Structural Geology of the Region between Pacoima and Little Tujunga Canyons, San Gabriel Mountains, California.

Thesis by

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Most of the area mapped lies within the jurisdiction of the U. S. Forest service. The author appreciates the help of the several rangers in the region who aided the work materially by granting permission to use certain of the forest service roads and other favors.

ABSTRACT.

An area of about 25 square miles in the western part of the San Gabriel Mountains was mapped on a scale of 1000 feet to the inch. Special attention was given to the structural geology, particularly the relations between the different systems of faults, of which the San Gabriel fault system and the Sierra Madre fault system are the most important ones. The present distribution and relations of the rocks suggests that the southern block has tilted northward against a more stable mass of old rocks which was raised up during a Pliocene or post-Pliocene orogeny. It is suggested that this northward tilting of the block resulted in the group of thrust faults which comprise the Sierra Madre fault system. It is shown that this hypothesis fits the present distribution of the rocks and occupies a logical place in the geologic history of the region as well or better than any other hypothesis previously offered to explain the geology of the region.

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I. INTRODUCTION.

Location.

The area described in this report is located on the southern edge of the San Gabriel Mountains north of the city of Los Angeles. Its center is approximately twenty-seven miles north-northwest of the Los Angeles City Hall. The area consists of parts of that shown on four United States Geological Survey topographic maps. Most of it lies in the northern half of the Sunland quadrangle and the southern half of the Little Tujunga quadrangle, while its western edge lies in adjacent parts of the Pacoima and Sylmar quadrangles.

Its southern boundary approximately follows California State Highway 118, Foothill Boulevard. The western margin lies just west of Pacoima Creek; on the north the boundary is at the northern edge of sections 15, 16, 17 and 18, T3N R14W, referred to the San Bernardino base line. The eastern border is at longitude 118° 20' west. The tract is roughly a rectangle $4\frac{1}{4}$ miles wide and $5\frac{1}{2}$ miles long.

Previous geological work.

Four previously published geological reports include descriptions and maps of this area. The earliest of these is Kew's paper (1924*), "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California". The area discussed in the present report is shown on Kew's map on a scale of 1/62,500. The most detailed previous treatment is that of Mason L. Hill (1930). Hill described a region which includes that of this report, and mapped it on a scale of approximately 1/31,250.

William J. Miller (1934) treated the area in his paper, "Geology of the Western San Gabriel Mountains of California". His map, on a scale of 1/85,000, does not distinguish between the different sedimentary formations, but does discriminate between different elements in the crystalline basement. Considerable reference to the district is also made in his paper "Geomorphology of the Southwestern San Gabriel Mountains of California" (1928). G. B. Oakeshotte (1937), in his report, "Geology and Mineral Deposits of the Western San Gabriel Mountains, Los Angeles County", includes all of the district described here, most of that mapped by Hill, and much of that mapped by Miller.

Reason for remapping the region.

Considering how much excellent geologic

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* All references are given at the end of this paper, listed alphabetically under the author's name and the year of publication.

work has already been done in this vicinity, it may be asked whether another mapping is required. The justification arises from the geologic importance of the region. Within it are two of the major fault systems of southern California, the San Gabriel and Sierra Madre-Santa Susanna-San Cayetano fault systems. They come within a mile of each other at the surface, possibly closer at depth; and their branches may even intersect. The region lies on or close to the northern edge of the Los Angeles basin, a major depositional trough during most of the Tertiary. It also includes what may possibly have been at times part of the land mass supplying the sediments for this basin. It is one of the few regions along the edge of this trough where the contact of the sedimentary rocks on the basement is exposed, and not either covered by alluvium or faulted out. For these reasons it is a crucial location for revealing the structure of a complicated region.

It was felt that a more detailed study might bring to light features which were not revealed by the earlier, more general surveys. The principal problem was to determine, if possible, the relations between the two major fault systems mentioned above. In attempting this the region was remapped on a scale of 1/12,000 using two times enlargements of new United States Geologic Survey topographic maps, which were not available when the earlier work was done, to make a base map. This map is in the folder at the back of this report.

This survey did not uncover any major structural features overlooked by previous investigators. The map differs from Hill's (1930), which is the most detailed previous publication, only at a few places; and the differences are of a minor nature. It has, therefore, been possible to retain the stratigraphic and structural nomenclature of the earlier reports, with only a few minor additions. These terms will be defined in the appropriate sections below. The names of the sedimentary formations are those used by Kew (1924), those of the crystalline rocks were given by Miller (1934). On the geologic map accompanying this dissertation, however, the different members of the crystallines are not mapped separately, but are grouped together as the "basement complex". They consist entirely of metasediments and intrusives of the San Gabriel formation. The amount of structural information bearing on the principal problem of this study to be gained by mapping the basement members separately did not seem to justify the work required to trace out their obscure contacts in this region, where these contacts are poorly exposed, especially since all members of the basement complex appear to have behaved in the same manner to the Cenozoic deformation with which this investigation is primarily concerned.

II. PHYSIOGRAPHY.

Big Tujunga Valley.

The tract described in this report lies along the southern edge of the San Gabriel Mountains, which are one of the Transverse Ranges. The southern edge of the range is separated from the San Fernando Valley by the Verdugo Mountains and Pacoima Hills. Between this ridge and the San Gabriel Mountains lies a deep valley that is occupied south of the Little Tujunga watershed by the flood plain of Big Tujunga Creek, which when it is not all impounded behind Hansen Dam, drains between the Pacoima Hills on the west and Verdugo Mountains on the east into San Fernando Valley. Pacoima Creek drains in the same direction past the west end of the Pacoima Hills.

Between these and the foothills of the San Gabriel Mountains lies a low divide that separates the watersheds of Pacoima and Big Tujunga Creeks. This saddle is at present underlain by a thin veneer of alluvial wash from the adjacent ridges of Tertiary sedimentary rocks. At places these project thru the covering as low ridges. Well logs show that the alluvium is only a few feet to a few tens of feet thick at most places, and that the sedimentary material is continuous between the Pacoima Hills and the southern edge of the San Gabriel Mountains. The thickness and character of the alluvium is an economic factor, as where it is thick and coarse surface water rapidly sinks into the ground making ineffective the irrigation of the citrus groves and flower nurseries that occupy the largest part of the cultivated land.

Big Tujunga and Pacoima Creeks are dry except after storms and in the winter, particularly in their lower reaches. However, both have cut for themselves wide channels in the soft sedimentary rocks which lie south of the San Gabriel Mountains. These channels are at present filled with coarse detritus brought down in recent floods, so that the original channels of the two streams are buried. In general the drainage of the area is south from the San Gabriel Mountains to Big Tujunga Creek, though some of the streams die out in the alluvium before reaching the main stream. All the streams are intermittent, though the larger ones have continuous underground drainage, as is shown by pools and running water in the more confined parts of their channels.

At the north edge of the depression described above the foothills of the San Gabriel Mountains rise abruptly along a sharp line. Previous authors have suggested that this sharp physiographic break may be related to a now unexposed fault, named the Tujunga fault (Hill, 1930, p.153; and Miller, 1928, p.210). However, no direct evidence for such a fault has yet been reported, nor does it appear to be required to explain any of the geologic features observed in the area. On the contrary, slope retreat of the type typical in a desert cycle of erosion may be adequate to explain the present aspect of the mountain front. Such a cycle need not be initiated by faulting, though this is common (See for instance Gilbert, 1928, p.1-8; Cotton, 1945, p.256-7). To quote Cotton:

> "Thus the mountain slopes retreat not only from lines parallel to the initial outlines of tectonic blocks but also from the sides of eroded valleys which have been cut by ravines in the early youth of the landscape, and which develop in this way flat floors. The line along which back wearing causes the base of the slope to retreat is not horizontal but slopes up, so as to leave a rock surface with a sufficiently steep gradient to allow the debris of further back wearing to be carried across it by floods."

The possibility of a buried fault somewhere under the alluvium is not excluded; but until positive evidence for its existence can be adduced it seems best not to postulate it.

The present pediment may not be entirely of recent origin, as there is considerable evidence that the present Big Tujunga Valley had at one time an alluvial fill at least 150 feet thicker than that which is now found there. On the spurs of the ridges around the mouths of Schwartz and Oliver Canyons remnants of this fill remain. These bodies appear to be parts of a once extensive alluvial fan. Similar deposits occur at the mouth of Kagel

Canyon, suggesting that at one time this fan flanked the whole mountain front for an unknown distance to the west. That this alluvial material is older than that now lying on the surface of the pediment is attested by its more weathered condition, and at places, perhaps where it once was deep, by its partial lithification.

Southern ridge and anterior depression.

To the north of the nick line rises a uniform ridge thru which only the larger streams have succeeded in cutting valleys. This ridge rises about 800 feet above the floor of Big Tujunga Valley. It appears to be an excavated feature, since it is everywhere capped by coarse hard conglomerates and sandstones which have resisted removal better than the softer shales, siltstones and fine sandstones that lie along the south side of the ridge. These beds dip to the north and are overlain by a series of terrestrial sediments, which are often poorly cemented and are generally easily eroded. This results in a marked depression running east-west across the whole area, and having on its south side the dip-slope of the underlying harder beds. This depression will henceforth be referred to as the "anterior depression" because of its relation to the higher land lying just north of it.

Fault block mountains and posterior depression.

The northern side of the anterior depression is marked by a series of faults which separate it from upraised crystalline masses that stand as mountains 1500 to 2000 feet higher than the floor of the depression. These fault blocks are tilted to the north, with sedimentary rocks similar to those found to the south outcropping on the north dipping slopes.

The front is itself broken by faulting, and following these lines of weakness several streams have cut across the blocks, and are rapidly excavating the soft sediments from the surface of the crystallines. As a result of this excavation there is another depression north of this upfaulted ridge similar in some ways to that to the south. This will henceforth be called the "posterior depression". It is a less continuous feature than its southern counterpart because of the division of the region into separate fault blocks along lines cutting diagonally across the ridge of crystallines.

The northern mountains.

The anterior depression is bounded on the north by the members of the San Gabriel fault system, beyond which lie mountains of granitic and metamorphic rocks, rising in the area mapped to a maximum elevation of 3867 feet above sea level. This is a region of mature topography; deep canyons and high, sharp ridges are prevalent. The principal drainage is by way of Pacoima Creek. That this stream is superposed is proven by its meandering course in the bottom of a deep canyon.

Remnants of an old topography.

Although the present drainage south of the San Gabriel fault is largely subsequent to the faulting, and appears to be related to differences in the hardness of the two principal groups of rocks, the soft terrestrial sediments and the hard crystallines, remnants of an older topography are still present. This old surface is clearly discernible on the block east of Little Tujunga Canyon. The summit here is a gently rolling surface containing broad valleys. The streams, which drop off the sides of the block in precipitous, narrow, deep canyons, are rapidly working headward into the upland.

Traces of a similar topography are to be found around the upper reaches of Nehr Creek, a western tributary of Little Tujunga Creek. Much of the Nehr drainage has already been pirated by the expanding Buck Creek tributaries, and only a 35 foot high, 150 foot wide divide separates the whole upper part of the Nehr watershed from another headward expanding branch of Buck Creek.

The fact that this drainage pattern in Nehr Canyon appears to be superposed from some previous condition does not indicate that it is antecedent to the faulting. On the contrary, it is more likely that it became intrenched at some early stage in the erosion of the blocks, and has deepened its channel since then insufficiently to keep up with the more rapid erosion of the surrounding streams. Thus Nehr Canyon may once have occupied the same position relative to the fault block that the lower part of Buck Canyon now occupies; it may have been located at the foot of the dip slope of the sediments on the crystallines. The reaching of a temporary base level of erosion may have allowed this intrenching to take place. Due to the slower wearing away of these harder rocks, the upper part of Nehr Creek, which lies mostly in sediments, has almost reached a local base level. It now has a much lower gradient than the lower part, which drops in a series of waterfalls to the level of its juncture with Little Tujunga Creek, which has cut down rapidly thru the soft sediments in which it flows for almost all of its course below this fork in the stream.

Limerock Canyon bears a similar position in relation to Nehr Canyon. It, too, drains southwestward across the fault block from its northwest-sloping upper surface, and Nehr Creek has pirated this stream's northern tributaries.

Gold Creek is another example of a superposed stream. It drains all of the posterior depression east of Little Tujunga Creek, lying at the foot of a dip slope where the sediments have been cleaned off the north flank of the easternmost of the fault blocks previously mentioned. Just before it reaches little Tujunga Creek, however, it turns sharply southward, and, flowing in a 300 foot deep canyon, runs parallel to Little Tujunga Creek for over half a mile before it finally joins it. At one time the upper part of Little Tujunga Creek may have been tributary to Gold Creek, joining it at the present wind gap 1500 feet south of Reese Ranch. At that time Gold Creek probably followed the contact of the sediments and the crystallines as it does farther upstream. But, once it became intrenched into these hard rocks, it could no longer migrate down the dip slope, and eventually a tributary, working headward thru the softer rocks, captured the main part of the drainage.

Already Little Tujunga Creek is becoming entrapped in the same way. Just below its juncture with Limerock Creek it has cut down into the crystallines instead of flowing along their western edge. However, the cycle may never have a chance to repeat itself, as just below this point the canyon appears to have reached base level, and unless the whole region is rejuvenated, the mature stage of lateral erosion will in time extend up the canyon past this point.

Age of the topography.

Except in the northern mountains, the area can be said to be in a youthful stage of erosion, since the valley profiles of all except the largest streams are steep and V-shaped, with remnants of an older topography common around the headwaters of some of the principal tributary streams. The major streams, on the other hand, such as Big and Little Tujunga Creeks have reached a state of maturity along their lower courses, and are developing wide flood plains. In the area under consideration this base level is local, but none the less it is the controlling factor of the fluvial erosion. South of the southern ridge the pediment slopes down to this stream bed, ending in a bank that is rarely over ten feet high.

In the northern mountains the area has a mature topography of maximum relief. This greater physiographic age of the higher land may have structural significance. It may mean that this upraised mass has been exposed to erosion longer than the downthrown block, particularly since the latter has a large area of soft sediments which would tend to be less resistant to removal.

Under these circumstances one would expect that this lower block would have progressed farther in the geomorphic cycle than that to the north.

On the other hand, it is possible that what appear to be remnants of the pre-faulting land surface on the southern blocks are actually the even more ancient surface at the top of the basement complex exposed by removal of the soft Tertiary sediments.

Little Tujunga Valley.

That the present base level has not been in existence long is proven by the wide distribution of terraces flanking the lower courses of the larger streams. There must have been several stages of uplift, for at places these terraces occur at several levels. It is difficult to draw any general conclusions about the rejuvenations of the region as a whole, since no two canyons illustrate exactly the same sequence of events. For this reason the procedure to be followed here will be to describe the transverse profile of each major stream valley in some detail, and at some places to describe several sections along the stream's course. From these some general conclusions will be apparent.

Little Tujunga Valley will be treated first, as it is the largest one having both ends in the district under consideration. Little Tujunga

Creek rises near the northern edge of the mapped region, just east of Dillon Divide, which is occupied by the county highway which crosses the area. It flows east-south-east for about a mile, its course being determined by the several branches of the San Gabriel fault. It finally breaks thru the fault zone in the north central part of section 22, T3N, R14W, from which point it flows south and southwest to where it joins Big Tujunga Creek.

South of the fault its branches are deeply intrenched into the soft sediments in narrow canyons that separate flat divides, on which at many places occur terrace deposits dipping southward away from the fault (Figure 6*). North of the fault the valley is filled with similar sediments to estimated depths of some tens of feet. The tributaries on the north flow in these deposits for much of their length. The main stream lies along their southern edge, with banks of the alluvium ten to twenty feet high at many places. It appears that at some time the adjoining fault blocks have supplied material faster than the streams could carry it away, and a steep alluvial fan has choked Little Tujunga Valley above the narrows where it crosses the fault. Either the narrowness of this gap has prevented rapid removal of the debris, or these

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*All photographs are included at the end of the paper instead of in the text.

deposits are a continuation of one of the terrace levels found farther to the south in the canyon. Similar deposits of alluvium are common at other places along the fault in this area, and attest to the recency of movement there, since the active streams would have removed all such soft bodies if they had been exposed to erosion for a long time.

Immediately south of the fault similar conditions prevail throughout the posterior depression. Locally temporary base levels have been reached where the outcrop of a relatively resistant formation impedes the downcutting of the stream, permitting widening of the valley above the barrier. In general, however, most of the valleys are in a state of extreme youth. Terrace deposits lying half way up the sides of the canyons show that a stream pattern identical to the present one existed previously, and reached a stage where either aggradation replaced degradation generally, or material was locally supplied too rapidly for the streams to carry it away. Since almost all of the larger deposits of this alluvial material lie on the relatively depressed blocks, it is likely that this material is related to the latest stage of faulting. Its extreme coarseness in many places and its subangular nature support this. South of the posterior depression all the alluvial deposits are poorly, or not at all, stratified, but in the posterior depression and to the north of it the reverse is more often true. This suggests that the movement on the southern line of faults was the greater.

North of the narrows where Limerock Creek joins Little Tujunga Creek the alluvial bodies are small and irregular in shape and distribution. South of this point they are larger and cover a considerable portion of the surface. Figure 1 is an east-west topographic profile across Cottonwood Glen. The lowest level is the flat, 400 foot wide flood plain of Little Tujunga Creek. On either side of the canyon is a 100 foot high terrace. This is best developed on the east where it is relatively flat. On the west it is represented by alluvial fills which choke the tributaries of Little Tujunga Creek from the western bank of the main stream up to their source, the upraised fault blocks to the northwest.

Since similar deposits lie on the lower terrace and on the next one above this, all the alluvial deposits on the east side of the canyon may be the eroded remnants of one earlier fan. The upper terrace is from one to two hundred feet higher than the lower, and its surface slopes up to the edge of the Sunland fault block. This level west of Little Tujunga Canyon is represented by a surface of relatively gentle relief into which the canyons tributary to Little Tujunga Canyon are making rapid headward erosion. At places here

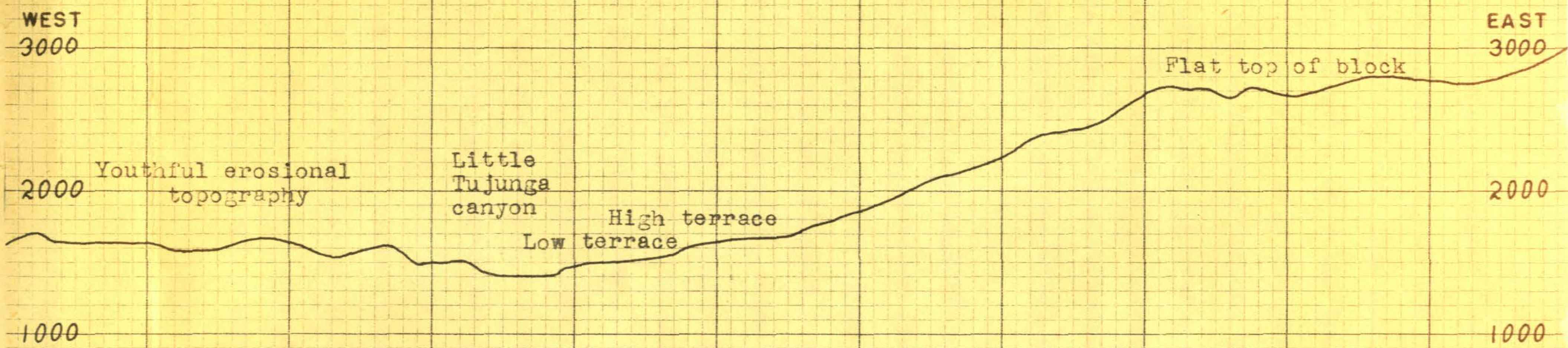


Figure 1.

East-West topographic profile across Little Tujunga Canyon at Cottonwood Glen, illustrating relationship of terraces.

two old alluvial deposits lie along the crests of the ridges, one dark and the other, the earlier, light grey in color. They appear to be different from the alluvial deposits that fill the nearby valleys and merge with the lower of the two terraces along Little Tujunga Canyon. The level on which these deposits lie is nearly 200 feet above the level of the rolling topography into which the streams are cutting immediately to the southeast and the higher terrace level east of Little Tujunga Canyon.

Above these easternmost terraces the slopes of the Sunland fault block rise steeply for 1000 feet. Triangular facets along this slope may be related to the major fault here, but more likely are erosional features, since they coincide with the dip slopes of the sediments. At the top of these slopes lies the gentle topography on the summits of the Sunland fault block. It is possible that this level is even older than the faulting.

As one proceeds southward toward the mouth of Little Tujunga Canyon the pattern changes. The canyon, where it passes thru the southern ridge, has steeper sides, though it is still wide. South of this a different valley profile is encountered. The banks of the stream are about twenty feet high. Above this there is not a terrace, but instead a gentle alluviated slope rises to the high ridges of older, tilted sediments. Patches of two higher, alluviated terraces are discernible, but these have not been correlated with the terraces of the middle part of Little Tujunga Canyon. Neither of these terrace levels coincides with the surface of the pediment along the foot of the southern ridge. Little Tujunga and Kagel Canyons are cut into this pediment, and Kagel Canyon has at least one intermediate level of terrace deposits below the level of the pediment and above that of the present canyon bottom.

East of the mouth of Little Tujunga Canyon terraces are not prominent until the southeast corner of the area is reached. There the southern ridge and Big Tujunga Canyon directly adjoin, and the pediment is truncated by the sidewise erosion of Big Tujunga Creek, which has become slightly intrenched into it, with terraces resulting along the mountain front. These terraces are capped by alluvium that apparently had a very nearby origin. Higher alluvial bodies along the mountain front appear to be much older; and their distribution suggests that they are a part of a once extensive bolson as mentioned previously.

Marek and Kagel Canyons.

Two of the tributaries of Little Tujunga Creek are large enough that we might expect to find its erosional pattern repeated in them. The first of these, Marek Creek, lies in a very deep canyon, having only a little more gradient than the main stream. Marek Canyon, particularly in its upper part, was at one time alluvium filled. The surface elevation of this material is close to that of the upper terrace level in Little Tujunga Canyon at approximately equal distances from the juncture of the two streams. Near the mouth of the canyon there is at least one terrace level beneath this, also alluvium covered. Thus the two canyons appear to have undergone similar histories of burial and rejuvenation.

The next canyon to the west, Kagel Canyon, is very different. Kagel Creek is confined to a narrow gorge where it cuts thru the southern ridge. Above this its canyon spreads out to form a wide, alluvium filled basin, into which the present streams are intrenched at places to a depth of over a hundred feet. The eastern edge of this broad basin drops off sharply to Marek Canyon, the floor of which is 250 feet lower in elevation. In spite of this difference the two canyons are both choked with detritus to about the same degree; and the deposits are lithologically similar. Marek Creek appears to owe its lesser elevation to the greater cutting power of Little Tujunga Creek, to which it is a tributary, and which has cut a deeper trench across the southern ridge than has Kagel Canyon. Thus Marek

Creek has a lower level from which to cut back thru the soft sediments of the anterior depression than does Kagel Creek.

The surface of the deposits in Kagel Canyon is 100 feet lower than that of the highest similar fans on the west side of Little Tujunga Canyon directly to the east. West of Kagel Canyon and 250 feet higher than the Kagel fan is a large loaf-shaped hill (maximum elevation 2075 feet) capped by 150 feet of alluvial deposits. The lower surface of these is on a level close to that of the two patches of old grey alluvium west of Little Tujunga Canyon, and correlates in level also with deposits around the head of Lopez Canyon. These scattered deposits appear to be the remnants of an old fan which covered all of what is now the anterior depression. The highest point which still remains of this old fan is about 800 feet west of where Lopez Creek crosses the southern edge of the basement crystallines. The surface of the Kagel Canyon fan rises to the north and northwest, so that at the Kagel Creek-Lopez Creek divide the two deposits are at about the same elevation.

Lopez and Limekiln Canyons.

Northwest of Lopez Canyon it is difficult to tell whether the alluvial deposits are of the Kagel Canyon type, or whether they are related to the higher group of the loaf-shaped hill. To the south a group of deposits lying on the ridge tops is recognizable on lithologic grounds, and appears to be related to the loaf-shaped hill alluvium. These deposits in turn, if projected northward, seem to correlate with dark alluvium deposits which are a part of the old fan mentioned above. Remnants of this huge fan are well exposed around the fringes of the Limekiln Canyon drainage. Limekiln Creek is a main tributary to Pacoima Creek from the east, and similar deposits occur on the west side of Pacoima Canyon.

Limekiln Canyon itself is choked by a fan, which may, however, be younger than the valley fills to the east, as the material looks a little fresher than that choking Kagel and Marek Canyons.

Pacoima Creek has cut a broad flood plain south of the Sierra Madre fault zone, and the side erosion along this flood plain has cut into the Limekiln Canyon fan forming a steep bank about twenty feet high. This bank continues south of Limekiln Canyon as a terrace on which is deposited material that appears to be mainly washed down from the sides of the canyon.

Lopez Canyon, on the other hand, is singularly lacking in terraces or alluvial fill in its upper reaches. There is much present day detritus in the wide stream channel, but the only terraces are some low banks near its mouth which seem to have been formed of material washed down from the canyon's sides, and into which the present stream has rarely cut for more than ten feet.

The widespread distribution of soft alluvial deposits in a region where erosion is active may seem surprising to some, especially since many of these deposits occur capping the ridges, or forming low divides separating small streams which are cutting rapidly into older, harder sediments. The reason for this appears to be that the rainfall sinks into the porous alluvium, escaping as underground drainage without removing any clastic material, whereas on the better lithified sediments it can not sink in, and hence has worn channels in which the surface streams can run following rains.

Pacoima Canyon.

North of the Sierra Madre fault zone, Pacoima Canyon has a typical youthful valley profile. As mentioned previously, the stream exhibits intrenched meanders, showing that a preceding land surface must have reached a stage of maturity in which the valley floors had widened to permit their development.

South of the fault zone the valley is everywhere filled by recent alluvial detritus, the transition from active degradation to aggradation being very sharp. This change in character takes place at the probable location of the Sierra Madre fault. Since this break is nowhere exposed near the mouth of Pacoima Canyon, we must conclude that dissection and alluviation have already concealed its outcrop. However, a considerable portion of the present difference in elevation along the scarp is probably a result of the uplift of the northern block rather than the excavation currently taking place most rapidly south of this huge fracture.

Conclusions.

The present stage is one of dissection almost everywhere in the area mapped. Although Little Tujunga and Pacoima Valleys have broad flood plains, and are alluvium floored, it is doubtful if the deposits are more than a few feet thick. In Little Tujunga Canyon frequent exposures of bed rock in the center of the valley bottom show that this stream has not yet begun to aggrade appreciably. Big Tujunga Creek is held at its present level by Hansen Dam, but even before the building of the dam the fans surrounding San Fernando Valley were reaching up into this depression and Pacoima Valley, and the present cycle there seems about ready to revert to the aggrading stage, which it has experienced on at least two previous occasions, if this has not already taken place.

The old fan whose apex appears to be just northwest of Lopez Canyon may be related to the terrace remnants on the north side of Big Tujunga Valley and east of Little Tujunga Valley. Both are at places partially lithified, though the more southerly fan in general contains more rounded fragments than the northern. This may, however, be due to its greater distance from the source of the material. Even though these two fans were of the same age, they were probably separated except at a few places by the southern ridge which is much higher than the highest remnant of the fan anywhere along its flanks.

The great extent of this early fan suggests that it may be related to movements on the Sierra Madre fault. Unless the uplift took place very slowly, the rise of the fault block mountains must certainly have produced a flood of coarse detritus. The Lopez fan may once have been much more extensive than even the distribution of its remnants indicates. According to this theory, the land surface on which this deposit accumulated may be related to that found on the summits of the fault block mountains.

The valley fill deposits, on the contrary, show less evidence of correlating with each other. In general, there seem to have been similar developments in each canyon, but possibly at different times.

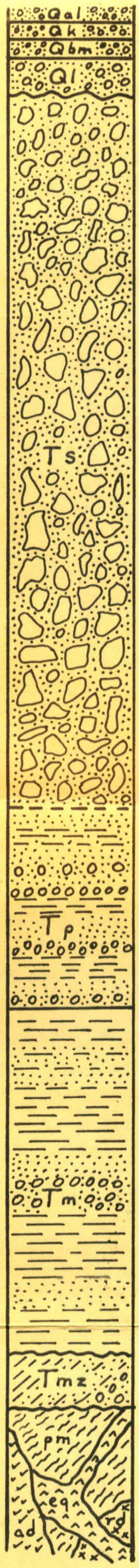
As one proceeds from east to west one finds that the fills become less dissected, and the material of which they are composed becomes fresher. This may mean that the successive stages of orogeny on the Sierra Madre fault progressed from east to west. Structural evidence of the age of the different branches of this fault is not clear enough either to confirm or disprove this. In Little Tujunga and Marek Canyons there seem to have been at least two stages of local terrace formation, the second surface possibly being formed by excavation rather than deposition. The sequence of events recorded in Kagel and Limekiln Canyons is simpler, there being only the one alluviation preceding the present rejuvenation.

III. STRATIGRAPHY.

Basement complex.

Figure 2, which follows this page, is a stratigraphic column of the rocks encountered in the region studied. The oldest formations, which have been mapped indiscriminately as basement complex, are largely what Miller (1934) has named the San Gabriel formation. It is composed of rocks of several other units so intimately mixed by intrusion and diastrophism that it is not convenient to map them separately. In the Little Tujunga region the commonest of these components are, using Miller's terminology, the Placerita metasediments, the Echo granite, the Rubio diorite, and an unnamed gabbro-diorite.

Of these the Placerita metasediments are presumably the oldest. In the area mapped they consist largely of reddish quartzite, fine grey micaceous schist, and grey or white marble, generally impure, with probably both calcite and dolomite as common minerals. These rocks are much broken by injections of intrusive bodies, of which the commonest is granite. Over a large area near the junction of Little Tujunga and Gold Creeks, the rock is an intimate lit-par-lit, granite injection gneiss, the intrusive probably being Echo granite. This injection gneiss is widely distributed wherever basement rocks are exposed. Scattered over the



0-? feet. Recent alluvium.
Disconformity
0-100 feet. Kagel formation. Pleistocene or recent.
Disconformity.
0-100 feet. Beehive Mesa formation. Pleistocene or recent.
Tan sands and gravels.
Relation unknown.
0-400 feet. Lopez formation. Pleistocene or recent.
Unconformity

Saugus formation. Lower to Upper Pliocene. At least 7800 feet of red and white, continental, arkosic sandstone and conglomerate.

Conformable contact.

Pico formation. Lower Pliocene. 0-2500 feet of grey, brown or tan marine conglomerate and sandstone with lesser amounts of siltstone and shale.

Disconformity

Modelo formation. Upper Miocene. Marine. 0- over 3700 feet of grey to tan silty shale, white to tan sandstone, and occasional conglomerate beds.

Unconformity (not exposed).
Martinez formation. Lower Eocene. Marine. Thickness unknown.
Mottled conglomerate, tan siltstone, and black shale.
Unconformity (not exposed).

Basement complex. pm Placerita metasediments.
rd Rubio diorite and hornblendite.
eg Echo granite.
ad Gabbroic and dioritic facies of anorthosite.

STRATIGRAPHIC SUCCESSION OF THE ROCKS
IN THE LITTLE TUJUNGA REGION

FIGURE 2

area in the basement complex are bodies of the marble, outcropping at most over only a few hundred feet in the largest exposed dimension. Quartzite is the only metasediment occurring as a large continuous element of the basement. The ridge separating the headwaters of Limerock and Kagel Creeks is composed almost entirely of this rock, and there are extensive deposits of it near the mouth of Maple Creek, a tributary of Pacoima Creek. The original bedding of these sediments can only in rare cases be recognized. The present trend of the schistosity is in general northwest-southeast, but is locally very irregular.

Perhaps the commonest of the intrusives is the Echo granite, which occurs wherever the Placerita metasediments are found. In color it is pink or dirty white to grey, in texture medium to fine grained. It occurs usually in the form of veins or dikes cutting the Placerita formation or lit-par-lit injected into it, though sometimes larger bodies of irregular or undetermined outline occur. Miller (1934, p.13) has pointed out that the Echo granite and Lowe granodiorite are difficult to distinguish, and it may be that much of the granitic material in the Little Tujunga region is the latter.

Nearly as common as the granites are numerous bodies of more basic rocks, most of which are presumed to belong to Miller's anorthosite series.

The rocks are dark grey to black, coarsely crystalline, massive to gneissic. Oakeshotte (1937) considers much of this material to be a monzonite. The largest body occurs immediately north of the Dillon branch of the San Gabriel fault. The northern edge of the mapped area is underlain almost entirely by this material.

Similar dark colored, coarse grained, igneous rocks are common at scattered locations wherever the basement is exposed. Oakeshotte considers these to be examples of the Rubio diorite, an older intrusive; but in the field it is often difficult to distinguish weathered outcrops of these two rocks. On the other hand, some intrusive bodies of Rubio hornblendite are very distinctive. The largest of these, between the headwaters of Lopez and Kagel Creeks, is an almost pure, intense black hornblendite. Other smaller bodies of coarse grained, hornblendite rich rocks are common, all south of the San Gabriel fault.

Some of these dark crystalline rocks may belong to what Miller has called the Wilson diorite, or to other of his formations. However, the author has made no attempt to distinguish one igneous formation from another except by its lithologic appearance in the field, so he is unable to indicate more than the three igneous types: the granite, wherein the Echo granite has not been distinguished from the Lowe granodiorite; the diorite, which includes the diorite-gabbro facies of the anorthosite, the Wilson diorite and the Rubio diorite, and lastly the Rubio hornblendite.

The age of these formations is uncertain. Certainly they are all pre-Modelo, since that is the oldest formation found lying on any of the basement rocks in the region mapped. Miller considers the Placerita, Rubio, Echo, and the diorite-gabbro-anorthosite bodies to be Precambrian, and the Wilson and Lowe to be probably late Jurassic. He has shown that the Placerita metasediments are the oldest formation, and that they were intruded successively by the Rubio, Echo, diorite-gabbro-anorthosite, the Wilson, and the Lowe formations in that order. Oakeshotte believes that the Placerita may be as late as Carboniferous, the Rubio Pennsylvanian or Permian, and the rest late Jurassic. Considering the dearth of direct evidence, it seems best to call all of these rocks probably pre-Cretaceous, and not try to date them more closely.

Martinez formation.

The oldest unmetamorphosed formation occurs in two wedges entirely within the San Gabriel fault zone. It consists of three different rocks. The most distinctive of these is a mottled, green and red conglomerate, with small rounded pebbles up to several inches long in a matrix of impure quartzite. Interbedded with this is a soft, black shale. The rest of the formation consists of fine grey to tan siltstone, occasionally coarsening to sandstone. Because of the intense deformation of the fault wedges, it is impossible to estimate accurately the total exposed thickness of these rocks, but it must certainly exceed several hundred feet. Clements and Oakeshotte (1934) believe this formation to be Martinez (Lower Eocene) because they found one specimen of Turritella pachecoensis in the conglomerate.

Modelo formation.

The exposures of Martinez are entirely surrounded by faults. The only other sedimentary beds besides Quaternary alluvial deposits that are younger than those of the basement complex are a series of three formations of Tertiary age. They are exposed continuously in an east-west belt across the southern part of the area, and the upper unit outcrops commonly on the top of the blocks north of the Sierra Madre fault zone. The thicknesses of these formations change from south to north across the region, thinning by omission of the lower members, and possibly by thinning of the beds. The oldest rocks exposed are coarse sandstones and conglomerates, weathering to a tan color, with occasional cherty layers a fraction of an inch thick. Most of the lowest member, however, is composed of a siliceous shale, with interbedded sandstones and conglomerates. The shale beds are from a small fraction of an inch to two inches thick, generally grey in color, and weathering light grey to brown. The sandstones are white to tan and occur in beds up to several feet thick. Conglomerate is the least common rock type, but is more plentiful in the western end of the area than in the eastern. West of Kagel Canyon there is an outstanding marker bed about 200 feet thick, which can be traced until it strikes out under the alluvium half way to Lopez Canyon. East of Kagel Canyon this bed can not be traced continuously, though there are a number of conglomerate beds which indicate that it is probably still present in the section.

Kew (1924, p.66) concluded that these beds were a part of the Miocene Modelo formation on the basis of their lithologic similarity to beds known to be of that age. Hill (1930, p.143) found an Upper Miocene fauna in them; but it is difficult to tell from his description of the location of this fossil bed just where it is. The Modelo beds shown on his map that are nearest to the described location are north of the Sunland fault. Only about 150 feet of Modelo rocks are exposed there along the southwest edge of the upraised block. These beds lie unconformably on the basement complex on a major erosional surface. The beds are grey to brown sandstones containing marine fossils. They are cut off on all sides except the northeast by faults. Since these beds northeast of the fault differ considerably from the beds presumed to be Modelo that lie to the south the relative ages of the two parts must be considered to be uncertain. For the purposes of this report all post-Martinez beds stratigraphically beneath a certain characteristic basal conglomerate have been mapped as Modelo.

The thickness of the Modelo formation in this area can not be determined, as it is nowhere completely exposed, being surrounded by younger rocks on all sides, except for the three small patches northeast of the Sunland fault. The thickness of Modelo exposed is 3750 feet. The total thickness is almost certainly greater than this. The Modelo everywhere is a marine formation.

Pico formation.

There is a marked erosional disconformity at the top of the Modelo throughout the area. Following this hiatus there was deposited a thick conglomerate bed. The surface beneath this conglomerate is irregular, showing that erosion took place, but everywhere the dips and strikes above and below the break appear to be the same within the limits of accuracy of the measurements. This is in marked contrast to the area south of Big Tujunga Wash, where the top of the Modelo underlies a marked unconformity. The formation above this unconformity was identified as Pico by Kew (1924, p.77) and Hill (1930, p.143) on fossil evidence.

It is grey to brown in color, cliff-forming, and contains many rounded boulders of igneous and metamorphic rocks such as constitute the basement complex. These cobbles are often over a foot long. The ground mass is largely unsorted sand of mixed composition. Higher in the section the conglomerate grades into coarse and fine sandstone, and finally into silty shale very similar to the Modelo. In the western part of the area this sequence is repeated at least three times. In the eastern part only one easily traced conglomerate bed is found. In the vicinity of Kagel Canyon the continuity of the outcrop of the beds is affected by faulting and folding, so that it is impossible to be sure which of the conglomerates in the west corresponds to the one conglomerate in the east. However, since the lowermost of the conglomerates in the sequence in the west is easily traced and appears to be the most prominent, it has tentatively been correlated with the one found east of Kagel Canyon. Everywhere beneath this bed there is a thick section of soft shales, while above it such shales as are present are limited in extent, and are generally very sandy.

The upper part of this formation consists primarily of grey, yellowish or tan sandstone varying in coarseness, but with only occasional and thin conglomerate facies. Shale beds up to five feet or more in thickness are common, but represent considerably less than half of the total section. The maximum exposed thickness of this formation is about 2300 feet.

Saugus formation.

The Pico, which is a marine formation, grades upward into a terrestrial facies. The contact is traceable by a bed of white to yellowish sandstone, very soft, and weathering to a bleached white color. It is arkosic, and contains fragments of some dark colored material. This marker is sometimes a single bed, ten to twenty feet thick, but at other times it spreads out into a zone fifty feet or more across in which the white arkosic sand is the principal, but not the only, constituent present. Beneath this sand the marine Pico shale members weather brown, above it they are usually red. Approximately here in the section the per cent of arkosic material notably increases. The sediments appear to change gradually, but within a few hundred feet in vertical section, from marine to terrestrial. The marker bed is most easily recognized in Little

Tujunga Canyon where it crosses the county road. It becomes gradually less distinct as one goes east from there, and it is also poorly exposed west of Lopez Canyon.

Above this contact the rock is uniformly arkosic conglomerate and sandstone, the material being unsorted detritus composed of what appear to be igneous and metamorphic rock fragments of all sizes up to several feet across, but mostly small fragments less than ½ inch long. Fragments are commonly angular or subangular, though some rounded pebbles can be found. It was referred to the Saugus formation by Kew (1924, p.84) on the basis of its lithologic similarity to the Saugus beds of the Santa Clara Valley. No fossils have been discovered in it in the Little Tujunga area, but it is probable that it is a terrestrial facies of the Pico, and may be as old as Lower Pliocene. It will, however, be called "Saugus" here for convenience in discussing the geology of the area.

The lower part of the Saugus formation is largely a dirty white in color, but higher in the section red beds become more common. In the deposits north of the Sierra Madre fault system the presence of alternating red and white layers is typical of the formation. These red beds appear to be due to the presence of a greater percentage of clayey material than is present elsewhere.

From a distance they make the sedimentary bedding very clear, but when one examines an individual contact between a red and white layer, no distinct bedding plane is to be seen, the two rocks being alike in texture and massive in nature.

North of the Sierra Madre fault zone, the Saugus is deposited directly on the basement complex. Therefore, except for a very small amount of Modelo on the southwest edge of the Sunland fault block, Saugus and more recent alluvial deposits are the only sedimentary rocks above the basement north of the fault zone. This means that in a distance of only 12,000 feet, at least 5900 feet of Modelo and Pico have been omitted from the section. Since the Saugus seems to have been deposited without discontinuity of any kind on the Pico, it seems unlikely that the Pico can ever have extended more than a short distance north of its present northernmost outcropping. Evidence will be presented later that there has been some crustal shortening in a north-south direction along the Sierra Madre fault zone, but it is doubtful if this can exceed more than a few thousand feet. In the light of this it is not surprising that we find the marine Pico changing to terrestrial Saugus, since there must have been a very steep shoreline.

The Pico deposits are notably coarse. Apparently the streams running off of a sharply rising land mass filled up the adjoining sea and built a large fan deposit along the mountain's edge. This Saugus fan appears to have a maximum thickness of at least 7840 feet, as measured from the cross sections. However, this figure may be exaggerated, as the fan must have been built up the mountain front burying a surface that was far from level. There may not have been a complete section of Saugus under any place where this formation is now exposed, since there is no reason to assume that the lowermost Saugus which we find at different places in the area is all of the same age.

The sudden lateral disappearance of the Pico presents a special problem when one attempts to draw a north-south section, such as section E-F. Here the bedding has been drawn in using Busk's method (1929). It is clear that more Saugus is exposed on the northern limb of the Merrick syncline than on the southern limb. In drawing the sections we must, therefore, violate Busk's assumption of parallel folds and constant bed thicknesses, or assume, as was done here in the sections, that the original deposition was on a sloping surface, and that conditions of deposition changed from marine in the south to terrestrial in the north. Another alternative is to assume that first the Pico lensed out by omission or thinning, and then the Saugus lensed in by thickening or addition of beds. Such lensing, first out and then in, seems unlikely in a series of beds apparently deposited in a continuous sequence. In any case, the disappearance of Modelo as well as Pico suggests that the formations overlap to the north. Since the north is presumed to be the direction from which the sediments came, overlap is more likely the cause of their disappearance than is thinning.

The Modelo appears to have extended farther to the north than the Pico. The angular discordance between these two formations which one finds just to the south of the region mapped indicates that there was an interval of some orogenic activity between the two ages. It is clear that the Modelo extended some unknown distance farther north than its present distribution, and was eroded off just before the Pico was deposited or during this time. The basal conglomerates in the Pico may be the result of several unheavals of the old San Gabriel range as a result of which these Modelo deposits were removed. These uplifts may have created the steeply sloping mass against which the Saugus sediments were laid down.

On the other hand the apparent concordance in dip between the Pico and Modelo suggests that in the Little Tujunga region the time separating these two ages was one of relatively quiet emergence without much tilting. If so, this was only a local condition. However, it is possible that the Pico beds once covered as much territory as the Modelo, and have since been eroded off the top of the Sunland block; but this is unlikely because of the apparent conformity beneath the Saugus. Though it is predominantly shale, even the Modelo has a considerable amount of coarse material in it, suggesting that the Little Tujunga region is near what once was the border of the Modelo sea. If this is the case, then the San Gabriel mountains may have been a land mass even in late Miocene time.

The basement surface on which the Saugus was deposited was at least in large part highly irregular in shape. Also, there is abundant evidence at many places that it was covered by a layer of soil, which is still today not completely lithified. This pre-Saugus surface may have differed very little from the present land surface in its nature. Although a considerable period of orogenic action and erosion has passed since Saugus time, it is not certain that the uplift which raised the source rocks of the Saugus fan has ceased. It is true that the sea has retreated a long way from the foot of the San Gabriel mountains, and that the present cycle is one of erosion; nevertheless, a sharp division between upraised mountains and lowlands still occurs at the old shore line.

Lopez formation.

The post-Saugus history is one of successive ages of deposition and renewed uplift. The fanglomerate beds which give this information are all so fresh that they are almost certainly Quaternary, and all may even be Recent. The oldest appearing deposits of this sort occur along the tops of the ridges west of Lopez Canyon. They are mottled, reddish, partially lithified, porous conglomerates and coarse sands, composed of fragments of basement complex rocks of all sorts. Hill (1930, p.144) has named them the Lopez formation. They appear to be part of a large fan that once covered most or all of the region mapped south of the Sierra Madre fault zone.

Fanglomerates which appear from their degree of decomposition to be of about the same age occur along the mountain front from Pacoima Canyon to Lopez Canyon. Near Pacoima Canyon these deposits are several hundred feet thick, light to dark grey in color, and deeply weathered. The deposits were laid down on a highly irregular surface. Their highest point appears, from the deposits which remain, to have been near where the present Lopez and Kagel Creeks cross the Sierra Madre fault zone. The large loaf-shaped hill on the west side of Upper Kagel Canyon is capped with 150 feet of coarse, dark colored, much weathered alluvium. Its lower surface is at about the same elevation as the deposits on the ridges west of Lopez Canyon, and presumably it is a part of this same fan.

On the east side of Marek Canyon there are two alluvial deposits, the older light grey in color, the younger dark grey (Figure 4, at the end of the paper). The light colored member is exposed only in a few cliffs on the eastern side of Marek Canyon, and is different from any other alluvial deposit in the area. The darker variety buries the lighter. It more closely resembles the alluvium on top of the loaf-shaped mountain west of Upper Kagel Canyon, and occurs at a level which suggests that it, too, is a part of the Lopez fan.

Along the southern edge of the mountains are more deposits of semi-lithified gravels. These deposits are composed of both basement fragments and material that appears to have been derived from the Modelo shale against which these beds lie. At other places these deposits are completely unlithified, and are composed entirely of sand and rounded to subangular boulders of basement rocks. Because of their different composition it is impossible to correlate them with certainty with the deposits to the northwest; but it seems likely that they are of about the same age because of their similar degree of weathering and lithification, and from the fact that they, too, seem to have formed part of a large fan. It is possible that this fan joined the Lopez fan by filling the river valleys which cross from the anterior depression to Big Tujunga Valley; or they may have been two separate fans of the same or different ages. The alluvial deposits along the southern edge of the mountains may not all be of the same age. Because of this uncertainty, they have been given a special symbol on the geologic map.

Kagel formation.

Filling the present valleys of Kagel, Marek and Limekiln Creeks are alluvial deposits into which the present streams are intrenched to a depth of as much as 100 feet. Similar deposits choke the valleys of some of the western tributaries of Little Tujunga Creek (Figure 5, at the end of the paper). These deposits lie mostly at lower elevations than the nearby Lopez fanglomerates. They are composed of unlithified, unsorted, subangular fragments of the basement complex, considerably weathered, but on the average less so than the Lopez deposits. They are generally so porous that the streams have tended to cut their channels in the adjoining outcrops of Saugus where surface runoff is possible, and left these fills as relatively level surfaced areas between the adjoining, rugged, Saugus ridges. Hill (1930, p.144) has named this fanglomerate the Kagel formation. At the northwestern end of Upper Kagel Canyon the highest part of this fan is at the same level as deposits west of Lopez Canyon that are thought to be of Lopez age. The lithologic differences between the two are so small that it can not be said with certainty where one formation ends in this region and the other begins, particularly since the younger Kagel must contain reworked material from the older Lopez.

The Kagel deposits in the different canyons may not all be equally old. The deposits in Kagel Canyon are 250 feet in elevation above those in Marek Canyon, though the more western deposits reach right up to the divide between the two canyons. Thus the Kagel alluvial deposits do not represent part of one fan, but are a similar development in the several canyons where they occur, whereby the material was supplied faster than the streams could carry it away, and they were forced to drop a part of their load, choking their channels. The degrees to which the channels were filled appears to be dependent on the stream profile of each individual canyon.

On the eastern side of Little Tujunga Canyon there are extensive terrace deposits that appear to be more weathered than the average Kagel sediments. Also these terraces do not coincide exactly with the surfaces of the Kagel fanglomerates on the western side of the canyon. On the other hand they are, in general, lighter colored than the typical Lopez fanglomerates. They have been mapped as a part of the Kagel formation since they more closely resemble these deposits than the others.

Above the juncture of Limerock Creek and Little Tujunga Creek are scattered fragments of terrace deposits that are lithologically similar to the Kagel deposits, and are, therefore, tentatively correlated with them. The distribution of these deposits is such as to suggest that Little Tujunga Canyon was at one time choked with fanglomerate in the same manner that Kagel Canyon is now choked. Similar deposits occur in the upper part of Little Tujunga Canyon as far as Dillon Divide on the county highway, and on the Pacoima Creek side of that summit.

Beehive Mesa formation.

In the same region there is another series of fanglomerates that are lithologically very different from the Kagel deposits. The largest outcrops of this material are on the terraces north of Buck Creek just above its juncture with Little Tujunga Creek. These deposits are well bedded sands and conglomerates, various shades of brown in color. They differ from the Kagel fanglomerate in their more uniform texture, greater fineness, pronounced bedding, and in color. Similar deposits occur in smaller patches higher in Buck Canyon. The degree of weathering is about the same as in the case of the Kagel deposits, and the two may be of the same age. However, in at least one place gravels are deposited on top of the Beehive Mesa formation which closely resemble the Kagel fanglomerates. It is therefore probable that the Beehive Mesa deposits are older than most or all of the Kagel. They can not be dated with reference to the Lopez formation with the available evidence.

Most recent alluvium.

Along the lower part of the stream courses of Little Tujunga, Pacoima and the other larger streams are terraces of material apparently of extremely local origin, washed down from the adjoining ridges, but standing often as much as 20 feet above the present streams, and with their surfaces sloping up to the adjoining ridges. In spite of their terraced nature, these deposits do not appear to be of great age, and are being built up at places by the current drainage. These terraces, and other low terraces along the lower reaches Pacoima, Lopez, Kagel and Little Tujunga Canyons have been included in our classification as Recent alluvium (Qal), for they appear to be a result of the current cycle of erosion and deposition. In the next unusually large flood most or all of these terraces will be covered with water, and material may be added to them in some cases. In the same manner the whole slope from the foot of the hills to Big Tujunga Wash is receiving material carried down by intermittent streams and floods, and this slope is, therefore, similarly mapped as Recent alluvium.

IV. STRUCTURAL GEOLOGY.

Introduction.

Structurally the Little Tujunga region is divided into three main parts by the two major fault systems. The northernmost of these divisions lies north of the San Gabriel fault. Here the rocks are what Oakeshotte considers to be monzonite, presumably a part of Miller's anorthosite series. The mountains rise to heights considerably greater than in the area to the south. The highest point in the region mapped is 3867 feet, but even higher peaks lie just to the east and north. This is a part of the main core of the San Gabriel range described by Miller (1934).

To the south lies the posterior depression and the fault block mountains raised along the Sierra Madre fault system. The posterior depression is formed by the removal of the Saugus sediments from the northward dipping slopes of these basement blocks. South of the Sierra Madre fault system the rocks form a belt of north tilted sediments of the Modelo, Pico, and Saugus formations, mildly folded and with some relatively minor faulting. Big Tujunga Wash forms the southern edge of the area, and south of it are more, similar sediments. There may be another big fault in Big Tujunga Valley, but if so, it has nowhere been observed at the surface.

San Gabriel fault.

The San Gabriel fault is one of the major structural features of southern California. It extends from the vicinity of Tejon Pass to Camp Baldy, at the foot of San Antonio Peak (see Geologic map of California, 1938). Although the surface outcrop of this fracture is relatively straight, it by no means possesses this characteristic as strongly as does the San Andreas fault a few miles to the north. It has been suggested that the San Gabriel is, like the San Andreas, a strike slip fault. This is however, by no means certain. With the possible exception of Pacoima Creek, there are no offset streams in the area mapped. However, if the bend in Pacoima Creek where it crosses the fault zone is a result of strike slip motion, then the direction of movement of the two blocks is in the same sense as that of the San Andreas, the northeastern block moved southeastward relative to the southwestern block.

The San Gabriel fault, where it was studied, consists of four main branches. The northernmost of these was named the Dillon fault by Hill (1930). It separates the dioritic rock mentioned previously from lighter colored granites to the south. The measured dip varies from 89° north to 49° south, but is generally steep. The outcrop of the fault is very straight, regardless of the topography.

Because of the extreme brecciation of the rock on either side of the main fracture, a precise measurement of the dip of the fault plane at any one location can rarely be made. Measurements made on any individual plane of movement are not necessarily typical of the fault as a whole. The best estimates of the dip are obtained by standing on the fault on one ridge and noting the angle at which the trace crosses the far sides of the adjoining valleys. The fault is generally a wide crushed zone, grading into less brecciated rock on either side. The block north of the fault is generally less brecciated than the blocks lying between its north and south branches, though no such contrast exists between the rocks on either side of the south branch. The fault zone proper varies in thickness from a fraction of an inch to twenty feet or more. Where it is narrowest, as in the southeastern corner of section 7, T3N, R14W, it dips steeply north. Here it is a fine black band of altered rock, and it is very flat in shape. The adjoining rocks are much less brecciated than normally.

Just southeast of the northwestern corner of the mapped area the Dillon fault splits into two branches, the northern branch being that called the Dillon fault by Hill. The middle branch is marked by a series of brecciated zones that usually weather white, so that they can be easily traced across the landscape. This branch lies completely in the granite. Its course is also usually marked by low spots on the ridges where erosion has proceeded faster in the brecciated zone than in the adjoining material. East of the bend in Pacoima Creek where the creek turns northward and leaves the fault zone the rock is so generally broken that it is difficult to trace this branch, and its eastward extent is unknown. Where measurable, its dip is from 74° south to 88° north. Since this break is entirely in the granite, its displacement can not even be estimated.

West of section 22, T3N, R14W, the southern branch of the San Gabriel fault is known as the De Mille fault. Its course is marked by a series of low points in the topography. For over a mile the bed of Pacoima Creek approximates its course. Throughout most of this area it is a 100 foot wide zone composed of crushed Martinez shales and conglomerates. However, at the west end of the area like the Dillon branch it reduces to a ½ inch wide, flat, black crack between two bodies of granite. Here the fault plane dips 81° north. Elsewhere the dips vary towards the vertical and to 85° south. The belt of Martinez sediments appears to be a thin wedge dropped down on the north side of the main De Mille fault on a plane which joins this with a dip of about 63°.

In section 22 the De Mille fault again splits into two branches, the southern of which Hill has named the Watt fault. The wedge in between is again composed of Martinez sediments, this time less distorted, but still badly broken and squeezed. The Watt fault is a low angle reversed break where observed, dipping from 33° to 41° north (Figure 7, at the end of the paper). The juncture of the Watt and De Mille faults in the area mapped is not exposed, being covered by a large body of Beehive Mesa fanglomerates. According to Hill's map, the eastward extension of the Watt fault never quite joins the De Mille as far east as he has traced it. Miller, however, shows the two joining in Gold Canyon, on the Big Tujunga watershed. West of their juncture, the De Mille fault separates granite on the north from a complex mixture of igneous and metamorphic rocks on the south, Miller's San Gabriel formation, in which granite is still the commonest element. East of the juncture, Saugus sediments lie south of the fracture.

The material south of the Watt fault is folded into a synclinal structure. However, the rocks are everywhere so disturbed within 500 feet of the principal shear plane that it can hardly be considered a simple syncline. The series of small connected folds may in large part have been caused by drag along the Watt fault, though its persistence suggests that it is more likely a compressional feature, possibly a yielding to the same forces which raised the block north of the fault.

Where the De Mille fault lies between igneous or metamorphic rocks, these rocks are badly shattered on both sides of the main break, but where it is bounded by Martinez sediments on one side, the northern, igneous wall is much more brecciated than the opposite one. The Tertiary sediments adjoining the faults have adjusted to the movements largely by folding rather than by brecciation. The Saugus sediments in particular, wherever they have been displaced, appear to be less disturbed than the adjoining rocks. This is presumably due to their pliancy, which permits them to adjust without intense fracture. It does not mean that this formation has adjusted entirely thru folding, as it is generally broken near the faults; but individual blocks of Saugus have yielded by a plastic-like flow, whereas the basement rocks are everywhere crushed into small fragments by the intense deformation, each fragment itself being weakened by small breaks along which motion may once have occurred. The smallest piece of basement rock that can be found anywhere near one of the faults can almost invariably be broken along existing cracks. The Saugus, on the other hand, appears to be massive right up to the slickensided surface of the fault plane. Separating it from the fractured Martinez sediments there is a zone at most a few feet thick of powdery gouge. The Martinez yields in much the same manner as the Saugus.

It is difficult to tell how much dislocation there has been on each of the different branches of the fault. Mendenhall Peak, 3600 feet east of the northeastern corner of the mapped area, is between 4625 and 4650 feet above sea level. In Gold Creek valley the contact between the Saugus and basement occurs between 1750 and 1775 feet, making a total difference in elevation of 2875 feet. To this must be added the thickness of the Saugus at the Watt fault, which from section E-F is 420 feet, but which thickens to about 900 feet just to the east of the area shown on the map. Adding these figures we find that the minimum throw on the San Gabriel fault is between 3295 and 3775 feet. This does not include the wedge of Martinez of unknown thickness between the Watt and De Mille branches. This represents an unknown amount of pre-Saugus movement. Furthermore, it is not possible to tell what thickness of rock has been eroded off the top of Mendenhall Peak that should be added to the figure for the throw.

On the other hand the vertical component of motion may be exaggerated in this figure. It has already been mentioned that the Saugus was laid down on an irregular surface. The total thickness occurring north of the Sierra Madre fault zone is much less than that found to the south, suggesting that the formation may be thinning as one goes north. It may be that the Saugus never extended as far beyond the site of the present San Gabriel fault as Mendenhall Peak. Also, since the strike slip component is unknown, the block immediately north of this structure in the mapped area may have been brought horizontally from some distance to the east or west, in which case the absence of the Saugus on the north block is not so meaningful.

This argument applies equally well to the Martinez sediments, which may also have been brought into their present positions by strike slip movement. The nearest outcrops of Martinez to those in the Little Tujunga region are at St. Francis reservoir 16 miles to the northwest, and in Aliso Canyon, a distance of about 19 miles to the southwest (Kew, 1924: Geol. map of California, 1938). The Martinez is not found anywhere in the Little Tujunga area, nor in the Verdugo mountains, beneath the Modelo or Saugus at any place where these formations are found in sedimentary contact on the basement rocks. If the present outcroppings of the Martinez in the San Gabriel fault have not been brought from some distance away, then Martinez sediments must have been deposited over the whole surrounding region at some time in the past. Since they are not at present found beneath the Modelo or Saugus, they must have been removed before these formations were deposited. If this is the case it would seem strange that they are preserved where they are now found unless they had been downfaulted at some date earlier than the deposition of the Modelo, in order to preserve them in their present position. This would mean that the San Gabriel fault was already moving in pre-Modelo time. Since Saugus beds are cut off, it must also have been moving in Middle or Upper Pliocene time, and since Quaternary beds are not disturbed, the end of the movement must have been before these beds were laid down. It has already been pointed out that the San Gabriel Mountains appear to have been a land mass just north of the Little Tujunga region in Pico time, since the marine Pico changed to the terrestrial Saugus continuously. It may be that the Saugus sediments lapped up to the then rising scarp, and never crossed it at all, and that the present offset appearance of the Saugus is due to movement of the fault against the mass of sediments which were being built up against its scarp. In that case the minimum late Pliocene vertical displacement on the fault would be the difference in elevation of the basement on its opposite sides, which would be 2875 feet. The unknown thickness of the Martinez would be the minimum movement which occurred in pre-Modelo time.

If the horizontal component of motion was large, then the situation may have been completely different. It is not possible to make any estimate of the relative amounts of horizontal and vertical displacement on the basis of the direction of observed slickensides since striae can be found which show movement in almost every direction. This is partly a result of the very wide zone of disturbance stretching from the Watt fault on the south to the Dillon fault on the north. Within this zone the present directions of the striae may be far from what they were when the causing motion actually took place, as these rocks have been broken and twisted about by later motion. The trace of the fault as a whole is far from straight, as shown on the geologic map of California, and therefore it is doubtful if strike slip can be predominant unless it has been flexed since the last movement on it.

The dips of the Dillon (both branches) and De Mille faults where best exposed are 80°

to 90^o north. The Watt fault is a comparatively low angle, north dipping, reverse fault. At present the relative elevations of the blocks suggests that in every case, except possibly that of the south branch of the Dillon fault, the north block has been raised. Certainly, treating the San Gabriel fault as a whole, the northern block has been raised with reference to the southern one, since basement rocks rise against the Martinez, and the latter lies over and above the Saugus. However, as mentioned above, at one time the motion on the Watt fault may have been in the opposite direction.

It is difficult to tell to what degree the present scarp is due to the original uplift of the main mass of the San Gabriel range, and to what degree it is due to the erosion of the soft sediments from the southern block. Certainly erosion has lowered this, and the relative softness of the sediments would indicate that this erosion must have been much more rapid than that of the basement. However, nowhere is there exposed a recognizable top of the Saugus sediments, so that it is impossible to say how thick they once were. It has previously been suggested that they were built up against the side of an already existing mountain range, and and if this is the case, it is possible that much of the difference in elevation now existing across the San Gabriel fault may have already existed at the time of deposition of the Saugus. On the other hand this formation may have been many thousands of feet thick, and may have extended miles north of its present limits, in which case the present scarp would be a fault line scarp.

The relative ages of the different fractures in the area mapped can not be determined, as none of them except the two branches of the Dillon fault intersect. Hill, however, has suggested that the Watt may be older than the others (p.154-155), because it has been folded whereas the others have not, and that the De Mille is older than the Dillon, since the latter cuts off the former east of the area mapped here.

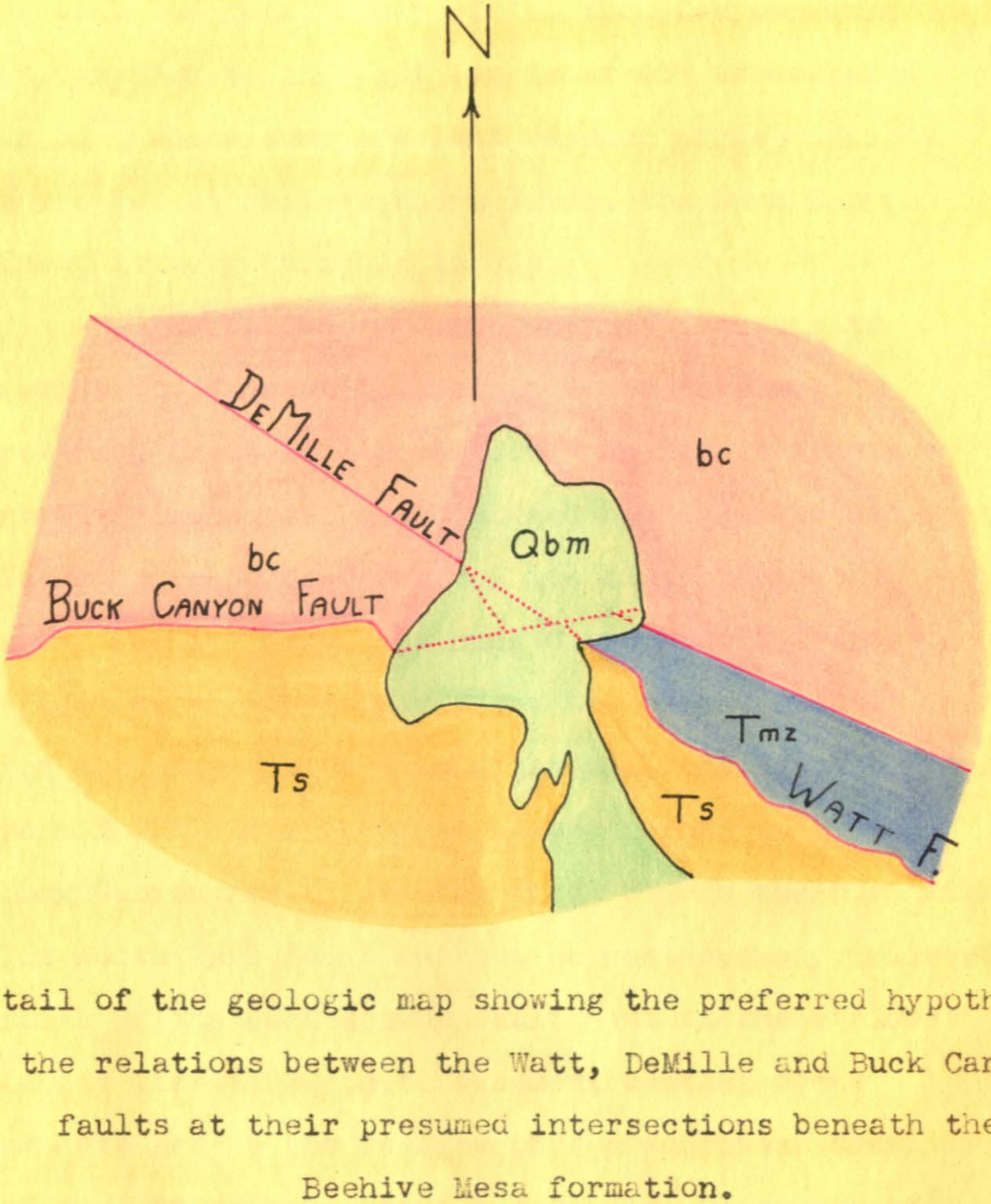
Immediately south of the San Gabriel fault zone the rocks are broken into a series of blocks that are separated from each other and from the lower land to the south by more faults. From northwest to southeast these are the Maple Canyon, the Buck Canyon, the Lopez, the Little Tujunga, and the Sunland faults.

Maple Canyon fault.

The first of these, named the Maple Canyon fault from its best exposure along the south side of Pacoima Reservoir near the mouth of Maple Canyon, is entirely in the basement. It strikes slightly northeast of east from the mouth of Cougar Canyon past the mouth of Maple Canyon, and either dies out or is cut off by the De Mille fault to the northeast. It dips about 70° north where seen. The block on the south is largely underlain by Placerita quartzite intruded by granitic rocks. The north block consists largely of similar granitic rocks. The course of Pacoima Canyon follows the trace of this structure for about 3000 feet. From the available evidence it is impossible to tell the direction of movement.

Buck Canyon and North Fork faults.

Five thousand feet to the southeast is the Buck Canyon fault. Its eastern end is buried by the same body of Beehive Mesa fanglomerate which 1000 feet farther east covers the western end of the Watt fault. The De Mille is also buried here beneath these deposits. The simplest picture of the intersection of the three structures would be one wherein the Buck Canyon fault offsets the De Mille. Since the Watt fault is presumably older than the De Mille, the Buck Canyon fault must offset both the Watt and De Mille, as shown in figure 3. Although the Buck Canyon fault has not been observed north of the De Mille, the apparent offset of this fracture, which can be seen if one projects the direction of its outcrop under the Beehive Mesa cover, is most easily explained if



Detail of the geologic map showing the preferred hypothesis of the relations between the Watt, DeMille and Buck Canyon faults at their presumed intersections beneath the Beehive Mesa formation.

Figure 3.

one supposes that the Buck Canyon fault is responsible.

An alternative explanation is that the Watt and Buck Canyon faults are both the same structural break and do not join the De Mille at all. The greater dip of the Buck Canyon fault as compared to the Watt (at least 45° as compared to 33°) where they are last exposed argues against this, but as will be shown later, the Buck Canyon fault is very variable in dip.

The surface outcrop of this fracture is such as to suggest that it is a moderate angle reversed fault at its eastern end. Highly fractured granitic rocks lie north of and above Saugus sediments. Three thousand feet west of its disappearance under Beehive Mesa, the Buck Canyon fault is itself offset by an interesting fracture which we shall for the purposes of discussion call the North Fork fault. This break is almost normal to the Buck Canyon fault, dipping about 85° to the northeast. The North Fork fault can not be continuously followed south of the Buck Canyon fault, but in three places in the first 1500 feet, basement complex rocks are brought to the surface on the southwest side of displacements cutting the Saugus. These structures do not line up perfectly with the North Fork fault, but their trend and location makes it almost certain that they are a part of one belt of fracture. On them the western block is raised exposing basement rocks; but where the North Fork fault crosses the Buck Canyon fault, we have the anomalous condition of young Saugus sediments being raised up against overlying basement complex by a normal fault. This is due to the reversed nature of the Buck Canyon fault.

East of the North Fork fault the Buck Canyon fault has a northward dip of the order of 45°, but west of it the dip is much lower, as proven by its sinuous outcrop. At the western edge of the cross fault it is almost horizontal, as can be seen in figure 8 (at the end of the paper). This difference in the attitude of the Buck Canyon fault on opposite sides of the North Fork fault makes estimating the slip of the cross structure difficult. At present the outcrops of the intersections of the two are separated by 1100 feet horizontally and 275 feet in elevation; but it would be an unlikely coincidence if these two points have ever been adjoining.

The North Fork fault is not a regular break, but is a jagged group of fractures in a zone of breccia up to several tens of feet thick, and with large chunks of both Saugus and basement included in the zone. There is one piece of Saugus whose exposed size is about 20 feet by 50 feet. South of the Buck Canyon fault, the North Fork fault is a much cleaner break with little or no gouge.

The trace of the Buck Canyon thrust can be followed for about 3500 feet southwest from its intersection with the North Fork fault, during which time it maintains its low angle aspect. The present scarp, which appears to be a fault line scarp, is rapidly being eroded back in large part by a series of small landslides in the steep mountainside. The soft Saugus sediments are rapidly being carried away by stream action, and the rainwater percolating thru the much fractured mass of the Buck Canyon block weakens the sediments even under the overthrust mass, so that they can not carry the weight of the heavy crystallines.

Where the fracture crosses the main branch of Buck Canyon in the southwest $\frac{1}{4}$ of the northwest $\frac{1}{4}$ of section 20, T3N, R14W, the stream has cut back into the thrust block for 1500 feet horizontally, and excellent exposures of the sole are abundant. Although along this plane the sediments appear to be relatively little disturbed except for the grinding up of a zone of slick gouge, the overlying basement rocks are intensely brecciated for the full thickness of the wedge. This is particularly true for the part of the block south of Buck Creek. The overthrust plate here probably never exceeds 300 feet in thickness, and is surrounded on three sides by Saugus sediments. The dip of the fault plane is about 9° north.

This wedge may be cut off from the main mass of the raised block by a steep fault along Buck Creek. This is suggested by a slickensided surface dipping 61° north at the saddle between Buck and Limekiln Canyons. However, exposures thru this area are too poor to afford good evidence of its existence.

On top of the plate is a small patch of what appears to be Saugus sediments, the only outcrop of such rocks north of the Buck Canyon fault in the area mapped. The rock is a dark brown sandy conglomerate and dips 10° south. If this is truly a patch of Saugus, and not a particularly well bedded and lithified alluvial deposit, then it indicates that the upper surface of the Buck Canyon block has not been greatly eroded away below the old pre-Saugus surface.

West of the saddle at the head of Buck Creek the Buck Canyon fault appears to steepen again and to die out or become lost in the basement rocks east of Pacoima Creek. About 3500 feet east of Pacoima Creek are two small shears which, though they are not seen to join the well exposed part of the Buck Canyon fault near the head of Limekiln Canyon, may well be its westernmost, split end. The southern one dips approximately 71° northeast, and the northern one dips approximately 89° south.

The Saugus sediments dip under the Buck Canyon fault at a steeper angle than the fault plane in many places. Therefore, either the sediments must flatten out or reverse in dip somewhere beneath the thrust, or the break must steepen, or both. The last view is the most likely. The outcrop of Saugus farthest up Buck Canyon where a dip could be measured was dipping south compared to the generally northerly dips of this formation elsewhere around the edges of the block, indicating that the sediments reverse in dip. On the other hand, if the lowest dips of the fault plane are projected back toward Pacoima Canyon without any increase in dip, they should come to the surface in Ant, and possibly in Maple Canyons, which they do not do. Therefore, the fault must steepen toward its root. This is likely from another point of view. North of the Buck Canyon block is the San Gabriel fault, a line of much greater fracture in the crust than the Buck Canyon fault. If the Buck Canyon block is entirely a low angle thrust wedge, then there is no source south of the San Gabriel fault from which it can have come. These lines of evidence, and the fact that at its eastern and western ends the Buck Canyon fault has a moderately steep to steep reversed attitude, all suggest that the low dips in its middle section must increase rapidly towards its root.

With so great a variation in dip, it is difficult to estimate the amount of movement on the Buck Canyon fault. Just south of where the supposed Saugus is found on top of the Buck Canyon block the thickness of Saugus under the thrust appears to be only about 125 feet, though it may increase with depth, as the beds are dipping more steeply than the fault plane. The thrust has shoved basement out over Saugus at least 1800 feet, the distance from Buck Creek to the southern edge of the moved plate, and possibly much more than this. It is doubtful if the thickness of the sediments is much greater than 125 feet, as in spite of the wide area over which these deposits outcrop, they appear to be nowhere very thick on any of the raised blocks.

Lopez fault.

The next major fracture south of the Buck Canyon fault is the Lopez. Its scarp can be followed easily east from Limekiln Canyon to Kagel Canyon, where it forms the southern boundary of the fault block mountains. Measured dips along it vary from 48° north to 33° south, the last named figure being exceptional, and probably influenced by landsliding. It is a low angle reversed fracture, possibly at places overthrust, with the basement rocks riding out over Saugus sediments. The Saugus is relatively little shattered, though the basement rocks are intensely so. The rocks north of the fault consist of metasediments and intrusives. Where best exposed in Lopez Canyon it consists of an inch thick zone of powdery, red gouge in a zone of intense fracture approximately 50 feet thick. Adjacent parts of both the upper and lower blocks continue to be greatly disturbed for hundreds of feet on either side of the main shear zone. The fault can not be traced under Kagel Canyon, since this valley is choked with recent and old alluvium. The situation is also confused by a group of landslides at the head of the alluvial deposits. East of Kagel Canyon are two faults, one along the mountain front, and one cutting northeast to the headwaters of Limerock and Nehr Canyons. Between the two is a north-tilted block of basement crystallines with Saugus sediments dipping off of its northern edge under the more northern fracture.

Either of these two breaks could be a continuation of the Lopez fault, or both could be branches of it, but the projection of the northernmost of the two appears to join the Lopez fault more clearly than does the projection of the southern. Hill believed the reverse to be true, but much of the evidence relating the northern shear to the western part of the Lopez fault is to be found in road cuts on a recently built forestry road and was not exposed when Hill did his work. The name "Lopez fault" will be used here to refer to what Hill called the Lopez fault west of Kagel Canyon, and its northeastward extension into the region of the headwaters of Limerock and Nehr Canyons; and the name "Little Tujunga fault", which was given by Miller (1928), will be used for the eastward extension of Hill's structure.

It might seem to be more desirable to give new names to both of these. However, since Hill has adopted the policy of using "type localities" to describe and name his faults, the use of the term "Lopez fault" for the fracture whose type locality is that used by Hill, but whose course appears to be different from that originally supposed by him, appears to be justified.

Northeast of Kagel Canyon the Lopez fault can be traced for about 4000 feet where it separates Saugus and basement complex rocks, but beyond that point it runs out between Saugus on both sides and can no longer be seen. A section in the upper part of Nehr Canyon shows that where the break would be expected there is instead a sharp and steep monocline, showing that in the basement rocks the Lopez fault persists. This monocline does not extend more than 2000 feet farther northeast, and beyond where its projection meets the projection of the North Fork fault there is no evidence of either the fold or the underlying shear. It may not even reach this far, but the particular locality where the projections of the two structures meet is densely brush-covered, and the author was unable to measure accurate dips through here to determine whether the monocline died out or is cut off by the cross structure. It is possible that the North Fork and Lopez faults are genetically connected, in which case the Lopez would also be later than the Buck Canyon fault.

West of Limekiln Canyon the Lopez fault is not exposed. Large bodies of Lopez and Kagel alluvium cover most of the Limekiln Canyon area, and the displacement presumably dies out beneath this cover or continues across Pacoima Creek under the similar alluvium on the western side of this stream.

A continuous section of Saugus 7840 feet thick is exposed south of the break. Under this Saugus about 2500 feet of Pico is exposed, and 3750 feet of Modelo. However, 7000 feet northeast of the north end of this section the Lopez fault dies out in more Saugus sediments at the head of Nehr Canyon. These sediments in turn lie directly on basement complex without any Pico or Modelo sediments beneath them. Some of the motion of the Lopez fault east of Kagel Canyon may be taken up on the Little Tujunga fault, but we must conclude that at least 2500 feet of Pico and 3750 feet of Modelo did not lie across the site of the fracture when the Saugus was laid down. It is doubtful if anything like 7000 feet of Saugus ever were deposited at its present site. Considering the suddenness of this disappearance of the two formations, one is led to wonder if the Lopez fault had not already become active before Saugus time, at least along its western end.

The minimum possible throw on the Lopez fault is of the order of 500 feet, as this thickness of Saugus is exposed where it projects into the monocline at the head of Nehr Canyon. To this should probably be added the height of the Lopez block above the fault's outcrop, an additional 600 to 900 feet. East of Kagel Canyon there appears to be considerable drag in the sediments under the Little Tujunga fault, as evidenced by the dips of the underlying Saugus formation. West of Kagel Canyon there is no evidence of drag under the Lopez fault except very near to that fracture. Thus here, since in many cases the beds dip down at angles greater than the dip of the fault, we might expect the displacement to be considerably greater than to the east.

Hill believed that some of these dips were reversed, but an almost continuous section of Saugus sediments is exposed in the walls of Lopez

Canyon from the fault south, and at no point did the author find any evidence of a reversal of the order of the beds.

Little Tujunga fault.

Landsliding obscures much of the western end of the Little Tujunga fault. Its westernmost exposure is a small outcrop about 1000 feet north of the center of section 29, T3N, R14W. Here basement complex rocks adjoin Saugus sediments. The exposure is too poor to tell the relationship, but 700 feet to the southeast the basement rocks lie unmistakably on top of the Saugus, so that here again we are dealing with a reverse fault or a thrust. Almost in the center of section 29 is a hill composed of highly fragmented and intensely jumbled basement rocks. The south face of this hill has been cut away showing a good cross section of the formations (Figure 9, at the end of the paper). The basement rocks are almost too jumbled together to be the result of even an overthrust, and the hill may be the eroded remnant of an old landslide, or rather two old landslides, as a "fault" crosses its face showing that it has been created by two outthrustings of basement material. The hill is two thirds surrounded by outcrops of Saugus sediments, and on the other side by Kagel fanglomerates thru which at places more Saugus outcrops. Therefore, the hill is a true outlier either of a two part overthrust or landslide. Similar conditions persist for about 5000 feet to the southeast along the mountain front, three other outliers occurring at the eastern end of this stretch. The only place where the dip of the fault can be accurately measured along here is in Marek Canyon, and there it appears to be about 49° to the north. Since landsliding is common all along here, it is impossible to say whether this dip is typical, or whether the break tends to be much flatter, as is suggested by the sinuousity of its surface trace.

Two thousand feet west of Little Tujunga Creek it turns almost a right angle and runs northeastward along the northwestern side of Little Tujunga Canyon. The dips here are moderate, 41° northeast being typical. Thus here again the fault is of a reversed nature, basement rocks as usual being raised over Saugus. It can be traced northeastward to near the juncture of Buck and Little Tujunga Creeks, where it strikes out into the Saugus and disappears.

Between Marek and Little Tujunga Canyons 4200 feet of Saugus are exposed south of the break. In Little Tujunga Canyon only 1000 feet of Saugus lie exposed southeast of it. Thus as in the case of the Lopez fault, as we proceed east and north along the fracture, the Saugus section appears to decrease. Some of this motion may be taken up on the Sunland fault even farther to the east. The rapid disappearance of the shearing where the trace enters the Saugus suggests that its movement has become small here.

The relative ages of the Little Tujunga and Lopez faults are uncertain. The former's strike is terminated by what is here called the Lopez fault, but it may instead join this structure, in which case the two are contemporaneous for at least part of their movement.

Sunland fault.

The Sunland fault is nowhere well exposed in the area mapped. Hill measured a dip of 45° northeast in the southeastern corner of the southwest half of section 34, T3N, R14W. The writer's best measurement was a very rough 53° east at a point 3000 feet north of here. The course of the break is easily traced along the eastern side of the Little Tujunga Valley by the prominent scarp. At one place it intersects a small cross fault, which appears to be older than the main fracture. The plane of motion of this cross fault was never found, but Modelo beds clearly strike into basement rocks across a small canyon east of what is called Herrere's ranch on the map. The Sunland fault separates Saugus sediments from basement complex and overlying Modelo. Oakeshotte believes that the Sunland fault dies out before reaching the mouth of Gold Creek. On page 236-237 he states (1937):

> "Widening of the Little Tujunga road, where the contact crosses the road, perfectly exposes Saugus beds dipping inconformably to the southwest off Rubio diorite gneiss at an angle of about 25°. Three hundred feet east of that point a similar contact is found and 1800 feet farther east another exposure shows Saugus beds lying unconformably on the granodiorite and dipping 40° toward the southwest. <u>Thus direct evidence of the most convincing kind shows that the Sunland fault dies out about 2000 feet southeast of Little Tujunga Canyon.</u>"

There is no doubt about the correctness of his observations in the Little Tujunga road cut. However, 200 feet southwest of this sedimentary contact is a disturbed zone within the Saugus. A series of rather minor looking breaks in the Saugus actually represent altogether an unknown but considerable displacement, and the sudden change in dip at this point from 27° to 71° southwest suggests that the underlying basement has been considerably displaced. A large cut bank formed by Gold Creek 1800 feet east of this point is shown in plate XIIA of Kew's report (1924, facing p.101), and is used by him to illustrate the Sierra Madre fault. Wash of material from above has obscured the relationships of the rocks in this exposure so that the author was unable to determine whether there really is a fault here or not. However, the disturbed nature of the Saugus bedding suggests that the contact is not the simple sedimentary one suggested by Oakeshotte. On the basis of this evidence the writer is convinced that the Sunland fault continues to the west of Little Tujunga Canyon. Miller (1934, p.81) is of the same opinion. The break is last observed 1300 feet east of the Little Tujunga fault. which does not appear to be offset by the Sunland. Therefore, it appears probable that the Sunland fault is older than the Little Tujunga, unless the former dies out rather rapidly west of Little Tujunga Canyon. The Sunland fault has been traced by Hill east to Big Tujunga Canyon.

In section P-Q southwest of the Sunland fault there are shown 2150 feet of Saugus, 2300 feet of Pico, and 3750 feet of Modelo. Northeast of the shear this is reduced to at most 150 feet of Modelo. The maximum possible throw would therefore appear to be in excess of 8200 feet. However, it has already been pointed out that the section must be thinning in this direction, as the Pico and Modelo are both completely missing 4500 feet to the northwest, where Saugus lies directly on the basement. Nor is the elevation of the fault block any measure of its displacement, for the present dip of the Modelo on its southwestern edge (33° southwest on the average) suggests that the block may have been largely raised by bowing rather than faulting. The only certain throw is therefore represented by the thickness of the

150 feet of Modelo dipping off the block. Since the outcrop of the fault is very irregular, we can conclude that the motion was largely or entirely dip-slip. This direction is common to all the members of the Sierra Madre system in the area mapped as far as could be determined.

Merrick Syncline.

South of the Little Tujunga and Sunland faults is a well developed syncline plunging northwest. Hill has named this the Merrick syncline. He believed that he was able to trace this structure as far west as Pacoima Canyon, but the writer found no traces of it west of the north end of Marek Canyon. On Hill's map the northern end of the syncline is shown as recumbent west of Marek Canyon; but the author found no region thru which the dips reversed, nor any evidence for believing that the section was upside down. Near the northern end of Marek Canyon there are a few places where the beds probably are overturned, but these dips are rare. The Merrick syncline appears to strike under the outlier of basement rocks near the center of section 29, T3N, R14W, on the eastern side of Kagel Canyon. Hill has indicated that it extends for some distance east of the area mapped by this survey. However, it is difficult to trace it more than 1500 feet southeast of Little Tujunga Canyon, And it is more likely that what Hill believed to be one structure actually is a series of folds, possibly complicated by undiscovered faults. The irregular pattern of the dips in the Marek Canyon region strongly suggests that some undiscovered additional structural feature, such as a fault, remains to be found there. Since the Saugus consists of massive beds it is difficult or impossible to prove whether the section is right side up or inverted. In determining what its probable attitude is, which position gives the most likely or simplest structural picture is often the only usable criterion.

Near its northwestern end especially this fold appears to be very sharp. In a rough way its course is parallel to the Sierra Madre fault. It is possible that it is simply a huge drag fold or group of drag folds beneath the south thrusting mass of the Little Tujunga and Sunland blocks. However, it is questionable whether there ever was enough motion on either of these two fractures to drag over so large a structure as the Merrick syncline. It is more likely that it represents a yielding to the same forces which caused these fractures. In the basement beneath the fold there may be another fault like the others in the Sierra Madre system. Such a break, if it exists, must join the Lopez fault about where the Little Tujunga fault also joins it. From the steepness of the dips in the sediments we can guess that this shear would also be a reversed fault. The syncline crosses Little Tujunga Valley where there appears to be less thrusting than to the east or west, and the forces may be absorbed here by the folding. On the other hand, this does not explain the prominence of the fold east of the area mapped.

A Tujunga fault?

South of the Sierra Madre fault system there is exposed a continuous section of Saugus, Pico and Modelo rocks, ending finally at the edge of Big Tujunga Valley, which is flanked by alluvium coated slopes thru which project what lithologically resemble Modelo beds. South of Big Tujunga wash lie more Modelo beds, moderately folded. The edge of the hills north of the stream where the alluvium laps up against the older sedimentary rocks is remarkably straight. Miller (1928) and Hill (1930) have suggested that this may indicate that a fault exists somewhere in Big Tujunga Valley. However, this is vague evidence, indicating only that a fault is likely. The similarity of the rocks on either side of Big Tujunga Creek would suggest that such a fault can not have a large throw if it does exist. Hill believed that he had a possible correlation of beds across Big Tujunga Canyon, but the folded nature of the beds south of the canyon greatly weakens the argument that the relative displacement of such a stratum is likely to be the result of faulting. Because of the lack of positive evidence for its existence, no fault has been indicated on the map or sections.

Kagel fault.

South of the Sierra Madre faults there are numerous small breaks, only one of which is large enough to require detailed discussion. This structure, named the Kagel fault by Hill, is best exposed on the southwestern side of a small saddle on the western side of Bartholomaus Canyon, north of the hill marked "1675". It is a steep reversed fault, Modelo being raised against and over Pico sediments, with an estimated dip of 60°. Hill, on the other hand, measured a northward dip of 79° east of Kagel Canyon, which would indicate a steep normal fault. Hill believes that there is some strike-slip motion, the north side having moved southwest (1930, p.152), but the present writer found no evidence bearing on possible horizontal movement. The displacement appears to die out somewhere between Kagel and Little Tujunga Canyons.

Where the Kagel fault crosses the ridge just west of Kagel Canyon it cuts off a second fault on which the direction of motion appears to be normal. This fracture we shall call the

Wildwood fault. It dips to the north. It or a similar structure continues for at least 2500 feet east of Little Tujunga Canyon.

Where the Kagel and Wildwood faults join the relations are very difficult to determine. The exposed rocks consist of shales, sandstones, and conglomerates of the Modelo and Pico formations which can not be distinguished with certainty solely on lithologic grounds. At least three prominent basal conglomerates are involved. The distribution of rocks is such that it is almost certain that there must be at least one more fault, though this was never found in the field. In order to explain the presence, between the Wildwood and Kagel faults, of a wedge of conglomerate which appears to correlate with the basal Pico, a small cross fault terminated by both the Kagel and Wildwood faults has been assumed. The aspect of this fracture is unknown, but the wedge between the three breaks appears to be dropped with respect to the territory to the east. The estimated throw of this small fracture is 400 feet. On the Kagel fault the stratigraphic throw appears to be about 700 feet as measured in section A-B. The stratigraphic throw of the Wildwood fault is about the thickness of the Modelo above the mapped conglomerate marker, which can be seen to be about 500 feet just west of Bartholomaus Canyon where these rocks are best exposed.

The amounts of these displacements are made difficult to estimate by the presence of a clearly developed syncline and anticline, which are well exposed in the cliffs on the western side of Kagel Canyon. It is likely that the folds are genetically related to the faults. They appear to be limited to the region just south of the intersection of the Kagel and Wildwood faults. The latter terminates the folding on the northeast, the corresponding beds beyond the break being relatively undisturbed except for drag adjacent to the Kagel fault. To the west the folds are again cut off, this time by the Kagel fault. It is as though forces from the north had tried to squeeze more material into the region underlying lower Kagel and Bartholomaus Canyons than was possible, and the strata had as a result welled up along the Kagel fault, with compression and resultant folding in the upraised wedge.

Interrelations of the faults.

Chart III is a sketch map showing in outline the larger structures in the area mapped. These fall into three groups, the San Gabriel fault system, the Sierra Madre fault system, and the group of folds and associated faults, largely but not always normal, and with the northern block usually dropped, in the southern part of the mapped area. The Kagel fault is the largest of this group and the only one which indicates compression, though the presence of folding would lead us to expect largely this type of adjustment. Transmission of some of the thrusting forces which caused the larger deformations to the north into the Kagel Canyon region could easily account for the Kagel fault and resulting folds. The magnitudes of the strains which took place in the northern part of the area make it almost inevitable that some stresses must have spread to the adjoining part of the region to the south, though the presence of both tensional and compressional features is rather difficult to explain.

The problem of the relations between the two northern groups of faults is one which has until now not been satisfactorily answered. These northern groups have one thing in common, the northern blocks were all raised. The principal difference between the two is that the members of the northern group seem to be steeper in dip than those of the southern. Section C-D indicates that the two sets of fault planes converge at depth. This convergence may be in part the bias of the author, but it represents a sincere effort to project the surface data into a logical subsurface picture. If it is a true picture, then it may be that the San Gabriel and Sierra Madre faults are simply different expressions of the same feature, steep fault planes where the shear has taken place in the basement, and low angle reversed faults where the planes lie between sediments on the one side and basement on the other. According to this theory the low angle of the fault planes, which at places may even be reversed, is a result of the failure of the sediments to support the weight of the overlying blocks of heavy basement rocks. This picture works out very nicely for fractures such as the Little Tujunga fault, which at its roots, according to this theory, might be very similar to the neighboring Watt fault. However, for the thin wedges of the Buck Canyon fault block and the eastern part of the Lopez fault block, which rest on only a thin layer of sediments, such a theory seems unsatisfactory. Also, if the faults did flatten by shoving aside the underlying sediments by motion essentially perpendicular to the fault planes, then one would expect to encounter a much more complexly distorted series of strata immediately beneath the break than the single simple fold, and even that not universally present, that we do find.

Miller (1934, p.77-82) had a similar idea to this. He suggested that the faults steepened, then reversed in direction of dip with depth, thus having their origins in deep seated normal faults. The thinness of the wedges argues against this theory as applied to the Little Tujunga region.

It is difficult to believe that such long narrow slices as are exhibited in section C-D could maintain their identity to such great depths as are required by Miller's theory.

It has also been suggested that the thrust wedges were the result of forces acting perpendicular to the San Gabriel fault zone as a result of the pinching of wedges of rock dropped into the fault zone when openings developed temporarily along its length. In principle this theory appears very good, but when one considers the magnitude of the thrusting involved, the theory does not seem quantitatively adequate to account for the observations.

It is also possible that the forces causing the thrusting originated north of the San Gabriel fault, but it is inconceivable that such forces can have produced the complicated pattern of the Sierra Madre fault zone without disturbing the simple pattern of the San Gabriel zone, unless the motion on the latter is later than the Sierra Madre deformation. And elsewhere evidence was given that the presence of Martinez sediments in a wedge in the San Gabriel zone indicated that the San Gabriel fault has been in motion since at least Miocene time, whereas the motion of the Sierra Madre system must have been post-Pico.

Another possible explanation for the thrusting is that the wedges were chipped off the edge of a fault block as it tilted sharply to the north. To see how the present structure might be developed according to this theory, let us go back to the time of deposition of the Modelo, and watch the region undergo a history which appears to satisfy the requirements of the geologic record, and in most of its events to be required by it.

In the Upper Miocene the region must have been submerged by the ocean, at least in large part, in order for the Modelo formation to be deposited. This is the end of a relatively quiet period of deposition. A few interbedded conglomerates show that rejuvenations of the source land of the sediments have occurred. The probable source of such sediments was to the north, and so we can picture the region as in section I of chart I, all submerged, and with the seaward end of the wedge of deposits the thicker. It is not necessary to assume that the section thickens to the south, since, in the stage which followed the Modelo, erosion took place, and most of the sediments were removed; so the thick section at the south end could be merely the result of such erosion.

For this to have happened, the section must have been raised above the sea. We shall assume that this was accomplished by the rising of a land mass in the northern part of the area which concerns us, and to the north of there.

The southern part of the area remained submerged. The Modelo beds were worn off the land mass in the Lower Pliocene, and together with other detritus from the new land were deposited in what was left of the sea as the Pico, as shown in section II of chart I.

At first the rise was slow and intermittent, as proved by the sequences of conglomerate and shale in the Pico formation; but as time passed the orogeny increased in intensity, and the sea filled. A huge fan covered the new mountain front, the Saugus formation of our sedimentary section. Eventually the stress in the earth's crust became so great that it cracked. The most natural place for it to crack was along some old zone of weakness, which in this case was represented by the San Gabriel fault, as shown in section III.

Up to this time the whole southern part of the area had been carried up by the rising of the land to the north. When the fault broke, this block became unsupported. It fell back either under its own weight, or because for some reason it was forced down. Let us now suppose that the forces which acted upon it rotated it in a counterclockwise direction as we look at it from the west. This could result simply from the foundering of the block, or from the block being turned between the fault shown and another steep fault to the south. Section IV shows what it would look like if the block or simply its northern end rotated without changing in shape as it turned.

If this were to occur, a large gap would open up along the fault. Since this is impossible the corner of the block adjoining the fault must yield in some fashion. Where the rocks are brittle they will become faulted. Where they are pliable, folding will result with probably some secondary faulting. The result might closely resemble what is shown in section V. This is simply a scale reduction of section C-D taken across the Little Tujunga region.

To see more clearly how this theory of the origin of the observed structures was developed, let us reverse the process. We start with section C-D reduced to section V of chart I, which is reproduced again as section I of chart II. Let us assume that the amount of tilting involved is 45°. First we draw a line tangent to the Saugus-Pico contact and at 45° to the San Gabriel fault. Using the intersection of this line and the section line of the fault as a pivot we turn the assumed line and the section in which it is located until it is perpendicular to the fault. Next we slide successive parts of the section back until their points are against the fault as shown in section II of chart II. This leaves some big gaps along the fault and tears the sedimentary section to pieces. In section III these inconsistencies have been smoothed out by flexing the sediments until their relative parts adjoin, and omitting the gaps along the fault which presumably are kept closed by crushing of the rocks closest to the fault. Section III of chart II is plainly the same as section IV of chart I would be if some of the material were eroded from the top of the blocks. Sections III, II and I of chart I were sketched in roughly starting with IV and working successively to I.

It is not necessary to the theory that the whole fault block tilt, only that the end adjoining the San Gabriel fault bend down. Some of the normal faults in the southern part of the area mapped may have resulted from cracking due to the stretching of its surface as its north edge sank. South of the section shown the rocks must continue to yield in some fashion. It is likely that in the basement there are more faults which are not shown at the surface, the motion being absorbed by folding in the sediments. At some depth the basement rocks must become plastic enough to adjust without fracture, and hence no matter how large the block tilted, there is a distance from the border of the block beyond which no edge effects complicate the structure.

The fact that this sequence fits all the observational data is no proof of its correctness. The author offers it only as an hypothesis for further investigation. Examination of the areas immediately east and west of the one mapped should help to prove or disprove its validity. The sketches presented here offer another, and perhaps a simpler explanation of the observed phenomena than any presented previously.

Relations to the faults to the west.

At the beginning of this paper it was suggested that the Sierra Madre fault was the eastward continuation of the Santa Susanna fault. Kew (1924, p.100-101) held this view. On his map the two structures are shown as being continuous except for portions buried by alluvium. However, the general trend of the Sierra Madre fault is more continuous with the Pico anticline than the Santa Susanna fault. It may be that in the basement the Santa Susanna is not a single break, but is a group of fractures just as the Sierra Madre is, and that the Pico anticline is the surface expression of one of these.

The Santa Susanna fault outcrops along a very irregular line. At shallow depth it appears to be a low angle thrust, but at the greatest depths where it has been observed in oil wells it has become a steep reversed fault (Hazzard, 1944).

The rocks above and below the break are Tertiary sediments, moderately folded. The structural pattern is a type generally thought to be the result of horizontal compression.

The Sierra Madre fault is a group of cracks having roughly the same general trend. Near the surface they too appear to be of a thrust nature, becoming steep reversed faults at greater depths. The raised blocks in this case consist largely of basement rocks, whereas the dropped ones more commonly consist of late Tertiary sediments at the surface. According to the theory presented above, these structures are an edge effect of the tilting of a large block of the earth's crust. The principal forces involved were acting primarily vertically, the compressive forces being secondary.

If this theory is incorrect, and large scale compressive forces were responsible for the Sierra Madre faults, then they are very probably closely related to the other structure. However, it is difficult to see how regional compression can have acted in this district and left the San Gabriel fault just to the north as an almost straight fracture both east and west of the area mapped.

On the other hand, if the Santa Susanna fault is primarily the result of vertical forces, and the thrusting is some sort of surface effect due to lack of support of the raised block, then again the two fractures may be genetically related.

More knowledge of the nature of the disturbing forces is required to decide whether these two breaks are really one. Both vertical and horizontal forces were active in each case; the differences in the two structures are merely the effect of which direction of stress was predominant, and of the differences in the types of rocks involved.

Pre-Tertiary structural trend.

Before leaving the subject of structural geology it should be mentioned that the present structural trend of the San Gabriel and Sierra Madre fault systems is not a new one. As pointed out by Miller (1934, p.57), the foliation of the metamorphic rocks and the trend of the elongate igneous intrusions is roughly that of the main faults and of the range as a whole. Although considerable local variation was observed, the strike of the foliation throughout the area mapped south of the San Gabriel fault was roughly northwest-southeast. North of the San Gabriel fault this trend is less apparent, possibly because the rocks there are largely igneous and the foliation is less well developed.

V. GEOLOGIC HISTORY.

In discussing the geologic history of a region as small as that mapped for this report, it is necessary to choose between discussing only the limited part of the sequence of events that are illustrated in the exposed rocks that have been mapped, as against drawing on nearby areas to fill in the gaps. As the distance from the mapped area to the source of this additional data increases, there is increasing danger that the two regions underwent different histories, at least during part of the time. In a district such as the Little Tujunga region, where it is known that the area lies on the border of a basin, probably including areas where both deposition and erosion were active at the same time, it is particularly dangerous to make inferences on the basis of evidence from other locations.

The discussion which follows, therefore, has been limited to those conclusions that can be drawn from observations made within the mapped area, and in immediately adjoining areas that were visited while the main part of the survey was being made, and which are known from the continuity of the structures to have had essentially the same history as the mapped region. This limitation of the discussion makes the geologic history very incomplete. Information on the events during these omitted intervals can be obtained in many cases from reports on other regions at no great distance. Miller's (1934) and Oakeshotte's (1937) papers give much information on the pre-Cretaceous history, and the voluminous literature on the Los Angeles basin and adjoining areas, such as Kew's (1924), Hoot's (1931) and English's (1926) papers, cover the Cretaceous to Recent history.

In the Little Tujunga region the oldest recorded event is the deposition of the Placerita strata. These range in composition from limestone thru sandstone, now marble and quartzite. Their large quantity and widespread distribution indicate that at the time of their accumulation the region was a part of a large depositional basin, presumably marine. Although other authors have attempted to guess the age of this formation, no direct evidence of this has been found, except that it is earlier than the formations described below.

The Placerita was intruded by a succession of igneous rocks ranging from granite to gabbro. No attempt was made to distinguish between these different intrusives, nor to determine their relative ages. The Echo granite, one member of this sequence, is intimately injected lit-par-lit into the Placerita sediments. Probably either during or before the time of this intrusion the Placerita sediments were intensely metamorphosed, the limestones becoming marbles; the shales, schists; and the sandstones, quartzites. Nothing is known of the true age of any of these rocks, except that they are older than the oldest sediments found lying on them.

Following the metamorphism and intrusions of these old rocks the region very probably underwent a period of erosion, though no traces of such an erosional surface remain exposed. The oldest unmetamorphosed sediments known are a few isolated outcrops of shale, siltstone, sandstone and conglomerate, completely surrounded by faults. Since they are not metamorphosed, they are presumably younger than the much altered Placerita sediments, but there is no evidence in the Little Tujunga region to prove that they are not older than at least some of the intrusives. However, since they are nowhere cut by any of these old intrusives, this is unlikely. Clements and Oakeshotte (1934) have shown that these deposits are of Lower Eocene (Martinez) age. The presence of shale and siltstone in this formation suggests that the region was widely inundated by the sea, but it is not possible to tell whether the exposed deposits represent a large or small part of the section that was deposited during this submergence.

Following the deposition of the Martinez beds, the region must have undergone a period of erosion, and probably emergence, during which almost all of the Martinez formation was removed. It is likely that movement on the San Gabriel fault had begun by this time. All the discovered outcrops of Martinez are on fault wedges within the zone of this fault, and it seems unlikely that these deposits would have been preserved when no other exposures of this formation remain unless they had already been lowered out of reach of erosion before the end of the post-Martinez interval of degradation.

The post-Martinez erosion surface is exposed along the southwestern side of the Sunland fault block. Here it appears to be a nearly flat plane, which has since been sharply tilted. On it are deposited evenly-bedded silty sandstones containing marine fossils. These fossils are of Upper Miocene age, showing that by the end of that epoch the region had again been submerged in the sea. Deposits believed to be of the same age, unknown thousands of feet thick, are exposed all along the southern edge of the area mapped. Since shale is the predominant sediment, an extensive, quiet sea may be postulated.

Toward the end of this period deposition became more irregular. A prominent marker bed of conglomerate indicates that high land was exposed nearby. Although none are exposed in the area mapped, immediately to the east there are basalt flows which are generally believed to have been extruded during the period of deposition of the Modelo formation.

Following the Modelo deposition there was a period of emergence of unknown duration represented by a disconformity. During this time a land mass began to rise in the northern end of the area, and any Modelo that may have been deposited there was removed. This land mass persisted into the Pliocene, and was probably the source of the Pico sediments, which overly the Modelo with little or no angular unconformity in the mapped area, though to the south the Modelo was generally more disturbed. At least three basal conglomerates in the Pico, each grading upward into finer sediments, indicate that the land mass was rising at an irregular rate. The northern edge of the Pico sea must have lain close to the present southern edge of the Sierra Madre fault zone, for no Pico sediments occur north of this line. Since a large part of the Pico consists of coarse, unsorted, conglomerate, composed of fragments of the types of rocks making up the basement complex in the northern part of the region, it is likely that a part of these sediments came from there. Indeed, activity on the San Gabriel fault may have been responsible for much or all of the rise of the land mass from which these sediments came.

The Pico grades continuously from a marine into a terrestrial facies. A huge alluvial deposit was built up against the mountain front in the central part of the area, and extended at least as far as the present trace of the San Gabriel fault. Over 7800 feet of beds of this fanglomerate are exposed. If one attempts to draw a section across the area, keeping an even thickness of this formation, the Saugus, it is difficult or impossible to obtain a physically likely picture. Therefore, it is probable that there is rapid onlap of this fan on a steep mountainside.

The top of the Saugus is nowhere exposed. The diastrophism which built the mountain front against which the Saugus was deposited culminated at the end of this stage of deposition. Large movements occurred on both the San Gabriel and Sierra Madre fault systems. The time of these movements was probably either late Pliocene or Pleistocene. There is no evidence of recent motion on any of these faults in the mapped area, though Hill (1930, p.154) discovered some offset of recent alluvial fans to the west.

Following the post-Saugus orogeny, which formed the present San Gabriel mountains, erosion set in and developed a drainage pattern essentially the same as that which exists today. The region south of the Sierra Madre fault zone was largely covered by a huge alluvial fan, indicating a considerable period of erosion. Rejuvenation allowed this fan to be almost completely removed, and the present drainage pattern south of the Sierra Madre fault is probably subsequent to the fan. This rejuvenation has not taken place all at once. Many of the canyons became locally choked with alluvium, which may mean that the rejuvenation reversed itself on occasions, or it may mean that the land mass to the north was still rising intermittently, from time to time increasing the supply of sediments faster than the streams could carry them away across the foothills. In any case many of the streams were temporarily choked with sediments, possibly not all at the same time. These alluvial bodies are left as terraces or partly removed and intrenched valley fills.

The present cycle is one of erosion throughout most of the area, though along the southern edge material is being carried down and at places probably deposited on the alluvial fans in Tujunga Canyon. Pacoima Creek is depositing material behind Pacoima Dam which previous to the dam's construction was accumulating along the edge of San Fernando Valley immediately adjoining the area mapped. Similar conditions exist in Big Tujunga Valley. Little Tujunga Creek, though the local base level of erosion appears to be reaching up into the canyon, has a very shallow fill of alluvium, and most or all of it probably moves in the largest storms.

VI. CONCLUSIONS.

In the introductory part of this dissertation it was stated that the purpose of the survey was to determine whether a very detailed study of a region such as the Little Tujunga area, which had previously been mapped by several competent observers, would reveal features of significance not previously described, and to try to find out more about the relationships between the San Gabriel and Sierra Madre-Santa Susanna-San Cayetano fault systems.

From comparison of the previously made maps of the area and that accompanying this report, it can be seen that the present survey has uncovered no important errors or omissions in the previous work, but that numerous detailed corrections and additions have been made. The faults can be traced in greater detail on the larger scale map that has been made, and much new information has been secured concerning their true nature. Faults which at depth appear to become steep reversed faults are shown to be near the surface more often low angle, or even overturned, thrusts. Much of the detail is seen to be confused by landsliding, some of which is very recent, and some many years old. Such landsliding is prevalent along all branches of the Sierra Madre fault, and also along steep slopes in the sediments to the south.

Branches of the Sierra Madre fault are

never seen to join the San Gabriel fault, which forms the northern edge of the tilted block in which the Sierra Madre faults occur. The suggestion has been made that the Sierra Madre faults may not be genetically closely related to the Santa Susanna and San Cayetano faults, and that the apparent linear continuity of these structures may be entirely a coincidence. A theory of the origin of the Sierra Madre faults has been offered wherein they are believed to be the result of fracture of the northern edge of a fault block tilted against the main mass of the crystalline core of the San Gabriel Mountains.

The problem of the relations between the San Gabriel and Sierra Madre faults is really too big a problem to be solved by the examination of so small a region. The speculations presented here would receive much support if similar conditions were found to prevail at other places along the San Gabriel fault. The amount of detail of the faulting and generally related folding revealed by a survey of such great detail as this one may serve as a stimulus to others to examine the adjoining regions with equal care. Sufficient work of this nature should show whether the theory presented above is valid, and even if it is not, such work would be bound to increase our understanding of these two probably related fault systems.

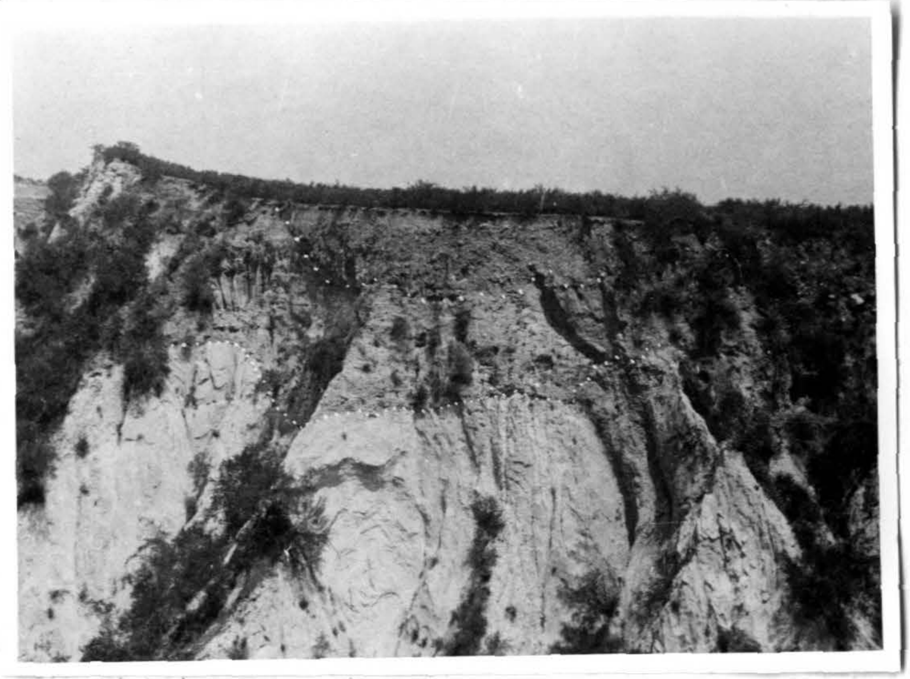


Figure 4. Lopez alluvium overlying the Saugus formation, exposed in cliffs on the east side of Marek Canyon. Deposits consist of upper, dark colored and lower, light colored gravels.

Figure 5. Kagel fanglomerate lying on Saugus deposits, exposed in a road cut on the west side of Little Tujunga Canyon.

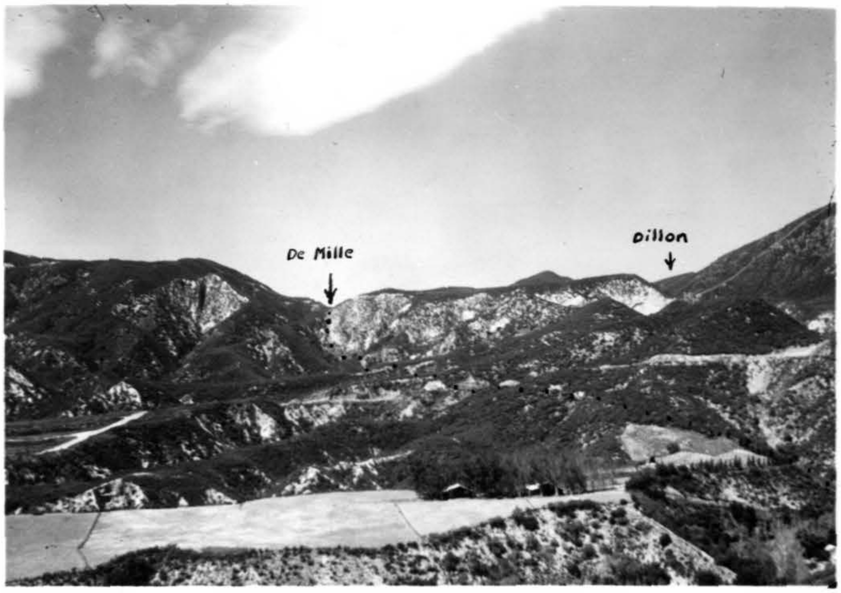


Figure 6. View looking west across sections 21 and 22, T3N, R14W. The terraces are underlain by Beehive Mesa deposits. The De Mille and Dillon faults cross the indicated saddles.

Figure 7. The Watt fault in a stream bank 1000 feet east of the border of the area shown on the geologic map. Martinez is raised over Saugus.

Figure 8. The Buck Canyon fault zone just west of where the North Fork fault offsets it.

Figure 9. Overthrust or landslide? The south side of the outlier of basement complex lying between Kagel and Marek Canyons.

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SUPPLEMENT.

Fossil identifications.

Dr. W. P. Popenoe of the Department of Geology of the University of California at Los Angeles has very kindly examined the fossils collected by the author in the Little Tujunga region. Unfortunately, his identifications were not received in time to include them in the main part of the text of this dissertation. A summary of his findings follows:

Locality #1. Hillside overlooking Little Tujunga Canyon from the east about 1000 feet south of the mapped Saugus-Pico contact.

Dosinia ? sp. indeterminate;
Turritella sp. indet.
Pecten sp. cf. P. healeyi Arnold
Probable age, Pliocene.

Localities 44, 45, and 50. Three localities within a few hundred feet of each other in the wedge of presumed Modelo lying on the southwestern edge of the Sunland fault block.

Dosinia sp. indet.
Nuculana sp. indet.
Pecten cf. P. andersoni
Chione ? sp.
Ostrea sp. (large thick-shelled form)
"Cardium" sp.
Age, most probably Upper Miocene.

Locality 33. Cliff on the east side of Bartholomaus Canyon about 100 feet south of the mapped Saugus-Pico contact.

Polinices sp.
Chione sp. cf. C. fernandoensis English
Lucina acutilineata (Conrad)
Pecten sp. indeterminate
Trophosycon ocoyana? variety
Age, probably Lower Pliocene, approximately equal to English's Elsmere Canyon fauna.

Though the poor preservation of these fossils makes it impossible to give accurate, certain age determinations, what data is available agrees with the conclusions of Hill (1930) and Kew (1924) which were discussed in the main part of the text.