G E O L O G Y

of the

ALISO AND BROWNS CANYONS AREA

SANTA SUSANA MOUNTAINS

CALIFORNIA

By

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INTRODUCTION

Previous Geological Investigations.

The first work published on the Santa Susana Mountains was contributed by G. H. Eldridge and Ralph Arnold of the United States Geological Survey, who in their report, "The Santa Clara Valley, Puente Hills, and Los Angeles Districts, Southern California", (1) discussed the oil possibilities of this region.

(1) U. S. Geol. Survey Bulletin 309, 1907

In 1916 the United States Geological Survey published the report of W. S. W. Kew on the "Structure and Oil Resources of the Simi Valley, Southern California". (2) Kew's report covers an area

(2) U. S. Geol. Survey Bulletin 691-M, pp. 323-325, 1916

the eastern part of which includes a portion of the western part of the area to be described. In 1924, Kew's much larger work entitled "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California" (3) was published. This report

(3) U. S. Geol. Survey Bulletin 753, 1924

covers a large area and includes the entire Santa Susana Mountains. However, as this mapping was on the scale of one inch to the mile, detailed mapping was not possible. In 1930 W. P. Woodring published a short paper entitled "Pliocene Deposits North of the Simi Valley, California".(4) Woodring's

(4) Calif. Acad. Sci. Proc., Vol. 19, No. 6, pp. 57-64

paper deals with the region west of that mapped by the writer and describes a Pliocene fauna similar to that collected in the Aliso and Browns Canyons area.

Acknowledgments.

The writer is obligated to Dr. W. S. W. Kew of the Standard Oil Company of California for his interest, help, and for the time he spent with the writer in the field. Sincere gratitude is also extended Mr. Hershel Driver and Mr. Wm. Holman of the Paleontological Department of the same company. Mr. Holman, in addition to making most of the micro-fossil determinations included in this report, spent several days in the field with the writer collecting foraminifera and observing the geology of the region. Gratitude is also extended to Dr. Buwalda and Dr. Popenoe of the California Institute of Technology and to Dr. U. S. Grant IV of the University of California at Los Angeles.

Location and Accessibility of the Area.

The area discussed in this report lies on the southern slope of the Santa Susana Mountains in the mountainous region north of the town of Chatsworth. Chatsworth is located in the northwest corner of the San Fernando Valley, Los Angeles County, California. The area includes approximately the southeastern quarter of the Llajas quadrangle and the southwest quarter of the Newhall quadrangle. It is about four miles long and two and one-half miles wide.

The Santa Susana Mountains, whose eastern extension forms the northern boundary of the western part of San Fernando Valley, trend northwest-southeast and extend from Fernando Pass for approximately twelve miles to the vicinity of Tapo Canyon, west of which the mountain range is known as Oak Ridge.

The area mapped lies about twenty-five miles northwest of Los Angeles. Good paved highways lead from Los Angeles and vicinity to the foot of the mountains. The road leading into the area from the north side of San Fernando Valley turns off Devonshire Boulevard on De Soto Street (just east of Chatsworth). This joins a private dirt road which follows Browns Canyon to the area mapped. At Logan's ranch near the head of Browns Canyon the road turns and runs westward, thus traversing two-thirds of the length of the western part of the area. After leaving the area, one may continue westward on this road and, via Las Llajas Canyon, eventually reach Simi Valley. The fire control roads and some of the ranch roads have locked gates and cannot be used; consequently many parts of the area must be reached on foot.

Purpose of the Investigation.

The report was made as a partial requisite for the degree of Master of Science in geology at the California Institute of Technology. The field work for this report was done during the summer and fall of 1938.

Methods.

The mapping was done on Fairchild Aerial Survey photographs having a scale of one inch to fifteen hundred feet. In areas where more detailed work was necessary enlargements of one inch to seven hundred and fifty feet were used. U.S. Geological Survey topographic sheets were also utilized. For this report the mapping on the aerial photographs was transferred to a mosaic. Putting all of the mapping on one photographic mosaic shows interrelation of areas and makes it easier to get a complete picture of the geology. However, a considerable disadvantage is introduced by the fact that in making the mosaic and piecing the many smaller photographs together, certain parts of the area were cut out or shifted in relation to their relative position to the area of the adjoining photograph. Wherever this difficulty is quite serious, the word cut has been inserted in the cut-out and shifted area and the mapping has been put on the separate pieces of the photograph in its correct position up to the cut area.

SUMMARY

The most important factor in the area to influence both structure and stratigraphy is the Santa Susana overthrust. Overthrusting along the Santa Susana fault has in many cases taken place along more than one plane, producing an imbricate structure. Structurally the period of orogeny which culminated in this overthrusting resulted in close and overturned folding and faulting. The most prominent anticlinal fold is that which extends in a nearly east-west direction across the entire width of the area and passes just below the Holt Ranch, in Browns Canyon. Faults which are older than the Santa Susana orogeny are found, and include both the normal and reverse types. Some of these earlier faults have cut out varying thicknesses of formation, introducing local stratigraphic gaps. Several periods of folding, uplift and erosion, indicated by unconformities, are evident, and provide lines of weakness which have been influential in guiding and controlling the later folding. Thin development of formations and the numerous unconformities point to a very unstable area. Recent diastrophic movement is indicated by folding and faulting of the (Pleistocene) Santa Susana overthrust plane.

Through the medium of this overthrusting, an entirely different stratigraphy from that native to the area has been introduced. Above the thrust, a thick section composed of Modelo shale, (lower Monterey) (Valvulineria californica zone)shale, and non-marine Topanga sandstone, conglomerate, and basalt is found. This section, which has been overthrust from the north, presents an entirely different environmental lithology. The lithology below the thrust, and native to the area, is much less well-developed, and differs considerably from the introduced section found above the thrust. The poor development of these formations, and the fact that they thicken northward and that they are nearly all separated by unconformities, suggests a marginal oscillating environment in the old Miocene-Pliocene depositional basin. The overthrust section and sections to the north, as at Pico and Elsmere canyons, are much thicker and lack many of the unconformities present in this area. These areas undoubtedly occupied a position nearer the center of the Miocene-Pliocene depositional basin.

The oldest rock native to this area is the great thickness of Chico (Upper Cretaceous) sandstone, which makes up the boldly outcropping Simi Hills. Unconformably overlying this is the basal Martinez conglomerate (lower Eocene), which, in the particular area mapped, is in fault contact with younger Eocene to Pliocene formations. The only other Eocene formation mapped was the thick section (1300 feet±) of Llajas (middle Eocene) shales and silts, which grade downward to sandstone and conglomerate near the base of the formation. The Llajas is abundantly fossiliferous. A big stratigraphic break separates the Llajas

from an unconformably overlying upper Topanga conglomerate and silt, 50 to 100 feet thick. This thin section of marine fossiliferous Topanga, limited above and below by unconformities, is a marked contrast to the thick section of non-marine sandstone, conglomerate, and basalt which lies above the thrust and was introduced from an area to the north by overthrusting. Disconformably above the Topanga, in the section native to the area, is found a thin section of argillaceous Modelo shale, varying in thickness from about 25 feet in the southern part of the area to more than 100 feet in the northern portion, where sandstone lenses and layers are found interbedded. This relatively thin section is in marked contrast to the thick overthrust section of Modelo, which is in excess of a thousand feet thick. The Valvulineria californica shale section found between the Topanga non-marine and Modelo shale lying above the thrust is not found in the section below the thrust.

Disconformably above the "native" Modelo shale is found a late lower and early middle Pliocene concretionary silt which is equal in age to about the middle of the Pico formation at the type section in Pico Canyon. This partial equivalent of the type Pico has been designated as the Pico formation in the area mapped. An unconformity separates these Pico silts from an overlying sandstone, conglomerate and fossil reef formation which has been designated the San Diego formation because of the similarity of its abundant fossil content with that of the type San Diego. This 75 to 100 foot thickness of upper middle Pliocene-San Diego strata is, however, an age equivalent of the upper Pico formation at its type locality. Both mega-and micro-fossil evidence points to this. Thus it may be said that the time represented in the accumulation of the strata at the type locality of the Pico formation has its equivalent in the Aliso and Browns Canyons area. This time equivalent is represented by the San Diego formation, the so-called Pico silts of the area, the unconformity separating the two, and by part of the time represented in the unconformity below the Pico silts and above the Miocene Modelo formation. The San Diego formation grades upward into brackish and non-marine Saugus deposits composed of 500 feet of sands, conglomerates and mudstones.

All of these previously mentioned formations were involved in the latest severe folding which culminated in the Santa Susana overthrust. Lying on the erosion surface formed by the partial beveling of these folded deposits are found younger Pleistocene terrace and river channel deposits consisting of large,hard, sandstone boulders, mud, and Modelo shale fragments.

PHYSICAL CONDITIONS

The eastern part of the Santa Susana Mountains, although having a maximum elevation of about 2800 feet above the San Fernando Valley, has a moderately subdued topographic form. Hanging valleys and dissected terraces give evidence of several periods of rejuvenation of this land surface. Recent diastrophism is evidenced by the fact that at several localities the Santa Susana overthrust itself has been slightly folded as shown in upper Browns Canyon. In the area mapped south of the Santa Susana thrust, the topography seems to resemble a dissected plateau, whereas the area north and above the thrust is represented by much steeper slopes and greater relief. Drainage of the south slope of the eastern part of the Santa Susana Mountains is south into the San Fernando Valley and thence into the Los Angeles River.

The climate is semi-arid, which is typical of Southern California. The streams in the area are intermittent with the exception of certain perennial sulphurous springs which are found in the vicinity of the Santa Susana fault zone.

As is so often the case, the vegetation of the region is varied, since it is governed by the type of soil and the altitude. Areas underlain by Modelo shales, by terrace deposits derived from them, or by other Miocene or Pliocene shales usually support a growth of grass or tall weeds. Black walnut trees, white sage, and yucca are found on some of these slopes. Soil derived from sandstones of the San Diego, non-marine Topanga, Chico and other formations support a dense growth of sumac, greasewood, and other dense brush which makes getting about difficult. The Pleistocene loose gravel supports yucca and low brushy growths. Sycamore, oak and occasional black walnut trees are found on the floors of the canyons. At higher elevations occasional pines are found. A well-defined change in vegetation, caused by formational differences, as between sandy and shaly soil in some cases, shows on the aerial photographs and demarcates formational contacts.

In the heads of the larger canyons, as Browns and Aliso canyons, the rocks are well exposed. However, over other parts of the area the rocks are covered by alluvium or Modelo slump, which is noteworthy for the large areas it covers. Slumping on a large scale, in many places, not only makes mapping difficult, but frequently may present large outcrops of Modelo shale, which to all appearances seem to be in place and easily may be mapped incorrectly.

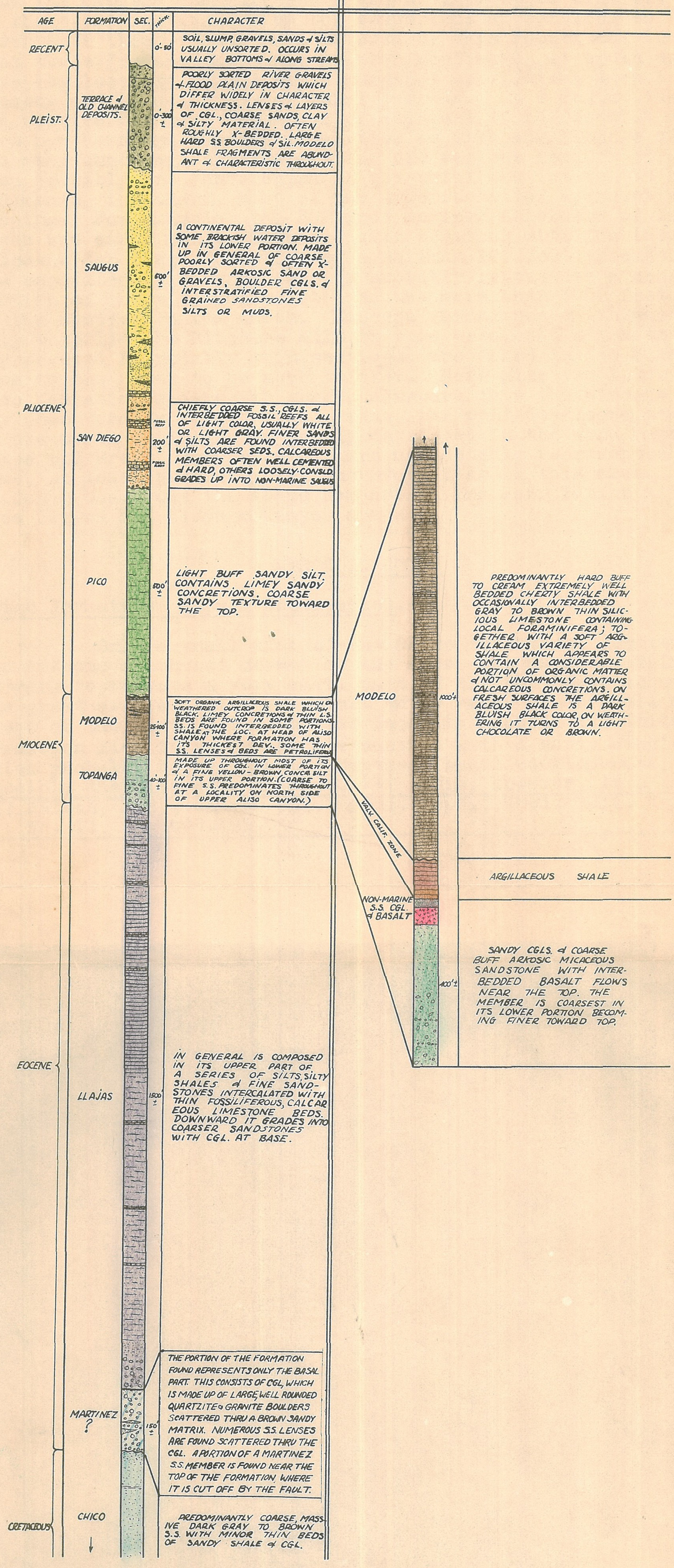
GEOLOGIC CONDITIONS

Stratigraphy.

The rocks of the eastern Santa Susana Mountains are entirely of detrital (sedimentary) origin, with the exception of the Miocene basalt flows found in upper Browns Canyon and the

STRATIGRAPHIC SECTION BELOW SANTA SUSANA THRUST AND NATIVE TO THE AREA

STRATIGRAPHIC SECTION ABOVE SANTA SUSANA THRUST INTRODUCED INTO AREA BY OVERTHRUSTING



area immediately east. These sedimentary rocks range from Upper Cretaceous to Recent.

The most conspicuous fact concerning the stratigraphy of the region is that two distinct types are represented: (1) that "native" to the area, and (2) that above the Santa Susana overthrust plane which has been brought into the area by movement on this fault. The stratigraphy "native" to the area lying below the thrust has much thinner and more poorly developed members. In most places the formations differ lithologically from the Miocene and Pliocene sections introduced from the north by the overthrusting. From the comparison of sections to the north with those in the area covered by this report and the fact that these "native" sections thicken northward, it would seem that the locality mapped was a marginal oscillating area in the Miocene and Pliocene depositional periods. As a result, the area did not receive the same thickness of sediment as represented by such more northern and eastern localities as Pico and Elsmere canyons. The many unconformities separating the various members of the area probably are represented in the thick section to the north by sediments, for there, most of the unconformities apparently are missing. For example, the 500 foot maximum thickness of late lower and early middle Pliocene silt together with the late middle Pliocene San Diego formation of a maximum 100 foot thickness, which are separated by an unconformity probably represents a considerable portion of the time represented by the more than 3000 feet of Pico in the section to the north. Miocene formations which unconformably underlie the Pliocene silt in this area, and which are represented by notably thin sections, are found in the Pico Canyon area to the north to be much thicker. Here also the lower Pliocene Pico formation apparently grades downward into the Miocene without any unconformity represented. Thus, the well-developed sections to the north which are so poorly developed in the area mapped Aliso and Browns canyons area, are undoubtedly represented in time, at least partially, by unconformities in this area. Fossil evidence bears out the above comparison and correlation with the Pico Canyon and Elsmere Canyon areas.

MESOZOIC ROCKS

Chico Formation (Upper Cretaceous).

Only a small area of the Chico formation, located in the extreme southwest corner of the area, was mapped. This Chico terrain represents a very small part of the northeast corner of the great area of Chico sandstone which makes up the bold outcrops of the Simi Hills. At the locality mapped, the Chico formation lies in unconformable contact with a sandy conglomerate which probably represents the Martinez basal conglomerate, or possibly the Simi conglomerate. [1] This, however, is a tentative

(1) Nelson, R.N., Calif. Univ. Publ. Dept., Geol. Bull. Vol 15, No. 11, pp. 400-401.

correlation, for the author did not find any fossil evidence, and the upper contact of this conglomerate at this locality is a fault contact. The Chico formation, whose age has been previously determined by Upper Cretaceous fossil evidence, (2) is predominantly made up of coarse, massive, dark gray to brown sandstone with minor amounts of thin beds of sandy shale and conglomerate.

(2) Kew, W.S.W., U.S. Geol. Survey Bulletin 753, p. 12.

TERTIARY ROCKS

Martinez (lower Eocene)

The Martinez conglomerate mapped is located in the southwest corner of the area, in Aliso Canyon and vicinity, just north and east of the outcrop of Chico formation. It lies unconformably above the Cretaceous and is limited to the north by a fault against which it is in contact with formations ranging from "Llajas" (middle Eocene) in the bottom of Aliso Canyon to San Diego (Pliocene) located on the ridges above. This conglomerate is several hundred feet thick. The boulders in it consist chiefly of quartzites and granites, all of which are large and well-rounded and which are scattered through a brownish colored sandy matrix. Local phases of brown sandstone are found in the conglomerate. A brown sandstone is present at the top of the Martinez, where it is faulted against the Llajas formation. Whether this relatively thin exposure of sandstone represents a part of a distinct member in the Martinez, or whether it is just a sandy phase of the thick basal conglomerate member, was not determined because of the limited lithologic section observed.

No fossils were found in the Martinez conglomerate, and this fact, together with its unconformable relationship with the Chico below and fault contact with the formations above, make its age determination tentative. However, the writer feels that this conglomerate represents that previously described by W. S. W. Kew in his report covering this area, (1) and therefore represents the Martinez basal conglomerate. Kew also suggests that it may be the Simi conglomerate, a Paleocene formation which underlies the Martinez and Santa Susana shales. The fact that only a small part of the whole extent of this member was mapped leaves the true relationships of the member incompletely solved. However, the idea that the member represents the basal Martinez was recently corroborated by a personal communication from W. S. W. Kew, who has mapped the member in its entirety.

(1) Kew, W. S. W., Op. Cit.

Llajas Formation (middle Eocene)

In the area the deposits now known as the Llajas formation were first mapped and described by Kew in his report covering this area, and were included in his Meganos formation. The name Llajas was first applied by J. H. McMasters.[1]

(1) J. H. McMasters, 1933 (Geol. Soc. Am. Bull., Vol. 44, No. 1, pp. 217-218.)

The Llajas formation as mapped in this report is exposed in a north-south strip in the bottom of Aliso Canyon. The formation, in general, is composed in its upper part of a series of silts, silty shales, and fine sandstones intercalated with thin fossiliferous limestone beds. Downward it grades into coarser sandstones, with conglomerate near its base. The lowest basal portion of the Llajas in contact with an older formation was not observed in the limited area mapped. Although faulting of the exposures mapped greatly complicates working out a sequence with certainty, the writer has recognized a number of lithologic members. None of the members were systematically collected. The small incomplete species list after each member merely represents random collecting in the various members, while mapping. In the fauna collected only the more common and characteristic species were identified and listed. The members are as follows:

1. 300'± Olive-brown fine sandy silt. Bedding is thick and poorly developed. The member is abundantly fossiliferous. Species collected and identified are:

   Amaurellina clarki Stewart

   Globularia hannabali Dickerson

   Venericardia (Venericar) hornii (Gabb)

   Crassatella uvasana Conrad

2. 400'± Blue shale. The beds vary in color from blue to bluish-gray to gray. The top of the member is mottled with worm impressions and contains thin limestone glauconitic or micaceous beds. This member is well stratified. Fossils collected were:

   Turritella andersoni Dickerson (Loc. H29)

   Turritella lawsoni Dickerson (Loc. H29)

   Balanophyllia variablis Nomland (Loc. H29)

3. 500-600' Fine sandy silt. This member is greenish-gray to buff or yellowish-brown on weathering and is fine grained micaceous, and poorly bedded. Numerous fossil reefs and ledges are intercalated in the member. Sandstone reefs are found near the top. Fossils collected were:

Gastropods

Amaurellina clarki Stewart (Loc. H28,H26)

Globularia hannabali Dickerson (Loc. H28,H26)

Ectinochilus (Macilentos) macilentus (White)(Loc.H28,H26

Turritella buwaldana Dickerson (Loc. H28)

Conus weaveri Dickerson (Loc. H26)

Gylichnina tantilla Anderson & Hanna (Loc. H28,H26)

Pelecypods

Cardium, sp (Loc.H28)

Corbula complicata Hanna (Loc. H28, H26)

Crassatella uvasana Conrad (Loc. H28)

4. 40-50' Sandstone. This member is medium coarse, has angular grains, a silty matrix, tightly binding calcareous cement, and is characteristically iron stained, giving it a yellowish-brown color. Fossils found in the member from locality H-27 are:

Balanophyllia variablis Nomland

Amaurellina clarki Stewart

Turritella andersoni Dickerson

Solena (Fosolen) columbiana (W. & P.)

Ectinochilus (Macilentos) macilentus (White)

Conus weaveri Dickerson (?)

Glycimeris maccrayi Waring

5. 100'± Conglomerate. This conglomerate is poorly sorted and contains interbedded sandy phases throughout. The pebbles, which are scattered through a sandy matrix, consist chiefly of quartzitic and granitic rocks together with darker pebbles derived from more basic igneous and metamorphic rocks. The pebbles are all fairly well rounded. A few fossils including

Venericardia (Leuroactis) aragonia (A. & H.)

were found in the more sandy phases of the conglomerate.

The only locality in which the Llajas formation was mapped in contact with an older formation, was in the lower part of Aliso Canyon where it was in fault contact with the Martinez conglomerate previously described. The upper contact was widely mapped and in most cases was an angular unconformable one with the overlying Topanga (middle Miocene). In one case, on the northern flank of the Llajas anticline, the Llajas formation was found to be in unconformable contact with the middle Pliocene San Diego formation. Due to these stratigraphic breaks, resulting from faulting and erosion, age determination is dependent, in the limited area mapped, entirely on fossil evidence. The fossils, previously mentioned under the descriptions of the lithologic members of the Llajas, contain many characteristic middle Eocene forms, as: Amaurellina clarki, Globularia hannabali, Ectinochilus (Macilentos) macilentus, Venericardia hornii, Turritella andersoni, Turritella lawsoni, Balanophyllia variablis, etc., thus pointing to middle Eocene age. The combined occurrence of many of these forms in certain of the lithologic members seems to indicate a relationship with the divisions of the nearby Llajas exposures established by Frank Tolman in the Simi Valley area just west of, and contiguous with, this Llajas area. It would seem that a zonal relationship exists between these greatly separated divisions. However, not enough work has been done to be certain that it is not merely a lithologic and faunal facies similarity within the formation.

Topanga formation (middle Miocene).

The Topanga formation mapped by the writer is found exposed in two north-south strips on either side of upper Aliso Canyon where it is found overlying unconformably the previously mentioned Llajas formation. The upper contact with Modelo shale, where exposed, is disconformable.

The lower portion of the formation, throughout most of the exposed area, is represented by a conglomerate, whereas the upper part is made up of a fine, yellow-brown, concretionary sandy silt. The conglomerate member is composed of well-rounded pebbles of granitic, quartzitic, gneissic, and other types rock derived from metamorphic and igneous rocks which are of a much more basic nature than those found in the younger Pliocene conglomerates. The latter have a very acid character. As a result, in exposure, the Topanga conglomerates present a much darker appearance than the distinctive white-colored Pliocene conglomerates of the area. The pebbles are imbedded in a brown sandy matrix. In its lower portion near the unconformable Eocene contact, the conglomerate contains abundant Eocene shale fragments. The conglomerate varies from about 15-50 feet in thickness, although throughout most of its exposure it is about 25 feet thick. The fossil fauna found in the more sandy phase of the conglomerate contains Pecten andersoni - Arnold and Turritella ocoyana - Conrad. The upper sandy silt member contains abundant well-rounded, limy sandstone concretions averaging about 3 inches in diameter.

Several very small indeterminate pelecypods and a gastropod were found in the silt at locality H-20. In examining its micro-fossil content, abundant characteristic middle Miocene foraminifera were found, as:

Uvigerinella californica Cushman, var.

Valvulineria miocenica Cushman, s.s.

Valvulineria californica var. appressa Cushman

Valvulineria depressa Cushman (?)

Nonion costiferum (Cushman)

Nonion incisum (Cushman)

Baggina californica Cushman

The joint occurrence of several characteristic foraminiferal species shows the age of the silt at locality H-14, H-15, H-16 and H-20 to be of uppermost Topanga or upper middle Miocene in age. This silt varies in thickness from about 25 feet to over 75 feet in thickness. It seems to thicken northward, that is, in a direction toward the head of Aliso Canyon.

On the east side of Aliso Canyon, in the upper northern part, Topanga outcrops are partly obscured by soil and slump from the overthrust Modelo formation which makes up the entire upper canyon slopes, and as a result the upper Topanga-Modelo contact was nowhere found. The outcropping Topanga formation at this locality is represented by a fine, buff-colored concretionary sand (containing numerous Pecten andersoni) about 10 feet thick overlain by a 5-foot hard, white sandstone formation which forms a bold ridge. Exposed at fossil locality H-34 a sandy conglomerate and sandstone underlying the Pecten andersoni sand comprises a thickness of about 10 to 15 feet. About 10 feet stratigraphically down-slope at this locality, Eocene shale is encountered. Besides abundant Pecten andersoni, the fine buff-colored concretionary sand at locality H-34 contains crab claws,

Nuculana aff. taphira (Dall), and some small unidentifiable pelecypods. The hard sandstone formation above it was found to contain a very poorly preserved fauna. Some of the species recognized are: Cardium vaqueroensis (?) Arnold, Clementia (Egesta) pertensis (Gabb), Chione sp., Calyptraea filosa Gabb, Pecten andersoni Arnold, Neverita recluziana (Deshayes)(?), Turritella ocoyana Conrad and an undeterminate Venerid. In addition a new species of echinoid was found. Dr. U. S. Grant IV has described this species and named it
This represents the lowest occurrence of this genus yet recorded.

The relationship between the Topanga at this locality and that previously described, and which makes up the greater portion of the Topanga exposed, is not clear, as the interrelated areas are covered by soil and slump.

From a foraminiferal sample section taken across the Topanga-Modelo contact on the west side of Aliso Canyon (Loc. H20, H21), it was possible to determine a marked temporal and stratigraphic break between the Topanga and Modelo, represented by a disconformity. With this disconformable contact above and the angular unconformable contact with the Llajas below, all that is possible to tell of the age of this formation from stratigraphic evidence is that it is older than the Modelo shale (upper Miocene) and younger than the Llajas (middle Eocene). For more exact age determination, fossil evidence must be relied upon. From such index species as Turritella ocoyana, Pecten andersoni, etc., a middle Miocene or Temblor age is indicated. The joint occurrence of certain definite-ranged species of foraminifera point to upper middle Miocene or uppermost Topanga age.

Non-marine Deposits (middle or upper middle Miocene ?)

The non-marine deposits exposed in the heads of Browns and Mormon canyons consist of sandy conglomerates and coarse buff arkosic micaceous sandstones with interbedded basalt flows near the top. In the Mormon Canyon area parts of the sandstone and conglomeratic sandstone have a peculiar bluish-gray color or staining. The very top of the formation in the Browns Canyon area is marked by a medium fine-grained white arkosic sandstone.

These non-marine deposits are limited below by the Santa Susana overthrust fault planes. The lower portion of this non-marine member exposed above the thrust consists of a massive, coarse-grained, brown to buff sandstone with well-rounded metamorphic and igneous pebbles, cobbles, and boulders roughly bedded with, and irregularly scattered through, the sandstone. The metamorphic and igneous types represented in the rock making up the conglomerates strongly suggest rocks similar to the San Gabriel mountain rock types at the source. This conglomeratic sandstone in the lower portion grades upward into a brown to buff sandstone which lacks the igneous and metamorphic cobbles and boulders of the lower part. The sandstone is variable in grain size. It is, however, finer than the sandy portions of the lower member and consists of about 55% quartz, 30% feldspar and 15% ferro-magnesian minerals. (The predominant femic is biotite.) The whole is fairly loosely consolidated and seems to be cemented by kaolin. The upper and lower portions together comprise about 300 feet of sediment. Basalt immediately overlies these sandy conglomerates and sandstones both in Browns and Mormon canyons. In Mormon Canyon the basalt flows are intebedded with sandstone, whereas in Browns Canyon the basalt flows seem to be all one unit. The basalt is quite vesicular with abundant amygdaloidal zeolites in the vesicular flow-tops. The dark color of the basalt was in most outcrops changed to a red color due to the almost complete oxidation of the ferro-magnesian minerals. The thickness of the basalt in Browns Canyon is about 50'± . In Mormon Canyon the basalt is somewhat thicker, which with the interbedded basalt, probably reaches about 100' in thickness. The white sandstone overlying the basalt in Browns Canyon averages about 40-50'± . The sandstone lying above the uppermost basalt in Mormon Canyon did not possess this distinctive white color. Contacts with the formation overlying this non-marine member were obscured in Mormon Canyon. In Browns Canyon, however, a zone of Valvulineria californica argillaceous shale was found lying conformably above the non-marine member, thus dating the formation as older than lower Monterey, and thus probably of about Topanga age. A list of some of the species found in association with the Valvulineria californica zone, and which characterizes the lower part of the type Monterey formation, is as follows:

Valvulineria californica	Cushman
Valvulineria californica	Cushman var. appressa Cushman
Dentalina obliqua	(Linne')
Siphogenerina reedi	Cushman (?)
Baggina californica	Cushman
Bolivina impricata	Cushman
Pullinia miocenica	Cushman
Nonion costiferum	Cushman

Lack of fossil evidence in the non-marine formation, itself, and the fact that its lower stratigraphic relationship is not known because the lower limits of the formation are cut off by the Santa Susana thrust make positive correlation very risky. The above Topanga correlation is a tentative one.

Modelo Formation (upper Miocene)

The Modelo formation, with the exception of the Aliso Canyon exposures, is only found above the Santa Susana thrust fault, where it makes up the higher ridges of the eastern Santa Susana Mountains. This thick section above the Santa Susana thrust plane, or planes, has been introduced into the area by overthrusting. Its exposures cover more territory than any of the other formations in this part of the Santa Susana Mountains. The thin section of Modelo found below the thrust plane in Aliso Canyon is "native" to the area and differs greatly in lithology from the overthrust Modelo section. In either case, the Modelo usually presents rounded slopes supporting a growth of grass, burr sage, and wild walnut trees.

The portion of the extensive area mapped lying above the Santa Susana thrust is made up, for the most part, of a hard, buff to cream-colored, extremely well-bedded cherty shale with occasionally interbedded gray to brown, thin silicious limestones with local occurrences of foraminifera, together with a soft argillaceous variety of shale which appears to contain a considerable percentage of organic matter. On fresh surfaces the argillaceous shale is dark bluish-gray to black in color, and on weathering turns a light chocolate brown. Calcareous concretions are not uncommon in this shale. The Modelo shale is at many localities highly contorted, which is undoubtedly due to its position above the thrust and to the very incompetent nature of the shale itself. The total thickness is about 1000 feet, in the area mapped, of this Modelo shale.

Correlation of this area of Modelo above the Santa Susana Fault was made on the basis of lithology, stratigraphic position and micro-fauna, as no mega-fossils were found in this particular Modelo section. Lithologic similarity of the formation described with that of Modelo localities described by other writers is apparent. The area mapped did not include the upper limits of the Modelo section. However, the formation was shown to be no older than uppermost Miocene by the fact that lower Monterey (Valvulineria californica zone) shales were mapped disconformably underlying the Modelo in the upper Browns Canyon area and the area immediately east. In addition to the above mentioned age criteria, final age correlation was made by foraminiferal evidence. The occurrence together of several characteristic species in the microfauna collected from limestone beds intercalated in the Modelo shale decisively shows the formation to be of upper Miocene age. (See end of this section for faunal list).

The Modelo formation exposed in Aliso Canyon, below the Santa Susana thrust, is made up almost entirely of a soft, organic, argillaceous shale, which on a weathered outcrop is a light chocolate-brown color. An exception to this is found at the head of Aliso Canyon where the shale is interbedded with layers and lenses of white and gray to brown sandstones which commonly vary from one inch to 25 feet in thickness. Many of these beds and lenses are petroliferous, probably having derived their oil from the enveloping organic shales. In this same vicinity near the head of Aliso Canyon, in a deeply cut east-west tributary, there is a sandstone member of much greater thickness than any of the previously mentioned Modelo sandstone beds. This member is about 150 feet thick. Its upper contact is a normal contact with Modelo argillaceous, chocolate-brown shale carrying a typical Modelo foraminiferal assemblage (See end of this section for faunal list) which shows the shale to represent a stratigraphic horizon well up within the Modelo. At the contact sandstone and shale are interbedded. Below, the thick sandstone member lies unconformably over the Llajas (middle Eocene). The sandstone, which is angular, arkosic, and massive, is usually brown in color. It varies from a true sandstone to a pebbly conglomeratic sandstone. Petrographically, it is similar to other Modelo sandstones. The sandstone is unfossiliferous. Age determination of this particular member obviously depends only on its stratigraphic relation to the conformably overlying Modelo shale, which represents a horizon well up in the Modelo. Positive correlation as Modelo from this meager evidence is obviously not possible. Its stratigraphic relations and petrographic content, however, strongly suggest a Modelo age correlation.

Another exception to the usually argillaceous shale found below the thrust is found in the bluffs below Brugher's Ranch, where the top of the argillaceous Modelo shale is marked by a limestone bed. This limestone bed, at its top, is broken up and presents an unconformable contact to the lower Pliocene formation immediately above it. The organic shale at this locality contains abundant concretions which are elongated in the direction of the bedding. The exposures along the bluff in many cases are fairly fresh and the organic Modelo shale is seen to be of a very dark blue or black color.

The Modelo shale of Aliso Canyon is found least developed in the southern part of the canyon mapped. It thickens northward (up-canyon). This is best shown on the west side of the canyon where the Modelo shale increases from about 25 feet in thickness in the southern portion of the canyon mapped to over 100 feet in thickness to the north, where it is exposed in the bluff below the Brugher Ranch.

A long dike-like area of this argillaceous organic Modelo shale trends in a northwest-southeast direction and crosses the lower part of Aliso Canyon. This dike-like outcrop is bounded by two parallel high angle reverse faults and is remarkable for its uniform thickness. Shearing and spreading out of shale between the two faults is indicated on examining the dike-like mass. This so-called dike is further discussed under the topic <u>Structure</u>.

The age of the brown-colored argillaceous Modelo shale, which is the common lithologic representative of the Modelo formation below the Santa Susana thrust, is indicated by both stratigraphic and foraminiferal evidence. The shale lies unconformably above the Topanga (middle Miocene) formation and unconformably below the Pico (middle and lower Pliocene). An age between middle Miocene and lower Pliocene is thus indicated. The joint occurrence of certain forams of definite ranges found associated in the micro-fauna collected from this argillaceous shale show it to be of upper Miocene age as is indicated by its stratigraphic position.

A faunal list characterizing the upper and lower Modelo formation of this area, together with the locality numbers from which the fauna was collected is as follows:

Upper Modelo
(Locality B3 and D2)

Uvigerina hootsi Rankin
Uvigerina subperegrina Cushman and Kleinpell
Bolivina hughesi Cushman
Pulvinulinella Cf. *P. bradyana* Cushman
Frondicularia advena Cushman

Lower Modelo (Diatomaceous)
(Locality H13, H21 and at Modelo locality above the)
(non-marine sandstone at the head of Browns Canyon)

Pulvinulinella gyroidinaformis Cushman and Goudkoff
Baggina californica Cushman
Gyroidina soldanii var. Cf. *rotundimargo* R.E. and K.C. Stewart
Valvulineria grandis Cushman and Galliher
Virgulina californiensis Cushman var.
Bulimina Cf. *B. Uvigerinaformis* Cushman and Kleinpell
Uvigerina hootsi Rankin

Two different species of mega-fossils were also found. (Locality J1, just south of H21) One species was *Nassarius* sp., of which the writer collected about 25 or 30 specimens, all from a hard, limy concretion found in the Modelo shale. The second species collected was represented by the imprint of both valves of a *Tellina* species.

Previous workers in this area have mapped the Topanga silt, Modelo organic shale, and lower Pliocene sandy silt series in the Aliso Canyon vicinity together as the Modelo formation. This paper indicates the first separation into these formations. The west side of Aliso Canyon in this area shows the divided section, together with the overlying San Diego (middle Pliocene) above, and the Topanga conglomerate and Llajas formation below, all well exposed. It includes the Miocene-Pliocene foraminiferal section; the fossil reef containing abundant strongloocentrotus (new species), abundant large sharks teeth, and numerous characteristic and well preserved middle Pliocene fossil species; the fossiliferous Llajas formation; and last, but not least, the stratigraphy.

Pico Formation (lower middle Pliocene)

The two best exposures of this formation in the area mapped are to be found in the Aliso Canyon area, one on the west side of Aliso Canyon just south of Brugher's Ranch, the other on the east side of Aliso Canyon about two miles south and a little east of the Brugher Ranch. This Pliocene silt in the eastern part of the area is probably nowhere present except in a small exposure just north of fossil locality H11. This is due to the fact that it lies beneath the Santa Susana thrust plane. Only the younger San Diego and Saugus (late upper Pliocene and lower Pleistocene) formations are exposed south of the thrust. This lower middle Pliocene formation is made up of a light buff colored sandy silt, throughout which calcareous concretions are common. The formation changes from a fine silty texture in its lower part to a sandy texture in its upper portions. That the change in texture is due to a shallowing of the water in which the sediment was deposited is shown by the fact that deeper water or neritic zone forms near the base of the formation, such as Uvigerina peregerina Cushman var., Cassidulina translucens Cushman, Globigerina sp., give way progressively upward to shallower water depth zone faunas. Near the top of the section such characteristic shallow water forms as Elphidium hughesi, Discorbis sp., etc., are found. Where best exposed, the formation is about 350' thick. An average thickness is about 200'.

The Pico formation is unconformably underlain by the Modelo organic argillaceous shale of Aliso Canyon, previously described. This unconformity is well shown by the foraminiferal and stratigraphic gap found on making a section of the silts and shales exposed on the west side of Aliso Canyon below the Brugher Ranch. Stratigraphically above, the bedding of the Pico formation is unconformable with the overlying low-dipping San Diego formation. Thus the stratigraphic position of the Pico sandy silt indicates that the formation is younger than upper Miocene (Modelo) and older than upper middle Pliocene (San Diego). The mega- and micro-fossil content of the silt indicate it was deposited in the later part of early Pliocene and early part of mid-Pliocene. According to W. H. Holman, of the Standard Oil Company paleontological department at Los Angeles, the micro-fauna is similar to the fauna of the middle part of the Pico formation as developed in the type Pico section in Pico Canyon, and to the fauna of the silts in Elsmere Canyon. The 400-foot maximum thickness of lower Pliocene silt in the area mapped represents in time equivalence about the lower middle portion of the section at the type locality of the Pico in Pico Canyon. There is no evidence that Pliocene as old as the basal Pico of Elsmere and Pico Canyons is represented. The time equivalent of the upper part of the Pico formation at the Pico Canyon and Elsmere Canyon areas is represented in this area by the San Diego formation and the unconformity that separates the San Diego and the lower middle Pico silt.

In view of the age equivalence as established by stratigraphic position and faunal similarity, the writer suggests tentatively the use of the formational name Pico for the lower Pliocene sediments as mapped and separated in this report.

A typical example of a micro- and mega-fossil section across the portion of the Pico formation as represented in this area is found on page 19a.

<u>San Diego Formation</u> (upper middle Pliocene)

The San Diego formation outcrops at intervals from east to west across the entire breadth of the area. It is well exposed in the Browns and Mormon canyons areas in the east and caps the older formations along the Aliso Canyon area in the west. Good exposures are also to be found immediately south of the east-west road leading from Browns Canyon to Aliso Canyon. Much of the San Diego formation is covered by older Miocene formations through the action of the Santa Susana overthrust fault.

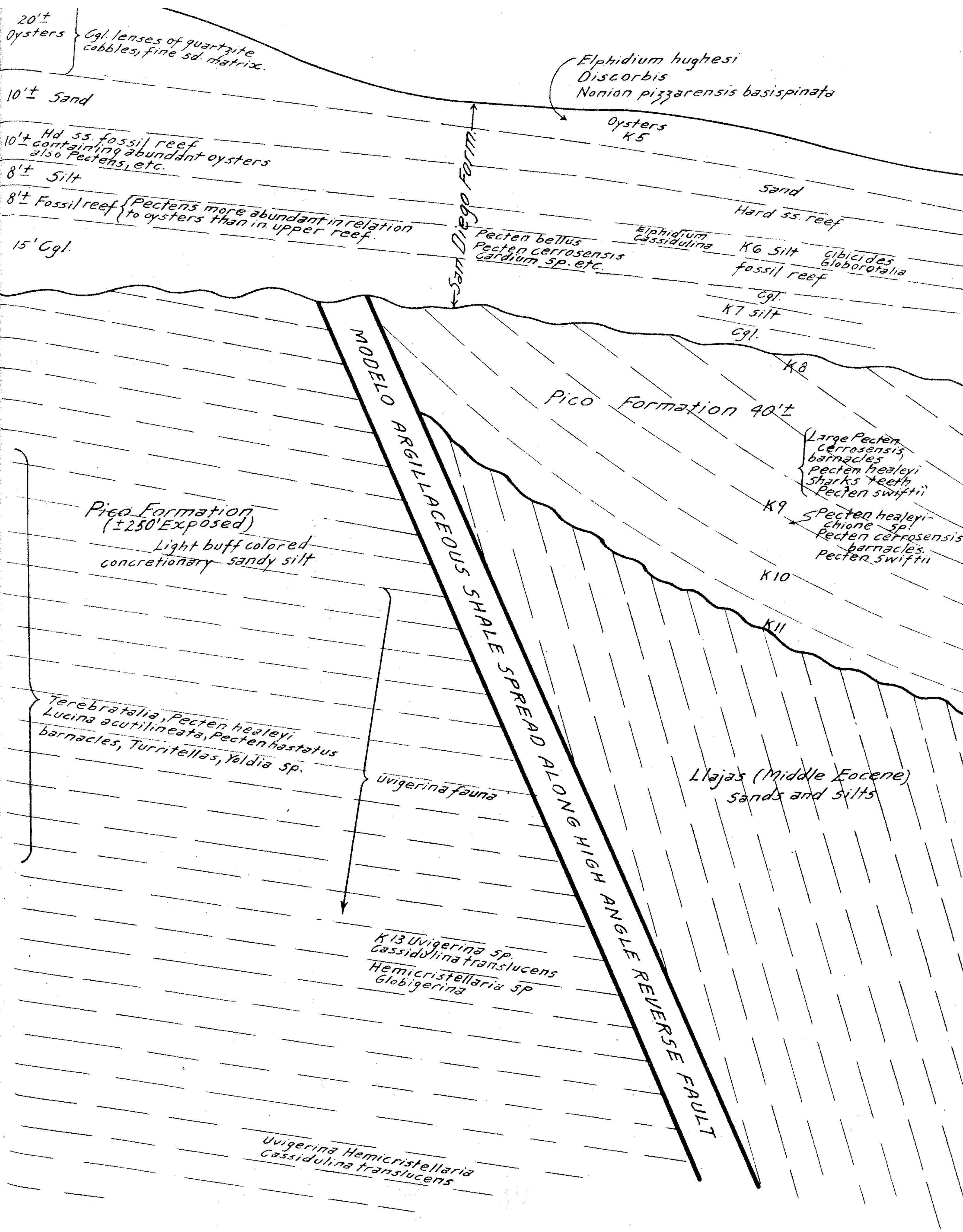
In general, the San Diego formation is made up of coarse sandstones and conglomerates all of which are usually white or light gray in color. The light color is due to the fact that the rock material making up the sandstone and conglomerates is all of an acid character. Thick fossil reefs are also characteristic. Finer sands and silts are interbedded with these coarser sandstones, conglomerates, and fossil reefs. The more fossiliferous or calcareous members of the formation are commonly well-cemented and hard, other members are loosely consolidated.

In the localities of its thickest development, Browns and Mormon canyons, the San Diego is cut off by the Santa Susana thrust, and as a result its full thickness is hidden, even so, the formation reaches a thickness at these adjoining localities of over 200 feet. The outcrops in Browns Canyon are connected with those of the Mormon Canyon area immediately eastward though they are covered by a large slumped area of Modelo formation. The San Diego formation in these areas consists of fine and coarse sands and conglomerates with fossils scattered throughout. Local concentration of fossil material forms coquina reefs.

In the east branch of Aliso Canyon the San Diego formation caps the mountain tops where it does not exceed 100 feet. The formation overlies with angular unconformity the lower Pliocene silt at the locality where it caps the eastern side of Aliso Canyon in the southern part of the canyon as mapped. It comprises, together with the unconformably underlying Pliocene silts, the lithologic units represented in the sketch and estimated section shown on the following page.

A list of the micro-fauna characteristic of the lower sandy phase of the Pico is as follows:

Uvigerina peregina Cushman var.
Hemicristellaria sp.
Cassidulina translucens Cushman and Hughes
Cassidulina sp.
Cibicides cf. _illingi_ (Nuttall) var. A.
Valvulineria araucana (d'Orbigny
Robulus sp.
Bolivina spissa Cushman
Bolivina interjuncta Cushman



SKETCH OF PICO-SAN DIEGO SECTION ON
EAST SIDE ALISO CANYON SOUTH OF HOLT RANCH
W. R. CABEEN MAY, 1939

The sketched section, which is just a visual estimate of thicknesses represented, shows the stratigraphy on both the south and north side of the high angle reverse fault, which cuts the exposed section at this locality. Along this fault (or two closely parallel faults) a sliver of Modelo shale has been injected with uniform thickness both laterally and horizontally. The dike-like mass of Modelo shale averages between 20 and 40 feet in thickness. The faulting (which will be more completely described under Structure), took place before San Diego time. This is shown by the fact that the fault does not cut the San Diego formation lying unconformably above the Pico silts, but has been truncated with the silts at this unconformity. On the south or upthrust side of the high angle reverse fault only a small fraction of the original thickness of the Pliocene silt is to be found unconformably overlying the Llajas, Eocene. Undoubtedly the explanation is that the section on this side of the fault, being raised by the fault movement, was greatly eroded before the San Diego was deposited unconformably above it. On the north side of the fault a much thicker section is found, (see section given above) as this was the side which moved down along the high angle reverse fault and as a result was not subjected to erosion comparable to that on the uplifted south side.

At the locality on the west side of Aliso Canyon, just south of the Brugher Ranch, the San Diego consists of a fossil reef containing in addition to the many characteristic species (listed on page 23) found throughout the San Diego, abundant specimens of an echinoid, Strongylocentrotus, sp. These echinoids are found in a fossil zone in about the middle of the reef, where they occur in abundance closely packed together in a matrix of their own spines. This echinoid zone is about 3 feet thick. The form was described and named for the writer by Dr. U. S. Grant IV of the University of California at Los Angeles. This new species represents the oldest occurrence of the genus in the Tertiary of California. The formation at this locality is about 40 feet thick. The base is a thin conglomerate fossil reef composed of pholad-bored limestone fragments derived from the Modelo formation. This bed is characteristically found near the base of the San Diego throughout the area. Another echinoid new to the late middle Pliocene was found at locality K12, just east of Aliso Canyon and about a half mile below the Holt Ranch. The horizon in which it occurs is near the base of the San Diego formation at about the same horizon as that containing Strongylocentrotus sp., mentioned above. The latter echinoid was identified as Astrodapsis fernandoensis Pack. Previous to this discovery this form had only been found in the Elsmere Canyon area where it was a marker for the basal Pliocene beds of this area. This species is very abundant at locality H12 and is associated with P. bellus and other pelecypods.

Lithology and fossil content suggests, in general, a shallow warm water environment for the deposition of the San Diego formation. The sands and conglomerates in the upper portion, with their associated fauna, are typically littoral zone or beach deposits.

Foraminifera found in fine grained phases of the San Diego interbedded with fossiliferous reefs near the top of the formation, are such shallow water forms as Elphidium, cf. granulosum and Nonion, cf. scapha which also indicate a very shallow water environment. The lower portion of the San Diego formation, however, undoubtedly represents a relatively deeper water fauna than the upper portion, as indicated by the deeper water forms such as the brachiopods, Chlamys hastatus (Sowerby), etc., which occur toward the base of the formation. A section across the San Diego formation, taken just west of the Logan Ranch, shows a gradation in depth zone faunas from these deeper water forms to faunas containing shallower water affinities, as oysters, razor clams, etc. These faunas in the younger beds above, give way to a sand bed containing an abundance of Dendraster. This is very likely a beach deposit. Above this is found a marl containing fresh water gastropods. Stratigraphically above, are cross-bedded sands and conglomerates, all of which were very clean. Stratigraphically above these clean sands and conglomerates, more typically non-marine and terrestrial aspects were noted in the sediments, e.g., the sands and conglomerates contained more mud, were more poorly sorted, more angular, and contained mud balls. This gradation from marine San Diego to non-marine deposits marks the gradational contact between the marine San Diego and overlying non-marine Saugus.

Although the San Diego grades upward into the Saugus, it lies with an angular unconformity above the Pico silt (lower Pliocene) formation. The impossibility of definitely dating the non-marine Saugus in this area makes the use of the stratigraphic position of the San Diego of little value. The most that can be said positively from stratigraphic evidence is that the San Diego formation is younger than the late lower and early middle Pliocene (Pico silt).

Abundant fossil evidence, however, makes it possible to date the formation much more closely. The mega-fossil assemblage is characteristic of that found at the type locality of the San Diego formation. The San Diego affinities of the fossils from this locality were first recognized by Arnold. (1) W. P. Woodring's

(1) Arnold, Ralph, New Characteristic Species of Fossil Molluscs from the Oil-Bearing Tertiary Formations of Southern Calif., Proc. U.S. Nat. Mus., Vol 32, p. 527, 1907

paper on Pliocene Deposits North of Simi Valley(2), further

(2) W. P. Woodring, California Acad. Sci. Proc., 4th ser., Vol. 14, No. 18, pp. 57-64, 1930

elucidated this idea, and pointed out, after giving his fossil list from the San Diego of this region, that the fauna listed to date represented only a small fraction of the fauna living when these beds were laid down. Woodring believed that solution in the coarse-grained sediments from which he and previous collectors, had collected their specimens was responsible for the absence of the host of molluscs with less durable aragonite shells than those of calcite shells found, such as brachiopods, echinoids, oysters, and pectens, and epitonids. The writer in mapping found two localities (one in particular - Loc. H13) which represented a finer grained and more silty member of the San Diego formation. From these two localities new additions to the San Diego fauna of the Santa Susana Mountains were collected and identified. The necessary time to collect fully these two localities was not available, and as a result, further collecting would probably yield more species not before recorded from this area. On the following pages - 23 and 24 -, with their locality numbers which are recorded on the map accompanying this report, are listed the San Diego species collected throughout the area.

(x* - indicates that the form predominates
at the locality)

LOCALITIES

PELECYPODS	J2	J3	N1	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12
Ostrea vespertina Conrad	x	x						x*	x				x
Pecten bellus hemphilli Dall	x	x			x					x	x		x
Pecten Cerrosensis Gabb	x	x								x	x		
Pecten healeyi Arnold	x	x									x		
Pecten stearnsii Dall	x		x								x		
Pecten purpuratus Lamarck var.											x		
Chlamys opuntia (Dall)		x									x		
Chlamys hastatus (Sowerby)	x												
Cardita ventricosa Gould						x	x						
Cardium													
Lucina nuttallii Conrad													
Lucina acutilineata Conrad												x*	x
Laevicardium cerastoderma corbis (Martyn)?												x	
Transennella sp.						x	x						
Apolymetis biangulata (Carpenter)		x					x						x
Mytilus sp.			x										
Schizothaerus nuttallii Conrad													x
Tivela stultorum (Mawe)													x
Macoma secta (Conrad)													x
Solen sicarius Gould (?)					x								x
Valsella fornicata (Carpenter)(?)		x											
Venerupsis (Callithaca) tenerrima Carpenter		x											
Trachycardium quadrigenerium Conrad var. fernandoensis		x											
Saxidomus nuttallii Conrad		x											x
Monia macroschisma (Deshayes)			x										
Lithophaga, sp.													

	LOCALITIES													
	J2	J3	N1	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	K13
GASTROPODS														
Opalia varicostata Stearns	x													
Crepidula princeps Conrad					x									
Turritella jewetti Carpenter			x											
Turritella cooperi Carpenter			x											
Conus californica Hinds						x	x						x	
Neverita recluziana (Deshayes)					x								x	
Nassarius perpingus Hinds (?)		x				x	x							x
Cantharus humerosus Gabb													x	
Cantharus fortis Carpenter													x	
Astraea (Pomaulax) gradata (G. & G.)													x	
ECHINOIDS														
Dendraster diegoensis Kew	x	x		x*	x								x (few)	
Astrodapsis fernandoensis Pack														x
"Strongylocentrotus", sp.	x													
BRACHIOPODS														
Dallinella occidentalis (Dall) (includes both varieties - the strongly plicate one and that with no folds and very weak ribs)		x									x			
BRYOZOA		X								X				

In addition to the above mega-fossil list indicating an affinity to the type San Diego, and thus a probably middle Pliocene age (middle Pliocene when considering the Pliocene-Pleistocene boundary in the sense of Grant and Gale), W.H. Holman and the writer collected a foraminiferal section across a part of the San Diego formation. The foraminifera collected also indicated an upper middle Pliocene age for the formation. The section was taken in a steep north-south canyon just west of the Logan Ranch, which is located in Browns Canyon at the corner where the Browns Canyon road turns west towards Aliso Canyon. The lithology, as well as the micro- and mega-fossil content collected along this section, indicates, as previously mentioned, a transition from a very shallow water environment in the upper portion of the formation to a deeper one toward the base. A faunal list from the successive lithologic facies going from younger to older is as follows:

Upper Dendraster Sand facies

Pattelina sp.
Nonion pizzarensis Berry var. *basispinata auctores*
Discorbis campanulata Galloway and Wissler. *Discorbis* sp.
Bulimina marginata Brady
Elphidium cf. *hughesi* Cushman and Grant
Quinqueloculina sp.

"San Diego" fmn. marly facies

Angulogerina sp.
Elphidium crispum (Linne') auctores
Cassidulina limbata Cushman and Hughes
C. tortuosa " " "
C. californica " " "
C. quadrata " " "
Cibicides cf. *illingi* (Nuttall)
C. tenuimargo (Brady)
C. conoideus Galloway and Wissler
C. lobatus (d'Orbigny)

<u>Orbulina universa</u> d'Orbigny
<u>Planulina</u> cf. <u>ariminensis</u> d'Orbigny
<u>Globorotalia</u> sp.
<u>Discorbis campanulata</u> (Galloway and Wissler)
<u>Guadryina arenaria</u> Galloway and Wissler
<u>Guttulina</u> cf. <u>austriaca</u> (d'Orbigny)
<u>Textularia</u> 3 species
<u>Globigerina bulloides</u> d'Orbigny
<u>Polymorphina elongata</u> Galloway and Wissler
<u>Bulimina marginata</u> d'Orbigny
<u>Bryozoa</u> several species
<u>Ostracods</u> " "

<u>Saugus</u> (upper Pliocene and probably lower Pleistocene)

The Saugus formation is best exposed in that part of Browns Canyon below the Logan Ranch. It does not occur in the western portion of the area mapped. The formation as a whole is made up, in general, of coarse, poorly sorted arkosic sands or gravels, boulder conglomerates and interstratified fine grained sandstones, silts, or muds. The greater part of the formation is continental, with some local brackish water deposits in its lower portion. The terrestrial origin of the Saugus is indicated by its poor sorting, cross bedding, angular appearance of sand grains, arkosic nature of the sands, angularity of many of the conglomerate pebbles, scoured and filled channels, the presence of mud balls, and lack of marine fossils. The nature of the Saugus deposits with their abrupt changing lithology suggests that the Saugus formation, at least during the early part of its deposition in the area mapped, was deposited on a flood plain near the sea by a meandering river. Hills of moderate relief must have been near the basin of deposition to supply the abundant, coarse deposits included in the Saugus. Brackish water areas suggest minor depressions near an old coast line or the encroachment of the marginal seas in the earlier transitional stage (from San Diego marine to Saugus non-marine) of the Saugus. Although the lower limits of the formation are not exposed in Browns Canyon, a thickness of over 500 feet is estimated. Visits to the region east of the area mapped have shown that the formation becomes coarser and thicker in this direction, which suggests the San Gabriel Mountain mass as a source area of the sediments. Examination of the pebbles in this formation shows them to be derived from granodiorite,monzonite, diorite, aplite, acid pegmatites, quartzites, peridotites, gabbro and hornblende schist. All of these hard, acid metamorphic and igneous rocks are found in San Gabriel Mountains.

As no fossils were found by the writer, stratigraphic position alone must be relied on for age determination. In the Browns Canyon area the Saugus overlies the San Diego by a normal transition from marine to brackish water and non-marine sediments. The Saugus is, in turn, overlain by terrace material which has been uplifted and dissected since deposition. Exact age determination of this terrace material, with the present evidence, is impossible.

However, the writer believes it to be as old as the upper Pleistocene, as indicated by its deformation and resultant dissection. Then it may be surmised from the stratigraphic position of the Saugus that it is younger than upper middle Pliocene (San Diego formation) and older than upper Pleistocene. Thus an estimate of the age of the Saugus formation in this area would be that it is upper Pliocene and possibly lower Pleistocene. The transition period from San Diego to Saugus must have taken place in early upper Pliocene, that is, if we put the San Diego deposition in upper middle Pliocene time, as do Grant and Gale with their idea of the Pliocene-Pleistocene boundary.

<u>Quaternary Terrace and Channel Deposits</u> (middle or upper Pleistocene)

The Quaternary deposits are found mostly in the eastern two-thirds of the area mapped. In this part of the area they are found as irregular scattered patches and remnants. In some places they are nearly flat-lying, while in others they have been notably disturbed by folding. The deposits are, in general, made up of poorly-sorted river gravels and flood plain deposits which differ widely in their character and thickness. There are some lenses and layers of conglomerates, coarse sands, clay, and silty material. The deposits are often very roughly cross bedded. Fragments of siliceous Modelo shale are common to abundant in the deposits. The boulders of the conglomerates frequently consist of large, hard sandstone which were derived from the Eocene sandstones present to the west.

There are three particularly interesting occurrences of this Quaternary material. (1) In the area immediately west of the S. S. Holt Ranch the Quaternary deposits are found with a general northward dip. They are overridden at this locality by the Santa Susana thrust fault. This indicates that the thrusting along the Santa Susana is a very recent movement. The material at this locality seems to occupy a depression in the Pleistocene surface. The materials of the deposit consist of large lenses of Eocene sandstone boulders, sands, and silts. (2) Immediately west of the above locality and apparently part of the same deposit due to overthrusting, this Quaternary terrestrial conglomerate material is found sandwiched in between San Diego white sandstone and pebbly conglomerate above and Miocene deposits below. The San Diego formation which has overridden the terrestrial conglomerate is itself overridden by Modelo shale. To explain this reversed stratigraphic order, at least two thrust planes must exist, one above the Quaternary to explain the San Diego stratigraphically above it, and one above the San Diego to explain the Modelo overlying it. The thrust between the San Diego and Modelo is particularly well shown at this locality. (3) In the Browns Canyon area, about one-fourth mile above the Logan Ranch and immediately north of a large San Diego fossil reef, there is found what appears to be an old, east-west, deeply cut, and steep-banked river channel filled with Quaternary deposits. An interesting fact is that it trends in a direction at right angles to the present main drainage system. The stream in the bottom of Browns Canyon has apparently barely cut through the bottom of the deposits, showing a thickness for them of over 300 feet. These deposits consist of large sandstone boulders and fragments of siliceous Modelo shale, all mixed together in an earthy matrix.

As there is no fossil evidence of age, stratigraphic position is the only clue to the age of these deposits. The Quaternary deposits overlie unconformably all earlier deposits of the area, including the Saugus (upper Pliocene and possibly lower Pleistocene). The deposits must be, therefore, at least as young as middle or upper Pleistocene. The fact that the Santa Susana fault has in several localities overthrust the Quaternary formation dates the formation as pre-faulting. This faulting must have been no later than late Pleistocene. Thus we may say that these deposits represent a lithologic equivalence of about middle Pleistocene time.

In the upper part of Browns Canyon the writer mapped some terrace deposits which have been dissected by recent uplift. The deposits lack the abundant large, hard sandstone boulders so characteristic of the previously described Quaternary deposits, and are made of an earthy matrix with abundant silicious Modelo shale fragments scattered throughout. These terrace deposits appear to be younger than the previously mentioned Quaternary deposits. The writer suggests questionable upper Pleistocene age for them.

STRUCTURE

General Statement

Close and overturned folding, overthrusting and the high degree of faulting show the eastern Santa Susana Mountain area to be one which has been subjected to very intense structural deformation. In general, the series of folds mapped more or less parallel each other and are overturned southward, or away from the direction of thrusting. The overthrusting, where stresses were very great, is either related to or subsequent to the Pleistocene folding. Numerous unconformities and buried faults testify to activity in this region since at least early Tertiary time. Faulting, folding and overthrusting of Pleistocene deposits, and even a slight folding of the Santa Susana fault thrust plane, itself, (in upper Browns Canyon) bear evidence to the recency of diastrophic movements. Undoubtedly the area is still geologically active with the process of orogeny still going on.

Santa Susana Overthrust

The most important structural feature in the area is the Santa Susana overthrust. This fault extends, in a northwesterly-southeasterly direction, across the entire length of the Santa Susana Mountains. The trace of the fault sharply defines a distinct break in topography. In the area immediately south of the fault, the topography is subdued, whereas to the north it is a steep-sloped topography formed by the Santa Susana overthrusting.

In general, along the exposed thrust contact, upper middle Pliocene (San Diego) sandstone is found overridden by upper Miocene Modelo shale. However, in Browns Canyon there is a thick non-marine sandstone and conglomerate (middle Miocene), which has been thrust over lower Monterey shale (Valvulineria californica zone). This shale, itself, in the western part of the head of Browns Canyon, is thrust over Modelo shale, which, in turn, is thrust over the San Diego Pliocene. In Mormon Canyon non-marine sandstone, (Topanga in age) overlain by lower Monterey and Modelo shale, is thrust over San Diego Pliocene. At one locality a slice of lower Monterey shale was found separating the non-marine sandstone from the underlying San Diego. This imbricate structure, which was found at several localities, will be discussed further in succeeding paragraphs.

The very incompetent Modelo shales, upon being thrust over the more competent Pliocene sandstones, are found to be highly folded, contorted, and broken. Both the non-marine (Topanga equivalent in age) sandstones and the San Diego sandstones are very little affected by crumpling; they, for the most part, in their contact along the thrust, have been broken and granulated by the shearing. The shearing has affected the sandstones for no more than 50 feet on either side of the fault. In the case of the incompetent Modelo shale lying above the thrust, this does not hold. These shales are folded, crumpled, and broken for great distances above the thrust. A good exposure of this contortion in the Modelo shales above the thrust is to be found at the head of Aliso Canyon.

Sulphurous springs, tufa deposits, and oil seeps are common along the trace of the fault marking its course. In upper Mormon Canyon, the actual exposure of the fault trace is shown excellently at several localities. Here a zone about 5 feet thick, of black petroliferous fault gouge containing crystals of sulphur, gypsum, and calcite, is found. Such thickness of gouge is unusual and may be explained by the fact that competent non-marine sandstone has been thrust over competent San Diego sandstone. The usual contact between San Diego sandstone below and Modelo shale above, is found to have a very thin gouge, in most places only a few inches. This gouge contact is usually marked by a massive black substance which gives the appearance of a streak of organic material. The dark color is due probably to manganese staining. The explanation of such a thin gouge zone always occurring along the contact between sandstone below and Modelo shale above, is to be found probably in the incompetency of the Modelo shale. Any friction-producing stresses are taken up in this very incompetent shale by contortion and flowage. In the Mormon Canyon occurrence there is competent sandstone against competent sandstone, such a relief of friction is not possible, and as a result the friction produces much thicker gouge zones.

Relief of stress along more than one thrust plane, thus shoving one sheet or slice of rock over another and giving an overlapping shingle-like or imbricate structure, is found along the Santa Susana thrust. This imbricate structure is shown both at a locality just north of the east-west road from Browns Canyon to Aliso Canyon and in the upper Browns Canyon area. In the former occurrence, Modelo shale is thrust over San Diego Pliocene which, in turn, is thrust over a Pleistocene terrestrial conglomerate which was lying on an erosion surface of older Miocene and Pliocene rocks. The overriding of this terrestrial conglomerate by the thrust plate not only dates the latest movement or overthrusting as not earlier than upper Pleistocene, but also together with the very thin zones of brecciation and gouge along the thrust indicates that this thrusting did not take place at a very great depth. This would seem to be reasonable because if the thrusting occurred at a considerable depth, with a consequent large overburden and great friction, it would seem that the fault surface should show marked evidence of differential movements. However, if thrusting immediately followed and was the end result of intense folding, the great thickness of sediments involved in the folding, point to a deeper movement for the thrusting. The great thickness of San Diego and Saugus beds folded, eroded, and bevelled off to their Quaternary erosion depth, bear evidence that the horizon representing this land surface was quite deeply buried at the time when the folding and culminating overthrusting took place. Now when we consider that this bevelled surface with later Pleistocene sediments deposited on it was overridden, folding and thrusting seem quite unrelated in time. The explanation to the above paradox probably is to be found in the fact that the thrusting, developed as we see it today, represents quite a long period of time. Overthrusting probably did follow intense folding, but not in the particular area mapped. The first development of the overthrusting probably took place somewhere to the northward at considerable depth and probably with a much steeper angle to the thrust plane than has the thrust plane as mapped at the surface. The fact that the overthrust sediments of equivalent age differ entirely in type of sediment, represent different depositional environment, and differ greatly in stratigraphic section, from those found below the thrust and native to the area, points to the conclusion that the overthrust material has been transported along the thrust for some distance from the north. During the long interval of time necessary for the overthrusting to develop in the north and be shoved southward into the area mapped, erosion cut into and bevelled the structures developed during the period of intense folding. Upon this eroded surface the late Pleistocene terrestrial sediments were deposited, and it was not until all of this had taken place that the southward moving overthrust plate or plates passed over, for a short distance, some of these Pleistocene terrestrial sediments. This complete picture, involving a considerable period of time, thus explains that the early development of the thrust might have developed very likely at considerable depth, but that the later movement of the fault, as represented in the area mapped, probably was quite surficial in character.

The common dip of the thrust, as indicated by its surface trace, ranges from about 12 to 15 degrees to the north, or even flatter. Such a dip is well shown in upper Browns Canyon. However, strange to say, wherever the dip was actually taken on the fault, it was usually more than 15 degrees. In some local cases the dip is much steeper. An example of this is at a locality about a mile northwest of the Logan Ranch, where the thrust contact between Modelo shale above and San Diego sandstone is nearly vertical. This, however, is very localized and probably due to the jamming of the softer argillaceous Modelo shale against the hard buttress-like obstruction of San Diego sandstone found at this locality.

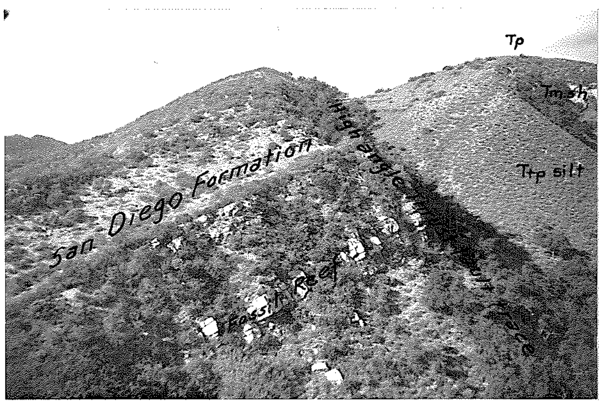
Other Faults

Several types and ages of faulting other than the Santa Susana overthrust are to be found in the area mapped. A most interesting high angle reverse fault, second only in size to the Santa Susana thrust, is located in the southwest part of the area mapped. Throughout the length of the fault as mapped a thin dike-like mass of soft argillaceous Modelo shale occurs along its trace. Due to the fact that the dike-like mass of Modelo shale is limited on either side by a thrust fault plane, this fault might be considered by some as two closely parallel reverse faults. The Modelo shale is very uniform in thickness, both laterally and vertically. This uniformity in thickness is due very likely to the plastic spreading quality of this shale which under heat and pressure distributed itself more or less evenly along the fault. (See pictures) In tracing this Modelo "dike" from ridges into canyons, it is seen to cut and be in contact with formations ranging from Eocene to lower Pliocene in age. The Modelo dike does not cut the San Diego formation, but is truncated at the unconformity between lower Pliocene concretionary silts (Pico formation) and the overlying San Diego formation. This dates the fault as pre- San Diego (upper middle Pliocene). The plane of the reverse fault strikes N. 50° W. and dips about 67 degrees southwest. Sediments to the north and below this high angle thrust seem very little disturbed by the overthrusting. Those overthrusted or lying above the thrust plane, however, seem in most places to be affected somewhat by drag. Very little gouge, however, was found along this thrust, the partial explanation for which is probably the lubricational qualities of this soft Modelo shale in cutting down friction. The Modelo shale along the thrust is everywhere lined up with laminations parallel to the thrust planes limiting it. (See picture)

How this Modelo shale got along this thrust plane is an interesting and speculative question. It is possible that a sliver of Modelo shale was included in the overthrusting and by pressure and further shearing action was spread more or less evenly between the overriding and overridden plane.

Another fault of importance and which is probably, as indicated by its trace, a rather high angle reverse fault, is to be found northeast of the "Modelo-dike" reverse fault previously mentioned. This high angle reverse fault (?), dipping to the south runs in

High angle reverse fault Modelo "dike" exposed
west of Aliso Canyon.



High angle reverse fault along prominent anticline just south
and east of the S.S. Holt Ranch.

a more or less east-west direction, and parallels and faults the south limb of the large anticlinal structure of this vicinity. The large, hard, massive fossiliferous sandstone beds of the San Diego lie on the upthrown south side of the fault. Miocene silts and shales are found in the downthrown or overridden north side of the fault. This fault is younger than the pre-San Diego "Modelo-dike" fault, because it not only cuts the San Diego formation, but is intersected by and does not cross the "Modelo-dike" fault. The stresses which produced overthrusting along this high angle fault of hard massive San Diego sandstones over Miocene silts and shales is probably related to the stresses that produced the anticlinal structure with which the faulting is associated.

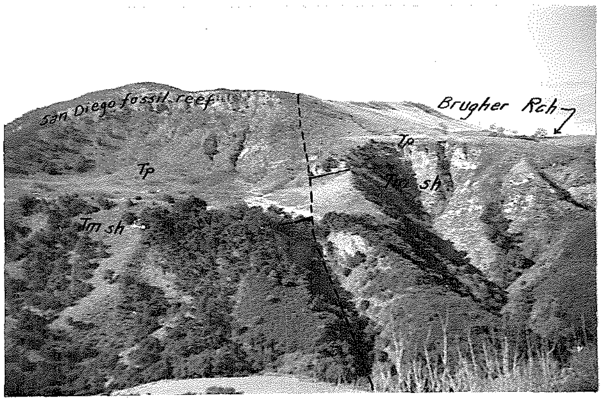
Just south of the above mentioned fault and just north of the "Modelo-dike" fault, an area of complicated disturbance and stratigraphic break is probably to be explained by a fault. The actual plane of the fault was not seen, although its trace was marked by broken and sheared rock. The most conclusive evidence pointing to faulting was the fact that on the north side of the canyon at this locality a thick section of south dipping San Diego formation was faced on the south side of the canyon by a great thickness of older south dipping Pico silts (lower Pliocene). Faulting seems to be the only solution to this stratigraphic break. At this same locality on the north side of the canyon an area of San Diego sandstone is found dipping northward apparently into the great mass of southward dipping San Diego which outcrops nearly as a dip slope. The appearance of this San Diego mass with reversed dip suggests slumping off of the hard San Diego sandstone dip slope as an explanation. Drag along the previously suggested fault might be another explanation or contributing factor.

Two other faults of interest and importance in the Aliso Canyon area are: (1) the northwest-southeast trending (normal ?) fault which parallels the Llajas anticline in the northern part of the area. This fault has Miocene sediments on the southwestern side in contact with Eocene sediments on the upthrown northeastern side. (2) the nearly east-west trending fault located in the southern part of Aliso Canyon which brings a Martinez conglomerate on its south side against the Llajas-Pliocene section found to the north of the fault. Southward this Martinez conglomerate lies with unconformable contact on the Chico series of sandstones.

Normal faulting younger than the overthrusting is to be found in uppermost Aliso Canyon. Older Miocene formations which had been thrust over younger Pliocene material, have since been faulted down below the thrust plane where they are now exposed. Because of the fact that contacts are much obscured by slump and soil at this

Faulted Santa Susana thrust plane at head of Aliso Canyon.

Modelo shale faulted against Pico silt along high angle reverse fault paralleling anticlinal structure just south of the Holt Ranch.



View across Aliso Canyon from the Holt Ranch west toward the Brugher Ranch. The fossil reef indicated is the one which contains Strongylocentrotus, sp. The throw of the fault is about 100 feet.

locality the normal faulted material seems to have no relation to the previous overthrusting. Inversion of formations is, however, suggestive of this fact.

Other normal faulting, older than the period of overthrusting, is to be found in Aliso Canyon. The oldest normal fault is that found in Aliso Canyon immediately west of the Volt Ranch. Here the basal Llajas conglomerate is faulted against Llajas blue shale. The fault is pre-Topanga, as it does not cut the unconformably overlying Topanga sediments.

Two faults which are younger than the Topanga, and cut it, are found immediately north of the previously mentioned older fault. Small scale drag folding is excellently shown along the southernmost of these two faults, where it cuts the steep western side of Aliso Canyon. These two faults are responsible for cutting off the northward extension of the Topanga formation outcrops on the east side of Aliso Canyon. The formation, which is upthrown on the north side against the Topanga, is of Eocene age. Because of concealment by soil and slumping at this faulted locality the sediments lying above the Topanga and Eocene exposures are obscured, and the amount of throw due to faulting cannot be discerned. North of this locality on the east side of Aliso Canyon, Modelo slumping has entirely obscured outcrops. However, near the head of Aliso Canyon a deep east-west tributary gully has exposed a considerable thickness of Modelo sandstone unconformably overlying Eocene sediments. Thus the explanation of a stratigraphic elimination of the Topanga in this tributary area is totally obscured by the previously mentioned big slump and soil covering which obscures the relation between this Modelo sandstone locality and the Topanga-Eocene faulted locality previously mentioned. This leaves an interesting and important question unanswered. It is possible that very careful and detailed work might in the future reveal the explanation.

Many smaller normal and reverse faults were observed during mapping. Many of these, however, were of small caliber representing very small movements, and not mapped. Their importance lies in their abundance and that they suggest and add to the evidence of the intense orogeny the region has undergone.

Folding

The series of folds mapped are, in general, parallel, and in a broad way follow the trend of the deformed Santa Susana Mountains and, the strike of the overthrust which is the dominant structural feature of the area. Some of the folds are tightly compressed and overturned, as is illustrated by the anticline immediately north of the Logan Ranch in Browns Canyon. The axial planes of the folds are overturned southward as would be expected from the southerly direction of thrusting. At the Browns Canyon locality of anticlinal overturning, the outcropping end of a south dipping limb of an east-west anticline is to be found overturned and dipping northward. The same limb at the bottom of the canyon is dipping southward. Just east of Browns Canyon, along the limb of this same east-west anticline, overriding of the upturned eroded edge of San Diego sandstone has caused a reversal of dip simulating overturned folding. The reversal of dip was probably caused by a revolution of the entire block-like thickness, rather than reversal of dip by bending of the upturned edges of the anticlinal limb by overriding. This is indicated by the thick section of upturned edges of sediments in the reversal, the relation of this reversed section to the surrounding anticlinal structure, and the fact that the great thickness is not broken and crushed as it would be if overturned by bending of the thick, brittle mass so near the earth's surface. The mechanics of such a block becoming broken off and rotated is something not uncommon to overthrusting, but is difficult to describe. The writer wonders if perhaps the overturning of the east side of Browns Canyon, previously mentioned, does not owe at least part of its overturning to overriding of the upturned eroded edges of the limb of the anticline rather than wholly to actual overturning of the fold at depth during the folding of the San Diego sandstone. That overturning did occur along this anticline during folding is, however, a fact and is well shown not only in Browns Canyon but in Mormon Canyon as well. This is shown by the constant much steeper dips on the south limb in both canyons.

Anticlinal structure in the area is best shown and exposed in Browns, Mormon and Aliso Canyons. The most prominent anticlinal structure in the Browns Canyon area, just mentioned in discussing overturning, is located immediately north of the Logan Ranch. The south limb, in particular, of this anticline is well exposed by erosion, and being extremely fossiliferous affords very good collecting. This structure is probably a continuous extension of the large southernmost anticline so well shown in Aliso Canyon. Northward and up canyon from this larger Browns Canyon anticline, another anticlinal structure and an intervening syncline were mapped. Due to the fact that, except in the narrow deeper part of the canyon, the structures are surrounded and covered by overthrust areas, this syncline and anticline are not prominently exposed. Minor crinkling to a small degree on the more important structures of Browns Canyon has been noted.

A dry hole was drilled just below the Santa Susana thrust on the north flank of the northernmost anticline in Browns Canyon. A well was also drilled approximately on the Browns Canyon syncline. This well started in beds of San Diego age (upper middle Pliocene) and probably reached rocks of middle Eocene age from which it is reported to have produced 1,5000,000 cubic feet of gas a day.(1)

(1) W.S.W. Kew, U.S. Geo. Survey Bulletin 753, p. 185, 1924.

Both Browns Canyon wells were drilled by Dr. F. C. Melton, of the Placienta Oil Company.

A broad, well developed anticline was mapped by the writer in Mormon Canyon. This anticline is undoubtedly the eastern extension of the large, well developed anticline just above the Logan Ranch in Browns Canyon. Between Browns and Mormon Canyons a large Modelo slump masks the thrust fault trace and structure in the underlying sediments. As a result positive correlation between the fold of Browns and of Aliso Canyons cannot be made.

Folding exposed and mapped in the Aliso Canyon area consists of two large, well developed anticlines, two synclines and a small anticline of minor importance. The Llajas anticline which is one of the large anticlinal structures of the Aliso Canyon area, was first mapped and named by W.S.W. Kew.(2) It is to be found near the north

(2) W.S.W. Kew op. cit.

end of Aliso Canyon. The anticline strikes in a northwest-southeast direction, and plunges both east and west from a point just east of the head of Aliso Canyon. The Llajas anticline at the Aliso Canyon locality, is fairly symmetrical and has dips as high as 42 degrees on both flanks. The extension westward from Aliso Canyon was not mapped and included in the area of this report. Erosion along this anticline has exposed a section of Pliocene, Miocene and Eocene sediments. This is especially true of the Llajas (Eocene), for the best exposures in the area mapped by the writer were found along this structure.

Encouraged by oil seeps from an oil sand in the Llajas formation is Las Llajas Canyon and the fact that the Tapo Oil field located to the northwest of the area was producing from sands lower in this same middle Eocene formation, the General Petroleum Corporation in 1919 drilled a test well at the head of Aliso Canyon on the Llajas anticline known as the Joughins No. 1.(1) No oil sands

(1) Kew, W.S.W. op. Cit., p. 184

were reached, though several gas pockets were encountered. This well started in Llajas strata stratigraphically below the outcropping oil sands in Las Llajas Canyon and is not on the highest part of the fold which plunges east and west from a point west of the location of the well. The more favored locality on the high point west of the plunging fold has not been tested. A well was drilled above the Santa Susana thrust in Modelo shale, approximately in line with the Llajas anticline which in trending eastward from the vicinity of Aliso Canyon passes beneath the thrust. Data on this old well was not obtainable.

The large southernmost anticline mapped, which runs in a nearly east-west direction just south of the S. S. Holt Ranch, shows exposed in Aliso Canyon a section through its axis, revealing the folded sediments from Pliocene to Eocene. An angular unconformity is shown separating the Llajas (middle Eocene) and the Topanga (middle Miocene). The Eocene dips are in some places nearly vertical in the anticlinal zone, whereas the unconformity overlying Miocene and Pliocene sediments have a relatively much gentler dip. Such an angular unconformity indicates an earlier pre-Miocene period of folding. That the earlier pre-Miocene folding was influential in guiding the later folding represented, is not to be doubted. Willis[2]

(2) Willis, Bailey, and Willis, Robin, Geologic Structure, McGraw-Hill, New York, Third Edition, 1934

has shown experimentally that small departures of dip of even one degree are very influential in guiding later folding, since they determine points of weakness. This fold, as previously mentioned, is probably a westward extension of the prominent anticlinal structure in Browns Canyon just above the Logan Ranch.

Between the southernmost fold mapped in Aliso Canyon and the Llajas anticline to the north, two synclinesand an anticline were mapped. These are of less interest and importance. The complementary syncline mapped, the axis of which is immediately north of the southernmost prominent fold mentioned above and which passes under the Holt Ranch buildings strange to say, was drilled for oil. The writer was unable to secure well log data and other information on the drilling, which would be of interest. The operators apparently thought they were on the anticlinal structure immediately to the south, not realizing the close folding in this region. This syncline involves sediments ranging from Eocene to Pliocene. The small anticline and syncline immediately north of this syncline seem to be chiefly confined to the Eocene.