GEOLOGY OF A PORTION OF PIRU AND SANTA SUSANNA QUADRANGLES

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Introduction

Location of Area

This area is situated adjoining the town of Piru, California, the area extending to the north and east of the town, in the northeast corner of the Piru quadrangle and the northwest corner of the Santa Susanna quadrangle. Piru is located on State highway 126 connecting the Ridge Route highway (U.S. 99) with the Coast (Roosevelt) Highway (U.S. 101) at Ventura. To reach Piru, travel from Los Angeles out Highway 99 to Castaic Junction, fifteen miles beyond San Fernando. Turn left on highway 126 and travel twelve miles to Piru. The southern extremity of the area borders on highway 126 and extends approximately from the Los Angeles- Ventura County border to Piru. All roads to Piru are well paved, except for one stretch just outside of Piru where a flood has washed out some two hundred yards of pavement.

Fig. 1. Location of area.

Size of Area

The area is shaped roughly like a trapezoid and contains approximately sixteen square miles. The boundary, beginning at Piru, extends east along highway 126 for approximately five miles, turns north for another four and one-half miles, turns west along Leckler and Santa Felicia canyons to Piru Creek, extends about one-half mile farther west, and then parallels Piru Creek cown to Piru. The hills are sufficiently covered with grass to warrant several large ranches with quite a few live stock. Several bee colonies are cultivated here. All of the area is leased by the Pacific Western Oil Company, and written permission must be obtained before anyone is permitted to trespass in the area. There is one road running along the bank of Piru Creek that originally had several offshoots to different parts of the area and to ranches in the canyons, but now the flood of March, 1938, has washed out all the side roads and nearly demolished the main road up the canyon.

Purpose of Investigation

The purpose of this work was to become practiced in the work of field geology and mapping. As this locality has been developed for oil, the investigation was also done to become acquainted with a type of oil structure. This paper is also part of the requirement of the degree of Bachelor of Science in Geology at the California Institue of Technology.

Method of Investigation

The work has been done with the aid of U. S. G. S. topographic maps made in 1900 by the U. S. Coast and Geodetic Survey, with the scale being 1/62500. The contour interval in the

Santa Susanna quadrangle is fifty feet, while the interval in the Piru quadrangle is one hundred feet. The use of such a small scale and contour interval was unavoidable, since the Piru quadrangle is in Ventura County, and the Santa Susanna quadrangle is in both Ventura and Los Angeles Counties; and the division of maps in Ventura County has not surveyed this territory in any greater detail than 1/62500. Because of the inconvenience and virtual impossibility of recording detailed structure on such a scale, the regular map was enlarged four times and the structure plotted on this. Contacts and locations of dips and strikes were located with the use of a Brunton compass and by topographic location; but on such a scale as the contouring is, exact locations are very difficult.

Physical Conditions

Relief and Elevations

The country is quite hilly, rising from 850 feet at the mouth of Piru Creek to 2500 feet within a mile of the creek bottom. There are numerous peaks in the area with a height of 2200 feet, indicating a possible original plane at this altitude. For example the altitudes of some peaks are 2216', 2221', 2225', 2219', 2243', 2266', and another 2266'. Considering the fact that there are only five other peaks in the area, all of which are less than 2200 feet, this fact is somewhat noteworthy.

Topography

Due to the fact that there are a good number of dip slopes in the area, the topography at times is a good indication of the structure. Particularly at the north end of the area, just north of Santa Felicia Canyon, a wide, gentle syncline is well depicted in the topography. There are a great number of undrained depressions in the Modelo formation at the north of the area. In the south of the area there is an unusual alignment of some ten or twelve saddles which seem to be due to a fault extending through the Pico sediments. The topography in general is quite rugged, the streams still cutting down in their canyons.

Drainage

The main drainage feature of the area is Piru Creek, which runs from north to south until just at the southern end of the area, at which point it turns almost due west for about a mile and a half, where it again turns south and empties into the Santa Clara River. The streams of the area present a rectangular drainage pattern, the streams entering Piru Creek flowing east-west, and the tributaries of these streams again flowing north-south. Piru Creek contains water the year round, being quite low in the summer, and reaching flood proportions in the winter. Most of the tributaries are dry during the summer months.

Vegetation

Since the country is semi-arid, vegetation is scarce. In the stream valleys, there are quite a few live oak trees, but with the exception of some trees along the banks of Piru Creek, these are the only trees in the area. The vegetation on the hills is typical desert chapparal, the bushes seldom reaching a height of four feet, and even these are scarce. There are some yuccas in the area, with Spanish needles at the base. Most of the shale slopes are covered with grass and wild oats.

Fig. 2. Typical vegetation and exposures of the Piru area.

Exposures and Geology

Due to the semi-arid conditions of the region, there are a great many places in which good exposures are available. The most valuable exposures are along the sides of Piru Creek; for this stream cuts through the area at right angles to the strike of the beds, thus giving a good clue to the structure of the area. Many of the tributary streams have cut back into the hills in such a fashion that the heads of two streams are separated only by a steep ridge which is made up of the more resistant beds of the formations and which for this reason presents an extremely rugged outline. Because the stream runs directly along the strike of the beds, Santa Felicia Canyon presents very poor exposures in a place in which exposures would be very desirable. This locality will be discussed in greater detail later in the paper. The southern part of the area has been sheet washed by floods to such an extent that the beds are no longer separable from one another, and structure is very difficult to ascertain. At the other extreme, Lime Canyon presents a wonderful series of exposures on both sides, from its mouth to its head. Notably on the west side of Piru Creek the character of the soil is such that exposures are completely covered by grass and are virtually impossible to pick up.

The geology of the area is confined to a sedimentary record. No igneous or metamorphosed rocks are present in the area, although some nine miles above the north edge of the area there is an intrusive body of some type. The rocks of the area are a gradation from fine mud shales to coarse conglomerates. The Modelo formation as a whole is finer grained than any of the other formations, containing only one or tow conglomerate beds, the rocks of which do not exceed an inch in diameter, and in the main is composed of shales. The Pico formation consists mainly of massive sandstones, although there are some shales and several very coarse conglomerate beds in the formation as exhibited here. The Saugus formation, what little is found in the area, consists of unstratified, white, coarse-grained sandstone. All three of these formations lie unconformably upon one another, the Saugus having been faulted in several places against the Pico, and the Pico lying upon the Modelo with an unconformity in strike and dip. While the Pico is reasonably uniform throughout its thickness, the Modelo exhibits interfingering of the sandstone and shale members. There is a major fault, a portion of the San Gabriel fault, in the Pico in the northern part of the area and another in the Pico somewhat farther south, both faults evidently dying out in the area. There are undoubtedly some smaller local faults in the area,[1] but this investigation was not sufficient to locate them.

Regionally the area has been worked for placer gold in the bed of Piru Creek, but as yet the returns have not warranted the importation of hydraulic equipment back into the head waters of the stream. By far the major development in the area is the search for oil. At present the Pacific Western Oil Company of Los Angeles is opening new developments in the area, particularly along the Modelo anticline, which first shows oil-bearing possibilities in this area and which is being worked even more extensively to the west. At present the Continental Oil Company is drilling in Hopper Canyon, three miles west of Piru, with virtually absolute certainty as to the discovery of oil at that point. Modelo anticline

(1) Dr. John H. Maxson. Personal communication.

pitches to the east and so affords an excellent trap for oil around this territory. The area has been subjected to severe deformation which was responsible for many minor anticlines in the area, but only the Modelo anticline seems to have trapped sufficient oil to be commercially workable.

Summary

The geology of the Piru area is the result of the application of compressional forces from the north and south with the subsequent release of these forces. The compressional forces, which were applied at some time following the deposition of the Pico and before the deposition of the Saugus, resulted in a relatively gentle bowing of the Pico formation into wide anticlines and synclines and a profound deformation of the underlying Modelo shales. This folding produced the Modelo anticline, which pitches to the east and affords a good oil trap. On the flanks of this fold, however, there are innumerable small, localized deformations of the strata into isoclinal folds, pitching synclines, and completely broken beds which have lost all their connections with the main continuity of the strata. The strike of the beds is often twisted through ninety degrees and back again by the intense forces which were applied. The subsequent relaxation of these forces after the deposition of the Saugus formation caused renewed action on the San Gabriel Fault, which extends through much of southern California, and brought forth another subsidiary fault parallel to the San Gabriel Fault. Both of these faults were normal faults, and movement on them raised the Pico formation above part of the Saugus and caused two sharp synclines and anticlines in the southern portion of the area. The cutting of Piru Creek directly across the strike of the beds in the area affords an excellent chance to study the results of the intense forces to which this area has been subjected.

Geologic Conditions

Stratigraphy and Petrography

The geology exposed in this area is a continuation of a portion of the geology exposed in the Sunland quadrangle, showing that the rocks in this part of southern California are at least fairly consistant in their regional extent. The lowermost formation with which we are dealing in Piru Creek is the Modelo formation of Upper Miocene age. The beds in this series vary from thick, massive, coarse sandstones to fine-grained, thinly laminated shales. On the south flank but near the center of the Modelo anticline in Lime Canyon there is a typical succession of beds as follows: massive gray sandstones ten feet thick; finely bedded coarse sandstone, each lamination being approximately one quarter inch thick; a sandstone bed one foot thick; a good thickness of thin sandstone laminations, each lamination being one inch thick; sandstone beds one to two feet thick interbedded with shale members; a one foot series of sandstone laminations, each one inch thick; a twenty foot series of shales and sandstones varying from one quarter inch to two inches in thickness; interbedded sandstones and shales; massive sandstones. In nearly all of the Modelo the beds show a high degree of sorting, with only one or two local beds of conglomerate in this area. The sandstone is composed of medium coarse grains which are predominantly quartz and which are well cemented together with what is probably secondary quartz. The shales, which are the most prominent members of this formation, are composed of very fine grains which are indistinguishable under a hand lens study. In some cases the shales have become distinctly silicious due to the perfect cementation of the already minute grains with secondary quartz. Finely disseminated throughout the Modelo shales are small flakes of gypsum which locally grow into crystals up to one half inch in length. In most cases, however, these gypsiferous shales are porrly cemented or else the cement has been leached out near the surface of the outcrop; for these shales are notably crumbly and hard to preserve as specimens. Locally there are sandstone lenses in the shale members.

Fig. 3. Typical Modelo shale.

The color of the Modelo outcrops is somewhat distinctive when compared to the color of the Pico beds. The sandstone is generally whitish in character with only a few rust colored beds in localized portions of the section. The shale which has not been subjected to oil seepage is a slightly brownish gray on a fresh surface, but on a weathered surface there appears a distinctive pale yellow to orange alteration product which is not quite the same as that on the Pico shales. The shales which have been saturated with oil present a somewhat purplish black aspect on a fresh surface, while the weathered surface is changed to an orange brown or brownish black.

Pico formation

Lying unconformably on the Modelo formation in this area is the Pico formation of Pliocene age. The outstanding feature of the Pico in this area is the massive sandstone beds which make up the majority of the formation. Locally at varying heights there are very poorly sorted conglomerate beds, and there are good thicknesses of shale in the area; but the massive sandstones make up the great bulk of the formation.

The conglomerates, although they are infrequent in the portion of the Pico exposed here, give the best clue as to the source material of the rocks of the whole formation. In one of the most readily studied beds, the pebbles are poorly sorted but are well rounded and decidedly stream flattened, sufficiently so to enable one to obtain a reasonably accurate dip and strike from their attitude. The pebbles in this bed are made up of material derived from granite-like bodies which apparently lay to the north of the area, from quartzites or previously formed conglomerates, and from volcanics of a basaltic nature. In the section exposed north of Santa Felicia Canyon there are a series of conglomerate beds with pebbles ranging from one quarter inch to six inches in diameter interbedded with loosely cemented sandstones with thicknesses between six and eighteen inches. Directly southward from this point the sandstone members thicken and the pebble size of the conglomerate approaches uniformity, with the maximum size being only two inches in diameter. North of Holzer Canyon and to the east of Piru Creek near the contact between the Pico and the Modelo formations are two conglomerate beds, the larger of which is fully fifteen feet thick and composed of very poorly sorted boulders of all sizes. In this locality there is no basal conglomerate to the Pico formation.

The sandstones of the Pico formation range from coarse to very fine grained. The coarser sandstones consist of grains ranging between one thirty-second and one-sixteenth inch in size. The grains seem to be all quartz, varying from rounded to angular in outline, among which there are disseminated fine grains of a mineral which under the hand lens appears to be olivine or a related mineral. This sandstone is very well cemented with secondary quartz. The next type of sandstone is made up almost exclusively of minute yet distinguishable quartz grains well cemented with secondary quartz and containing a few small flakes of magnetite as well as one or two grains of an opaque green stone. While all these grains are small they are exceedingly angular. In some places this type of sandstone has been penetrated by oil seeps. The result of this is to make the individual quartz grains stand out because the oil appears to have the effect of dissolving the intersticial quartz from between the primary grains. In the places where there are these oil-soaked sandstones there are also thin layers of limonite interbedded with the sandtones. The weathering of these sandstone beds gives either a rust color which is very distinctive or a gray color due to the oil, also a color which is rather diagnostic.

The shales of the Pico formation are very similar to those of the Modelo. Specimens taken from a distance of less than ten feet on either side of the contact between the two formations show scarcely any lithologic difference, the only noticeable feature being that consistantly the Pico shales carry more disseminated gypsum than do the Modelo shales. Locally in the Pico there are very thin, small deposits of gypsum plates occurring with the sandstones and shales. The weathering of the Pico shales is to a somewhat browner orange than that of the Modelo, but this method of distinction is to be handled with care. It suffices to say that the presence or absence of gypsum in the shales is the best method of establishing the origin of two isolated specimens.

Saugus formation

Lying unconformably on the Pico is the Saugus formation of Pleistocene age. Only two slim fingers of Saugus penetrates into this particular area. Both of these members consist of arkosic, loosely consolidated sandstones which weather to a chalky white and as a result are very distinctive from a distance. The grains are fairly coarse and are in the main quartz and feldspar, probably plagioclase. The grains stand out from the main rock mass because of the weathering and the lack of consolidation.

One fairly coarse conglomerate boulder somewhat over a foot in diameter and completely packed with fossils of Mollusca was found resting virtually on the summit of a hill in the Pico formation with no apparent connection to the Pico in any manner. Because of the absense of fossils elsewhere in the area (save for some fish scales found in the Modelo) this boulder has been assumed to be residual from the originally overlying Saugus formation. The sandstone of this specimen appears to be made up of quartz grains cemented with a mixture of secondary quartz and limonite. This limited amount is all that can be determined of the Saugus formation in this area.

Topographic Expressions of the Formations

The sandstone members of the Modelo and Pico formations give to the country its rugged appearance since they occur interbedded for the main part with soft shales. In the Modelo formation the sandstones stick up on the ridges in such a manner between the soft lying shale beds that the crossing of a saddle made by the headward cutting of two streams back to back is made impossible due to the comparatively high, steep ledges left by the sandstone. The sandstone fosters the growth

Fig. 4. Sandstone ridges in Modelo shales.

of typical chaparral on most of its slopes, while the shales give rolling, grassy slopes on which no dips and strikes are available. The drainage and weathering of the shales in Modelo have given rise to numerous undrained depressions which on first inspection appear to be sagponds left in saddles by some type of fault movement. Further investigation, however, shows that the depressions are due entirely to the differential weathering of the shale beds and have no connection with any fault movement in the area.

Fig. 5. Undrained depression in Modelo shales.

The topography in the area of the Pico beds is much more rugged than that of the Modelo. In the absence of the numerous shalebeds which are found in the Modelo, the topography has developed to a more massive consistancy than that of the underlying formation. Rolling slopes and grass covered areas are virtually missing from this portion of the area. The hills have a chunky appearance, a solid block aspect being given which is not present in the northern portion of the area.

The Saugus formation, because of its state of poor consolidation,forms, in the two narrow bands which penetrate the area, low points in the topography. The elevations rise sharply on both sides of the contacts between the Pico and the Saugus. Outside of the area the Saugus appears to give a somewhat choppy topography in comparison with the Pico which underlies it.

Geologic Structure

The regional structure of Los Angeles and Ventura counties is one of complicated and rather intense folding and faulting. Several major faults run throughout the territory, and myriads of minor faults can be found in almost any section of southern California.

The effect of this disturbance in the southern California area has been to send two somewhat major faults into the Piru area and to cause very interesting and complicated folding in the rocks of this region. Sharply folded anticlines and synclines rise and die out with such rapidity that several prominant folds on the west bank of Piru Creek cannot be traced across to the east side. The shales of the Modelo formation present such complicated folding within major folds that this topic will be taken up later in detail in this section of the paper. The Pico formation does not reflect this intense deformation in the sandstones but protrays only the major effects of the compression. The Saugus formation shows no deformation other than that which contributed to its present steep dip.

Post-Modelo Deformation

Comparatively speaking, little is known of the post- Modelo-pre-Pico deformation in this area. The only knowledge available is to be found at the contacts between the Pico and Modelo formations, and this knowledge is scant. The structure of the contact between the Pico and Modelo formations is poorly exposed in the Piru area in all except one locality. The northern contact runs east-west across some low foothills on the west side of Piru Creek. The vegetation and topography make study of the contact in this particular area impossible.

On the east side of the creek, the situation is no better. The contact runs directly up Santa Felicia Canyon to Leckler Canyon, where it turns and runs along this canyon deep into the area. The Modelo beds come down the north flank of the Modelo anticline and jut into the Pico sandstone under the alluvium of Santa Felicia canyon. On the north side of this canyon

Fig. 6. North view looking from Modelo to Pico formation.

these beds of shale do not reappear, and considering the trend of the beds on the south of the canyon, it is clear that were it not for an unconformable contact under the alluvium of the canyon that the Modelo beds would reappear on the north side. Instead, the north wall of the canyon is formed by massive sandstone cliffs of the Pico. Following the contact around its eastern extremity and back to Piru Creek there is no evidence of unconformity, and the appearance of continuous deposition is given at the outcrops.

But where the contact comes on the west face of Piru Creek, there is a very obvious unconformity. Fig. 7 and the accompanying sketch give the relationships of the beds of the Modelo and Pico formations. The only weak point in placing the contact

Fig. 7. Pico-Modelo unconformable contact.

here lies in the fact that this puts a massive conglomerate bed in the Modelo and places the contact at a thin, one-foot sandstone bed which separates two very similar shales. However, a study of the picture will make the relations reasonably clear. The Modelo consists of nearly vertical sandstones and shales which are at the axis of a syncline. The base of the Pico here consists in the main of a shale with a sandstone lens in it. Both of these formations have here been folded into a secondary syncline evidently unrelated to the original Modelo syncline. The Modelo beds strike approximately N 80°W and dip approximately 84° S, while the Pico beds strike approximately N 55°W and dip about 50° S. Some of the change in dip is due to the syncline, but the change in strike is definite and the change in dip at the contact is noticeable. The contact to the south of this, on the south limb of the syncline is apparently not exposed, being covered with the alluvium of the terrace which extends back from the creek at this point. From this evidence the only deduction which can be made is that the Modelo formation was folded to some degree into anticlines and synclines after which tilting and erosion made way for the Pico deposition.

Post-Saugus Deformation

Under this heading it will be necessary to group the post-Pico and post-Saugus deformations because of the almost complete lack of evidence to be used to determine the relations between the Pico and Saugus. At the contact between the two formations the dip of the Saugus appears to be near to 60° S, but due to the lack of bedding, only a rough estimate can be made. At this same place no dips can be obtained in the Pico formation. This point is one of the places where sheet washing has obliterated all trace of the bedding in the Pico. However, from the nearest locality in which a dip in the Pico can be obtained, the Pico dips at approximately the same angle as does the Saugus. The conformability of the contact between the Pico and the Saugus is therefore indeterminable in this area. Because of this the main period of deformation can not be definitely placed and will be discussed as post-Saugus.

The structure on the east side of Piru Creek will be considered first because it is somewhat different from that on the west side. To the north of the area is a gentle syncline which swings up into the Modelo anticline, an extremely large fold which pitches at an angle of 17° to the east and widens out extensively just to the west of Piru Creek. The axis of the anticline to the west of Piru Creek runs within a few degrees of an east-west direction. Across Piru Creek the axis of the fold turns southward about 18° for a distance of about a mile and a half, where it again turns toward due east. As a result of this eastward pitch a good section of the Modelo exposed here, consisting of interfingering series of predominantly sandstone and predominantly shale beds. Dips taken in the section exposed by the Piru Creek cut show the fold to be assymetrical with the south side being somewhat steeper than the north flank. The strike of the beds in this cut varies from N 89° W to N 73° W. Along the axis of the anticline to the east of Piru Creek dips and strikes were taken at points where one of the shale members plunges under the overlying sandstone series. Here the strike passes through N 30° W clear around to N 2° W. At these points the dips are 24° NE and 17° NE respectively. On the east side of the creek, from the center of the anticline southward, the rocks pass through a series of minor fluctuations. A few hundred feet south of the axis of the Modelo anticline, the dip takes a local flattening to 36° only to steepen again to 56° several hundred yards to the south. From here to Holzer Canyon, there are several noticeable minor fluctuations of dip and strike. The dip first flattens off again to 45°, then steepens abruptly to 76°, only to fall off sharply to a dip of 25° on the north flank of a small pitching syncline. The north flank of this syncline begins at the mouth of the stream situated halfway between the axis of the Modelo anticline and the mouth of Holzer Canyon. The lowermost beds visible are shale beds of one of the interfingering Modelo members. The strike on the north flank is N 65° E, and the dip is 25°. During the next six hundred yards downstream in Piru Creek the strike changes until it reaches N 20° E and then slightly opens out to N 40° E. In all the points within this area, the dip is constant at 25°,

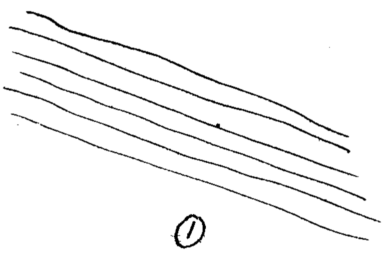
Fig. 8. Looking east across Piru Creek showing synclinal beds pitching to east.

and the syncline pitches approximately 25° to the east. The outcrop of this syncline on the east bank of Piru Creek is deceptive in that the beds rise from the north flank of the syncline to a topographic high at the axis of the syncline and drop to

Fig. 9. View looking east, somewhat south of Fig 1, showing apparent anticline, but what is in reality a syncline pitching east.

the original level at the south flank, thus giving the appearance of being an anticline. Just beyond the south flank of this syncline the strike resumes its normal direction of approximately E-W, and the dip increases steadily from 25° to 70° at the contact between the Modelo and the Pico formations just on the north side of the mouth of Holzer Canyon.

The structure south of this point consists of two sharp synclines and two equally sharp anticlines. The anticlines are very assymetrical, being relatively consistent and shallow on the south sides and quite steeip and abrupt on the north flanks. Further east, on the east edge of the area are two parallel vertical faults, one the western termination of the San Gabriel fault, the other apparently a subsidiary fault brought into being by movement along the San Gabriel. Both of these faults apparently terminate in this area, for no definite proof of formation is pinched out by the regular contact between the Pico and Saugus and the fault contact. It is the opinion of the author that these two faults are directly responsible for the structure exposed in the Pico. The sketches illustrate



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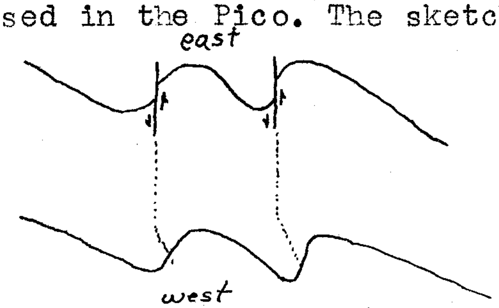

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the sequence ascribed to the formation of the two anticlines and synclines. Originally the structure in the Pico formation and underlying beds consisted of a homoclinal dip to the south. With the movement on the San Gabriel fault and fault parallel to it, the south side of the fault in each case was upthrown. (The evidences for this will be presented shortly.) The accompanying drag effects produced a north dip against the faults, thus giving a synclinal effect on the north side and an anticlinal effect on the south side. With the dying out of these faults, the structures obviously had to be continued for some distance in order to allow the strains set up to die out. Thus the anticlines and synclines in the Pico formation in this area are due to drag effects which were not quite strong enough to pull the bes apart.

The evidences of the faults consist in the main of two things: gouge and stratigraphic relationships. The faults in both cases are vertical. Their planes of movement are visible on the south sides of each of the two contacts between the Saugus and Pico formations. On this plane of movement in each case is a narrow but definite zone of gouge. The gouge consists of small, crushed fragments of Pico and Saugus sandstone. The zone shows many colors varying from brilliant reds to greens. The fragments are obviously unlike either of the formations, showing a high degree of pulverization. The stratigraphy shows the Pico formation overlying the Saugus if one ignores the fault, a situation which is not possible under undisturbed conditions. The erosion on both sides of a divide just to the east of the area is concentrated along the zones of weakness provided by these faults. Narrow canyons with steep sides mark the traces of the fault planes. In the area, Holzer Canyon has been eroded out directly along the strike of the San Gabriel fault and directly down the axis of one of the synclines. The fault to the south has its course marked by steep erosion of the hills along the lines of weakness, and its entrance into Piru Valley is marked by a distinct saddle in the hills (Figs 10 and 11.). There is a possibility that this fault may not die out until after entering Piru Valley. The steep south flank of the saddle shown in Figs. 10 and 11 contains a coarse, well cemented conglomerate bed among the

Figs. 10 and 11. Saddle produced by fault trace.

sandstone layers. Below this saddle on the flank of the hill, there is no evidence of this conglomerate. Whether this bed has been cut off by the movement on the fault or whether the bed is merely covered up lower down on the canyon wall by vegetation and sheet wash is difficult to say. Between this point and the last known definite point of movement on the fault there are no beds visible, the whole side of the hill having been subjected to vigorous sheet washing. All that can be said is that this saddle and the territory on both sides of it are definitely zones of weakness. No gouge is known at this point, and stratigraphic correlation is useless as well as impossible.

The evidences for the syncline and anticline caused by the southern fault are clear because of the frequent dips and strikes which denote this change. The location of the other flexure is more difficult, however. The only recognizable bed on which the change in dip can be noted lies approximately two hundred yards south of the bottom of Holzer Canyon. This bed is a resistant conglomerate which has a vertical dip and forms a ridge across the valley of Nuevo Canyon. On both sides of this bed the dips are fairly consistent with a homoclinal dip of the beds as a whole. Only the attitude of this bed serves as the clue to the sharp fold which lies generally hidden by the alluvium and sloping flanks of Holzer Canyon.

The minor folding so well observed in the Modelo shales are absent in the Pico because of the predominance of massive sandstones. In many places the beds have been sheet washed so badly that any structures would be entirely missed if they lay beneath this coating.

The formations on the west side of Piru Creek present a different set of folds than is found on the east side. In the shales of this section are the multitude of small folds which indicated the intensity of the deformation of the area. At the exposed center of the anticline on the west bank of Piru Creek, the beds have suffered only simple folding. Thicknesses of many feet of thin shale members have experienced little or no secondary deformation even though they are in the heart of the anticline (Fig. 12). On the other hand, directly

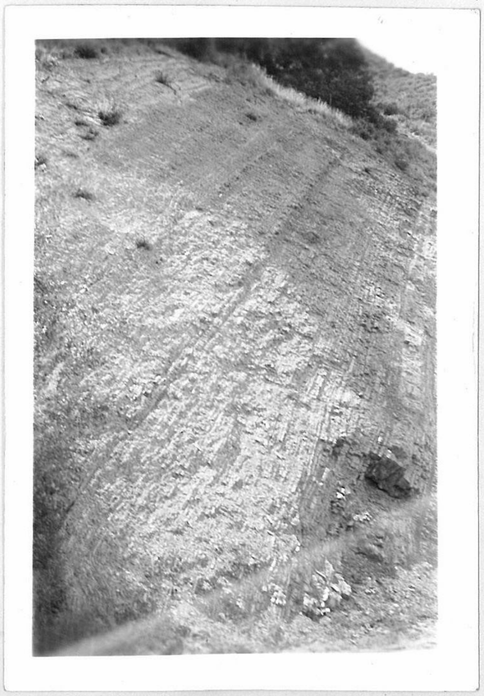


Fig. 12. Unfolded shales

Fig. 13. Small shale anticline

west of the exposure of the axis in Piru Creek, beds virtually in the center of the anticline show extreme auxiliary folding. Fig. 13 shows a sharp though small overturn in shale just a few hundred feet south of the exact center of the anticline. The other beds in this locality, although they show bending and strain, have a generally consistant dip to the south. This makes the presence of this complete anticline somewhat of a puzzling feature. The whole section there may have been sharply folded with the result that the rest of the beds have been broken off at the top of the fold, thus giving an apparently consistent dip because of two flanks of an isoclinal fold; or, the fold may be the result of a landslide pulling down the beds into a position resembling an anticline; or, the fold may be simply a local flexure complete in itself. In view of the other sudden, localized folds in the area, this last view is to be regarded as most logical.

Figs. 14 and 15 show quite well how quickly and deceptively the strike and dip of beds change in an amazingly short distance. These views are taken looking east and north across Lime Canyon at the heart of the Modelo anticline. Fig. 14 and

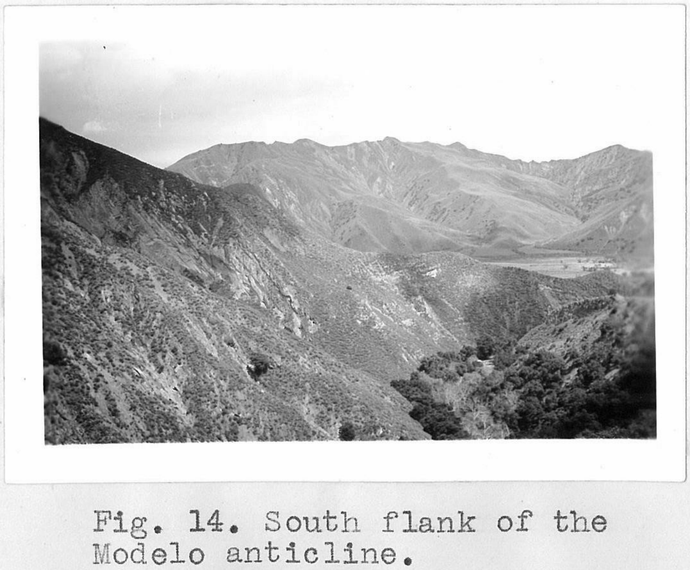
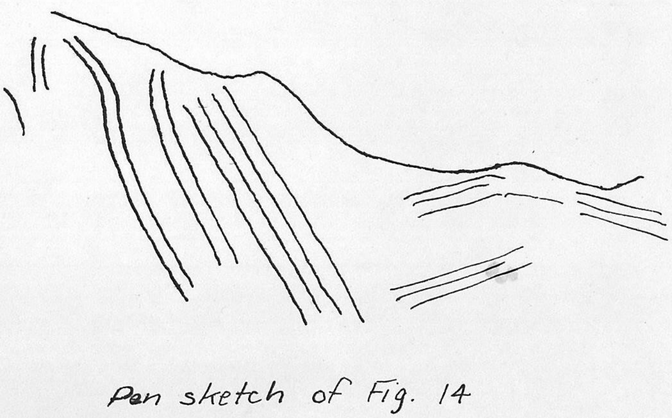


Fig. 14. South flank of the Modelo anticline.



Pen sketch of Fig. 14

Fig. 15. Looking north at beds in the heart of the Modelo anticline.

the accompanying sketch show the change in the beds from south to north in a space of not more than one hundred yards. On the south the beds have an approximate strike of east-west with a dip to the south. Further north, they appear to flex into an anticline, but in reality the strike has changed such that the structure approaches more closely a syncline such as the one already discussed which occurs on the east side of Piru Creek. Then for a space of not more than seventy-five feet, in one case the distance is not over twenty-five feet, the structure is obscured by landsliding and subsequent vegetation. On the south of this space the beds appear to dip to the northeast, while on the north the original strike has been regained with a steep dip to the south. The result is such that the beds to the south appear to be jutting at right angles against the beds on the north. Closer investigation proves that there can not possibly be any other solution other than a sudden flexure of the beds with a change in both dip and strike. Fig. 15 shows a similar change in dip at the heart of the anticline giving the appearance that the beds have been broken at the crest of the anticline, although it is only another of the sudden minor flexures.

Approximately three miles west of Piru Creek, in Hopper Canyon, are some of the best shale exposures for studying deformation in the territory. The stream which runs down Hopper Canyon cuts directly through a great thickness of these shales; and not only are they well exposed along the stream bottom, but the exposures on the sides of the canyon can scarcely be excelled. Fig. 16 shows a portion of the west

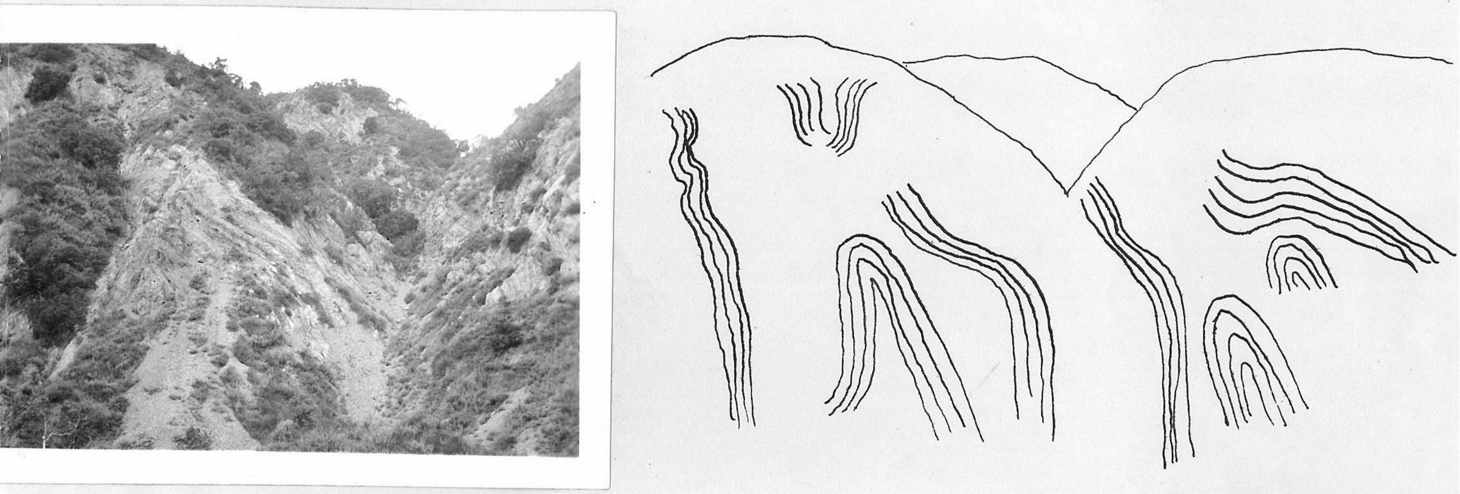
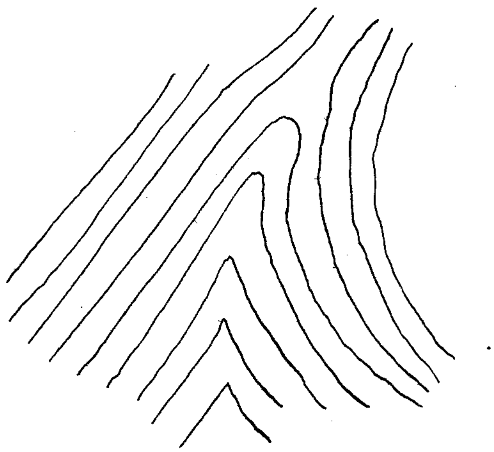


Fig. 16. West bank of Hopper Canyon.

bank of Hopper Canyon with the complex folding shown there. The sketch shows the relationships of the beds to each other, at least as well as can be determined. In a portion just to the right (north) of the picture the beds have a gentle, consistent dip to the north; but just at the right edge of the picture they fold over into an S-fold from which they emerge to continue with their original dip. Then just to the left of the small canyon seen in the right center of the picture the beds experience another sharp compressive stress. The only completely defined structure is a sharp anticline in the left center of the figure. The rest of the beds are so broken that correlation and interpretation of structure are virtually impossible.

Returning to the structure exposed on the west side of Piru Creek, south of the Modelo anticline the dips flatten out until at the mouth of Blanchard Canyon the axis of a syncline is reached. From this point the dip is to the north for approximately one-half mile, where the beds reach a vertical attitude. The beds then partially flatten off into a structural terrace from which they emerge into a partially overturned anticline. The upper part of this fold has been



Sketch showing partially overturned anticline.

developed to such a degree that the term "isoclinal" may be applied to it, although the fold opens out at the bottom. This fold is one of the few in the area which has sufficient length and consistency to be traced across Piru Creek and through the east side of the area. From this point the beds suddenly develop into a syncline just to the south of this point at the contact between the Pico and Modelo beds. The south flank of this syncline is the last exposed structure on the west side.

Historical Geology

The first of the history that is known of the area occurs during the deposition of the Modelo formation. The uniformity of the sandstones and shales, the fine, regular bedding of the shales, the even granularity of the sandstones, and the general lack of conglomerates in the Modelo indicate deposition probably just beyond the littoral zone in marine waters or in a sheltered embayment. The general character of the sediments, mainly the gypsum which is found in the shales, indicates that the climate of the area from which the sediments were derived was at least semi-arid. The interfingering of the sandstone and shale members of this formation indicates that there was probably a fluctuation of the waters necessary to vary the depth at which the sediments were deposited. Fig. 17 shows overlap indicative of interfingering of beds in the shale

Fig. 17. Depositional overlap of shale beds.

zones off shore. After successive depositions of sandstone and shale, the area was elevated and folded to some extent, resulting in such structures as the syncline seen at the contact of the Pico and Modelo formations. After the uplift and folding, there was a relatively long period of erosion, planing the structures down to a reasonably flat surface, evidently regardless of structure, as again evidenced by the syncline at the above mentioned contact. Upom this surface the sea again intruded, although this time not so far as before. The sandstones of the Pico formation were then laid down under even more arid conditions than were the Modelo formations and in a zone nearer to shore, as evidenced by the great predominance of relatively coarse, brown and red sandstones and interbedded conglomerates. The presence of interbedded shale beds show that at times the depth was sufficient or the current quiet enough to permit the deposition of muddy layers on the sea floor, but in both the Modelo and Pico formations, the lack of fossils seems to indicate that the turbidity of the water or some other disturbance created an environment unfavorable to faunal retention, although fish scales are found in some of the Modelo shales. There may or may not have been any crustal disturbances at the close of the Pico other than an emergence from the sea, so far as the relation between the Pico and the Saugus can be ascertained in this area. However, the Saugus was evidently deposited not far from its source because of the preservation of the quartz and feldspar with a lack of the heavy materials which probably originally accompanied these minerals. The Saugus was closed with violent crustal deformation in this region before the Saugus had much of a chance to consolidate. The first forces were compressional from the north and south, giving rise to the complicated folding. Then a sudden release of pressure caused the normal faulting found in the area. Further folding was dominated by action along the San Gabriel fault and its subsidiaries and involved the bowing and pitching of the great Modelo anticline in this area in such a manner as to form an oil trap. Since this movement in Pleistocene time, erosion has been forming the present history of the area. Several terraces along the banks of Piru Creek attest to the fact that uplifts of small magnitude have occurred from time to time, but Piru Creek has evidently maintained its course since pre-Pleistocene times in order to have been able to cross at right angles to the structure virtually throughout the entire length of the area except for an unusually soft zone in the syncline denoting the trace of the subsidiary fault in the area, through which the Piru Creek changed its course to follow the strike for a distance of somewhat over a mile.

Economic Considerations

Virtually the only product of the area worthy of economic consideration is oil. Several oil seeps occur in the area, one on the south flank of the Modelo anticline on the east side of Piru Creek, and another at the extreme eastern end of the area just north of the Saugus-Pico contact. All of the wells drilled on the east side of the area have been given up before oil has been reached, but the wells owned by the Pacific Western Oil Company that are situated on the crest of the Modelo anticline just to the west of the area are producing oil at a consistant pace with signs of new development to be begun in the near future. Although some of the Pico sands show oil staining, it is certain that the oil is coming from a horizon at least as low as the Modelo, and it would be useless to exploit the Pico formation for oil. The Modelo anticline appears to be the only structure in the area able to trap an oil supply sufficiently large to be exploited economically.

Structure Sections