# GEOLOGY OF THE

# PACOIMA-LITTLE TUJUNGA AREA

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Geology at the California Institute of Technology.

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Walter Stanley White

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ILLUSTRATIONS

# GEOLOGY OF THE PACOIMA-LITTLE TUJUNGA AREA

## INTRODUCTION

LOCATION: The Pacoima-Little Tujunga area is located in Los Angeles County, Cal., in the foothills of the western San Gabriel Mountains north and northeast of the town of San Fernando. The bounding meridians are Lat. 34° 17'-34° 20'N and Long. 118° 20½' -118° 24½'W. More precisely, the area includes about 11 square miles bounded by Little Tujunga Canyon on the east, Tujunga Valley on the south, Pacoima Wash on the west, and the Sierra Madre Fault (herein called the Lopez fault, a local name.) on the north. The location of the area is shown in Fig. 1.

PURPOSE OF THE WORK: The work was done in partial fulfillment of the requirements for the degree of Master of Science at the California Institute of Technology.

The primary purpose of the work was to extend knowledge of the stratigraphy and structure of this part of the Los Angeles Basin. It was also considered that the area might be suitable for mapping by students of field geology at the Institute.

METHOD OF FIELD WORK: The geology was plotted in the field on aerial photographs (scale 1500 ft. to the inch) made by the Fairchild Aerial Surveys, but the procedure is not recommended. Ease and accuracy of location are greater, but the labor and inaccurracies of transferring data to topographic maps more than make up for these advantages. With only limited field time and plenty of

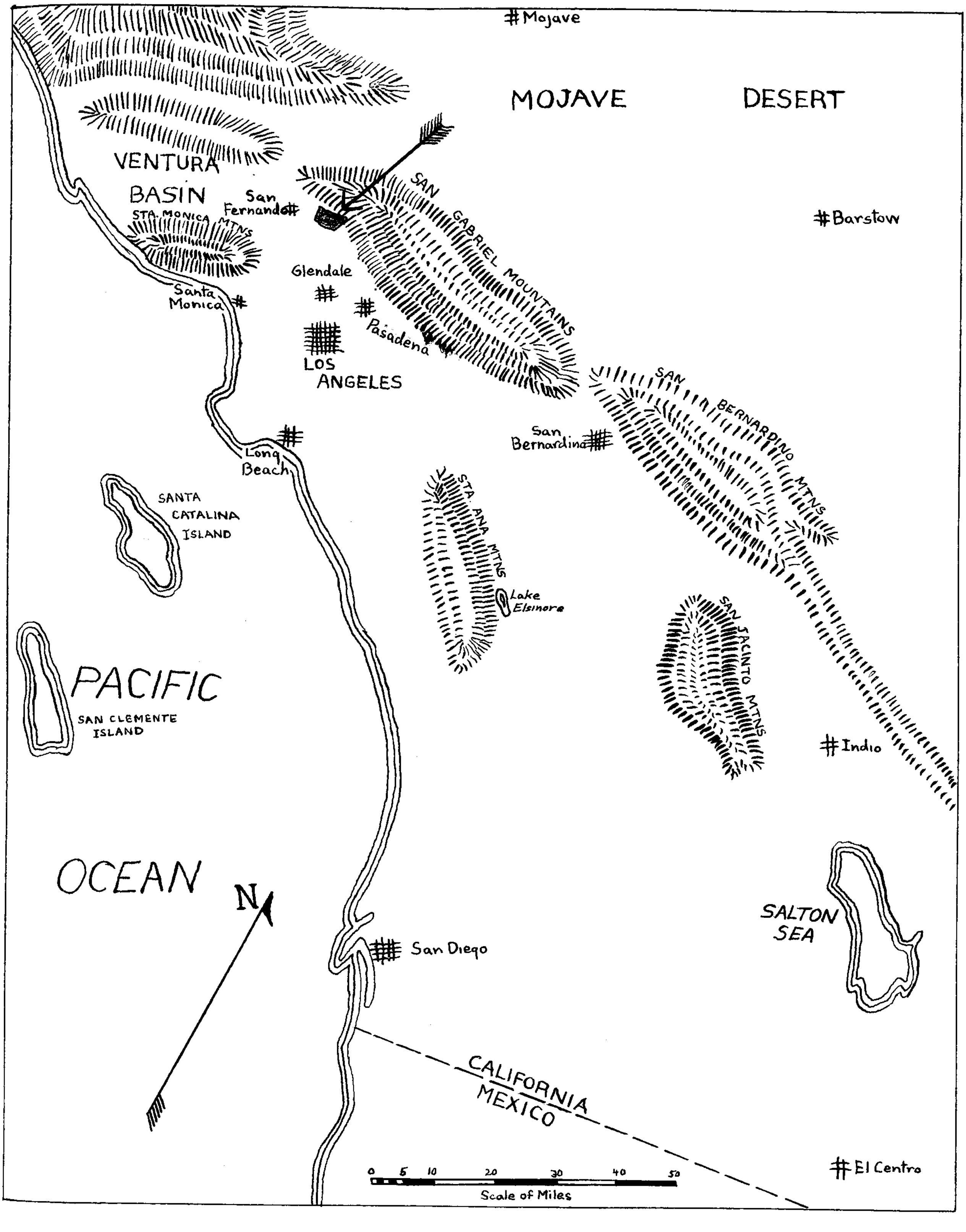


Fig. 1: Index Map of southern California, showing location of the Pacoima-Little Tujunga Area

time to work up results, however, persons will find this method very useful.

Location and measurements of attitude were made with a Brunton Compass.

Six weeks in the summer of 1936 and occasional days during the academic year 1936-37 were spent in the field, making a total of about 50 days of actual mapping.

PREVIOUS WORK: Inasmuch as a very complete summary of previous work in the region is given by M.L. Hill[1], it does not seem necessary to give a detailed account of it here. The only recent work of large enough scale to be of signifigance was done by Kew[2] and by Hill.

For purposes of uniformity, the structural nomenclature of the latter worker has been adopted here.

ACKNOWLEDGEMENT: The writer wishes to express his gratitude to Dr. F.D. Bode, who suggested the area and introduced the writer to the type of problem represented by the work.

TOPOGRAPHY AND DRAINAGE: A large part of the area mapped consists of typical bad-land topography with a rather heavy cover of brush; locally, however, there are large flat areas covered by terrace deposits of several cycles, now deeply dissected.

Relief varies from about 300-500 feet in the southern

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[1] Hill, M.L.--Structure of the San Gabriel Mountains--U. of Cal. Publ. in Geol., vol. 19, no. 6, pp 137-170, 1930

[2] Kew, W.S.--Geology and Oil Resources of Part of Los Angeles and Ventura Counties, Cal.--USGS Bull. 753.

part of the area, where the Modelo and Pico formations are exposed; in the northern part of the area, underlain by Saugus, 100-200 feet is more characteristic; lastly, north of the fault in the basement complex country, it is of the order of 1000-2000 feet or more.

Drainage is principally N-S along Little Tujunga, Merrick, Kagel, Lopez, and Pacoima Canyons and their more or less parallel main branches, but the smaller gullies are subsequent, being adjusted to the general E-W strike of the underlying formations. The streams are all intermittent.

Plate III shows the general appearance of the area.

## STRATIGRAPHY

### Introduction

The rocks of the area are north dipping sediments of Miocene to Quaternary age, bounded on the north by a fault which raises up Pre-Cretaceous crystalline basement rocks into contact with the younger sediments. As a consequence of the north dip, individual horizons have a fairly uniform strike slightly north of west across the entire area.

The relations are roughly shown in the Generalized Columnar Section in Fig. 2.

### Basement Complex

The basement complex in the area is mostly exposed north of the Lopez fault. There are a few masses, presumably thrusted outliers and landslides south of this fault, and in one place in

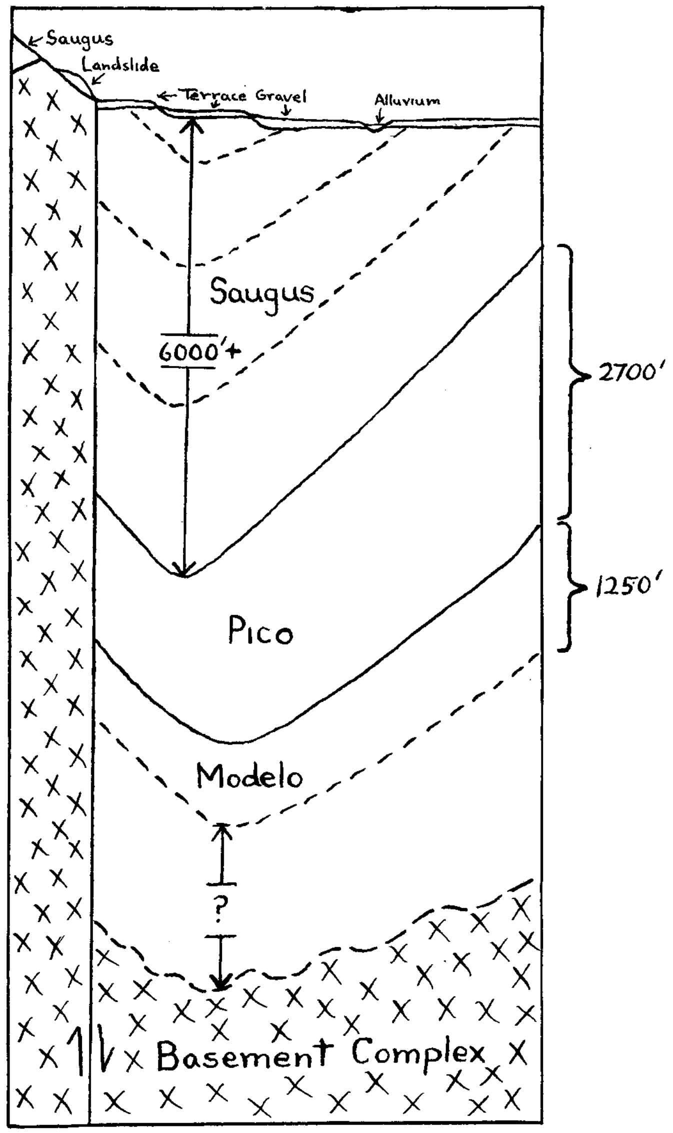


Fig. 2: Generalized Columnar Section of the Pacoima-Little Tujunga Area

Little Tujunga Canyon, a roadcut shows Saugus overlying metamorphics, unconformably in the core of an anticline. The westward projection of this anticlinal contact can be seen in section A-A', Pl. II.

The rock types are highly varied in this district, and no attempt was made to work out the internal structure. Briefly, the complex consists of highly biotitic gneisses and schists of sedimentary origin, diorites, amphibolites, and a rock composed almost entirely of very large crystals of hornblende. This latter rock forms very characteristic boulders in the terrace deposits, but none were noticed in the Saugus. It is exposed in place and as landslide masses at the head of Kagel Canyon. All these rocks are thoroughly cut up by large and small dikes of pegmatite and aplite.

The age of the complex is known to be pre-Cretaceous, but cannot be further delimited.

## Modelo Formation

The Modelo of the area has been subdivided into several stratigraphic units.

Lower Platy Shale: The lowest member of the Modelo consists primarily of a shale made up of hard white plates $\frac{1}{4}$-$\frac{1}{2}$ inches thick, usually with claystone partings. Interbedded with this shale are a few massive white sandstone beds from a few inches to eight feet in thickness, and some layers of punky brown shale.

The thickest section of this unit exposed is about 250 feet thick, but the total thickness may be greater.

White Sandstone: Overlying the lower platy shale is a member composed mainly of massive white or light grey, medium-grained feldspathic sandstone in beds up to 10 feet in thickness. Interbedded with this are some thinner beds (1-3 feet) of coarse tawny or brown sandstone. Between some of the sandstone beds are thin layers of punky shale.

The thickness of this member is 400 feet.

Middle Platy Shale: The lithology of the middle platy shale is the same as that of the lower. In the west end of the area, sandstone makes up a good part of the section. The shales are highly gypsiferous. Plate IV, A, shows the nature of this rock.

The average thickness of this member is 250 feet except just west of Bartholmaus Canyon, as shown in columnar section III, Fig. 3, where it is about 100 feet thick. This thinning accompanies an apparent pinching out of the overlying conglomerate and a thickening of the punky shale above the conglomerate.

Conglomerate: The conglomerate above the middle platy shale is composed of boulders up to 2 feet in diameter, deeply stained with iron oxide, and set in a matrix of brown pebbly feldspathic sandstone. The boulders are surrounded and composed, for the most part, of various types of crystalline rocks, with a few volcanics. Their average size is 4-5 inches. The conglomerate is very well consolidated and stands in cliffs.

Thickness of this conglomerate horizon is from 0-150 feet.

Punky Shale: The highest member of the Modelo over most of the area is a very thinly laminated brown and white punky shale. In

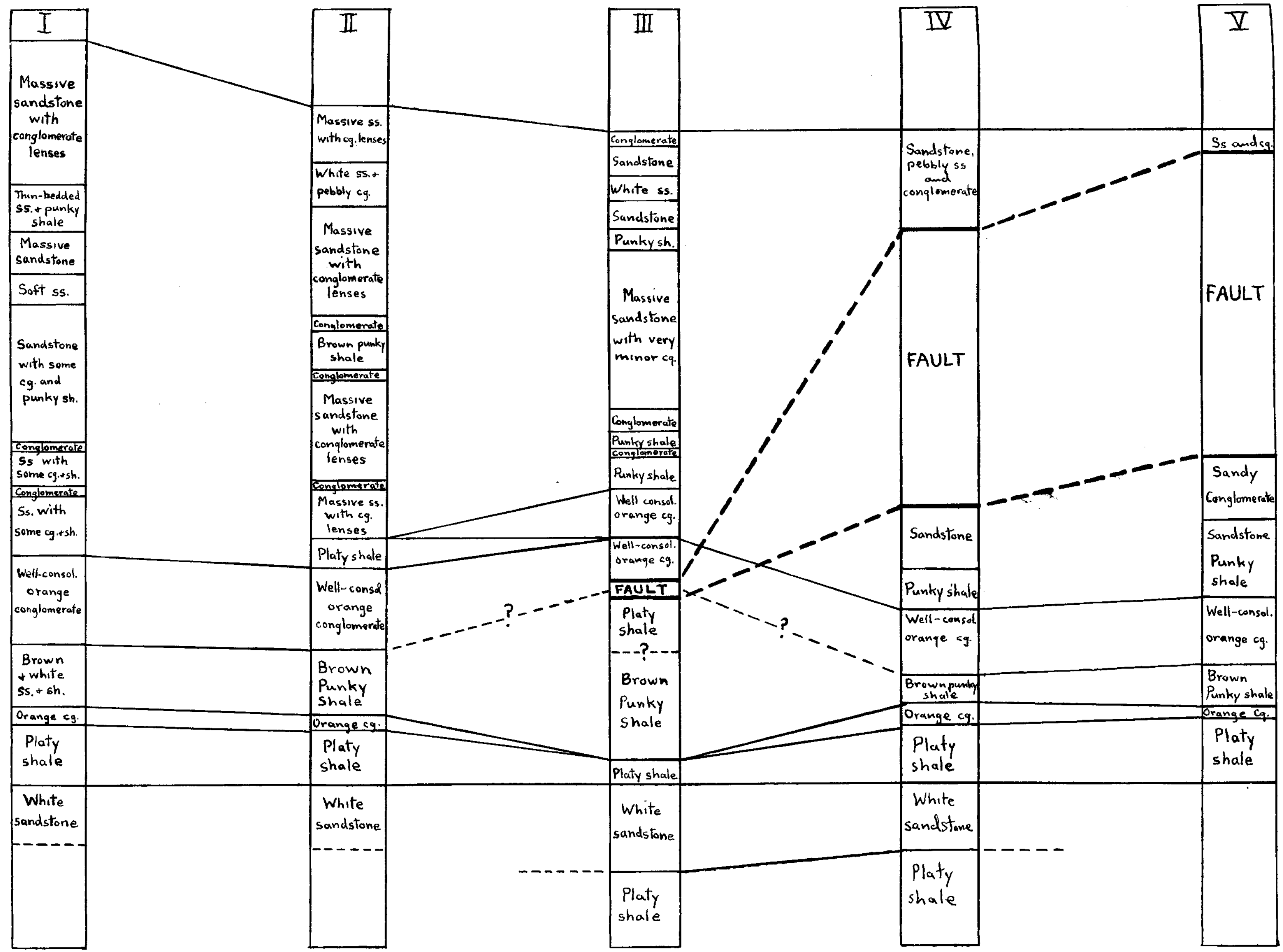


Fig. 3: Columnar Sections of Modelo and Pico Formations

the western part of the area, there is considerable interbedded brown and white sandstone, also thinly laminated.

The thickness of the punky shale is from 200-300 feet, thinning towards the east. Just west of Bartholmaus Canyon, there is exposed in a large cirque-like gully a section of this siltstone which is over 400 feet thick. The conglomerate which elsewhere occurs beneath it is absent, and the middle platy shale is much thinned. It is possible that this represents a lensing, but the writer considers a local unconformity to be more likely. Later it will be demonstrated that the whole section in this vicinity has been thickened by folding, but that this is not the case with regard to this particular horizon is shown by the undisturbed condition of the laminae.

The nature of these stratigraphic relations is shown in columnar section III, Fig. 3.

Upper Platy Shale: Overlying the thickest part of the punky shale between Kagel and Bartholmaus Canyons, the float and one or two gully exposures indicate that there is some typical platy shale, with also some very white, rather well-consolidated bobble conglomerate. Owing to the poverty of good exposures and the erratic attitudes of beds where exposed, no clear picture of the true nature of this occurrence was obtained. The proximity of the Kagel fault and fold to this area may have some connection with its position and character.

SUMMARY OF MODELO:

Thickness: The total thickness of the exposed section of Modelo is about 1250 feet.

Correlation: Lithologically this formation correlates well with the known Modelo of the Santa Monica Mountains and other parts of the Los Angeles Basin.

Age: Fossils found north of the Merrick syncline to the east of the area are stated by Hill as indicating Miocene (probably upper Miocene) age.

Origin: Lithology and fossils from the formation indicate marine origin.

## Pico Formation

The base of the Pico has been arbitrarily assigned to the base of a thick horizon of very well-consolidated iron-stained boulder conglomerate overlying the uppermost platy shales and punky siltstones mentioned above. This conglomerate is lithologically the same as that in the Modelo. The assignation has been made advisedly, since both Kew and Hill assigned the conglomerate bed in the writer's Modelo to the base of the Pico. There are several good reasons for not following this precedent. (1) The lower conglomerate is discontinuous, as shown, while the upper is readily traced across the area. (2) Platy shales, and more particularly, punky siltstones, so characteristic of the Modelo, and only occurring in the Pico as rather thin discontinuous layers, overlie the lower conglomerate. (3) Although the writer has assigned the cause for the apparent thickening and thinning of the shales between the two conglomerates to the folding and faulting in the district, as will be discussed later, it is still possible that the base of the upper conglomerate may be an unconformity, as indeed the writer long believed. (4) Conglomerates occur elsewhere in the Modelo, which makes such an occurrence not at all unlikely.

It is quite obvious that any such separation as the above is purely arbitrary, since the similarity of the two conglomerates, as well as of numerous other beds above and below them show that there was a general similarity of conditions of deposition. It may well be that sedimentation was quite continuous. But there can be little doubt that somewhere in this column there is a transition from the Modelo, with its siliceous shales, to the dominant conglomerates and sandstones of the Pico, and it has been most convenient to make the separation indicated.

Basal Conglomerate: The basal conglomerate is composed of subrounded iron-stained cobbles or boulders, occasionally over a foot in diameter, in a matrix of brown pebbly feldspathic sandstone. The cobbles and boulders are composed of various types of crystalline rocks, with occasional basic volcanic types represented. Consolidation and cementation are well developed, with the result that the conglomerate stands up as cliffs.

The thickness of the basal conglomerate is 300-400 feet. North of the point where the Kagel fault passes out under the valley fill, the conglomerate is about 650 feet thick, apparently due to a rather local lens of the same type of conglomerate in place of the sandstone or shale which commonly overlies the conglomerate elsewhere.

Upper Pico: The part of the Pico overlying the basal conglomerwill be discussed later, it is still possible that the base of the upper conglomerate may be an unconformity, as indeed the writer long believed. (4) Conglomerates occur elsewhere in the Modelo, which makes such an occurrence not at all unlikely.

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Upper Pico: The part of the Pico overlying the basal conglomerate is extremely heterogeneous in composition, and there seems to be a lack of good horizons, as a glance at the columnar sections, Fig. 3, will show. All of the types are highly arkosic.

In the eastern part of the area, most of the section is cut out by the Kagel fault. The exposed section consists of light colored, moderately well consolidated gravels, with some interbedded brown siltstone and punky shale in the lower portions. All of the gravels are highly lenticular with respect to the distribution of coarse and fine material. Some of the boulders in the coarser gravels are as large as 2 feet in their longest dimension. Most of the boulders and pebbles are sub-rounded. There are some massive sandstones in the lower part of the section which are characterized by large (6"-2') oval limonitic concretions.

In the central part of the area, the lowermost 400 feet are composed of fairly well-defined horizons of brown punky shale and light yellow sandstone and conglomerate. Overlying these are 700 feet of very uniform well-consolidated, medium grained, massive tawny sandstone, occurring in beds as thick as 30 feet. There are a few gravel beds up to 15 or 20 feet in thickness interbedded with the sandstone. The sandstones are not very concretionary, and the gravels do not have the intense iron oxide staining so characteristic of the underlying basal conglomerate, although they are more iron-stained than the gravels of the overlying Saugus. The upper 500 feet of the section is composed of interbedded tawny sandstone, white sandstone, brownish punky shale, and light colored gravel lenses.

In the vicinity of Lopez Canyon in the western part of the area, the massive sandstones which make up such a characteristic part of the section in the central part of the area are not so evident, and the whole may be summed up as a series of yellow brown sandstones, brown punky shales, and gravels from 2100-2300 feet thick.

Taking the Upper Pico as a whole, it is possible that horizons could be traced across the area, but the tremendous amount of lateral variation and lensing apparent at once to any worker in these sediments does not make the task an easy one. And after a number of futile attempts to work out a satisfactory correlation along the strike of the beds, it was obvious that the results were not repaying the labor.

SUMMARY OF PICO:

Thickness: The total thickness of exposed Pico is between 2200 and 2700 feet, the latter value being on the west end of the area.

Correlation: The Pico of this area can be traced with few breaks to the great section of this formation in the Ventura Basin to the west, described by Grant and Gale.[3]

Age: Fossils found in the area are stated by Hill to show Lower Pliocene age.

Origin: The Pico is of marine origin. (For detailed account of origin, see Grant and Gale.)

[3] Grant and Gale--Pliocene and Pleistocene Mollusca of California--Mem. San Diego Soc. Nat. Hist., vol. 1, 1931.

## Saugus Formation

Overlying the Pico conformably are almost 6000 feet of remarkably uniform white or very light yellow brown gravels, quite devoid of large scale stratification, and presumably of terrestrial origin. A few thin horizons of shale can be traced for short distances, one for over a mile (just south of the Merrick Syncline in the western part of the area.), but, in general, rapid lensing of coarse gravels into sandstones, pebbly or massive, is characteristic, and any attempts at long distance correlation along the strike are quite pointless.

Briefly, the formation may be described as a series of coarse gravels and sands, poorly consolidated, poorly sorted, almost without bedding, but frequently containing laminated sands. These laminae are due to layers rich in dark minerals, and occasionally are cut off by one another at very low angles. The pebbles or boulders reach a size of a foot or more in some places, and are mostly composed of various types of crystalline rock. They are subrounded. The matrix is highly feldspathic and granular.

The base of the Saugus has been drawn as a sharp line on the map, but actually the contact is transitional. Fundamental lithologic differences between the Pico and Saugus in the area are (1) much lighter color of the Saugus, due to poorer development of iron oxide; (2) poorer bedding and sorting in the Saugus; (3) coarser nature of most of the Saugus sand, that is, the characteristic sand (and gravel matrix) of the formation is made up of very white quartz and feldspar granules; (4) the Saugus is, with some exceptions, more poorly consolidated than the Pico, a fact brought out most prominently by the difference in relief of the terrains underlain by each; (5) shale beds are scarcer and very often pink in the Saugus; and (6) the Saugus pebbles are, in general, slightly less rounded than most of those in the Pico, but the difference is slight.

The first four distinctions are the only ones of any value in field determination, and the contact has been drawn, for the most part, on change of color. This line is, however, parallel to the bedding, which is negative substantiation of the legitimacy of the separation. But there is a zone as much as 200 feet wide on either side of this line in which beds typical of one formation may be found interbedded with those of the other. In addition, there occurs within this zone a very characteristic type of pebble conglomerate and a massive light grey sandstone with abundant development of a white substance resembling caliche along cracks running in all directions through it.

The pebble conglomerate is characterized by very smoothly polished ovoid or ellipsoidal pebbles, usually granitic or pegmatitic, but occasionally of basic volcanis rock, averaging in size from $\frac{1}{4}$-3 inches. The pebbles make up most of the rock, with the matrix merely filling in the spaces between pebbles which touch each other. (See Plate IV B) This matrix is a very white granular arkose, and the individual granules are quite rounded, as opposed to the characteristically angular ones of the typical Saugus. Frequently there is a thin limonitic incrustation on the pebbles.

The smooth polish on the pebbles, combined with the perfection of rounding (in distinction from a high degree of sphericity), suggest that these beds were deposited on a beach, for the following reasons: (1) The immediately underlying Pico and overlying Saugus were obviously laid down relatively rapidly, as shown by relatively poor sorting, rapid lateral variation, roughness of surface and incomplete rounding of boulders, and size of boulders (occasionally over a foot in both formations). (2) The gradual transition from one rapidly deposited formation to the other does not suggest that there was any interval marked by a cessation of this rapidity. (3) The Pico is a marine formation, as shown by fossils, while the Saugus is a typical fanglomerate. (4) Combining the above lines of evidence, in the time during uplift of the land to raise the surface of deposition above sea level, beach deposits are to be expected. Furthermore, even with conditions of rapid deposition, the reworking of material on a beach would produce the rounding and polishing evident in the pebbles of these beds, while rapid deposition in fans or deltas would not.

The above interpretation accords with the marine recession between the Pico and Saugus lithologic types described by Grant and Gale in the Ventura Basin to the west (pp 33 ff.).

Saugus Overlying Crystallines: The Saugus basal contact just considered lies to the south of the Lopez fault, but at the north end of Kagel Canyon, north of the fault, there is a narrow strip of Saugus apparently lying directly on granite, and dipping NW into a branch fault. The basal part of this section, immediately over the granite, seems to be a red clayey arkose which grades upward into interbedded red and white coarse pebbly arkosic sandstone similar to that of part of the Saugus in the eastern end of the area and north of the area in Little Tujunga Canyon.

This occurrence of Saugus directly over crystallines has two possible explanations, neither of which can be locally proved. First, the Pico and Modelo may be missing because of overlap at the edge of their basin of deposition, or, secondly, early movement along the Lopez fault may have allowed stripping of the Modelo and Pico from the basement before deposition of the Saugus here represented. The latter view is favored for the following reasons: (1) Starting at a distance of two miles south of the fault, a section of Pico and Modelo at least 4200 feet thick is exposed, which means, according to the first explanation, that the undeformed basement floor must have dipped close to 20 degrees. The fine grained character of most of the Modelo and some of the Pico does not suggest relief as great as this. (2) Uplift along this or similar faults before Saugus time, and perhaps even periodically from the Miocene on, suggests a possible origin of the relief which must have existed at various times to produce the coarser material now seen in the section.

A second locality of interest in this connection is a road cut exposure in Little Tujunga Canyon in which granite, underlying Saugus arkose, is brought up in the core of one of the anticlines in the folded Little Tujunga section. (See Plate V A) As nearly as can be calculated, this arkose is close to the same horizon as the base of the Saugus over Pico to the south, assuming constant thickness of beds, which may be further evidence for stripping of Modelo and Pico from the basement before the deposition of Saugus.

SUMMARY OF SAUGUS:

Thickness: The thickness of the exposed Saugus is about 6000 feet in the western part of the area. How much more has been stripped away, it is impossible to say.

Correlation: Like the Pico, this section can be traced westward with few breaks to the type section a few miles northwest of here, and is, therefore, quite definitely Saugus.

Age: The age is at least post-Pico, and although there is no fossil evidence, Grant and Gale assign the formation to the Pliocene and Lower Pleistocene.

Origin: Absence of marine fossils and lithologic character indicate a terrestrial origin, probably as a fanglomerate, for the Saugus.

## Terrace Deposits

Unconformably overlying the upturned edges of all of the older deposits are Quaternary terraces. Lithologically the material of these falls into two groups, but in correlation of different surfaces, the separation is probably artificial. The most striking type is a dark brown well-consolidated medium-grained sandstone, with a very few rounded pebbles scattered irregularly through it. It resembles closely bricks of adobe in texture. Occurrences are restricted to the large terrace just west of the Fairview Sanatorium in Lopez Canyon, and several exposures on the ends of ridges just north of the alluvium of Tujunga Valley. It is suggested that this type may represent a residual topsoil.

The other lithologic type is a very coarse gravel with highly angular fragments of crystalline rock, which are definitely recognizable as being derived from the basement north of the Lopez fault. The proportion of matrix to the larger constituents is small, and some of the boulders, particularly in the higher terraces close to the fault, may be as large as 6 feet across. There is no difference between these terrace deposits and the material now being deposited by streams in the area as seen in local washouts.

This second, and commoner type of terrace deposit, is found to make up successive terraces at many different levels down to the present stream bottoms. All are related to the present drainage pattern (except for the highest, whose relations are indeterminable.), although several cases of incipient or potential stream piracy were noted. The highest terrace, stratigraphically, is on top of the hill at the head of Indian Canyon (see Plates III B and V B); ~~it has~~ the gravels have a thickness of 150 feet and can be seen to lie flat over the upturned edges of the Saugus gravels. Below this there are at least four or five different levels marked by terraces, presumably representing a progressive lowering of the base level. The most recent terrace forms a low bench above the present stream channels, and grades, to the south, imperceptibly into the alluvium of the Tujunga Valley fan. The physiographic detail of the area has not been worked out, but would make a complex and interesting problem.

The implications of this progressive lowering of the base level of erosion will be discussed in connection with a possible fault along the base of the hills mapped.

## Landslides

Along the break in slope incident on the Lopez fault, there are, as indicated on the map, several large masses of landslide material from the basement complex which have slid down over the Saugus gravels. These are characterized by hummocky surfaces, occasional small undrained depressions, and a cover of large boulders. The base of the landslide shown to the west of Kagel Canyon (see Plate VI A) is exposed in a fire road cut. It shows evidence of shearing and some mixture of sedimentary with crystalline material. (See Plate VI B)

Just southeast of the sharp change in strike of the Lopez fault, there is a knob of crystalline material surrounded by terrace deposit. It is very strongly sheared up, contains some small rather rounded fragments of various crystalline types, and for the most part is highly feldspathic and does not resemble any of the sediments in the area. The shear planes dip at varying angles, mostly gentle, away from the mountains to the north, and the writer believes that this is a remnant of a once extensive pre-terrace landslide mass.

# GEOLOGIC STRUCTURE

## Introduction

The structure of the Pacoima-Little Tujunga area is treated herein as being the consequence of a single general period of deformation beginning sometime near the earliest Saugus deposition and continuing up the the Recent. (The possibility that deformation began earlier has been discussed in connection with the Saugus which overlies basement.) The reason for this treatment is the absence of definite evidence of earlier deformation, disregarding the orogeny represented by the basement complex as not pertinent to the problem, and the evidence that the stresses applied to the area are all of the same type, to wit, compression in a NE-SW direction.

The dominant structural feature of the area is the Lopez fault, which, as previously stated, is part of the Sierra Madre fault. This fault is considered by the writer to have formed the Merrick syncline by drag, and possibly is connected with the northward tilt of the sediments in the area mapped. The minor faults and folds of the area are related to the same forces.

## Lopez Fault

The Lopez fault, along which basement rocks have risen on the north relative to Saugus on the south, strikes approximately N70°W throughout most of its length across the area, but just west of Little Tujunga Canyon, there is a sharp change to a new direction, N60°E. As will be demonstrated, it is a thrust, dipping about 60 degrees northeast, taking the dip of the sediments on the footwall as indicative of its inclination. The fault surface itself is only exposed in one place, and is seen to consist of a very narrow zone a few inches wide of red gouge. The crystalline rock is badly sheared and crushed, in contrast to the Saugus, which shows only minor disturbance aside from its overturned dip.

Topographically the fault is expressed by a pronounced break in slope, basement standing higher, except where the line of outcrop is cut by canyons (see Plate VII A). No results of disturbance were noted in either terrace deposits or alluvium overlying the fracture, from which it is concluded that the fault has not been notably active in the immediate past. To the east of Sunland, however, for many tens of miles, the fault zone (Sierra Madre) is marked by scarps in the alluvium, and seismic data indicates considerable activity along this section (oral communication from Dr. J.P. Buwalda). This suggests that movement along the Lopez fault may not yet have ceased.

Kew recognized that the general Sierra Madre Fault and its westward continuations are frequently of the reverse type, but he states (p 101) that in the district here discussed, it is normal, dipping south. Hill's whole paper deals with the thesis of reverse faulting in the district and is quite definite as to its reverse nature; this view was independently attained by the writer, although his evidence is rather different. Hill's most convincing (on paper) piece of evidence is quite worthless. He states (p 149) that where this fault crosses Lopez Canyon, it is possible to measure its dip and strike as N65°W, 60°NE. The writer found that exactly in the stream bottom, there is a bend in the dip and strike of the fault, so that measurement of the dip gives values from vertical to 35 degrees northwest and of strike, from N80°W (typical for the fault) to N65°E. This last named strike continues down the canyon for several hundred feet. A possible explanation of this discrepancy in evidence was brought to the writer's attention by his noting that two feet of stream cutting took place here between two visits a month apart (during the rainy season, to be sure). Since the vertical dips are at the bottom of the gully, and the flatter dips a few feet higher up, it is quite possible that at the time of Mr. Hill's visit, the vertical dips were not exposed. This exposure must be viewed with caution, therefore.

Since there are no other exposures of the fault, and since all measurements based on topographic expression are impossible because of masking by gravels or talus, and the sinuous character of the fault surface, evidence as to the nature of the fault must be of another type. (1) Despite Hill's assertion (p. 152) that the Merrick syncline is not a drag fold, the evidence points in the opposite direction. The synclinal axis follows the fault faithfully. Where the syncline is broad and open in the east, it is farther from the fault than where the north limb is overturned in the west. Such a relationship as this seems more than a coincidence, particularly in view of the fact that east of Little Tujunga Canyon (according to oral communication from Messrs. J. Legge and C. Nolte who have mapped this area independently) a similar phenomenon is apparent. (2) Minor thrusts, whose attitudes can be accurately measured, occur as complications of the main fault; in addition, a NE branch of the main fault at the head of Kagel Canyon is definitely a reverse fault. (3) Dips of sediments next to the fault are in all cases to the north, usually between 50 and 70 degrees. The evidence that these beds are overturned will be presented shortly. (4) Lastly it is difficult to picture the mechanics of formation of a normal fault with an angle such as is found west of Little Tujunga Canyon if the compression indicated by the folds to the east in the canyon are considered as part of the same deformation. A reverse fault movement, on the other hand, is capable of producing all the observed effects. To summarize, throughout the area, the deformation indicates compression, and inasmuch as this deformation is intimately associated with the faulting, reverse movement seems a necessary conclusion.

The actual displacement along this fault is very difficult of measurement. One of the difficulties is connected with the age of the fault, that is, if the fault has had periodic movement along it since Pliocene or Miocene, then the total displacement is represented only by the displacement of the pre-faulting beds. But there is no Modelo or Pico exposed north of the fault. Furthermore, correlation of the Saugus north of the fault with that to the south is quite impossible.

Then, too, there is some question, purely technical, to be sure, as to whether the displacement should be calculated from the intersection of beds with the axis of the syncline, that is, the effective displacement, or from the intersection with the fault plane, the actual displacement.

Under different assumptions (as to (1) the amount of the northward wedging of beds, if any; (2) the age of earliest faulting; (3) the pre-faulting topography; (4) the manner in which the beds are projected into the fault, that is, whether parallel or similar folding is assumed; (5) correlation of Saugus north of the fault with that on the south; and (6) the allowance that is made for the depth of cutting down of the basement north of the fault if a hypothetical base of the Modelo is assumed there), values from about 500 feet to two or three miles can be obtained for the vertical displacement along the Lopez fault.

There is no indication of a horizontal component of any magnitude, unless the N60°E section could be shown to be a thrust or normal fault, which the writer was unable to do. Certainly along this latter section there must have been a considerable horizontal as well as vertical component, as the relations of this section seem to show that it is a strike-slip fault.

### Minor Reverse Faults Associated With The Lopez Fault

In addition to flexures in the Lopez fault, such as that described at the head of Lopez Canyon, there are several masses of crystalline basement rock south of the line of the main fault which can be shown to be wedges thrust out over sediments.

The largest of these is just east of the head of Merrick Canyon. Its thrust nature is demonstrated by the record of a well drilled on the prong shown extending south on the west side of the mass; this hole was started in granite, and, according to the present owner of the property, encountered sediment at depth. The well is 200-300 feet deep. The mass is presumably bounded by strike slip faults, but these were not exposed. The evidence that the Lopez fault passes behind this mass and that it is not merely a sharp tongue in a groove in the fault plane is purely topographic.

A smaller mass occurs on a knob just east of upper Kagel Canyon. Here, in an excellent exposure, two thrusts are visible, along which crystalline rock has been faulted over Saugus. (See Plate VII B) One of these, whose attitude is N10°E, 15°SE, terminates at its intersection with the other, which strikes N70°E and dips 50°NW. The faults are marked by a shear zone of iron-stained gouge derived from the crystallines which is, in places, over 5 feet thick. This granite mass is separated, on the surface, from the Lopez fault by a thin strip of north dipping Saugus, but owing to masking by talus and alluvium, the relations to this strip are not apparent. Whether the sedimentary strip overlies the basement slice unconformably, or is another fault slice itself, the formation of the crystalline knob is undoubtedly due to minor thrusting in front of the major Lopez fault.

Similar relationships probably exist in the small mass of basement rock shown just east of the largest mass first described, although no faults were seen.

Another type of associated fault is represented by that shown north of the main fault at the head of Kagel Canyon, along which, as usual, basement rocks have been thrust south over Saugus. Good exposures along a fire road show that its dip is 70°NW and its general strike N65°E. (See Plate VIII A) Most of the strikes obtained directly are about N80°-85°E, which means that either the fault has sudden jogs in it, or else it is cut by small cross faults. The zone of gouge is only a few inches wide, and the crystallines are far more badly broken up than the footwall sediments.

An inspection of the map suggests that the total displacement of the Lopez fault west of Kagel Canyon is taken up to the east partly along this fault and partly along the Lopez proper, since here the northwestern hanging wall has risen relative to the footwall. This probably explains the greater intensity of folding of the Merrick syncline west of Kagel Canyon.

## Minor Folds Associated With The Lopez Fault

Just west of Lopez Canyon, as indicated on the map, there is a small west-plunging overturned anticline, which is apparently intimately associated with the fault movement, and is probably a drag fold.

The folds in Little Tujunga Canyon represent a greatly diminished continuation of the compression represented just to the west by the Lopez fault.

## Merrick Syncline

The Merrick syncline is a major structural feature, more or less parallel to the Lopez fault, whose axis occurs south of the fault from 3000 feet in the east to a few hundred in the west.

In tracing the beds on the north limb from east to west, progressive stepening and finally overturning is noticed---a fact well brought out in the geologic structure sections (see Plate II). Because of the almost isoclinal character of the fold in the western part of the area, there is often some difficulty in locating the axis, but a diligent search usually reveals some clue, such as a place with very local south dips, or even a place where, in a few feet horizontally, the change in attitude can be followed. Since the formation lacks good horizon markers and good indicators of top and bottom (high angle cross laminations, ripple marks, mud cracks, etc.), the structure must be traced from east to west, step by step, in order to demonstrate its character and relationships west of Kagel Canyon. By doing this, however, the overturned nature of the fold to the west can be definitely proved.

In the central part of the area in particular, an additional feature worthy of note is the progressive overturning north from the synclinal axis to the fault. (See Section B-B', Plate II)

In the eastern part of the area, the broad open nature of the fold has been indicated by means of a secondary branch axis, representing a rather minor, but perceptible, change in strike.

The plunge of the syncline is, in most places, between 15 and 30 degrees westward.

## Kagel Canyon Fault and Fold

The deciphering of the structure involved in the Kagel Canyon fault and fold constituted one of the most difficult problems of the area. The fault strikes N70°E and passes through the south end of Dexter Park. The only exposure (on the west side of the hill just west of the mouth of Merrick Canyon) where the dip could be measured showed that it was 60° SE, a value supported by the topographic expression of the fault. It is readily observed from the map that the south side has moved up relative to the north, which means that the fault is reverse. A displacement of the Saugus-Pico contact is suggested in Merrick Canyon, but the vague character of this contact makes it difficult to prove. The southwest end of this fault is shown in Plate VIII B.

The most remarkable feature of this fault is that the stratigraphic displacement of the top of the Modelo white sandstone member is only 300 feet, while that of the base of the Pico, a few hundred feet higher, is some 600 feet.

The fold (well marked by the outcrop pattern of the Modelo conglomerate bed as shown in Plate IX) comprises a west plunging anticline on the north and a syncline on the south. The south limb of the anticline (north limb of the syncline) dips vertically, while the other limbs dip 45 degrees or less to the north. Treated as a drag fold, it indicates relative south movement of upper beds over lower.

The chief problem in connection with this structure is the apparent differential displacement of the two horizons mentioned above. The difference is obviously taken up in the fold, that is, the thickening represented by the folding of competent conglomerate and the incompetent "flow" of the overlying shales is sufficient to explain the form taken by the 300 foot difference in displacement. The manner in which these relationships were brought about, however, and the forces which produced them are more difficult to picture. Possible explanations fall into two main groups with subdivisions.

A. The Tilting is Earlier or Contemporaneous with the Folding and Faulting.

(1) The fold is later than the fault.

This need not be considered as any relative southwest movement of upper beds over lower sufficient to produce the fold would have disturbed the fault.

(2) The fold is contemporaneous with the fault.

The implication of this statement is that both are the result of the same forces. The drag fold indicates a force acting upward and to the south. It is conceivable that such a force might produce in one place a shear parallel to the bedding, which might not be apparent, and as a consequence, there would be no thickening normal to the bedding; while in another place, the friction between beds might be sufficient to cause local drag folding, and hence thickening, There would, then, be a tendency of the beds overlying the thickened portion to rise relative to those over the portion which was simply sheared and not thickened; and this tendency would give rise to differential movement between the two portions, the result of which is faulting. Application of this principle to the case in hand is as follows: The tilting of the beds towards the north produced a shearing couple, the upper parts tending to move south over the lower. The effect of this couple on the northwest side of the Kagel fault was bedding plane shears, which are usually undetectable. On the southeast side, however, folding took place, the section was thickened, and the differential movement between the thickened and unthickened areas caused the movement now evident along the Kagel fault.

The shearing couple must have acted more or less parallel to the Kagel fault, because it is obvious that faulting would go hand in hand with folding, and it is difficult to picture a couple acting across the fault without affecting it.

(3) The fold is earlier than the fault.

Movement along the fault was such that it brought to the level of the present surface an older structure (the fold) which continues at depth or at some level above the present surface on the opposite side of the fault. This movement must have been essentially in the plane of the regional dip, whether it was up or down, so that the southeast "bulged" (by folding) zone was roughly adjacent to its stratigraphic equivalent on the opposite side of the fault.

Under this assumption, the displacement is slightly more horizontal than vertical, since the fault makes an angle with the 45 degree average dip of the sediments, but the amount of movement and determination of which block actually moved up is almost impossible.

The possibility that the fault is later than the fold raises the question of the age of the fold. As an inspection of the map readily shows, the stratigraphic distance between the Modelo conglomerate and the base of the Pico in the vicinity of the fold is highly variable. There are three possible explanations of this: (1) Lensing, which undoubtedly plays some part, as the columnar sections show; (2) An unconformity at the base of the Pico, that is, the fold is pre-Pico and there was erosion before the deposition of the Pico---there is no evidence of such an unconformity elsewhere in the area, no fragments of Modelo were found in the overlying beds, and beds above and below are of very similar type, indicating little or no fundamental change in conditions of deposition; (3) Solid "flow" of the shales between the two competent conglomerates---this seems quite possible, but due to poor outcrops, no convincing evidence can be brought forward.

B. The Tilting is Later than the Folding and Faulting.

The consequences of this assumption are merely to change the dip of the fault from SE to steep NW and make the fold steeply overturned at the time of formation, assuming an average tilt of 45-50 degrees toward the north. The fundamental relationships implied in the first set of assumptions are unchanged. The couple which formed the Kagel fold, however, is exactly the same type that would be produced by the tilt and formation of the Merrick syncline, suggesting that the tilting is part of the general deformation of the area.

Summary: From the evidence available in the area, the writer was unable to determine which of the favored views (A2 and A3) is correct. Either one is possible, and inasmuch as the direction of movements under either assumption may be almost the same, good distinguishing criteria are difficult to develop.

## Minor Fault

A small fault with a displacement of about 100 feet and unknown attitude is shown to the west of, and parallel to the south end of the Kagel fault. The north side has risen relative to the south, and the outcrop is marked by slight displacements and crumpling of shales.

## Possible Foothill Fault

The straightness of the topographic line between the top of the fans and the southernmost foothills suggests a possible fault at or close to the break in slope. This line cuts across the horizons in the Modelo to some extent, and is, therefore, not due to mere differential erosion. It stands some 200 feet above the present course of Tujunga Wash, and there has, for a considerable period of time, been more than enough material supplied from the mountains to keep this wash on the opposite side of the valley; therefore, it does not seem likely that an E-W stream cut the break in slope.

The manner in which Kagel and Little Tujunga Canyons widen out to the north in the relatively uniform Saugus material suggests an upward movement to the south. The repeated cutting of higher terraces and formation of newer lower ones seems to indicate repeated uplift and consequent dissection.

Lastly, just west of Lopez Canyon, there are exposures of the adobe-like terrace material mentioned above apparently faulted down on the south against Modelo. That this rock is not part of the Modelo at this point is shown by inclusions of bits of platey shale, flat dip; and comparison with similar rock elsewhere. A combination of evidence indicates that the contact is a fault. (1) To fit the topography, the contact must be very steep or vertical. (2) If such a contact were depositional, coarser material of the nature of talus would be expected in the adobe. (3) The contact across three ridge terminations is quite straight.

Hill mentions a doubtful correlation of certain horizons across Tujunga Valley, indicating a displacement of the nature postulated, that is, the south side down relative to the north.

The nature of such a fault, whether normal or reverse, is only a matter of speculation, but the evidence that some sort of displacement has taken place close to the foot of the hills seems quite definite.

## GEOLOGIC HISTORY

(1) Pré-Cretaceous. Formation, metamorphism, and erosion of the basement complex.

(2) Miocene and Pliocene. Deposition of the Modelo and Pico under marine conditions.

(3) Gradual uplift, formation of beach deposits, followed by terrestrial deposition. Faulting in the Sierra Madre zone may have begun at or before this time.

(4) Pliocene to Pleistocene. Faulting along Lopez fault, probably all during Saugus deposition, causing tilting, folding and minor faulting throughout the area.

(5) Quaternary. Erosion accompanied by faulting along Lopez Fault. Different uplifts represented by successive terraces. Possible

movement along a Foothill fault.

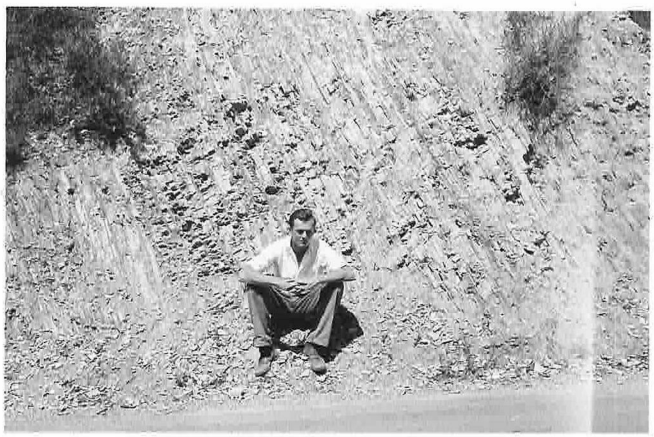
(6) Recent. Present stream erosion, and deposition.

PLATE III

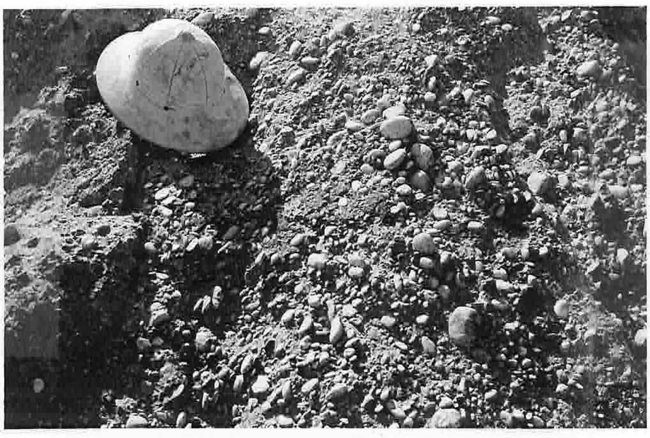
A. View of southern part of the area from Tujunga Valley


B. View of the Area from the San Gabriel Mountains (Gravel capped hill marked on the photograph is described on page 19)

PLATE IV

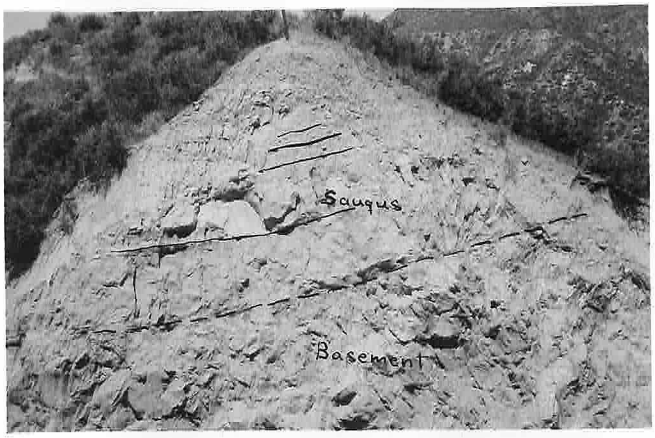


A. Roadcut exposure in Kagel Canyon showing characteristic appearance of the Modelo siliceous shale



B. Roadcut exposure just west of Dexter Park showing the appearance of the "beach gravel"

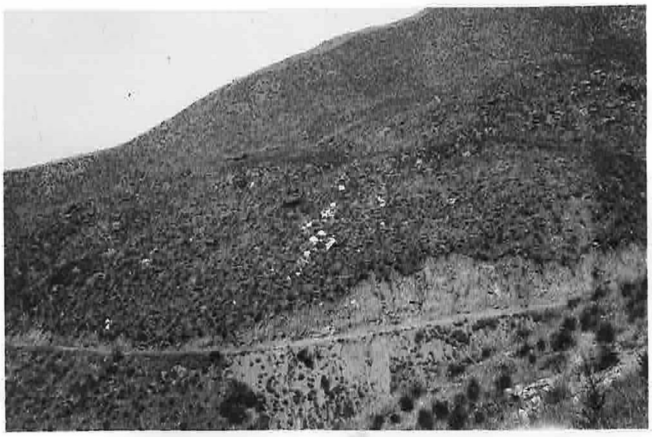
PLATE V




A. Roadcut exposure in Little Tujunga Canyon showing Saugus unconformably overlying crystalline basement rock


B. View from Lopez Canyon of the hill at the head of Indian Canyon

PLATE VI



A. Landslide at the west side of the head of Kagel Canyon


B. Exposure of the base of the landslide shown above, south end

PLATE VII

A. View looking north across Lopez Canyon of the break in slope characterizing the outcrop line of the Lopez Fault


B. View from the south of the thrusted outlier at the head of Kagel Canyon

PLATE VIII


A. Gully exposure of the branch fault north of the Lopez Fault (fault surface dips away to the north from the point of observation)


B. View from Tujunga Valley of the foothills, showing the location of the southern end of the Kagel Fault

PLATE IX

Modelo Conglomerate in the core of the Kagel Anticline