THE GEOLOGY OF
THE UPPER LAS LLAJAS CANYON AREA
SANTA SUSANA MOUNTAINS
CALIFORNIA

A thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Geology

by

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ILLUSTRATIONS

ABSTRACT

The Upper Las Llajas Canyon Area, California is some six and one-half miles long and three and one-half miles wide. It is situated five to twelve miles northwest of the town of Chatsworth. It gives a representative picture of the geology of the California Coast Ranges.

The main Santa Susana Range here trends almost due west. It is cut by steep-sided, youthful canyons which generally produce a relief of some five hundred feet. The highest point in the area is 3741 feet in elevation; the greatest relief, however, is not over 2500 feet.

The dominant rocks are, east-west-striking, faulted and folded sediments of Tertiary age; some late Mesozoic and Quaternary sediments also appear. The oldest rocks in the area, a series of sandstones and intercalated shales, comprise a part of the Chico formation. The portion mapped attains a thickness of more than 750 feet. Apparently unconformably above the Cretaceous lies a section of 350 feet of very coarse massive ferruginous conglomerates of lower Eocene Martinez age. The Martinez seems to grade into the middle Eocene Llajas formation. The Llajas consists of a series of fossiliferous shales, silts, sandstones, and black limestones which crop out over a large portion of the area south of the Santa Susana thrust zone. In the western portion of the area the Sespe formation appears and is composed of variegated

sands and silts, possibly varying in age from upper Eocene to lower Miocene. The Sespe lies disconformably on the Llajas formation and wedges out to the east. Sediments, ranging in age from Pliocene to middle Miocene, overlie the middle Eocene with pronounced angular unconformity. Of these, the lowermost formation, the Topanga, consists of a basal fossiliferous conglomerate some 50 feet thick overlain by 100 feet of fossiliferous sandy silts. The uppermost member of the Topanga is a zone of silt from 25 to 100 feet thick characterized by the foraminifera species, *Valvulineria californica* Cushman. The upper Modelo diatmites overlie this zone in places with possible slight angular discordance. The average thickness of the Modelo is 200 feet.

North of the Santa Susana fault zone, a thick series of upper Miocene shales, sandstones, and grits, which have apparently been pushed into the area by overthrusting, crop out.

In most localities above the Modelo diatomite, and generally in unconformable relationship with it, are a series of fossiliferous sandy silts some 250 feet thick and of lower middle Pliocene Pico age. Unconformably above the Pico lie upper middle Pliocene sediments which become nonmarine upward in the section and grade into the Pleistocene (?) Saugus sands and gravels. The whole series exposed here is over 1150 feet thick. At least two ages of alluvial deposits were mapped.

The main structural feature in the area is the northward-dipping Santa Susana thrust fault which became active in the Pleistocene epoch. The thrust zone itself is, as the name implies, not one clean-cut fault but a zone of roughly parallel faults forming a somewhat braided pattern. Most of the faults are rather steep-angled, northward dips from 30 to 70 degrees being recorded and the average being around 50 degrees. The total displacement of this zone is not known but is at least several thousand feet. The strata along the front of the overthrust block are in many places overturned. Numerous strike-slip faults, trending normal to the strike of the Santa Susana thrust zone appear to have offset the structures in the block itself and also those in front of the overthrust mass including the Quaternary alluvial deposits in places as much as 3000 feet. The area to the south of the Santa Susana fault zone is faulted and folded but not to the degree of the region to the north.

The topographic features suggest that the region owes most of its present relief to uplift by faulting and folding in the Pleistocene epoch. The presence of terraces and inner gorges in several of the main canyons as well as the courses of the main streams indicates an erosional history that is far from simple. The relatively older topography, found south of the overthrust zone, and the younger topography appearing in the overthrust block itself, corroborate the geologic evidence indicating late movement along the Santa Susana thrust zone.

INTRODUCTION

PURPOSE OF THE INVESTIGATION

This work was undertaken by the author for several reasons. First, because of some previous experience in the region about Sunland which is a few miles to the east his interest was aroused concerning the nature of the stratigraphy and the geologic structure of the Southern Coast Range Region in general. He desired to become further acquainted with these features through the detailed study of a specific area. Secondly, an opportunity presented itself to have the cooperation of the Standard Oil Company of California in a detailed study of the Upper Las Llajas Canyon Area. Thirdly, a report like this could be used as a partial fulfillment of the requirements for a degree of Master of Science in geology at the California Institute of Technology.

The actual geologic mapping was done by the writer during the summer of 1939. The area considered in this manuscript lies some six to ten miles northwest of the town of Chatsworth, California.

METHOD OF INVESTIGATION

The field procedure consisted of mapping the geology of the region on aerial survey photographs which had a scale of approximately one inch to fifteen hundred feet. These were used as base maps. For that portion of the area within Los Angeles County the U. S. Geological Survey topographic map of the Pico Quadrangle was found to be of some use. In constructing structure sections (Plate 2 in pocket on back cover) the Santa Susana Quadrangle was also helpful. However, its small scale restricted its value.

In order that a better idea of the geology of the entire area be obtained the aerial photographs were mounted together in a mosaic. The only drawback to this scheme was that, in certain cases, the same points on two aerial photos were shifted in relation to each other. Most seriously distorted areas were arranged to lie where the difficulty would not be a problem.

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to Professors J. P. Buwalda and F. D. Bode of the California Institute of Technology for their helpful advice and criticism. Thanks are due Professor U. S. Grant IV, of the University of California at Los Angeles, for his aid in identifying many of the megascopic fossils. Several men who are associated with the Standard Oil Company of California rendered valuable aid. Dr. W. S. W. Kew gave much helpful advice. The micropaleontological help so

obligingly given the writer by Mr. W. H. Holman and Mr. H. L. Driver was of inestimable value. Finally, the author wishes to express his deep indebtedness to Mr. J. P. Bailey of the same company for his guidance both in the office and in the field.

PREVIOUS GEOLOGICAL WORK IN THE REGION OF THIS INVESTIGATION

Before the turn of the twentieth century nothing worthy of note had been published concerning the Santa Susana Mountains or the region immediately around. Bulletin 309 of the U. S. Geological Survey published in 1907 contained a discussion of the petroleum resources of this area (Eldridge, 1907, pp. 1-101). Two pertinent papers were published seven years later by the Division of the Geological Sciences of the University of California. One dealt with the stratigraphy of the Fernando Group in a locality a few miles to the northeast (English, 1914, pp. 204-219). The other discussed the paleontology of the Martinez formation in general including that portion found in the Santa Susana Mountains. (Dickerson, 1914, pp. 61-180.) Soon afterward a paper by Kew (1919, pp. 323-349) appeared. Kew's paper dealt with the oil resources of the Simi Valley, and covers a portion of the area studied by the writer. Six years later, another paper by Kew entitled "Geologic Formations of a Part of Southern California and Their

Correlation" was published (Kew, 1923, pp. 411-420). In it the Topanga formation was named and described.

The stratigraphy of the Fernando Group in Ventura County was discussed by Waterfall (1929, pp. 71-92) toward the end of the twenties. In 1930 a brief paper appeared in the proceedings of the California Academy of Sciences which did little more than list the Pliocene fossils found by several field parties of the California Institute of Technology in the northeast side of the Simi Valley (Woodring, 1930, pp. 57-64).

Later, the Geological Society of America published an abstract by J. H. McMasters (1933, pp. 217-218) which suggested the name for the Llajas formation and subdivided it. According to their paper in 1934, Stipp and Tolman (1934, p. 79) believed that this formation was divisible into at least six mapable members. Cushman and McMasters were the co-authors of a paper which was published two years later describing the Eocene foraminifera of the Llajas formation (Cushman, 1936, pp. 497-517).

In June 1939 a Master's Thesis prepared by W. R. Cabeen and submitted to the Division of the Geological Sciences of the California Institute of Technology described an area immediately to the east of that studied by the writer.

GENERAL GEOGRAPHY

The Upper Las Llajas Canyon Area lies in a portion of the Southern California Coast Ranges (sometimes referred to as the Transverse Ranges or the Los Angeles Ranges). The Santa Susana Range has an approximate east-west trend. It is only one of several mountains which are oriented in the same manner.

To the east, on the other side of the San Fernando Pass, lie the San Gabriels. Westward is Oak Ridge which has no marked eastern boundary. Southward, from east to west, lie the San Fernando Valley, the Simi Hills, and the Simi Valley. To the north is the valley of the Santa Clara River.

The Santa Susana Range is some fifty miles long and thirty miles wide. Although it rises to a maximum height of 3741 feet, it is not as high nor as rugged as the San Gabriels. However, it does stand above Oak Ridge whose highest elevation does not reach much over 3000 feet. The Santa Susana Range might be described as a dissected highland, composed of Tertiary rocks for the most part, in the stage of late youth. The main relief and elevation are not due to differential erosion but to uplift accompanied by folding and faulting.

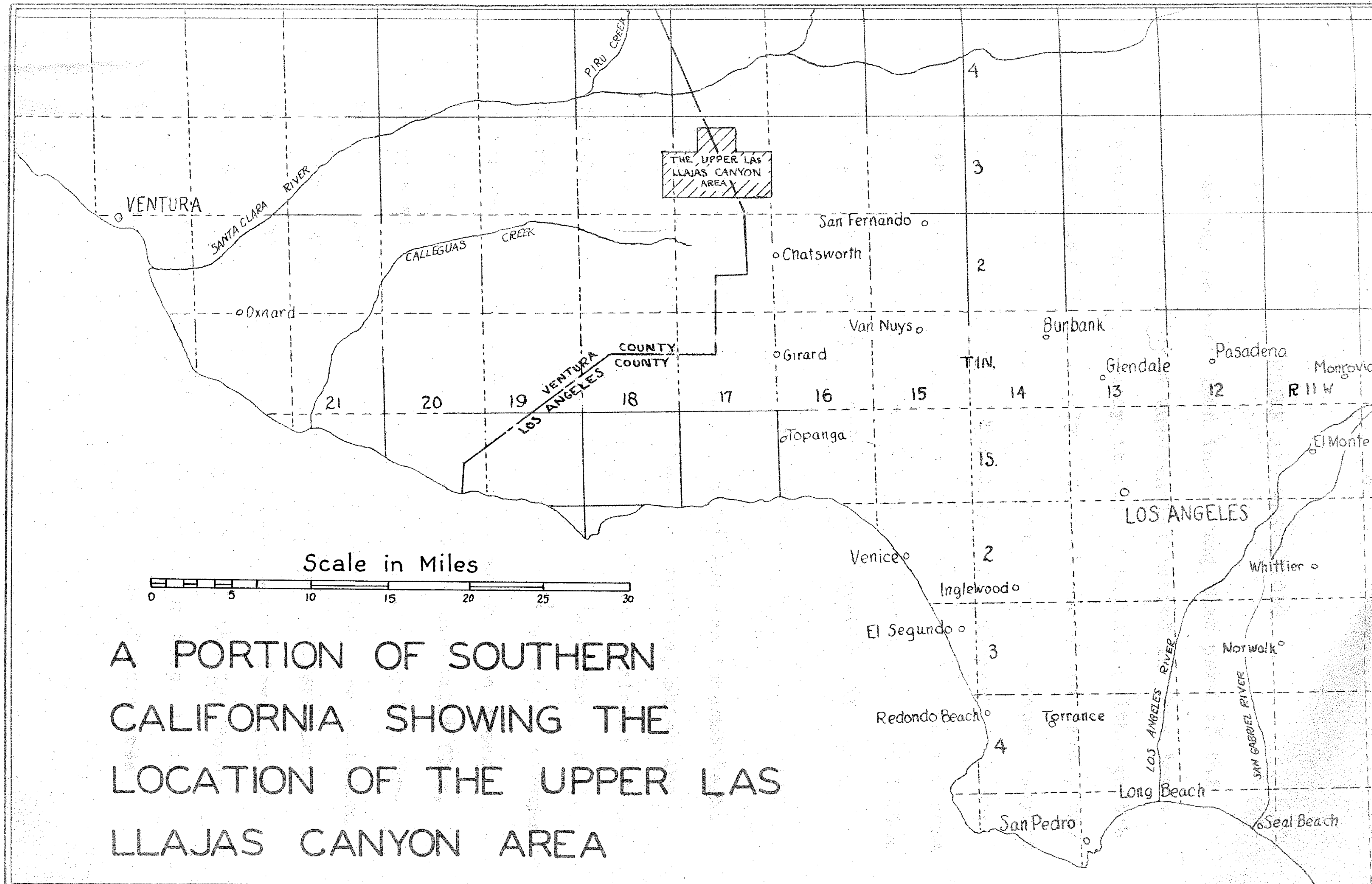
LOCATION OF THE AREA MAPPED

The area covered in this investigation consists of an east-west strip lying approximately between the 34° 18' and 34° 22' parallels of latitude some six and one-half miles long and on the average three and one-half miles wide. It is, as shown in Plate 3, approximately seven miles northwest of the town of Chatsworth and lies for the most part on the south slopes of the Santa Susana Mountains. Browns and Oil Canyons form its eastern and western boundaries respectively.

Cattle ranching is the main industry here. Grassy slopes formed over the Modelo shales offer excellent forage for cattle. No producing oil wells have been discovered in this area. Several abandoned wells exist in the vicinity of Aliso and Oil Canyons. Some of those in the latter locality have in previous years produced small quantities of petroleum.

ACCESSIBILITY OF THE AREA

Los Angeles and many of its suburbs are within two hours' driving distance of the area mapped. However, some parts of the region are very difficult to reach. The main highways are, of course, excellent but the roads linking this "back country" with main avenues of transportation are only fair. Many parts, particularly the north and south-central portions, could not be reached by automobile (due in part to an absence of roads and in part to the presence of locked gates on fire roads penetrating the areas). The steep cliffs, and the dense brush, found in several parts render travel by foot almost impossible.



A PORTION OF SOUTHERN CALIFORNIA SHOWING THE LOCATION OF THE UPPER LAS LLAJAS CANYON AREA

RELIEF AND ELEVATIONS

As may be seen upon inspecting that part of the Pico and Santa Susana Quadrangles mapped in this investigation, the topography is fairly rugged. Although the highest elevation is only 3741 feet above sea level, the relief is pronounced. Everywhere steep, V-shaped canyons cut into the Tertiary formations. The deepest does not exceed five hundred feet on the average and most are somewhat less. The lowest point in the region is around 2500 feet. The average, though, is more nearly 500 feet.

DRAINAGE

All of the streams in the region are intermittent. In the dry summer months, numerous springs, which are found in the canyons, may produce a small trickle for a few feet before the water is absorbed into the ground. During the wet winter months, some of the larger streams carry relatively large volumes of water. The creeks found to the south of the crest of the mountains flow, in general, southward into either the Simi or San Fernando Valley. There, the water seeps into the alluvium.

Both the Simi and the San Fernando Valleys have exterior drainage but little if any water flows out of them either in the Los Angeles River or the Las Posas River except in the wet months and, even then, it is doubtful if much water from the streams of this area reaches them. Much of the precipitation which falls is diverted into reservoirs and is stored for irrigation purposes. The Santa Clara River Valley, to the north, receives some drainage from this region.

CLIMATE AND VEGETATION

The Upper Las Llajas Canyon Area is located in a semi-arid region. The mean annual rainfall averages between fifteen and twenty inches, most of which falls during the winter months.

The temperature is fairly moderate in winter. Elevation determines to some extent differences in temperature. Summer temperatures of over one hundred degrees are not uncommon. However, the low humidity and cool breezes and fogs from the ocean moderate the climate somewhat.

The location of various types of vegetation is determined to a marked degree by soils. Of course, the water supply is also influential. It is worthwhile noting that northward-facing slopes and stream valleys usually possess denser growth.

The sandy soils derived from the Saugus, Chico, and Modelo sandstones are covered with luxuriant growths of chaparral. The thicker loamy soils of the Pico formation support white sage; the more clayey soils of the Modelo shales support various grasses and live-oak and walnut trees. The soils found in areas underlain by Eocene rocks are also covered with chaparral. In certain areas, particularly in the Devil's Canyon region, the prolific growth of mesquite, manzanita, and other varieties of chaparral are well-nigh impenetrable. Also the bottoms of several of the canyons are covered with dense masses of poison oak intertwined with a variety of bushes.

ROCK EXPOSURES

In areas underlain by all formations but the Modelo shales good outcrops may be obtained. Canyon walls and road-cuts furnish abundant exposures in most cases. However, in shale areas large-scale slumping and creep has taken place and rather deep soils are present. In these localities good exposures are rare and trustworthy attitudes are not frequently encountered.

The numerous excellent outcrops afforded by the fire roads recently constructed throughout much of the area were a distinct aid to the writer. Cuts in the road west of Sulfur Canyon enable one to see the various faults which are so abundant in the vicinity. Probably if as good exposures were obtainable in several other localities a better idea of the structure might be obtained.

STRATIGRAPHY

GENERAL STATEMENT

The rocks exposed in the area mapped are all of sedimentary origin and range in age from upper Cretaceous to Recent. The Cretaceous Chico formation is entirely limited to the Simi Hills. All of the rest of the area is composed of younger rocks. An excellent Tertiary section is exposed and comprises the following formations: the Martinez formation (lower Eocene), the Llajas formation (upper Eocene), the Sespe formation (upper Eocene to lower Miocene ?), the Topanga formation (middle Miocene), the Modelo formation (upper Miocene), the Pico formation (lower middle Pliocene), the San Diego formation (late middle Pliocene), the Saugus formation (upper Pliocene and probably lower Pleistocene), Pleistocene terrace deposits, and Recent alluvial deposits.

One salient fact stands out above all others concerning the lithology and areal distribution of these formations: Two distinct sections, which differ widely in thickness and lithology, occur in the area mapped. One has been called the "Thick Section" and the other the "Thin Section." The former has been pushed into the region by overthrusting. It crops out north of the Santa Susana thrust fault zone. The Modelo formation in the Thick Section is composed of cherty shales, coarse brown sandstones, and dark organic shales. Calculated from structure sections

COLUMNAR SECTION

Scale, 1" = 1000'

THE THIN SECTION

Period	Formation name	Symbol	Thickness in Feet.	Character of Rocks.
QUARTERNARY	Terrace deposits, alluvium	Qt Qal	0 – 150	Sand, gravel, clay. Terrace deposits characterized by Modelo chert fragments.
PLIOCENE	Saugus	Ts	900+	Terrestrial sands and gravels Well-washed In places well-stratified and light-colored Loosely consolidated.
PLIOCENE	San Diego	Tsd	100 – 250	A calcareous formation composed of a basal, calcareous-cemented cgl., fossil-reefs, and calcareous sands. Grades upward into the Saugus.
PLIOCENE	Pico	Tp	200 – 300	Buff, sandy, marine silt with interbedded ss. in upper portions.
MIOCENE	Modelo	Tmd	150 – 200	Buff-colored diatomite weathering to light grey color. At top a cherty member.
MIOCENE	Valv. californica Zone		25 – 200'	Highest phase a sh. or silt containing Valvulanaria californica.
MIOCENE	Topanga	Ttp	0 – 150	Buff-colored sandy silt. Marine. Well-cemented, fossiliferous cg.
OLIGOCENE (?)	Sespe	Tsp	0 – 1700	Variegated fine sands, clays, shales. No fossils found.
EOCENE	Llajas	Tlj	1600+	Series of dark-grey sands, silts, and shales – some containing oil. Black limestone interbedded with the silts. Massive cgl. some calcareous, others ferruginous. Extremely fossiliferous.
EOCENE	Martinez	Tmz	350+	Coarse, ferruginous, acidic cgl. Well-rounded cobbles and boulders.
CRETACEOUS	Chico	Kc	750+	Massive, resistant, dark, olive-grey, micaceous ss. Interbedded dark, fissle sh. No fossils found.

Section:

(see plate 2.), a thickness of at least 5000 feet was mapped. The Thin Section is composed of diatomite and some silt. The thickness averages about 150 feet. Kew (1924, pp. 70-80) shows the same relationship to exist between the two separate sections of the Pico formation. Within the area mapped, formations other than the Modelo are not exposed north of the Santa Susana thrust fault zone. Only a few feet of Topanga are seen south of this fault. However, some 1700 feet of the Sespe, 1600 feet of the Llajas, 350 feet of the Martinez, and over 750 feet of the Chico appear in the Thin Section.

MESOZOIC ROCKS

CRETACEOUS ROCKS

Chico Formation (upper Cretaceous)

The Chico sandstones are extremely resistant to erosion and weather into huge massive boulders. Everywhere a dense growth of chaparral covers the area underlain by the Chico.

Medium to coarse-grained sandstones, in the Chico, are dark-gray to olive-brown in color. Thick beds of sandstone are separated here and there by thin layers of a dark-gray fissile shale. Some feldspar, quartz, and biotite occur in these well-cemented sandstones. As may be seen in section B-B', plate 2, the portion of the Chico formation mapped has a thickness of 750 feet.

One characteristic section, which was roughly traversed from the edge of the map to the contact with the Martinez conglomerate, exhibited the following lithologic succession from top to bottom:

	Feet
Medium-grained gray to brown massive unfossiliferous sandstone. Some limonitic weathering..	450
Dark-gray fissile shale	6
Medium-grained clastic olive-gray sandstone	12

The fairly well-sorted character of the sandstones indicates deposition some distance from their source; on the other hand, their arkosic nature seems to suggest a short distance of transportation. No fossils were discovered in the area mapped; marine conditions of deposition, although seeming most likely, cannot be conclusively proved.

The Chico was identified on the basis of lithology and stratigraphic position. Since no fossils were found the age was not determinable. However, the fossils that have been collected by other workers farther to the south (Kew, 1924, pp. 12-13) indicate an upper Cretaceous (Chico) age.

TERTIARY ROCKS

EOCENE ROCKS

The Martinez Formation (lower Eocene)

The Martinez formation consists mainly of conglomerates with well-rounded pebbles and cobbles varying in diameter from one to twelve inches and held together by a sandy limonitic cement. The cobbles are mainly of crystalline material. However, it is believed because of their lithology that some are of sedimentary origin and were derived from the underlying Chico sandstones. Little matrix occurs in proportion to the cobbles. At numerous points throughout this conglomerate lenses of light-colored brown sandstone up to one foot in thickness occur. As measured in structure sections, this formation is around 350 feet thick.

No fossils have been discovered and no definite proof that the Martinez conglomerates were deposited under marine conditions exists. However, the good sorting, the consistently well-bedded condition extending over large areas, and the well-rounded cobbles all point to probable marine deposition, possibly in shallow areas near shore.

The underlying Chico formation has evidently provided one source of these conglomerates. However, the greatest part was derived from nearby areas of crystalline rocks.

Along the fire-road, leading over the divide between Hummingbird and Devil's Canyons and thence to the Santa Susana Pass, the Chico and Martinez are separated by an angular unconformity. In several other localities similar conditions exist.

The age of the Martinez formation was determined only on the basis of stratigraphic position. The Cretaceous is overlain unconformably by the Martinez conglomerates. To the west, where a brief reconnaissance was made of the Martinez-Llajas boundary the contact appears to be gradational. Fossiliferous Martinez south of the area mapped has been traced into this area where it becomes barren (Kew, 1924, pp. 16-18), and thus lower Eocene age is known to be correct.

The Llajas Formation (middle Eocene)

This formation crops out over a large portion of the region mapped.

The Llajas is composed of a series of muddy silts, dark-gray shales with minor quantities of interbedded dark-brown sandstones, black fossiliferous limestones, ferruginous, sandy and calcareous fossiliferous beds, and massive, ferruginous conglomerates--some of which are petroliferous. The whole formation consists of lenticular members; no one phase apparently extends laterally for any great distance.

In view of the variable lithology the Llajas can be better described by discussing several characteristic sections.

The Devil's Canyon Section

The Llajas shales in Devil's Canyon are definitely traceable from the vicinity of locality A-27 eastward to Aliso Canyon. They are contorted near the fault contact with the Martinez conglomerates but become progressively less disturbed away from this contact. As indicated on the structure section B-B' (plate 2), much overturning, due to drag along the fault, is present. That the basal part of the section in Devil's Canyon is older than the Llajas is suggested by several species of foraminifera of Eocene age collected at locality A-17. Mr. W. H. Holman of the Standard Oil Company of California identified some of them and believes that possibly they are lower Eocene in age. Names of two of the species follow:

Bathysiphon sp.
Haplophragmoides sp.

Above these shales are to be found a series of buff, limonitic, sandy silts with interbedded, fossiliferous, sandy limestone beds. A few thin layers of gray shales appear at various horizons. The harder, arenaceous, fossiliferous limestone beds are resistant and weather into boulders that may be found as float in the soil at numerous localities. Their iron content causes them to weather into various shades of red and brown. Throughout this lithologic section, many megascopic and microscopic fossils occur. A rather incomplete list of them as determined tentatively by the writer is given below.

Locality A-16

Pelecypods

Arca hornii eluso Clark and Woodford

Anthozoa

Trochocyathus (?) imperialis Nomland

Locality A-25

Foraminifera

Quinqueloculina sp.
Globorotalia cf. aragonensis Nuttall

Locality A-29

Pelecypods

Cardium breweri Gabb
Cardium (Protocardium) marysvillensis Dickerson
Diplodonta cretacea (Gabb)
Psammobia hornii (Gabb)
Tapes (?) quadrata Gabb
Tellina (?) undulifera Gabb
Venericardia (?) planicosta merriami Dickerson
Venus (?) sp.

Gastropods

Amaurellina moragai Stewart
Bulfifusus californicus Clark and Woodford
Conus weaveri Dickerson
Ectinochilus (Macilentos) macilentus White
Galeodea sutterensis Dickerson
Globularia hannibali Dickerson
Oliva meganosensis Clark and Woodford
Turritella (?) buwaldana Dickerson

Scaphapods

Dentalium cooperi Gabb
Cadulus (?) pusillus (Gabb)

Anthozoa

Trochocyathus (?) imperialis Nomland

Locality A-61

Pelecypods

Tivela kelloggensis Clark and Woodford

The Llajas Anticline and Aliso Canyon Sections

In Aliso Canyon, the Llajas is generally concealed by alluvium but, here and there, a few good exposures are to be found along the undercut banks of the creek. Here, the section consists of a series of dark blue shales and silts and interbedded, fossiliferous, arenaceous limestones. A list of fossils collected at localities A-30 and A-34.5 follows (determinations by the author):

Locality A-30

Pelecypods

Crassatellites meganosensis Clark and Woodford
Dosinia (?) lawsoni Gabb
Tapes (?) quadrata Gabb

Gastropods

Bullia (?) (Buccinanops) clarki Wagner and Schilling.
Odostomia diaboli Clark and Woodford

Locality A-34.5

Pelecypods

Psammobia hornii (Gabb)
Tapes (?) quadrata Gabb
Tellina (?) undulifera Gabb
Venus (?) sp.

Gastropods

Bulbifusus californicus Clark and Woodford
Galeodea sutterensis Dickerson
Oliva meganoensis Clark and Woodford
Whitneyella (?) sinuata Gabb

Scaphapods

Dentalium cooperi Gabb

A rather limited but well-exposed section may be obtained at the eastern extremity of the Llajas Anticline. Lithologically, it is composed of thin beds of well-cemented, dark-reddish, medium-grained, ferruginous sandstones; dark-blue shales and silts, and some arenaceous limestone beds. This series of interbedded sediments is extremely fossiliferous. The writer identified the following collection:

Locality A-5

Pelecypods

Cardium (?) sp.
Cardium breweri Gabb
Cardium (Protocardium) marysvillensis Dickerson
Crassatellites sp.
Diplodonta cretacea (Gabb)
Dosinia (?) lawsoni Dickerson
Glycymeris major meganosensis Clark and Woodford
Ostrea sp.
Psammobia hornii (Gabb)
Tellina (?) undulifera Gabb
Tapes (?) quadrata (Gabb)
Venus (?) sp.

Gastropods

Amaurellina moragai Stewart
Architectonica tuberculata Weaver
Cerithium (?) topangensis Arnold
Conus weaveri Dickerson
Ectinochilus (Macilentos) macilentus White
Galeodea (?) susanae Schenck
Galeodea sutterensis Dickerson
Globularia hannibali Dickerson
Lyria andersoni Waring
Molopophorus californicus Clark and Woodford
Natica (?) hannibali Dickerson
Odostomia diaboli Clark and Woodford
Oliva meganosensis Clark and Woodford
Polinices (Euspira) nuciformis Gabb
Surculites (?) mathewsoni (Gabb) cf. sinuata (Gabb)
Turritella buwaldana Dickerson
Whitneyella (?) sinuata Gabb

Scaphapods

Dentalium cooperi Gabb

Locality A-6

Pelecypods

Venericardia sp.
Venericardia (?) venturensis Waring

Gastropods

Amaurellina moragai Stewart
Architectonica tuberculata Weaver
Bulbifusus californicus Clark and Woodford
Conus weaveri Dickerson
Ectinochilus (Macilentos) macilentus White
Galeodea (?) susanae Schenck
Globularia hannibali Dickerson
Molopophorus californicus Clark and Woodford
Natica (?) hannibali Dickerson
Oliva meganosensis Clark and Woodford
Polinices (Euspira) nuciformis Gabb
Whitneyella (?) sinuata Gabb

Locality A-10

Pelecypods

Venericardia hornii Gabb

Gastropods

Amaurellina moragai Stewart
Cerithium (?) topangensis Arnold
Galeodea (?) susanae Schenck
Globularia hannibali Dickerson
Natica hannibali Dickerson
Whitneyella (?) sinuata Gabb

Farther to the north in Aliso Canyon, several isolated areas of Llajas were found. Although they are extremely difficult to outline, because of overlying detritus, they are thought to be bounded by faults. Thus, it is unsafe to correlate them with any specific part of the Llajas in the southern part of Aliso Canyon.

The Llajas is overlapped, at its western margin, by Miocene formations.

The occurrence of an active oil seepage in one of the small canyons just south of the Beesemeyer Ranch-house may be of economic interest. An oil sand, also, crops out at about the same horizon in the next canyon to the west.

The Oil Canyon Section

An extremely fossiliferous section of the Llajas occurs in the southwest portion of the area mapped. Here the series of sediments is divided into two parts by the extension of the Devil's Canyon fault. Since no members common to both sections could be found no attempt was made to correlate the northern and southern areas.

North of the Devil's Canyon fault, the top of the Llajas is composed of a series of silts with inter-bedded sandstones and limestones which resemble the section at Aliso Canyon. Here, in common with the Aliso Canyon locality, the fossil *Globularia hannibali* Dickerson is especially abundant. Downward in the section, reddish-brown, massive, unfossiliferous sandstones appear. West of Oil Canyon, in the canyon in which locality A-56 is located, a series of conglomerates, oil sands, and silts crop out. The sandstone is medium-grained and dark-green-ish-gray; the conglomerate is ferruginous and is made up of well-rounded cobbles and boulders of crystalline material that vary from four inches to two feet in diameter. The lowermost conglomerate in this section is petroliferous at its base. Just below the conglomerate an oil sand with a seepage occurs. In the next canyon to the north near its mouth a very large seepage appears accompanied by considerable asphalt. Near this point, at locality A-64, another oil silt and sand crops out. This is also accompanied by a small seepage.

The youngest Llajas section found in the west is made up of dark-gray shales and dark brown, medium-grained sandstones. These grade down into three hundred feet of a brown, ferruginous, massive conglomerate, composed of well-rounded boulders which, although they closely resemble the Martinez conglomerates, represent the base of the Llajas. This conclusion is further supported by the fact that the conglomerates are underlain by a series of dark-gray silts with intercalated fossiliferous, black limestone beds which grade eastward into the Martinez conglomerates.

As has been stated before, the fossil content of this section of the Llajas formation is very abundant. A representative collection was assembled and identified by the writer:

Locality A-55

Pelecypods

Tellina (?) undulifera Gabb

Locality A-56

Pelecypods

Dosinia (?) lawsoni Dickerson

Gastropods

Ficus (?) (Ficus) modestus (Conrad)
Globularia hannibali Dickerson
Melongina sp.
Surcula (?) merriami Dickerson
Turritella andersoni Dickerson
Turritella (?) applini Hanna
Turritella cf. pachecoensis Stanton
Turritella meganosensis Clark and Woodford
Turritella merriami Dickerson

Foraminifera

Globorotalia cf. aragonensis Nuttall
Quinqueloculina sp.

Locality A-57

Pelecypods

Lucina sp.

Gastropods

Turritella (?) applini Hanna
Turritella (?) lawsoni Dickerson

Locality A-58

Pelecypods

Lucina (?) acutilineata Gabb

Gastropods

Fusitriton (?) oregonensis (Redfield)

Locality A-63

Gastropods

Clairlithes (?) tabulatus (Dickerson)
Ficopsis meganosensis Clark and Woodford

Locality A-66

Pelecypods

Solen (Plectosolen) stantoni Weaver

Gastropods

Fusus (?) dumblei Dickerson
Fusus (?) flexuosus Gabb
Fusus (?) mathewsonii Gabb
Gemmula wattsi Anderson and Hanna
Natica (Gurodes) sp.

Locality A-67

Pelecypods

Glycymeris major meganosensis Clark and Woodford
Tellina (?) undulifera Gabb

Locality A-68

Pelecypods

Merex (?) stantoni Gabb

The lithologic character of the Llajas seems to indicate marine deposition under variable conditions. The conglomerate beds likely represent deposition in near shore, shallow water; the silts and black limestones probably accumulated farther out in deeper water. Lensing-out of numerous members suggests deposition near an unstable shoreline.

West of Devil's Canyon, the Llajas probably grades down into the Martinez without any recognizable break. In the Devil's Canyon Section near localities A-25 and A-29 the Pliocene San Diego formation rests on the Llajas with angular unconformity. West of Las Llajas Canyon, the Llajas lies disconformably below the Sespe formation. No noticeable variations in dip between the Llajas and Sespe are evident. However, as will be shown later, the lithology of these two formations is very dissimilar. Over the rest of the area mapped, and where it is not in fault contact with younger formations, the Llajas lies unconformably below the Topanga formation.

OLIGOCENE ROCKS

The Sespe Formation (upper Eocene to lower Miocene ?)

For the most part the Sespe is here composed of a series of variegated shales and silts. Colors such as yellow, orange, green, olive, brown, chocolate, and buff predominate. In lithology they resemble the Topanga sediments to a marked degree. Below the silts and shales lie poorly-bedded, extremely clean, yellow, white, and greenish clastic, terrestrial sands which contain much gypsum. They have a resemblance to the Saugus sands. At a few horizons, in both the sand and the silts, narrow beds of ferruginous, rather fine-textured conglomerates occur. At the widest portion of the outcrop, in the extreme western part of the area, some 1700 feet of Sespe crops out. However, on the average much less appears. This thick section thins rapidly eastward to a strip approximately 250 feet in thickness which extends eastward on across Las Llajas Canyon and finally wedges out between the Llajas formation and the younger Miocene and Pliocene sediments.

At several places in the Sespe formation, very poorly preserved bone fragments were discovered. Farther to the west, many mammalian species have been collected by field parties from the Vertebrate Paleontology Department of the California Institute of Technology. These vertebrate remains, besides indicating nonmarine conditions of deposition, have shown the Sespe to range in age from upper Eocene to lower Miocene[1].

[1]Wilson, R. W., Oral communication.

The correlation of this section of sediments with the Sespe formation is made on a basis of Kew's report (1924, pp. 34-35) of the lithology and stratigraphic position. The contact with the Llajas formation is marked only by a change in lithology; thus, it could be considered to be disconformable. However, the Sespe-Miocene contact is unconformable as is the contact between the Sespe and the Pliocene San Diego farther east.

MIOCENE ROCKS

Topanga (middle Miocene)

Because this formation almost everywhere occurs below cliffs formed by the softer Modelo formation, it is generally covered with much float. This, in addition to its slight thickness, makes it difficult to observe and to map. In certain localities, a conglomerate member stands out and this member is of considerable help to the geologist in mapping the Topanga.

Two main facies of the Topanga are practically everywhere present: (1) an upper member of brown to buff, sandy, fossiliferous silts some 100 feet thick, and (2) a lower member of dark-brown, fossiliferous, ferruginous conglomerate averaging 50 feet in thickness. The conglomerate is composed of well-cemented well-rounded fairly basic igneous cobbles up to six inches in diameter. It is not known over how great an area the conglomerate extends because the slight thickness and topographic position make outcrops poor.

Both microscopic and megascopic fossils were found. The latter are more rare in occurrence, having been found only at localities A-34 and A-60 in the conglomerate member. Foraminifera are abundant in the silty member and are extremely useful in mapping this formation. A list of the more representative forms follows (the microfossils were identified by Mr. W. H. Holman and the megafossils by the writer):

Locality A-34

Pelecypods

Antigona sp.
Dosinia (?) (Dosinella) merriami Clark
Clementia (Egesta) pertenuis (Gabb) conradiana (Anderson)
Dosinia ponderosa Gray
Macoma (?) sespeensis Loel and Corey
Ostrea eldridgei Arnold
Ostrea (?) titan Conrad
Pecten (Plagioctenium) andersoni (Arnold)
Solen sp.

Gastropods

Lunatia sp.
Neverita cf. reculuziana Petit
Oliva californica Anderson
Trophon sp.

Vertebrate Remains

Whale bone (?)

Localities A-48, A-58, and A-59

Foraminifera

Bolivina advena var. striatella Cushman
Valvulineria ornata Cushman

Locality A-60

Vertebrate Remains

Shark teeth

The Topanga formation seems to represent deposition under marine conditions near an unstable shoreline. The coarse conglomerates, composed of pebbles and cobbles with variable textures whose well-rounded nature gives evidence of intense water action, and the marine fossils characteristic of a shallow-water environment near the shoreline - both point toward this mode of origin.

The middle Miocene Topanga lies unconformably on the Llajas. It was impossible to tell the nature of the Topanga-Modelo contact in the area mapped except by a study of the foraminifera found in both formations. These indicate a stratigraphic break and thus a disconformable relationship between the two formations. From its stratigraphic position, the age of the Topanga may be defined between certain limits. However, the excellent foraminiferal assemblage indicates a definite middle Miocene age.

<u>The Valvulineria californica sensu stricto Zone (upper middle Miocene)</u>

As far as is known, outcrops of this zone are impossible to recognize lithologically in the area mapped. Landslides and creeping soil from the overlying Modelo have covered this zone almost everywhere it occurs; hence, since it is only a few feet thick, good exposures are practically impossible to find. Near Chivo Canyon, at localities A-51 and A-52, several excellent outcrops may be seen below the diatomite of the Modelo formation. Here, well-preserved specimens of <u>Valvulineria</u> <u>californica</u> Cushman occur in a light brown, friable, argillaceous siltstone over 100 feet thick.

At locality A-58, specimens of <u>Valvulineria</u> <u>californica</u> were discovered but it was impossible to determine the thickness of the zone because of landsliding. On the west side of Aliso Canyon, at locality A-22, the <u>V.</u> <u>californica</u> zone was recognized by its microfossil content. Here it is a gray, friable, argillaceous, silt probably not over 25 feet thick. It occurs immediately below the Modelo diatomite. Across the canyon and just southeast of Holt's Ranch this same zone was also recognized.

A list of foraminifera characteristic of the <u>V.</u> <u>californica</u> zone compiled from collections assembled by the writer and identified by Mr. W. H. Holman follows:

Localities A-22, A-47, A-51, and A-52

Baggina sp.
Nonion costiferum (Cushman)
Valvulineria californica Cushman
Valvulineria miocenica Cushman
Valvulineria ornata Cushman

Since it was physically impossible to collect at every point where this zone was thought to exist, it was therefore considered practical to dot in the estimated location of the contacts between points where they were known to be. Enough evidence was available to show that the zone thickens appreciably westward. The writer has been informed by Mr. J. P. Bailey of the Standard Oil Company of California that these silts also thicken to the east of the area mapped by the writer of this paper.

The lithology strongly suggests deposition in fairly deep and calm water. M. L. Natland (1933, pp. 225-230) has shown that, from a knowledge of their ecologic relations, microfossils may be helpful in determining the conditions of deposition of rocks in which they occur. According to R. M. Kleinpell (1938, figure 5) the typical foraminifera of the Topanga silts seem to have been characteristic of moderately deep marine waters but those of the V. californica zone are of somewhat shallower water. The fossil evidence, in addition to showing that the silts were probably deposited under shallow water conditions, show that sea above this area probably became shallower as the middle Miocene progressed.

The author was not able to distinguish a hiatus between the lower limit of the V. californica zone and the Topanga silts lying below. The lithology certainly exhibits no change and the foraminifera, although they, as previously shown, change gradually from moderately deep water forms to those characteristic of shallow water, do not give evidence of any definite break in the record. The same can not be said, however, concerning the upper limits of the V. californica zone. The microfossil assemblage changes considerably in the overlying Modelo formation. Cold and rather deep water forms, such as Bulimina montereyana Kleinpell, Buliminella curta Cushman, and Uvigerina subperegrina Cushman and Kleinpell, are most characteristic and seem to show that conditions of deposition changed somewhat in a rather short space of time. A marked lithologic change may be observed wherever these two formations are seen. The fine brown silts are replaced by a diatomaceous shale of the same color but much less fossiliferous. No angular unconformity can be observed between the V. californica zone and the Modelo formation at any one point. However, such a relationship is suggested by the fact that the silt containing V. californica thickens from about 25 feet around Aliso Canyon to probably over 150 feet in the vicinity of localities A-51 and A-52. As has been pointed out before, Mr. J. P. Bailey has informed the writer that this zone also thickens to the east of the area mapped. One may conclude, therefore, that, in all probability, a definite hiatus is present between the Modelo formation and the underlying V. californica silts.

The age of the V. californica zone is clearly shown by stratigraphic position and by the assemblage of foraminifera. The former evidence shows it to lie between the lower middle Miocene and the upper Miocene, and the microfaunal assemblage indicates a probable correlation with the V. californica sensu stricto zone of Kleinpell's (1939, figure 14). Thus, it is of lower Luisian age (lower upper middle Miocene). Also, a similar relationship seems to exist between this assemblage and that described by Hoots (1931, p. 99) from the Topanga formation of the Santa Monica Mountains.

The Modelo Formation (upper Miocene)

The Modelo is one of the most widely distributed formations in the area mapped. Since, geographically, wide differences exist in the Modelo from the northern to the southern part of the area, the Modelo will be described in two sections.

Southern Section (Thin Section)

South of the Santa Susana fault zone the Thin Section of the Modelo formation crops out. It is everywhere a brown, punky, diatomaceous, foraminiferal shale which weathers to a light gray. Near its top, a hard light-gray chert appears. The average thickness of the Modelo is about 150 feet. The cherty beds comprise only a very small portion of this thickness. In the plateau-like area to the west, the thickness increases to approximately 200 feet. The Modelo formation south of the Santa Susana fault zone thickens westward.

Northern Section (Thick Section)

North of the Santa Susana fault zone the upper Miocene section shows several abrupt lithologic changes. As shown in plate 5, the section is some 5000 feet in thickness. The lowest member is a hard, well-bedded, cherty shale containing a few microscopic and megascopic fossils. As nearly as can be determined, around 2500 feet of these Modelo cherts are present. The chert is overlain by 150 feet of yellow-brown to gray, medium- to coarse-grained, massively bedded, poorly sorted sandstones. A few local occurrences in the sandstone of unidentifiable fossils were discovered. Also, some members as that at locality A-41 contain a show of oil. Lying above these sandstones are, on the average, 350 feet of dark-brown to black, fissile organic shales which are petroliferous at various localities. The uppermost member is composed of about 2250 feet of sandstones and shales which strongly resemble those of the Thick Section previously described. The sandstones form the lower part

COLUMNAR SECTION

Scale, 1" = 1000'

THE THICK SECTION

Period (Epoch)	Formation Name	Symbol	Thickness in feet	Section	Character of Rocks.
	Alluvium, slump etc.		5 - 100'		Clay, sands, gravel.
MIOCENE	Modelo	Tms	2250+		(Note: Due to some repetition caused by faulting this entire section can be considered only approximate.) Yellow-brown to grey, medium to coarse-grained, massively-bedded ss. which in places is petroliferous. Contains numerous concretions and fragments of reworked older beds. Quite resistant. Sparingly fossiliferous. Is overlain unconformably by the Pico formation.
	Modelo	Tmsh	350 ±		Dark-brown to black organic shale. Some phases show oil.
	Modelo	Tms	125 ±		Similar to that Tms above.
	Modelo	Tmc	2500+		A hard, cherty sh. grey in color. Contains some megascopic fossils as well as foraminifera.

of the member and are yellow to brown to gray in color, medium- to coarse-grained--in places almost conglomeratic and in others gritty, poorly sorted, concretionary, locally fossiliferous, massively bedded, and resistant to erosion. In various localities the sandstones are cut by a network of faults of small displacement. The poorly sorted condition of the Modelo sandstones is well exhibited at a point west of locality A-43. At this locality some unidentifiable pectens were discovered in the sandstones.

In the upper part of the uppermost member some narrow beds of petroliferous shale appear locally, but, in the main, the sandstones continue and make an unconformable contact with the Pico formation above.

The northern section, as has been pointed out, is in no place a normal one but is everywhere complicated by faulting. Thus, it seems next to impossible to arrange a columnar section which can be regarded as correct. Plate 5 represents the best effort. Could one compute components of movement along the faults, of course, the situation might be different but due to the extremely disturbed condition of the overthrust block and the poor exposures in many of the most critical areas this is impossible. In fact, it is very likely that several faults have not been recognized.

Because of its great variation in lithology, the Modelo was probably deposited under changing conditions. The fossils found in it indicate marine deposition. The coarser members, however, may have been deposited in shallow water near shore or locally in deltas or in stream channels. The gritty facies indicate relatively little water-working and probably represent near-shore deposits. The diatomaceous, petroliferous, and bituminous shales show organic origin and suggest deposition in fairly quiet water.

The relation of the Modelo diatomite to the underlying formations has previously been discussed. The contact with the overlying Pico sandstones and silts is marked by a distinct lithologic break and is probably unconformable. Neither the lower boundary of the Modelo Thick Section nor the upper limit occurs within the area mapped.

The age of the Modelo formation may be determined by both its stratigraphic position and microfossil content. At localities A-12 and A-13 in the Thin Section, the following assemblage of middle Miocene foraminifera was collected by the writer and identified by Mr. W. H. Holman:

Baggina californica Cushman
Bulimina montereyana Kleinpell
Buliminella curta Cushman
Pulvinulinella gyroidinaformis Cushman and Goudkoff
Uvigerina subperegrina Cushman and Kleinpell
Virgulina californiensis cf. var. grandis Cushman and Kleinpell

The microfaunal assemblage dates the diatomite as upper Miocene in age and thus corroborates the evidence shown by the stratigraphic position. In the Thick Section one megascopic fossil was found in the cherty facies just below the lowest sandstone member at locality A-42. One foraminifer was also discovered.

Pectens

Pecten (Pseudamusium) peckhami Gabb

Foraminifera

Globigerina sp.

At locality A-43 imprints of several ribbed pectens were found. They were unidentifiable but somewhat resembled Pecten andersoni Arnold.

PLIOCENE AND PLEISTOCENE ROCKS

The Pico Formation (lower middle Pliocene)

The Pico formation is well exposed in the region mapped. It consists of a series of buff-colored, marine silts which become more sandy toward the top. The basal portion is a light-brown, well-stratified silt containing abundant marine fossils. Shark teeth and bone fragments are also common. The bones are probably whale remains. Most of the megascopic fossils are fragmental. Upward in the section, thin beds of a buff sandstone become more and more numerous. The Pico formation is about 150 feet thick in the eastern part of the area and thickens to around 300 feet at the western border.

The fossil content consisted of the following species (megascopic determinations by Mr. U. S. Grant IV, and the writer, microscopic identifications by Mr. W. H. Holman):

Locality A-62

Pelecypods

Pecten bellus Conrad
Pecten cerrosensis Gabb
Pecten healeyi Arnold
Pecten swiftii Arnold

Vertebrate Remains

Bone fragments
Shark teeth

Foraminifera

Bolivina interjuncta Cushman
Hemicristellaria sp.
Uvigerina peregina Cushman
Valvulineria araucana (d'Orbigny)

Locality A-24

Foraminifera

Globigerina bulloides d'Orbigny
Siphogenerina sp. (redistributed from formations below)
Valvulineria californica Cushman (redistributed)

Locality A-69

Foraminifera

Bolivina interjuncta Cushman
Cassidulina translucens Cushman and Hughes
Uvigerina peregina Cushman
Valvulineria araucana (d'Orbigny)

Locality A-70

Foraminifera

Bolivina interjuncta Cushman
Hemicristellaria sp.

Locality A-71

Foraminifera

Elphidium sp.
Globigerina bulloides d'Orbigny

As indicated by the lithology, and corroborated by the microfossil contents, the lower part of the formation probably represents deep water deposition. Near the top the sediments become more arenaceous and shallow water foraminifera such as Globigerina bulloides d'Orbigny and Elphidium sp. appear.

Excellent exposures of the unconformable relationship between the Pico and San Diego formations may be obtained at locality A-24 on the east side of Brugher's Hill and in the west sides of Las Llajas and Oil Canyons. Northeast of A-24 a good view may also be obtained of the unconformity between the Pico and Modelo formations.

On the basis of stratigraphic position, it is obvious that the Pico formation must be younger than upper Miocene and older than upper middle Pliocene (San Diego). The microfaunal assemblage shows it to be lower middle Pliocene in age.

The San Diego Formation (upper middle Pliocene)

The calcareous conglomerates and fossil reefs of the San Diego formation cap Brugher's Hill and the other high mesa-like elevations to the west.

The lowest part of the San Diego formation is a series of conglomerates composed of crystalline pebbles half an inch to six inches in diameter cemented by a calcareous matrix. Above lie several fossil reefs containing some sandy material. In Brugher's Hill the San Diego formation has an average thickness of 100 to 150 feet. To the west, in the vicinity of the lime mine, places were discovered where it has a thickness of at least 250 feet. Toward the top of the formation the fossil reefs give way to calcareous sands which in turn grade upward into the nonmarine sands and conglomerates of the Saugus formation.

At locality A-2, just south of Holt's Ranch, several megascopic fossils were collected and among them two species of echinoids which were identified by Mr. U. S. Grant IV. On the east side of Brugher's Hill at locality A-14 more echinoids were found. On the fire road northwest of Devil's Canyon, fossils were collected in the San Diego sediments (locality A-1). This is perhaps the most productive fossil locality in the San Diego formation. A list of the fossils (identifications by the writer except where indicated otherwise) is given below:

Locality A-1

Pelecypods

Chlamys opuntia (Dall)
Chlamys swiftii parmeleei (Dall)
Crassatellites sp.
Laevicardium corbis
Lucina acutilineata Conrad
Lucina nuttallii Conrad
Macoma secta Conrad
Mytilus expansus Arnold
Pecten bellus Conrad
Pecten cerrosensis Gabb
Pecten deserti Conrad
Pecten stearnsii Dall
Pecten subdalus Hertlein
Pododesmus macroschisma Deshayes
Schizothaerus nuttallii Conrad
Solen sicarius (Gould)
Trachycardium sp.
Venericardia sp.

Gastropods

Chlorostoma (Omphalius) dalli
Conus californicus Hinds
Neverita recluziana (Deshayes)
Turritella sp.

Brachiopods

Terebratula smithi Arnold
Terebratula transversa caurina Gould

Bryozoa

(Probably several unidentifiable species)

Echinoids[1]

Dendraster diegoensis Kew, variants
Strongylocentrotus drobachiensis of Muller

Crustaceans

Crab claws

Vertebrate Remains

Shark teeth

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[1]Determinations by Mr. U. S. Grant IV

Locality A-2

Pelecypods

Chlamys opuntia (Dall)
Chlamys swiftii parmeleei (Dall)
Crassatellites sp.
Pecten bellus Conrad
Pecten cerrosensis Gabb
Pecten deserti Conrad
Pecten purpuratus Lamarck
Solen sicarius (Gould)

Gastropods

Pholas borings
Turritella sp.

Brachiopods

Terebratula smithi Arnold
Terebratula transversa caurina Gould

Bryozoa

(Probably several unidentifiable species)

Vertebrate Remains

Shark teeth

Echinoids[1]

Dendraster diegoensis Kew, variants
Strongylocentrotus aff. drobachiensis of Muller

Locality A-14

Pelecypods

Chlamys hastatus (Sowerby)
Lucina acutilineata Conrad
Pecten bellus Conrad
Pecten stearnsii Dall
Ostrea vespertina Conrad

Gastropods

Purpura sp.

Vertebrate Remains

Shark teeth

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[1] Determinations by Mr. U. S. Grant IV

Echinoids[1]

Dendraster diegoensis Kew, variants

Foraminifera[2]

Cibicides conoideus Galloway and Wissler
Elphidium crispum auctores
Globorotalia campanulata Galloway and Wissler
Planulina ariminensis d'Orbigny
Rotalia sp.
Siphogenerina sp.
Valvulineria californica Cushman (redistributed)

Locality A-28

Foraminifera[2]

Cibicides conoideus Galloway and Wissler
Elphidium crispum auctores
Globorotalia campanulata Galloway and Wissler
Siphogenerina sp.

Locality A-46

Gastropods

Crepidula princeps Conrad

Locality A-44

Foraminifera[2]

Elphidium crispum auctores
Globorotalia campanulata Galloway and Wissler
Quinqueloculina sp.

Locality A-45

Foraminifera[2]

Elphidium crispum auctores
Globorotalia campanulata Galloway and Wissler
Quinqueloculina sp.

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[1]Determinations by Mr. U. S. Grant IV

[2]Determinations by Mr. W. H. Holman

As indicated by the lithology and the fossils, the sediments making up the San Diego formation were deposited in very shallow marine waters. In addition, the basal San Diego contains forms more characteristic of deeper water than those found higher in the section. The brachiopods, with deep water affinities, are replaced higher in the section by dendrasters, razor clams, and numerous pectens which are more characteristic of a shallow environment. Such a condition indicates a progressive shallowing of the sea in which the San Diego was being deposited.

An angular unconformity separates the San Diego from the underlying Pico formation. Upward, the San Diego grades into the nonmarine Saugus formation. Since the age of the Saugus has not as yet been determined it is only possible to say, on the basis of stratigraphic evidence, that the San Diego formation is post-Pico in age. However, from fossil evidence, it may be dated as upper middle Pliocene.

The Saugus Formation (upper Pliocene and probably lower Pleistocene)

Because of its lithology, the Saugus frequently forms steep slopes. Everywhere it supports a thick growth of blue sage and mesquite.

The part of the Saugus exposed in the area is more than 900 feet thick. It is composed of a series of arkosic gravels and sands, cleanly washed, light-gray in color, and sometimes well-stratified.

The fact that no fossils have been found in the Saugus formation strongly suggests a nonmarine origin. Also, the coarse nature and arkosic composition point toward conditions of continental deposition under unstable environments not far from a source.

The Saugus has been defined by some writers, such as Ellis and Lee (1919, pp. 58-67), to include all the later Tertiary nonmarine deposits underlying Recent alluvial deposits. Thus, the base of the formation could be mapped at the top of the uppermost marine San Diego bed. From the stratigraphic position, the age of the Saugus can be post-San Diego. At certain localities, terrace deposits unconformably overlie the Saugus. Since the terrace deposits also antedate the latest uplift, they may well be upper Pleistocene in age. The time of deposition of the Saugus deposits appears to lie between the upper middle Pliocene and the upper Pleistocene.

Quaternary Terrace Deposits (middle or upper Pleistocene)

Some scattered patches of Quaternary terrace deposits occur in the area mapped for this report.

The deposits closely resemble Saugus gravels in texture and color, but differ in containing many angular Modelo chert fragments. Their greatest thickness is probably not over 150 feet.

The terrestrial origin of these deposits is indicated by their lithology and the lack of marine fossils. The abundant Modelo chert fragments suggest that at least some were derived from the overthrust block to the north. They are cut by faults at several localities and are, hence, pre-faulting in age. It seems best to assign them a middle to upper Pleistocene age.

Quaternary Alluvium

Along most of the main streams, such as those in Las Llajas and Aliso canyons, limited amounts of alluvium occur. These deposits are generally composed of recently deposited sands and gravels. In addition, in at least one area north of Flynn's ranch-house in Aliso Canyon, calcareous tufa is also being deposited in considerable quantities by the streams. Because of the minor character of the alluvium, it was considered best to omit its boundaries on the geologic map.

STRUCTURE

GENERAL STATEMENT

The intricate nature of the folding and faulting in the upper Las Llajas Canyon area testifies to the extreme deformational forces to which this region has been subjected. The structural grain of the region trends roughly northwest-southeast; the axes of the folds and the traces of most of the faults strike in this direction. Overturning where it exists along the front of the overthrust block is toward the southwest.

That deformational forces have been active throughout the Tertiary is evidenced by numerous unconformities and pre-Pleistocene faults as well as the lithologic character of many of the sediments. Faulting and folding of Quaternary terrace deposits indicates that some of these forces have probably continued active into the Recent. Reports from the Seismological Division of the Department of the Geological Sciences of the California Institute of Technology locate epicenters seeming to have originated on the Santa Susana thrust fault zone[1].

[1]Richter, C. F., Oral communication.

FAULTING

At least four distinct types of faults are found in the area: (1) normal, (2) high-angle reverse, (3) low-angle reverse or overthrust, and (4) strike-slip or tear.

For the sake of clarity the region can be subdivided into three main sections: First, the Santa Susana thrust fault zone which might be considered to be the main structural feature in the region; second, that area north of the Santa Susana thrust fault zone, which in turn may also be separated into three main parts; and third, the region south of the Santa Susana thrust fault zone.

The Santa Susana Thrust Fault Zone

The Santa Susana thrust fault zone extends across the entire area in a northwest direction. The fault which separates the thicker section of the Modelo formation from the Thin Section previously described may be regarded as the main fault. At this line, the grassy, rounded slopes of the Modelo cherts cut by youthful, V-shaped canyons meet the relatively older plateau-like topography to the south (see plate 6, figures 1 and 2).

This zone which has been faulted into blocks of all dimensions, forms an area of weakness over much of the territory mapped. As a result, this zone has been lowered by erosion somewhat faster than the surrounding country and forms a depressed zone across the region. This almost east-west trending area, however, seems to owe some of its depression to actual movement along the faults.

The Santa Susana thrust fault zone is bounded to the south by the almost vertical north Llajas fault which extends in an east-west direction along the north side of the Llajas anticline. In most places this fault separates the Llajas formation from the Saugus gravels and at one point (south of locality A-35) it separates Quaternary terrace deposits from Eocene rocks. Thus, the north Llajas fault may be seen to have a very noticeable displacement. The fact that it cuts terrace deposits indicates its very recent activity and also suggests that it may be genetically related to the forces which caused the

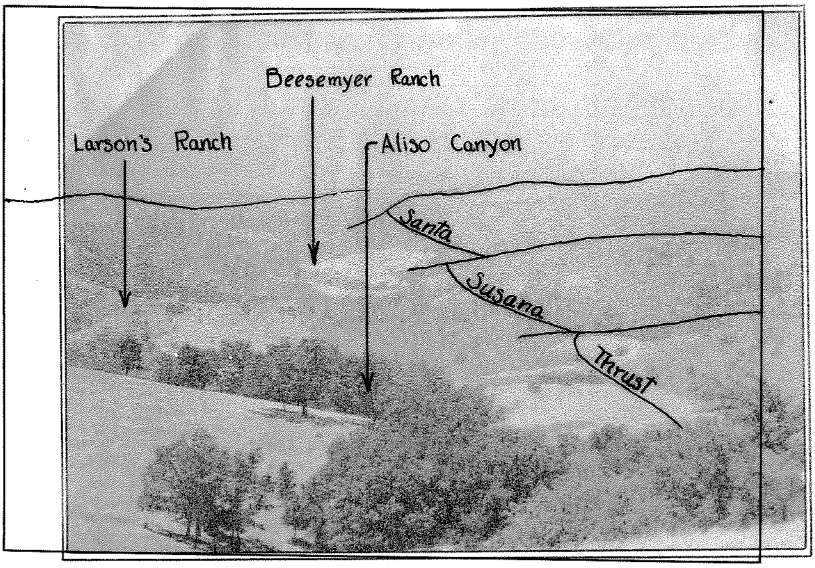

Figure 1. Westward view across the heads of Aliso and Las Llajas canyons showing the Santa Susana thrust fault zone.

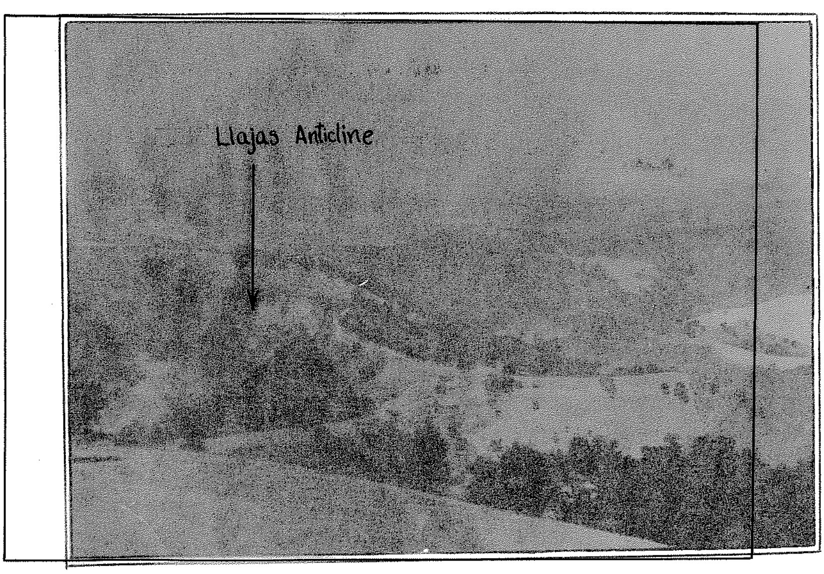

Figure 2. View immediately to the south of that shown in figure 1.

main fault in the area. The rocks on the north side of the north Llajas fault have evidently been lowered with reference to those on the south.

The main fault which bounds the north side of the whole Santa Susana thrust fault zone is the main Santa Susana thrust; therefore, this depressed region might be considered in general to have a graben-like structure.

The structure of the area between the two bounding faults (north Llajas and Santa Susana thrust) is far from simple. A network of faults lies between the two, cutting up this area into a jumbled mass of rocks. In the vicinity of Larson's ranch, most of the sediments can be mapped with considerable accuracy. But to the west on the Beesemeyer ranch the lack of exposures increases the chance for error. Particularly in the area northwest of Toro Canyon (between localities A-44 and A-40), much of the region is covered by Quaternary terrace gravels.

East of Aliso Canyon the Santa Susana thrust zone is covered with a notable amount of slump derived from the Modelo cherts which crop out high above. Here only occasional slickensides, springs, or breaks in the topography suggest where the Santa Susana thrust zone may lie. In the extreme southeast corner of the area (east of localities A-28 and A-30) the thrust zone may be mapped in detail bacause of the good outcrops available.

Commonly, the structure of the rocks in close proximity to the Santa Susana thrust is almost chaotic. In most places the Santa Susana fault has thrust Modelo cherts over the Saugus formation. In addition, although relationships are confused by landsliding, the Modelo cherts seem to be locally thrust over Quaternary gravels. Also, in a few places along the main thrust zone, an imbricate structure has been developed. At locality A-30 the Modelo chert is thrust over the diatomite phase of this same formation and the diatomite in turn has been thrust over Saugus gravels. In the extreme southeastern portion of the map the overthrust cherts lie in fault contact with the Saugus, San Diego, and the Pico formations.

Since the main Santa Susana thrust fault zone usually lies at the base of rather steep slopes cut in Modelo chert, it is generally covered with talus. This talus tends to conceal the fault. It has been suggested by most previous workers that the Santa Susana fault seemed to dip northward at angles of 10 to 15 degrees. The writer does not agree with these suggestions, for his field work indicates that the average dip of the fault is nearer 50 degrees with a minimum of 30 degrees and a maximum of about 70 degrees. Dips taken on the Santa Susana fault show that the average dip is much steeper than has heretofore been suspected. At the extreme eastern part of the area the thrust plane seems to have an approximate dip of 50 degrees north; westward, it becomes steeper until, near the head of Aliso Canyon, a dip of 70 degrees is encountered; north of Larson's ranch-house, however, the dip decreases to 30 degrees and remains at this angle over the rest of its trace through the area mapped. Most of the smaller faults in the zone seem to have even steeper dips, many being almost vertical. The meandering trace of the Santa Susana fault on the map suggests a low angle fault, since it is quite different from that which one would regard as characteristic of a steeply dipping thrust. The meandering trace is the result of offsets along tear faults whose horizontal displacement has shifted segments of the Santa Susana thrust zone in a direction normal to the strike of that zone. Conclusive evidence to support this theory was found in the field.

Near the head of Toro Canyon, evidence strongly suggests that the Santa Susana thrust has been horizontally offset between 2300 and 3300 feet by a strike-slip fault which trends in a direction perpendicular to the Santa Susana fault. This tear fault can be traced down Toro Canyon for some distance and also northward beyond the crest of the Santa Susana Mountains. In other words, the tear fault has been observed to offset horizontally the structures on both sides of the Santa Susana fault as well as the Santa Susana fault itself. Conclusive evidence is furnished by the San Diego formation. At locality A-44 south of the Santa Susana thrust, a narrow bed of corase San Diego conglomerate was discovered. This bed contains an assemblage of typical San Diego foraminifera and has a very easily recognizable lithology which differentiates it from the rest of the San Diego and Saugus around it. At locality A-45, north of A-44, a bed with the same characteristic lithology and microfossil assemblage was found. It is entirely within the realm of probability that these two beds are portions of the same one which has been cut off and separated by the tear fault running down Toro Canyon. In addition to this evidence, the Modelo chert to the east of Toro Canyon north of the Santa Susana fault and south of locality A-45 may be seen to butt abruptly into Quaternary terrace deposits lying over Saugus gravels. Remnants of these deposits can be seen to the southeast near locality A-44 and probably show that these old alluvial deposits have also suffered offsetting.

Near the head of the next canyon to the west, Chivo Canyon, another offset of around 500 feet seems likely. A tear fault has been traced up Chivo Canyon and over the crest of the Santa Susana Mountains. Here, typical rounded slopes, underlain by the Modelo chert, apparently butt into Quaternary terrace gravels.

Sulfur Canyon, to the east of Toro Canyon, also contains a tear fault which has apparently offset the Santa Susana thrust fault in a horizontal direction at least 3000 feet. In fact, two tear faults here bound a salient of Modelo sandstone which seems to have been pushed out into the Saugus that surrounds it on three sides. In this locality, unfortunately, the structure in the Saugus is concealed by soil. Movements here also probably have affected Quaternary terrace deposits.

Some distance north of Barney Flynn's ranch-house two tear faults converge, causing a salient of probable Eocene sandstone to jut out into the younger formations. The amount of horizontal displacement here is not over 1500 feet and likely is much less, particularly if any vertical component of motion occurred.

Because of the limited area mapped it has been impossible to determine the total displacement of the Santa Susana thrust zone itself. However, it seems safe to venture that the displacement was of large magnitude. The Thick Section of Modelo which now apparently rests over the Thin Section certainly must have been deposited a much greater distance away than it is now found.

The Area North of the Santa Susana Fault Zone

The area north of the Santa Susana thrust zone is greatly disturbed. Here the rocks are intricately folded and faulted.

The heads of Las Llajas and Aliso canyons cut back into the overthrust block generally along north-south tear faults which are perpendicular to the main structural grain of the region and offset the Santa Susana thrust zone. Erosion along the tear faults has exposed the main structural features and they are thus of much help to the geologist in studying the structures of the overriding Santa Susana thrust block.

The fault traces strike in two predominant directions: northwest-southeast and northeast-southwest. The former are of the dip-slip variety; the latter are strike-slip.

Strike-slip Faults

Evidently, faults of this type produce zones of weakness which were easily followed by streams. They are much easier to recognize than the faults striking parallel to the strata because they produce offsets. All of these tear faults can be traced over the crest of the Santa Susana Range. Sulfur Canyon exposes an especially intricate network of tear faults. However, this may be due to the fact that cuts along a new fire road in this vicinity have exposed many faults which ordinarily would not have been discovered because of the soil covering. It is interesting to note that the Toro Canyon fault apparently leaves that canyon at locality A-45 and continues up the ridge between Toro and Sulfur canyons instead of continuing in the bottom of the canyon as most of the faults do. Attitudes taken on this and other faults in the network indicate that they dip westward at angles of between 55 and 75 degrees. The Toro and Sulfur canyons faults have offset not only the Santa Susana thrust but also, as would be expected, the structure in the Modelo to the north.

In the canyon immediately east of locality A-46 a tear fault has been traced for some distance but seems to die out northward before the lowest Modelo sandstone member is reached. The fault which follows the east branch of Aliso Canyon seems to have a greater displacement than the fault at locality A-46. It may be traced across the summit of the Santa Susana Mountains and down a canyon emptying into the Santa Clara Valley. Where it crosses the fire road at the divide, the Modelo sandstone may be seen to be highly fractured.

Dip-slip Faults

The dip-slip faults which trend perpendicular to the tear or strike-slip faults are not as easily traced because they cause only a repetition of strata. If one is not of large displacement and does not cut across different phases of the Modelo, it is extremely likely to go unnoticed. Luckily, many of these dip-slip faults do cut through various phases of the Modelo and so offsetting is visible.

The Area South of the Santa Susana Fault Zone

As would be expected, the rocks occurring south of the Santa Susana thrust zone have not been subjected to as intense diastrophic forces as those to the north. Thus, less folding and faulting have resulted.

Trending in an almost east-west direction and running practically all of the way across the area is the steep-angled north Llajas fault. In the eastern portion of the area it seems to be a part of the intricate area of faults forming the thrust zone. On west it evidently crosses Aliso Canyon and may be traced along the northern limit of the Llajas anticline where it cuts off a part of this structure and has brought Saugus gravels in contact with the Eocene rocks. This relationship indicated a displacement of over 1000 feet in a dip-slip direction at this point. It has also disturbed Quaternary terrace gravels and forms an avenue for the escape of the oil found in the seepage southeast of the Beesemeyer ranch-house. An interesting feature of this fault is that it dips 55 degrees north where it crosses Las Llajas Canyon; however, where it is exposed in a road-cut southeast of Larson's ranch-house, the dip is 50 degrees in the opposite direction. On first thought such a thing may seem unlikely but, in view of the distortion prevalent here, it should not be impossible. The north Llajas fault may be traced on to the west where it apparently dies out near locality A-52. The high-angled east-west south Llajas fault occurs on the south flank of the Llajas anticline. Rough measurements indicate that its dip-slip movement was at least 250 feet. This fault brings Eocene rocks against the Topanga and Modelo formations. Eastward it seems to join the north Llajas fault and westward it dies out near Las Llajas

Canyon.

Two faults of rather large displacement were mapped which probably were formed by pre-Pliocene orogenic movements. One, the Devil's Canyon fault which cuts the Llajas, can only be dated as post-Llajas in age. It trends eastward across the area, and separates the Martinez conglomerates from the Llajas formation north of the Simi Hills. It may be traced westward into the Eocene Llajas to a point immediately west of Oil Canyon where it seems to die out. Attitudes obtained on the Devil's Canyon fault near its western extremity indicate that it dips north about 65 degrees and is a normal fault. The displacement evidently has been mainly in the dip-slip direction. The exact magnitude is impossible to estimate but the maximum is probably several hundreds of feet.

The Brugher fault lies north of the aforementioned fault and immediately south of Brugher's Hill. It trends in a northwesterly direction to within a few feet west of locality A-25. Its age can be relatively closely determined since, on the east side of Aliso Canyon just south of the south margin of the map, it can be seen to cut the Pico formation and to be overlapped by San Diego sediments (see plate 7, figure 4). An unusual feature, which the geologic map illustrates much better than any description, is the long narrow section of Modelo diatomite that is exposed apparently

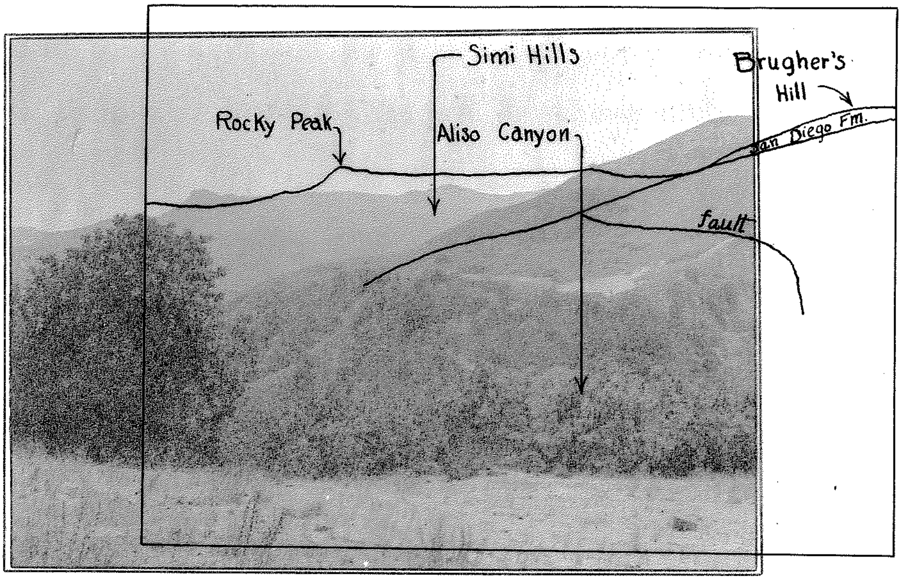

Figure 3. Southward view across Aliso Canyon from a point near Flynn's ranch-house.

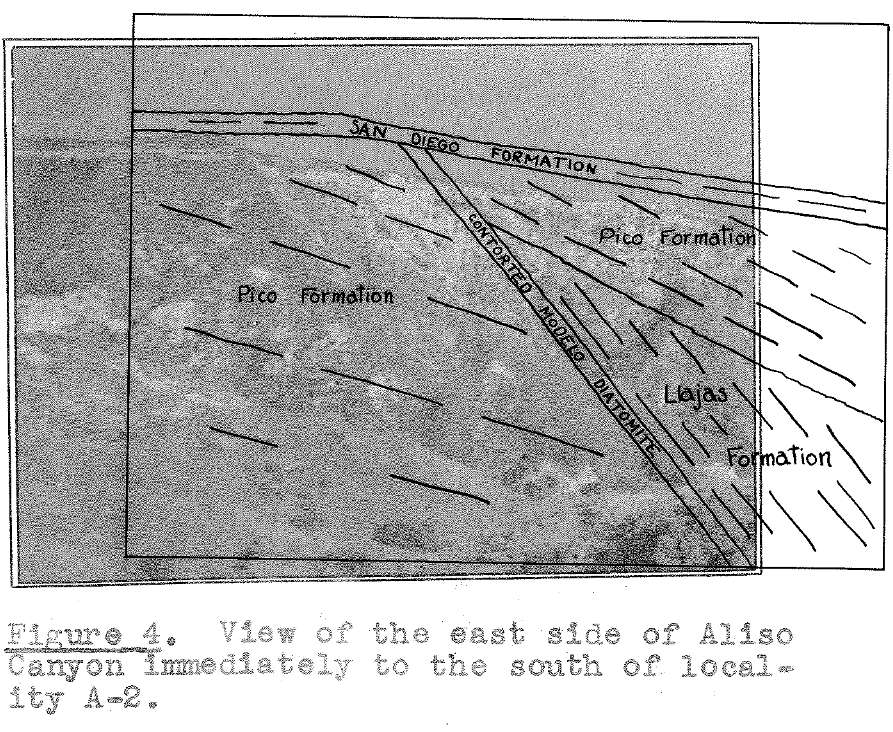

Figure 4. View of the east side of Aliso Canyon immediately to the south of locality A-2.

just north of the Brugher fault. From the southeast corner of Brugher's Hill, the Modelo diatomite forms a narrow strip not over 150 feet in width which can best be described as a dike of Miocene Modelo cutting between the Eocene Llajas on the south and the Topanga and Eocene Llajas on the north. Numerous fractures run through this dike-like mass of Modelo diatomite and dip about 50 degrees south. Since this rock is well-preserved, and not crushed into gouge, it seems best to consider it at this point as being bounded by two faults. Just east of locality A-18 a view such as that shown in plate 8, figure 6 may be obtained. Here the diatomite on its north boundary makes a fault contact with the Pico formation. On the south is the fault contact with the Eocene Llajas. The south-dipping fractures seen in the Modelo are probably not bedding planes but, most likely, foliation planes formed by the flowage of this rock under extreme pressure.

Since the diatomite is found on the southeast of Brugher's Hill in fault contact with the Llajas and Topanga and farther to the west with Llajas and Pico, this evidence would seem to point strongly to the theory that in the history of this fault, movement occurred in one direction which dragged the relatively weak plastic diatomite down along the fracture and then it changed to the opposite direction causing a

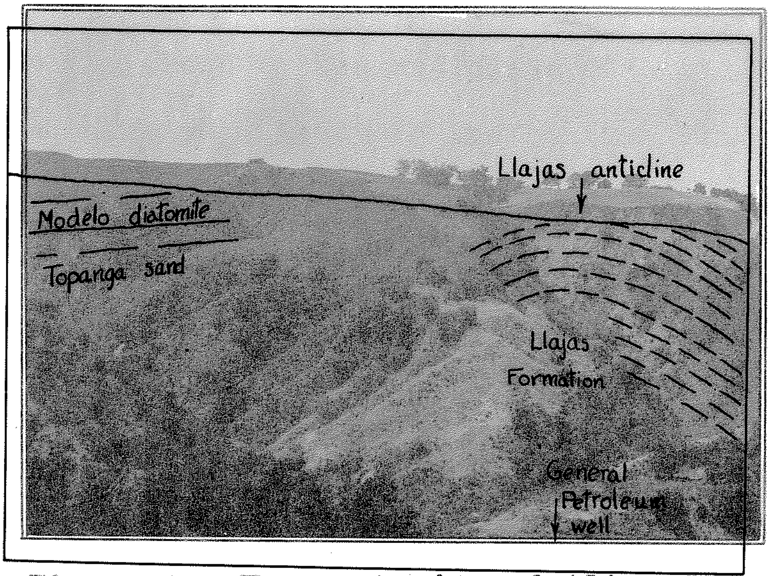

Figure 5. The west side of Aliso Canyon immediately to the north of the Brugher ranch-house.

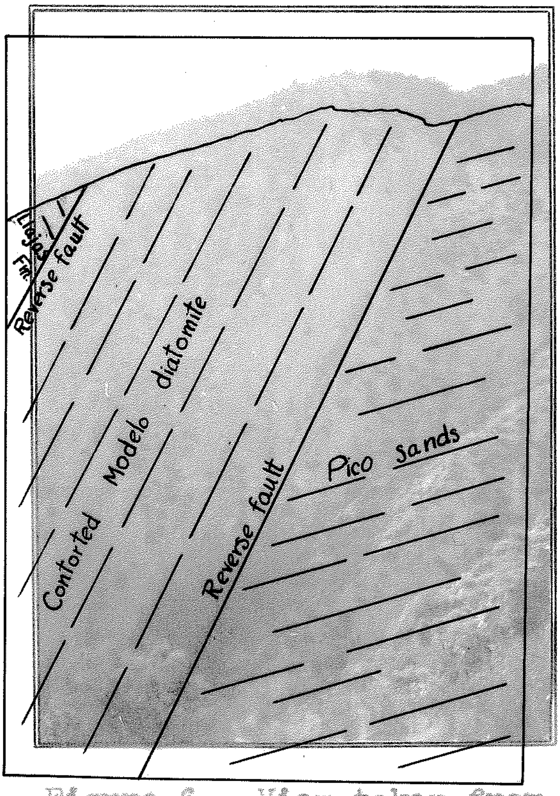

Figure 6. View taken from the southeast corner of Brugher's Hill showing a typical exposure of the Brugher fault.

reversal in the direction of movement of the diatomite.

South of the Holt ranch two faults are exposed: one in the crest of the anticline at locality A-34 and another immediately to the south. Plate 9, figure 7, gives a view of the latter probably of a steep-angled reverse variety. The dip of both of these faults is nearly vertical and they have relatively small displacements. The first has a dip-slip displacement of around 50 feet and the second one of approximately 150 feet.

On viewing Brugher's Hill from the east side of Aliso Canyon it becomes at once apparent that a broad anticline of the San Diego formation caps it. At the north side of the hill the anticline which has become sharper toward the east finally breaks and a minor fault has been formed. This feature can be seen in the east end of the hill as shown in plate 9, figure 8.

Another minor fault appears in the east side of the long mesa-like ridge capped by the San Diego formation and located in the southwest portion of the map west of Las Llajas Canyon. It is a very steep-angled fault of the dip-slip variety which has a displacement of about 100 feet. The writer believes that it can be traced westward into Oil Canyon; to the east it seems to die out.

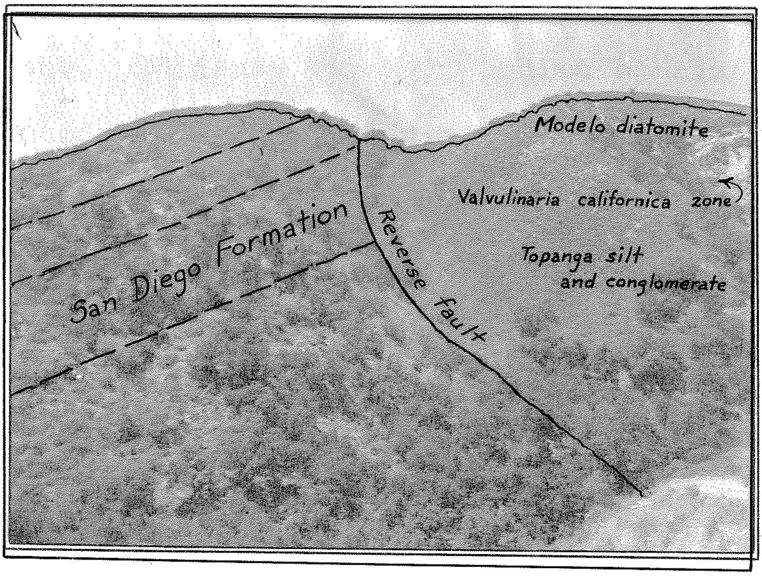

Figure 7. View of a high-angle reverse fault on the Holt ranch immediately north of locality A-2.

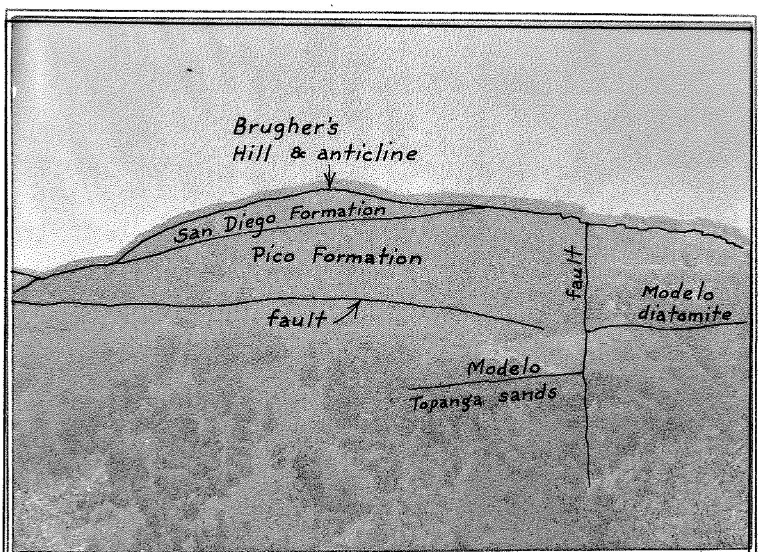

Figure 8. The eastern end of Brugher's Hill.

In Toro Canyon and between the north and south Llajas faults, several alternating Saugus and Eocene sands which apparently trend normal to Toro Canyon crop out. Evidence strongly indicates that they are separated by faults that connect with the main east-west fault that cuts off a portion of the northern flank of the Llajas anticline. The almost impenetrable brush and poor exposures make these sands difficult to trace for any distance, and so their boundaries have been dotted on the map to show that they have been recognized.

FOLDING

In describing the folding the method of treatment used in dealing with the faulting seems appropriate here.

The Area North of the Santa Susana Thrust Zone

North of the Santa Susana thrust, in the Thick Section of the Modelo formation, the main structures seem to be rather consistent over the area mapped. Directly north of the thrust zone a recumbent fold appears which has been overturned to the south. An excellent exposure of this fold is visible in the west side of Aliso Canyon near Larson's ranch. As shown in plate 10, figure 10, it is a rather sharp fold. The Santa Susana thrust lies directly in front of it and passes

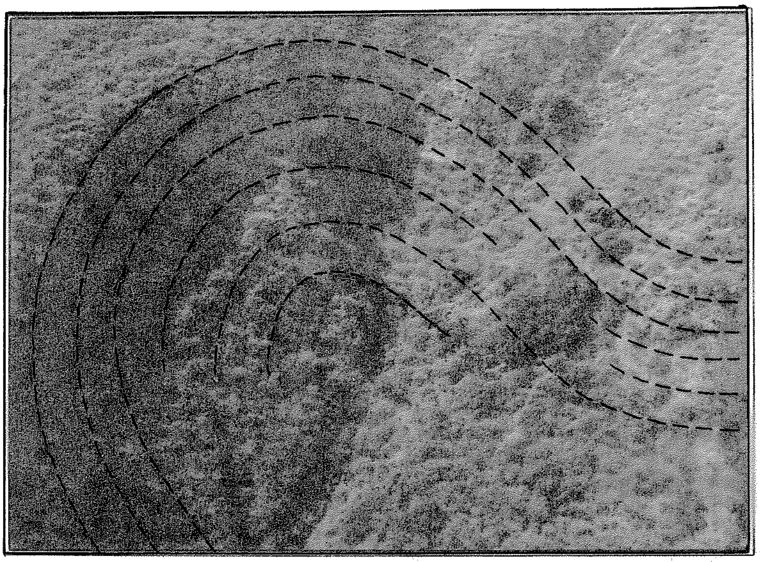

Figure 9. A rather poor view of the intensely deformed nature of the Modelo cherty shales in the overthrust block. Locality near the head of Aliso Canyon approximately 500 feet north of Johnson's ranch-house.

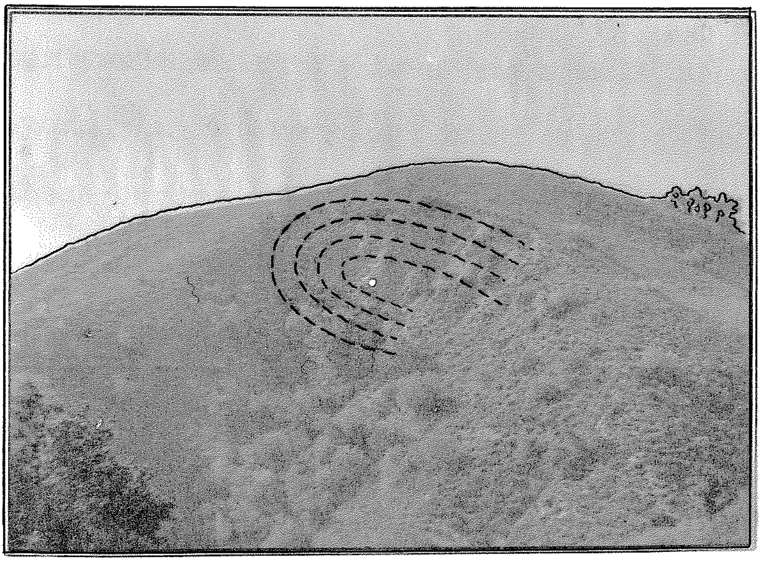

Figure 10. Recumbent anticline near the northern boundary of Larson's ranch.

underneath it. A good exposure of this fold is found near locality A-39. The fold is extremely contorted here as structure section B-B' (plate 2) shows.

As may be seen on the map this fold, as well as others to be described, can be traced for some distance. The tear fault east of Sulfur Canyon appears to cut off this fold to the west. Eastward the fold apparently terminates in the Santa Susana thrust zone.

The next fold of any mapable proportions occurs some distance to the north of the previously described fold. It has been named the Santa Susana anticline and apparently extends for quite some distance in the usual northwest-southeast direction. The writer believes that it can be traced from a point near the head of Sulfur Canyon southeastward beyond Oat Mountain a distance of more than three miles. The Santa Susana anticline seems to have been offset slightly by the tear fault which follows the middle branch of Aliso Canyon. An interesting thing about this fold is that the beds become overturned toward the southeast near the Santa Susana thrust. At the head of Sulfur Canyon, outcrops in the west wall indicate a very symmetrical anticline (see section B-B', plate 2). Southeast, though, where the Santa Susana anticline is exposed in Aliso Canyon it has become overturned. Plate 6, figure A, gives a typical view of this fold cropping out in the west wall of Aliso Canyon above Johnson's ranch and structure section C-C', plate 2, shows a cross-section of it. Along the fire road leading to the Oat Mountain fire lookout station this same anticline may be recognized again. The Santa Susana anticline is particularly well exposed in another fire road to the east of the Oat Mountain lookout. In this area, as shown in structure section D-D', plate 2, the anticline is very symmetrical.

On the west side of Sulfur Canyon, near its head, a portion of a fairly symmetrical anticline may be seen. This fold is terminated on both its northwest and southeast extremities by the zone of tear faults running up Sulfur Canyon. The relationship of this fold to the others to the east is not known.

A syncline which is overturned to the south lies between the two anticlines just described. The western extremity of this trough seems to be just east of Sulfur Canyon where it is apparently cut off by a tear fault. In this locality there appears to be no overturning. Eastward some overturning along the fold seems evident. The fault which runs up the middle branch of Aliso Canyon seems to have offset the syncline for some 1000 feet in a horizontal direction. When the syncline is again picked up it appears as a symmetrical trough. Again, offsetting seems to have taken place by the fault running up the east branch of Aliso Canyon. The small syncline found just south of the main anticline on Oat Mountain may be an eastward extension of the same feature.

West of Sulfur Canyon, the rocks, although they are of the same lithology, have not suffered nearly as much distortion as those to the east. North of the Santa Susana anticline which trends just south of the crest of the Santa Susana Mountains, a monoclinal structure is evident. The rocks dip northeast at about 30 degrees. This steepness of dip increases northward beyond the boundary of the map.

Summary

From the preceding discussion the structure of the overthrust block may be summed up as follows: It is a closely folded and faulted area composed mainly of incompetent Modelo cherty shales (that portion mapped). Most of the faults are of the strike-slip variety and are commonly known as tear faults. They trend perpendicular to the strike of the overthrust zone and cause considerable offsetting both in the block itself and in the overthrust zone bounding it on the south. In certain localities this gives to the overthrust mass an en echelon appearance. For the sake of simplicity the block may be roughly divided into three parts: That west of Sulfur Canyon, that between Sulfur Canyon and the eastern branch of Aliso Canyon, and that portion remaining which is to the east. Very little folding may be found in the first division and a monoclinal structure is indicated by the beds dipping consistently north at approximately 30 degrees. In the middle section the structure is quite complex but in general it may be said that directly north of the Santa Susana thrust zone an anticline occurs which is overturned to the south. North of it lies a syncline whose eastern portion seems to be overturned in the same direction. Farther north this trough changes into another fold, the Santa Susana anticline, which it is thought can be traced to the eastern limit of the map. Its central portion is apparently overturned to the south. East of Aliso Canyon lies an area so intensely faulted and folded and covered by slump that the structure can not be made out with any degree of certainty.

The Area South of the Santa Susana Fault Zone

The most prominent fold in this portion of the area is the Llajas anticline. On its northern flank as shown in plate 8, figure 5, dips up to 75 degrees have been discovered. This structure plunges west and extends from Aliso Canyon into Las Llajas Canyon where it runs parallel to the latter canyon for some distance before dying out in the area immediately west of locality A-60. The eastern extremity of the Llajas anticline apparently is bounded by the Santa Susana fault. Near the junction of Toro and Las Llajas canyons the axis of this Llajas fold has been displaced a short distance by that fault which cuts its southern flank. West of this point local disturbances of the strata make the structure difficult to trace.

To the south of the Llajas anticline lies a broad, open anticline, the Brugher anticline, plunging westward. It is expressed topographically in Brugher's Hill. An excellent view of this feature (see plate 9, figure 8) can be obtained in the east end of Brugher's Hill looking from a point to the east across Aliso Canyon. The fold may be traced eastward across the canyon where it passes south of Holt's ranch-house. Beyond this locality it becomes distorted and finally ends in the Santa Susana thrust zone. Immediately west of Brugher's Hill the fold becomes even less pronounced and apparently dies out.

Another major fold, a westward-plunging anticline, formed in the Chico sandstones, appears at the northwest corner of the area of outcrop of this Cretaceous formation. There the sandstones may be seen to plunge under the younger Martinez conglomerates.

The most extensive syncline in the area south of the thrust zone, the Happy Camp syncline, is exposed in the top of the ridge running east-west across the southwest portion of the map. It is a very broad fold plunging to the west. The structure is visible from almost anywhere in the area but perhaps is best exposed just north of locality A-68 where it has been cut through by Las Llajas Canyon. The San Diego, Pico, and Modelo formations are all seen to have been flexed in this syncline.

A sharp trough occurs in the Martinez conglomerates south of locality A-27. Apparently this feature is somewhat local because it can not be traced for any distance. Its origin is probably due to drag along the Devil's Canyon fault.

In addition to the larger folds many very small unmapable drag folds have been recognized. These are especially well-developed and widespread in the incompetent Llajas and Modelo shales.

Summary

South of the Santa Susana fault zone several folds occur. At least two major anticlines and complimentary synclines have been mapped. These folds trend very much in the same direction as those to the north, although, on the average, their orientation is slightly more east-west. The main difference between these folds and those to the north is that the folding to the south has been less intense. The former, as has been demonstrated, are very sharp in places, even being overturned and faulted and have thus suffered greater distortion. The former are more broad and open.

LANDSLIDES

The eastern end of Brugher's Hill when viewed in profile may be seen to drop off steeply at first, then to level off into a terrace-like feature, and finally to drop off into

Aliso Canyon. Plate 7, figure 3, is a view of this feature taken looking from the north, and figure 9, plate 8, gives a westward view of the same thing. From both pictures one may observe that the terrace does not have a normal slope toward the canyon but, at least in one place, slopes in the opposite direction. An anomalous situation then exists here. Through a careful tracing of outcrops it was discovered that this whole area has at one time, probably fairly recently, slumped downward toward Aliso Canyon, causing a fault to form along its base as shown on the geologic map. Even if geologic evidence could not have been found which had a bearing on the question, the physiographic evidence would be strongly indicative of the existence of a slump. The previously mentioned slope is certainly suggestive: the swampy area enclosed in a basin near the western boundary of the terrace and at the foot of a steep bluff indicates the poor drainage there and the possibility of a wet weather spring.

At one locality north of the Santa Susana fault zone evidence of more slumping was recognized. A rather large area of material (several acres) north of the crest of the Santa Susana Mountains at the head of Sulfur Canyon has apparently slumped down in recent time. It should be noted that the slumping was toward the Santa Clara Valley side of the divide.

Several other areas of landsliding were noted but are too insignificant to deserve discussion.

STRUCTURAL DEVELOPMENT

Some interesting observations were made regarding the structural development, and although they are not conclusive they are suggestive.

The general anticlinal structure of the Santa Susana Mountains is a fact worth mentioning. Reverse dips, overturned folds, and tremendous contortion along their southern flank would seem to indicate that the deformational forces acted in a north-south direction. It seems entirely possible that as Kew (1924, p. 93) says, the main forces came from the north and shoved the weak Tertiary sediments against the strong Chico sandstones forming the Simi Hills. The strike-slip faults trending approximately perpendicular to the dip-slip faults probably were formed by unequal distribution of forces or unequal response to them. Such a situation caused a rough en echelon arrangement of the various blocks into which the Santa Susana Mountains have apparently been divided. Naturally, the incompetent shales suffered the most from these diastrophic movements.

Whether the main Santa Susana thrust formed due to the breaking of the large Santa Susana anticlinal structure can not be stated with any degree of certainty. This main fold does seem too large to have formed as a drag feature along the thrust. Numerous smaller drag features are, of course, recognizable. The fact that the fault trends in general parallel to the anticlinal axes suggests its formation due to the breaking of this compound fold. The tear faults perpendicular to it probably formed at a later stage in the faulting since they do cut and offset the main thrust and the folded structures.

Thus, in summary, it seems likely that forces coming from the north first folded these Tertiary formations. When the limit of elasticity was reached, disruption occurred and overthrusting followed. Many drag effects probably occurred about this time. Then, due either to unequal reaction to the overthrusting forces or unequal application of them, the main overthrust block was broken by tear faults which cut all of the main structures. As has been pointed out previously, the compressive forces are apparently still active.

GEOLOGIC HISTORY

I. Deposition of the Chico formation in Upper Cretaceous time on older rocks of unknown character.

A. Series of sands and silts laid down.

B. Probably uplift accompanied by tilting or folding and followed by erosion.

II. Deposition of the Martinez and Llajas formations in the lower and middle Eocene.

A. Probably subsidence during deposition of the Martinez conglomerates under marine or nonmarine conditions.

B. Continued subsidence and deposition of the marine Llajas silts, conglomerates, and sandstones.

III. Deposition of the Sespe formation from the late Eocene possibly until early Miocene.

A. Emergence and marine regression followed by the deposition under terrestrial conditions of the Sespe formation.

1. Series of silts, sands, and local conglomerates.

B. Probably pronounced folding of the Sespe accompanied by some uplift and erosion.

IV. Deposition of the Topanga and Modelo formations in the middle and upper Miocene.

A. Subsidence and return to marine conditions.

1. Shallow-water marine gravels laid down forming the basal Topanga.

2. Continued subsidence and silts and sands deposited, the uppermost being the Valvulineria californica zone.

B. Probably slight uplift and local erosion of the Topanga silts followed by subsidence and deposition of Modelo diatomites. The Thick Section of Modelo shales and sandstones were laid down under somewhat shallower marine conditions an unknown distance to the north.

C. Gradual shallowing of the area of deposition with the possible occurrence of some local folding and erosion.

V. Deposition of the Pico formation in the middle Pliocene.

   A. Submergence and gradual uplift during which silts and sands were deposited.

   B. At least one and likely two high-angled dip-slip faults were formed by diastrophic movements. Erosion followed.

      1. The Devil's Canyon fault may have been formed at this time. It probably is quite old because it does not affect the topography as do the later faults.

      2. The Brugher fault formed at the end of Pico time.

VI. Deposition of the San Diego and Saugus formations during the middle and upper Pliocene and lower Pleistocene times.

   A. Fossiliferous near-shore deposits laid down above the Pico sands and silts probably following slight subsidence.

   B. Continued deposition in the region probably filling up the lower areas and resulting in nonmarine deposition of sand and gravels.

VII. Strong deformation of the area beginning at the end of Saugus time.

   A. All the sediments folded by compressive forces.

   B. Faulting.

      1. High-angle dip-slip faults formed.

      2. Strike-slip faults striking normal to those of the dip-slip variety and offsetting them probably formed at this time.

VIII. Erosion of the region to late youth or early maturity.

   A. Dissection of the overthrust block and the area immediately to the south by consequent streams.

      1. Larger canyons such as Las Llajas, Chivo, Toro, and Aliso eroded. They may be partially antecedent.

      2. Later development of subsequent drainage along the strike-slip faults and other zones of weakness.

3. Obsequent and resequent streams developed as tributaries to the subsequents.

B. Large quantities of alluvium derived mainly from the overthrust block deposited in the region to the south.

IX. Erosion rejuvenated probably by continued diastrophic movements.

A. Much of the older alluvium removed.

1. Remnants now appear in interfleuves and along several of the streams.

B. In some of the canyons as Sulfur Canyon, inner gorges formed.

X. Younger alluvial deposits now being laid down along the main streams.

XI. Continued diastrophic movements.

A. Older alluvium probably offset by further movement on tear faults as were the main structures of the overthrust block including the Santa Susana thrust zone.

B. Further development of the drainage.

1. The area eroded more deeply.

C. Mass movement of the soil derived from the Modelo cherty shale in the overthrust block.

1. Local landsliding in various places throughout the area.

ECONOMIC CONSIDERATIONS

Petroleum

Up to the present time no producing wells of any notable economic importance have been drilled in the upper Las Llajas Canyon area. Evidences of possible oil accumulations, nevertheless, exist. Further drilling, although it will involve much risk, may meet with success.

The most favorable structures in order of decreasing importance are: (1) The Santa Susana anticline, (2) the Llajas anticline, and (3) the Oil Canyon area lying immediately north of the Devil's Canyon fault.

Mining

On the west side of Las Llajas Canyon where the canyon cuts through the high east-west trending ridge in the southwest portion of the area, is a small lime quarry. At present three men are removing some of the purer phases of the San Diego coquina limestone. The almost pure calcium carbonate is ground, separated into various sizes, and sold to a local market for agricultural purposes.

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