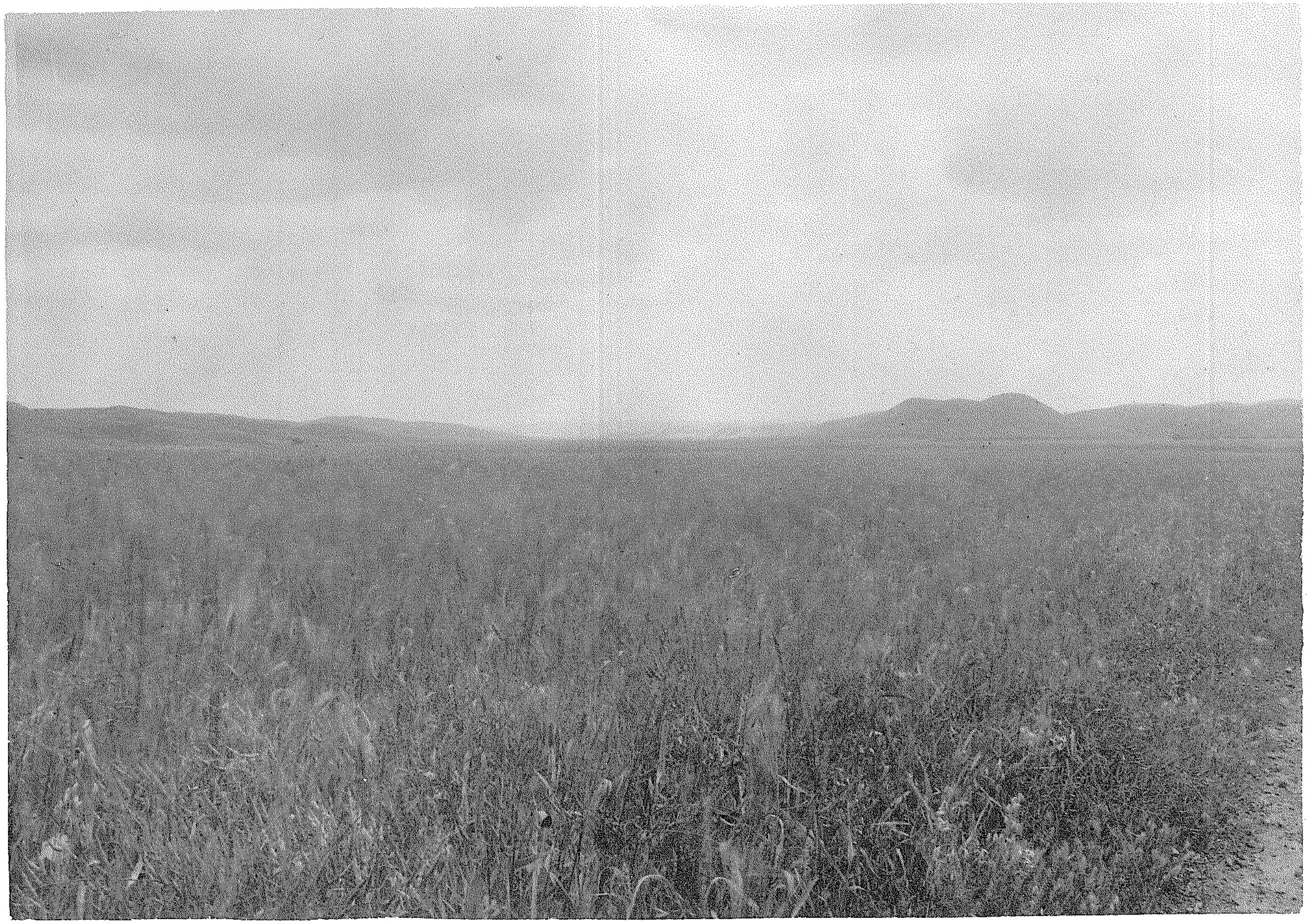
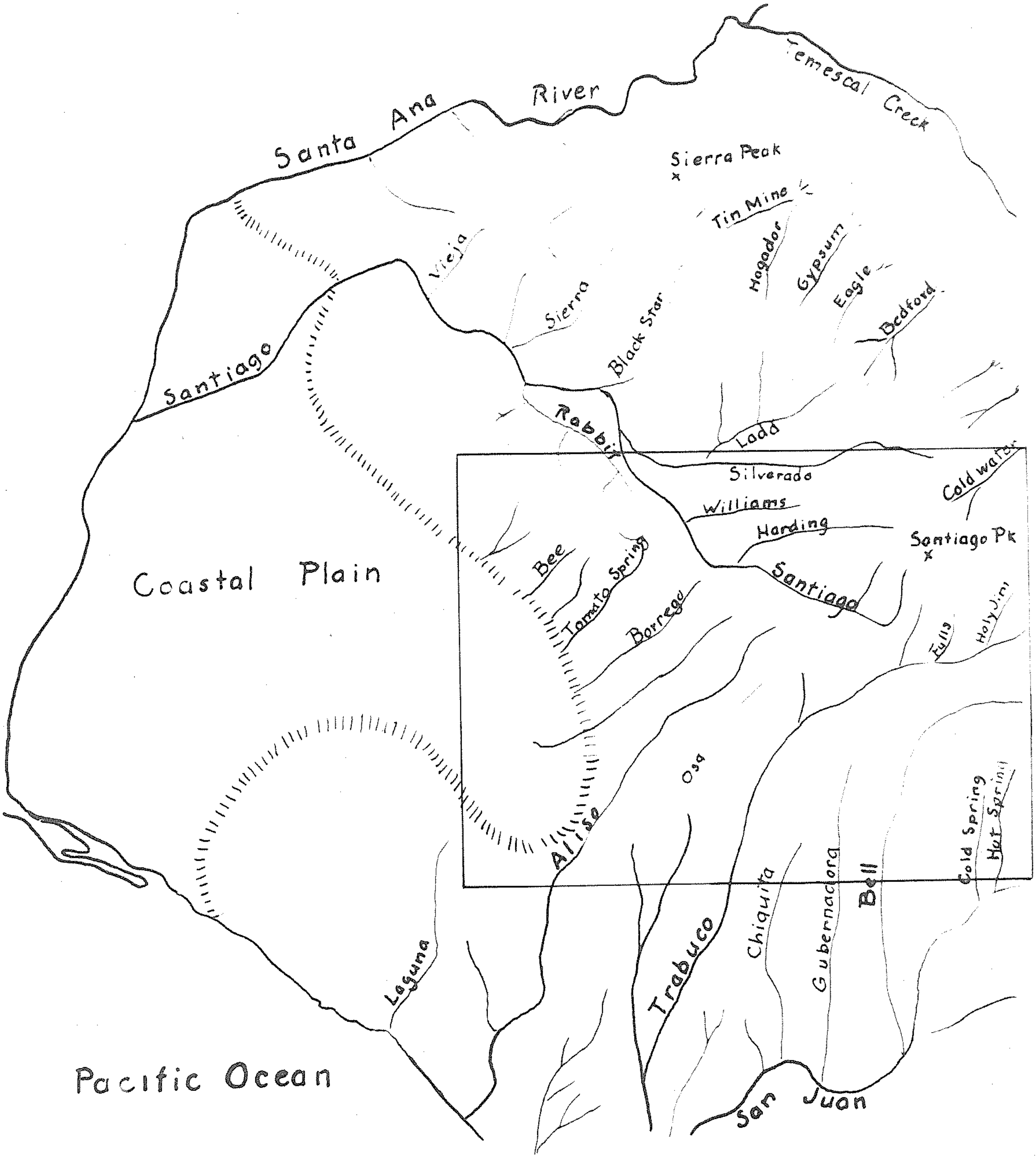


Plate XLII Plano Trabuco



Sketch Map
Showing the Drainage Pattern
of the Santa Ana Mountains

from the pivotal portion suffered not only greater uplift, but was located in hard resistant material. The lower parts located in the soft sediments could easily and rapidly reach a graded state. Consequently the upper parts are busily engaged in cuttin down the bottoms of the steep V shaped canyons while the lower parts are cutting laterally. Thus the original consequent stream course may be well preserved in the upper part while the drainage of the lower broader valleys is subsequent, with prominent structural control.

The striking relation of the drainage lines to the strike of the rocks in the casese of Aliso, Osa, Trabuco, Chiquita, Gubernadora, and Bell Canyons may be readily seen on any map. The drainage pattern sketch map (Plate XLII) shows the parallel nature of these streams very clearly. A view of these from Santiago Peak is very illuminating. The old dissected terraces between each canyon appear as hog backs separating the later undissected terraces or stream valleys. At the present time some of the streams are working back by headward erosion, cutting away the old terraces and forming new flat floored valleys. This is particularly well illustrated in the case of Plano Trabuco.

Plano Trabuco is a broad flat plain some hundred feet above Trabuco Creek. It is about five miles long and two wifle. It is a cut surface covered with a veneer of gravels. Along towards the southwestern part is an isolated hill made up of a very weàl cemented and hard Vaqueros sandstone. It is a monadnock or residual hill. Plano Trabuco is one of the younger and better preserved terraces although surrounding it on all sides are remnants of older ones. The surrounding country is the result of the dissection of terrace after terrace. Plano Trabuco represents a stage in the cycle through which the country has passed time and again in the evolution of its present form. The processes that led to the formation of Plano Trabuco are now at work in Canada Gubernadora. Here the stream is cutting laterally and forming a broad flat valley. Later,dissection will take place as is the case with Plano Trabuco at the present time. At some future date lateral planation will have removed most of the terrace and if uplift take place there will be a repetition of the process. Plate XLII shows Canada Gubernadora looking north. The tendency to lateral planation by the stream is quite apparent. Plate XLIII shows Plano Trabuco. The relation of this terrace to the older dissected ones on each side is interesting.

Up to this point we have considered the mountains proper. There,are, however, some very interesting features on the low country to the southwest. Perhaps the most striking of these is the scarp representing the front of the foothills. This is irregular in pattern with no suggestion of alignment of spurs. In most cases its apparent steepness is due to the sight of the steep amphitheaters eaten back into the hills by the streams. This scarp is not a fault scarp as has been shown in the section on Structure. It is undoubtedly due to erosion. The same agencies that were responsible for the cutting of the plain around Irvine and the terraces in the San Joaquin Hills are believed to have formed this scarp.

To the south in the San Joaquin Hills marine terraces are found at all elevations. They frequently have recent shell remains in the gravels according to oral communications of Messrs. Bode and Findlay. The author has found large boulders consisting of silicified portions of Puente shales drilled with marine borers in the San Joaquin Hills south of El Toro. From their appearance they seem to be recent beach boulders. The fact that the ocean has covered at least the lower plains is inescapable. That it surrounded the San Joaquin Hills is highly probable. The materials of many of the terraces around El Toro suggest a marine origin. The sands are clean and well washed and resemble the sands of the sedimentary formations. Their white color is in great contrast with those gravels around Plano Trabuco which are deep brown in color and contain much admixed clay. The relation of the terraces on the San Joaquin Hills to those of the country to the north suggests that for each terrace developed on one side a similar one was developed on the other. This is quite apparent in the vicinity of San Juan Capistrano.

The terraces around El Toro form a series of steps down to the country to the west. The presence of terraces formed by a north-south stream in this region is inconceivable. However the scarps bounding them are in the correct position if we admit marine origin. While evidence for marine origin is not as conclusive as it might be in the presence of shell beds, it is believed that the evidence is very strong.

The face of the foothills is considered to represent an old sea cliff. While the terraces around El Toro and San Juan Capistrano were being formed the ocean was cutting steadily into the base of the range. This cutting back produced a steep scarp and had the same effect upon the streams in the face that faulting would have had. Due to the softness of the sediments the streams have formed huge amphitheaters in the hills which eat their way into the soft rocks much like a cirque would do in harder material. One of these amphitheaters is shown in Plate XLIV. The shortness of the streams with respect to the size of these features is noteworthy. Due to the cirquelike action of the streams of the western face the whole divide is moving eastwards. The mode of travel preserves the topography to the east except for those parts completely removed by this sapping process. The contrast between these steep walled cirques to the west and the old valleys to the east is very striking.

Plate XLV shows the relations of the terraces around El Toro and a part of the face of the foothills. The north-south trend of the terraces is of interest as is also their relation to the foothills themselves.

In summarizing the geomorphogeny of the Santa Ana Mountains one would say that the mountains represent a part of the old surface correlated with the Perris peneplain. This has been raised along the Elsinore fault system. In this process Santiago Creek, an old stream, maintained its pattern. By the action of Santiago Creek, which has succeeded in maintaining its course, and the ocean, which has cut into the lower side of the block, the present topography has been evolved. The physiography may be summed up as a very interesting example of semi-arid climate modification of a simple warped block mountain range.

Plate XLIV   View of Foothills. An amphitheater may be seen neat right of picture.

Plate XLV Terraces around El Toro seen from Irvine

Areal Geology

C.I.100' Scale 1;42,000 approx.

Topography from U.S.G.S. Corona Quadrangle

Geology by Bernard N.Moore

Legend

Sedimentary

Quaternary	QAl	Quaternary Alluvium
Quaternary	QTe	Terrace Deposits
Pliocene	Tc	Capistrano
		Unconformity
Tertiary Miocene	Tp	Puente
		Unconformity
Tertiary Miocene	Tt	Topanga
		Disconformity
	Tv	Vaqueros
		Unconformity
Eocene	Td	Domengine
		Unconformity
Eocene	Tm	Martinez
		Unconformity
Mesozoic Cretaceous	K1, K2, K3, K4	Cretaceous

Metamorphics

Mesozoic Triassic	TrH	Hough
		Unconformity
Mesozoic Triassic	TrS	Silverado

Igneous

Mesozoic Jurassic	Jc	Glen Ivy Diabase
Mesozoic Jurassic	Jg	Granodiorite
Mesozoic Jurassic	Jd	Dacite Porphyry
Mesozoic Jurassic	Jm	Modjeska Diabase
Mesozoic Jurassic	Ja	Modjeska Andesite Porphyry