GEOLOGY OF

THE WHITTIER HILLS

Whittier, California

By

Miller Quarles

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ABSTRACT

This report is an attempt to unravel the structure of the very complicated western portion of the Puente Hills known as the Whittier Hills. The only comprehensive published study of it was made by English in 1926.[1] Of the Whittier Hills portion he said, "The Whittier Hills, comprising the area west of La Habra Canyon, show some of the most complicated structure to be found within this district. Steep irregular dips, numerous faults, unconformities, and lithologic variations in the different formations and members make the structure, as well as the stratigraphy, difficult to work out."[2]

The mode of approach has been that of a very detailed examination in which every attitude available has been recorded. The petrographic interests have been sacrificed to permit a closer structural analysis of a larger area. Some semblance of order has thus been obtained for most of the area.

The situation briefly is this: a section of upper Puente shale and part of the Repetto siltstone and conglomerate have been folded and faulted into apparently unrelated blocks. Included in these structures are one hundred mappable lithologic units, twenty-five different faults, and nine major folds. The most westerly portion of the Whittier Fault disappears in the area, and thereby presents the problem of determining its westward extension. The

1. English, Walter A., Geology and Oil Resources of the Puente Hills Region, So. Calif., U.S.G.S. Bulletin 768 1926
2. Ibid, p.58

area has two distinct oil-producing fields and has been mapped by many oil companies in exploration for others. The folds mapped may thus be of interest from an economic point of view.

INTRODUCTION

Purpose of Investigation

The work done is in partial fulfillment of field courses required for a Bachelor's and Master's degree in the Geology Department of the California Institute of Technology. Fifty units have been registered for, amounting to a total of five hundred hours spent both in the field and in other preparation. Twenty-five of the units may be considered as a Bachelor's Thesis, leaving another twenty-five to apply towards the Master's requirements. At least four hundred hours have been spent in the field during June, July, August, and September of 1939, leaving only one hundred hours for supplementary preparation.

Method of Investigation

U.S.G.S. maps of the area on a scale of 1/24,000 and having 25 feet contours have proven satisfactory though a trifle small for greatest accuracy. Locations were made by topography and Brunton compass. Attitudes were taken wherever practical.

Acknowledgements

The writer was very fortunate in receiving the interest of Dr. Hampton Smith of the Texas Company. Mr. Smith sugges-

ted the area as an interesting structural problem in which there has been much speculation as to its possible oil content. His familiarity with the region as a result of a professional survey enabled him to make valuable suggestions and criticism. Comment and criticism by the late Dr. Reed of the same company was likewise gratefully received. Mr. Smith also secured the services of the company's micropaleontology department for determining the age of various units. Mr. Hamill and Mr. Boris Laiming of that department graciously cooperated in washing, mounting, and determining the age of thirty-one foram samples as reported elsewhere.

Dr. J. H. Maxson of the Institute has been in active supervision of this work throughout the summer. He has given suggestions where needed and corrected this thesis before final presentation. He accompanied the writer in the field to help interpret difficult structural relations.

Previous Publications

Walter A. English's paper on the Puente Hills has been of great value in giving a generalized idea of the region. His report was most interesting and forms the basis for many of the interpretations to follow. A number of previous reports concerned with the existing oil fields have been published, but the writer has omitted a complete survey of previous publications in order to devote more time to field mapping. A pre-1926 list is given in English's bulletin. A Master's Thesis by Mr. Erickson of Caltech was concerned mainly with some faults of the area.

GEOGRAPHY

Location and size

The Whittier Hills may be considered the west portion of the Puente Hills lying north of the town of Whittier and extending eastward for about four miles to the La Habra Canyon through which the Hudson Road crosses the hills. This report covers the western two-thirds of the Whittier Hills whose southeastern boundary is a long canyon, parallel to and two miles SE of Turnbull Canyon. The boundary of the area on the other sides is where the bedrock disappears under the surrounding alluvium. The location with respect to the city of Whittier is clearly shown on the map. The road map on the following page shows the general location and the trend of the Puente Hills. The mapped portion covers about twelve square miles, exclusive of alluvium.

Relief and elevations

The relief is moderate. Complete dissection suggests maturity in the cycle of erosion. (Fig.1 is a general view.) The average height of ridge tops above alluvial plains is 900'. The lowest border elevation of 250' is found along the northwest. The highest elevation, Workman Hill near the head of Turnbull Canyon, is 1387'. The cultivated alluvial fans to the east of this highest point are nearly 600' in elevation. Conglomerate beds in some localities form cliffs as high as 100' (Fig.2) but slopes are generally gradual and valley floors flattened.

Drainage

The drainage system is dominated by three main southwest-flowing valleys which extend about two-thirds across the area and discharge along the southwest flank of the hills. They are Sycamore Canyon to the northwest, Turnbull Canyon in the middle, and the boundary canyon at the extreme southeast. Smaller canyons run into these from the sides at nearly right angles

Fig. 1
General view of topography.
Looking east along the Whittier fault
from ridge west of Turnbull Canyon

and likewise lead to the bordering plains. The seasonal rains are mostly absorbed by the low hills, leaving only excessive precipitation to flow into the San Jose Creek to the north. Both this Creek and Sycamore Canyon lead to the San Gabriel River west of the area. The southwest drainage is absorbed by the thick cultivated alluvium of Whittier and East Whittier. Sycamore and Turnbull Creeks remain barely wet through the summer from local seepage.

Vegetation

A large part of the area is covered with grass and is used for grazing. The underlying rock of such portions is generally shale or siltstone. The conglomerate and sandstone members us-

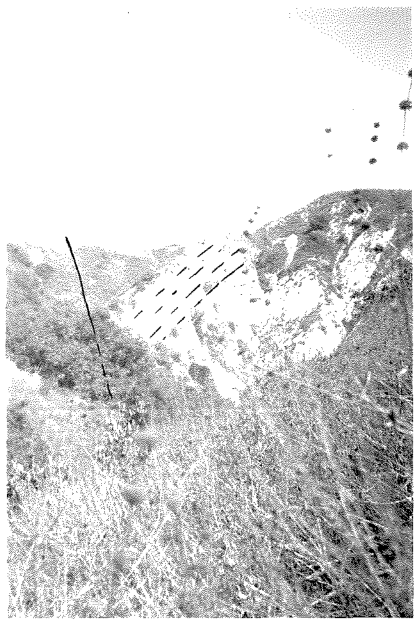


Fig. 2
Cliff where Puente and Repetto
conglomerate beds meet along Fault A

ually support heavier brush, low shrubs and trees, with little grass. Fig. 3 shows the brush along several separated conglomerate beds. The steeper slopes likewise are brush covered. In the larger valleys Sycamore trees are common and the smaller valleys have thickets of poison oak. Avocado and orange groves thrive near the edges of the area, especially in the more rugged portion northeast of Workman Hill.

Rock exposures

Rock exposures are generally available on uncultivated ridges, but the valleys and canyon floors are hidden by general aggradation. The siltstone is the most difficult rock type in which to obtain attitudes because it is massively bedded. Some conglomerates are likewise massive. Often large areas of grass-covered silt or shale are devoid of exposures.

Fig. 3
Showing heavy brush growing on two steeply-dipping conglomerate beds. On west slope of ridge to the north of Sycamore Canyon.

STRATIGRAPHY

The time range represented is part of Upper Miocene (Puente) and Lower Pliocene (Repetto). The only major age division then is the Miocene-Pliocene contact, as the uppermost Repetto and the lowest Puente are not within the area.

Puente Formation (Upper Miocene)

The name of Puente Fm was given the upper and middle Miocene beds of the Puente Hills and Los Angeles district by Arnold and Eldridge in U.S.G.S. Bulletin 309-1907. The formation corresponds to the Modelo Fm in other parts of the Los Angeles Basin. The upper Puente which is represented in this area is composed of finely laminated silicious shale beds resembling the Monterey Fm.

Areal distribution

The Puente Fm occupies a mile-wide strip beginning north of Whittier and extending southeast along the north side of the Whittier fault. The northeastern boundary is a criss-cross of truncated faults. Faults A, A', C, and the Turnbull Canyon fault are responsible for the contacts.

The boundary to the extreme east of the Puente strip is apparently the valley alluvium although there is some possibility that the conglomerate bed is Repetto. This bed is lithologically and stratigraphically similar to the conglomerate bed to be described as part of the upper Puente series. This evidence leads the author to place it in the Puente.

The southwest limit from Turnbull Canyon east is the Whittier fault and the doubtful fault H. Turnbull Canyon and the alluvium of Whittier form the remaining boundary as far as the questionable Puente-Repetto depositional contact. This contact, making the northwest boundary of the Puente, lies along one of the nearly east-west striking beds of conglomerate. The exact location involves a careful study of the nature of the Miocene-Pliocene contact.

Nature of Puente-Repetto contact

English locates this contact along the base of the closest conglomerate bed to Turnbull Canyon. This conglomerate bed constitutes the central bed in a series including shale below, then sandstone, conglomerate, sandstone again, and shale. His reasons for so locating the contact are that (1) elsewhere in the Puente Hills to the east the Puente has a sandstone top member, and (2) that an abrupt break is present between this sandstone and the conglomerate bed.

At station 1 there is visible at the head of the canyon in an isolated exposure an abrupt contact with apparently no gradation. However, only a slight disconformity or diastem could be present and the possibility of more conclomerate in the sandstone below the exposure cannot be ascertained. A much better exposure of the entire sequence from shale to conglomerate is available along a road on top of the ridge and adjacent to the cross fault. Here a distinct gradation through the three members is visible. Sandstone beds are prominent in the lower conglomerate, and a few conglomerate stringers lie in the sandstone. Fig. 4 shows the most prominent division between the sandstone and conglomerate which could easily be mistaken for an abrupt contact in an isolated exposure. Across the saddle at station 3 can also be seen the gradational sequence from shale, sandstone, conglomerate, sandstone, and back to shale.

Fig. 4
Showing a localized sandstone-conglomerate
contact in the Puente Fm along Fault A

The author has carefully traced the conglomerate beds and found that they have several lenses which grade into the sandstone above and below and form no continuous bed. It thus seems improbable that the rather normal succession of shale, sandstone, conglomerate, sandstone, and shale should be broken by an important epoch division.

In the writer's opinion the division more probably lies between the shale and conglomerate beds where indicated on the map. At locality 2 this contact changes abruptly from a fine bedded shale to a coarse conglomerate with no intermixing of shale and conglomerate. Although no evidence of a hiatus is visible, this type of contact is more apt to mark the end of an epoch than the sandstone-conglomerate gradation. It must be noted, however, that the Miocene-Pliocene division at many places represents a period of constant deposition with no lost interval. Mr. Laiming has observed this situation in much of his micropaleontology work on the base of the Repetto. He has generally found that the transition fauna of this shale-sandstone-conglomerate series above the Miocene contains a majority of Puente forms and is inclined to place the contact above it at the base of the overlying conglomerate-shale series. This Repetto-Puente division is thus localized on meagre evidence and can only be definitely located within a half-mile strip of parallel beds.

Lithology and thickness

The typical Puente formation exclusive of the uppermost sandstone and conglomerate beds is a finely bedded, light-colored, variegated shale with thin cherty layers and thick sandstone beds. All of these beds contain good bedding planes which made attitudes easy to take at outcrops and exposures. The color varies through black, gray, orange, yellow, and white, but is generally light gray. Secondary gypsum layers up to an inch thick are common. The orange chert layers vary from 1 inch to 5 feet in thickness, are resistant to erosion, and form many isolated outcrops. They contain abundant organic remains, mostly fish scales, sharks' teeth, and unidentifiable silicious matter. The chert grades into fine silicious shale on through fine shale to sandy shale and sandstone.

The sandstone is orange to tan and although up to 100 feet thick within the formation, it is not persistent to any extent. It lenses out and grades into sandy shale within very short lateral distances. Sandstone is generally more abundant in the east while an almost white, powdery-fine shale is more prevalent in the west. The ease of breaking along these planes and the tendency to separate on weathering causes surface creep or mass flow to be common. An area from a few feet to fifty feet wide may break loose from the mantle and slide down the slope as far as one hundred feet (Fig. 5), leaving a jumbled mass at the bottom. Such slides are more common where the

Fig. 5
Surface creep in Repetto siltstone.
NE corner of section 15
Height of ridge 100 feet

slope coincides with the dip of the beds, but they occur elsewhere also. They average three feet deep often forming exposures along their sides and slopes. Attitudes taken on the exposures have proven to be unreliable. Similar creeping and slumping has certainly happened many places where no evidence is now apparent. For that reason many of the attitudes taken at isolated exposures are undoubtedly erroneous. This element, added to the structural complexity of these typically incompetent beds, makes most of the Puente of this area appear to be a jumble impossible to interpret.

Although the thickness of the Puente is undoubtedly great, it can only be guessed because of the structural complexity and boundary limitations by faulting. The only uniform structure lies immediately to the west of Turnbull Canyon. There the thickness can be scaled and figured from the average dip at 2000'. This figure represents the minimum and offers no clue to the maximum, though it must be several times that amount.

Origin

The fish scales and forams are proof of marine origin. The presence of sandstone lenses, and the great thickness indicate a fairly shallow water deposition though at some distance from shore in order to have the very good stratification and fine bedding. The silicious portions and cherts may in part be the accumulation of organic remains during quiet deposition periods. Dr. Maxson suggests that some secondary silicification may have taken place.

Transition Puente Beds

The transition portion of the Puente northwest of Turnbull

Canyon is a gradational sequence of shale, sandstone, conglomerate, sandstone, and shale as previously mentioned. No absolute boundaries between them can be localized. The divisions as located on the map show where approximately fifty percent of each of the two rock types is present. The sandstone has a varied character. It is usually of rounded quartz fragments but grades into the products of decomposed granite near the conglomerate. Its composition then is mostly quartz, both angular and rounded, with lesser amounts of feldspar and small quantities of dark minerals. It is cream in color and well banded through sorting by sizes. There is little cementation, making samples continually crumble by handling. The thickness varies along the stike but the maximum, as scaled from surface outcrop and approximate dip, is 360 feet below and 300 feet above the conglomerate. Because of variation in dip and uncertain boundaries, the accuracy of measurement is no greater than 30%. Near the Whittier alluvium the total thickness of both sandstone members and the included conglomerate is only about 400 feet.

The conglomerate bed in the upper Puente series is a very coarse, unsorted aggregate of sub-angular to rounded particles of decomposed granite. The matrix is of the same composition and constitutes one-third of the volume. Boulders three feet in diameter and all sizes down to pea gravel are mixed in about equal proportions. Very irregular coarse sandstone lenses are abundant near the top and bottom. Some aplite and gneissic rock types are represented. The one bed that persists laterally from the fault at the northeast to the Whittier alluvium averages 80 feet thick and has a maximum of 200. Other lenses are present, none over forty feet thick and are of a similar texture and composition as the described bed. At the west end the series changes into a larger number of conglomerate lenses in the sandstone, making the sandstone-conglomerate divisions largely arbitrary.

The shale at the uppermost of the Puente along this same series is a light, well-banded, compact, silty bed about 270' average thickness. It has no chert layers and closely resembles the Repetto siltstone except for its distinct fine banding. Its lower contact grades into the sandstone and its upper contact is the abrupt change to conglomerate that I have interpreted as the Puente-Repetto contact.

The Puente conglomerate bed at the east end of the area is very similar to the conglomerate beds described in the upper Puente series. Above and below it is found an irregular thickness of sandstone which grades into the conglomerate. This conglomerate bed is nearly 300' thick at its east end but completely lenses out towards the west. The exposures are so rare in the vicinity that only the presence of the sandstone can be ascertained with no reliable thickness possible. The contortion of the beds adds to the uncertainty of thickness.

The texture of the conglomerate is the same coarse unsorted granitic base cut by irregular sandstone lenses. The main difference is that more dark gneissic boulders are included with a slightly higher degree of rounding common. Fine bedded silty shale similar to that of the uppermost Puente shale member previously mentioned is present where the 66 degree dip is shown. Because of this similarity in structure, texture, composition, and sequence to that of the upper Puente series northwest of Turnbull Canyon, the writer includes this portion with the Puente. The conglomerate forms low cliffs along a minor wash and its resistance to erosion enables it to form a small ridge across the normal drainage into the valley.

The uppermost Puente member obviously shows a different depositional process from the underlying beds. The lack of sorting, limited rounding, and the uniform composition make a beach deposit unlikely. A large delta deposit would be more likely to have the observed features. The process could be as follows: a gradual tipping of the land along the coast, slow at first but accelerating in its rate; the normal erosion of this final high topography would form the later series of conglomerate, sandstone, to shale again. The lateral irregularity and the lensing structure represent the varied current action on and near the delta.

Repetto Formation (Lower Pliocene)

The Repetto Fm was named by R. D. Reed in 1932. The type locality is along the west side of Atlantic Blvd. near Fremont St. The formation consists of siltstone, sandstone, and conglomerates which overlie the Puente Fm and are conformably overlain by the Pico Fm. As Reed considered the beds in this area as Repetto, that name will be used in this report.

Areal distribution

The areal surface not occupied by the Puente Fm is probably of Repetto age. Foram correlations, lithologic nature, and stratigraphic position insure this age for the large unfaulted portions. The other fault blocks are included in this age only through similarity in lithologic form. From the writer's observation alone the age determination is inadequate, forcing him to accept English's ideas resulting from a familiarity with the rock types throughout the Puente Hills. These uncertain areas include the faulted zones east of the head of Turnbull Canyon and the triangular portion north of the east end of the Whittier fault. Especially questionable is the conglomerate area east of the curved fault G. Exposures over much of the Repetto areas are good because of differential erosion between the siltstone and conglomerate. The topography is correspondingly more rugged. The large areas of siltstone in which stratification is poor sometimes offer little or no chance of obtaining attitudes.

Lithology and thickness

The typical Repetto formation is a series of conglomerates and siltstones which have abrupt contacts below the conglomerate and a slight degree of gradation through sandstone above. The conglomerate is typically stained a brownish color by limonite. The particles are well rounded and are mostly granites and syenites with lesser amounts of darker intrusives, gneisses, and shale. The sorting is good with sandstone and some silt layers making attitudes available. The matrix is a well cemented sandstone making the conglomerate resistent to erosion. Average size of constituents is 1½ inch with sizes up to 4 inches fairly common. The size of the particles is the main variable of the beds. Slightly less rounding is observed in the lowest beds along the Puente contact, and somewhat less sorting is found. These conglomerate beds occur usually in parallel groups of small thickness. Three of these groups are found, one at the north striking almost eastwest, another below it striking about N60° E, and a third apparently below this striking nearly north-south. The beds vary greatly in thickness and some entirely lense out within short distances. This lensing tendency is especially prominent in the southern portion below the Whittier fault where sandstone occupies a large area.

The most notable exception to the typical conglomerate is the large mass of conglomerate to the east of the long curving fault G near the northeast corner of the area. It is very coarse, unsorted, with a few very irregular sandstone lenses. It is 90% granite (or adamellite) with mostly a decomposed granite matrix. The large cobbles are sub-angular and the smaller ones rounded. It resembles the upper Puente conglomerate more than the typical Repetto though somewhat different from each. Its nearness to the Repetto foram sample at location 58 indicates that it is probably of that age, being perhaps one of the lowest beds. The lower Repetto beds tend to be thicker than the higher ones.

A form of silty shale or siltstone is the most extensively outcropping rock type. It is generally white or cream with occasional brown streaks showing stratification. When the streaks are absent, attitudes are hard to get in isolated outcrops. The material has little cementation and breaks easily. It resembles clay in some places and grades into a very fine sandstone at others. In the lower part of the Repetto it has a better sorting of sizes and forms better stratification. It then resembles more the Puente shale and sandstone. The absence of stratification, chert beds, and silicious organisms are its distinguishing features from the Puente shales.

The siltstone also contains poorly preserved, powdery megafossils at several localities. Several different forms of pelecypods and gastropods could be observed although they are not satisfactory for further classification. Forams are much more abundant and well preserved than in the Puente. The siltstone forms rolling hills and supports grassed areas useful for grazing. Large masses of it lie between the three conglomerate series in the northern part of the area. Slumping and mass movement is common throughout.

The large Repetto area below the Whittier fault is quite different from the northern portion and was probably laid down far to the southeast of its present position. Near the mouth of Turnbull Canyon the beds lying between the typical Repetto conglomerate are massive, medium grained, light yellow sandstone with many silt layers and fair stratification. The sandstone grades laterally to the east into the typical poorly stratified siltstone in which flat concretions are found. One concretion at foram locality 86 had innumerable tiny (maximum size 1/3 inch) megafossils in its center. This evidence tends to indicate that organic remains may be critical to the origin of the concretion. All the conglomerate beds lense out with the approach to the more silty sandstone except possibly one. The one uppermost conglomerate bed may be faintly traced by the observance of pebbles in the mantle to where it branches out into a thicker mass near the Whittier fault and the valley boundary line. This mass is considerably contorted and its connection with the above mentioned bed is not certain. Without further tracing to the east of the area, the relation of this bed must remain doubtful. The uppermost bed of this section is a thick siltstone of the usual Repetto type. This rock type occupies a large area in the east beyond where the conglomerate beds lense out. It grades into the sandstone laterally to the west by innumerable lenses which may persist as beds a few inches thick in the sandstone. For that reason no boundaries may be established and the convenient method of dotting the sandstone is used to advantage.

The writer feels that a description of every conglomerate and siltstone bed with the thickness of each would be of little significance and not worth the space required. The lateral variation is so great and the tendency to lense out prevents any typical cross-section from being described. Instead he will refer the reader to the sections accompanying the areal map which will as accurately as possible show the correct width of each bed at the indicated localities. Only a generalized succession will be given. The lowest portion of the northern section of the Repetto lying in apparent conformity above the uppermost Puente shale is composed of two conglomerate beds about 200' thick between which lies a silty shale of about the same thickness. The lower of the two conglomerates is coarse, poorly sorted, and not so well rounded as the higher one. They each have transition sandstone beds of only two or three feet above them, but sharp contacts below. To the west of the lowest bed this sandstone transition thickens into a mappable unit.

The next series of conglomerate beds is separated from the first by several hundred feet of typical siltstone. The lower contact with the siltstone is a disconformity. At the east end near the reservoir this break can be observed. The conglomerate series begins as a solid conglomerate mass with a few siltstone lenses at the west end and divides towards the east into five beds. These five gradually lense out eastward until only two persist to be cut off by a fault. The thickness of the conglomerate and interbedded siltstone and sandstone beds varies. At a central position where the extra conglomerate layer occurs above the series the thicknesses from the base up is as follows:

Conglomerate	15'
Siltstone	100'
Conglomerate	20'
White shale	60'
Conglomerate	25'
Shale	15'
Sandy conglomerate	25'
Fine white sandstone	10'
Conglomerate	40'
Sandy shale	15'
Typical Repetto conglomerate	60'

Near the eastern limit there are only two beds fifty feet thick with a 15 foot siltstone bed between. Some of the interbedded siltstones have good bedding planes and are thus nearer to the shale than the siltstone classification.

Between the middle and the upper conglomerate series is a great thickness of siltstone which contains excellent forams. It is divided in the west by two conglomerate beds, one of which divides and finally dies out after persisting for a mile and a half. Fig. 3 shows the heavier brush which grows on these two beds than on the surrounding siltstone. The upper bed is 30' and the lower 15' thick. The other bed which lenses out below this divided strip is up to 100 feet thick at one place. It has almost no clay or silt in its matrix and has consequently been used for concrete aggregate.

The uppermost series begins in the extreme west as a thin 15 foot bed. It thickens eastward and probably extends through the alluvium as suggested by the dotted lines. Only a few pebbles and cobbles in the thick mantle are the basis for this continuation. The bed divides, thickens, and acquires new members as it continues eastward. Exposures across valleys are sometimes so poor that the beds must be connected largely by the judgment of the observer. Near the east there are six definite beds that cover 2000' with their included siltstone members. The beds are similar in most respects and closely agree with the typical Repetto conglomerate previously described. The continuation to the east margin of the uppermost two conglomerate beds through heavy brush and thick mantle is most uncertain.

Another series of conglomerate beds is present extending north of the head of Turnbull Canyon and striking almost north-south. They begin along the arcing fault G in the north and extend southward, the upper one separating into four members.

The five beds continue with a fairly low dip, forming peculiar shapes with the topographic features that they cross. Before the beds separate, their thicknesses are as follows:

Upper conglomerate	200'
Middle siltstone	80'
Lower conglomerate	100'

After increasing to five beds, the lower two are about 100' each (shown in Fig. 6) with 80' of siltstone between. The upper three conglomerate members are from 25 to 40 feet in maximum thickness with similar amounts of siltstone between. The contacts are gradational through a foot or less and are clearly depositional.

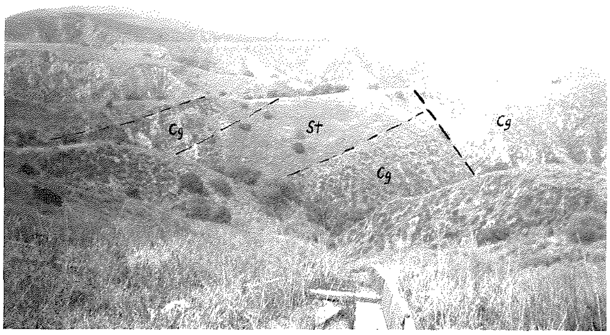


Fig. 6
Dipping Repetto series of conglomerate and siltstone beds. Also fault F visible. Ridge located along section EF

The faulted areas at Workman Hill and to the east and NE of it have thick beds of conglomerate with correspondingly thick siltstone and shale beds. The complex fault pattern prohibits any succession from being established, but many contacts are well exposed. A contact of conglomerate above siltstone along Turnbull Canyon road 800' NW of Workman Hill shows the typical abrupt change from siltstone to conglomerate. At this exposure (Fig. 7) a large slab of the lower siltstone eight inches thick and twelve feet long may be seen five feet above the contact in the conglomerate. The writer interprets this as showing that some erosion of the

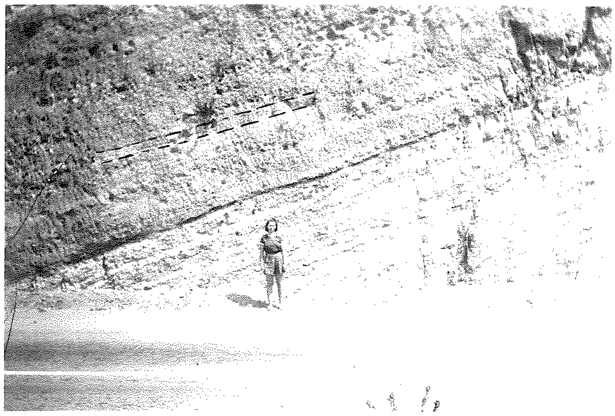


Fig. 7
Abrupt siltstone-conglomerate contact.
Siltstone slab visible 5' above contact.
Turnbull Canyon road, 800' NW of Workman Hill.

lower member took place at the same time that the conglomerate was deposited. A definite disconformity is thus indicated although no certainty could be established by observation of the contact itself. Fig. 8 shows another of the abrupt contacts within the highly faulted zone. The conglomerates of the faulted blocks agree very closely with the typical type described previously.

The most uncertain correlation of the entire area occurs in the triangular portion to the extreme east lying between the Whittier fault and fault H. The rock type below the conglomerate stringers is a sandy siltstone much like that occurring across the Whittier fault. Above it in a normal contact with some sandstone near the contact is a conglomerate bed which begins in the west only 10 feet wide and extends eastward, thickening to a maximum of 50'. A 15' bed occurs below it in the east portion, separated by approximately 100 feet of siltstone. The conglomerate is brown stained, poorly sorted, compact, mostly granitic, with very little matrix and no bedding visible. The sizes vary from 6 inches to pea gravel in nearly equal proportions, and are rounded to sub-

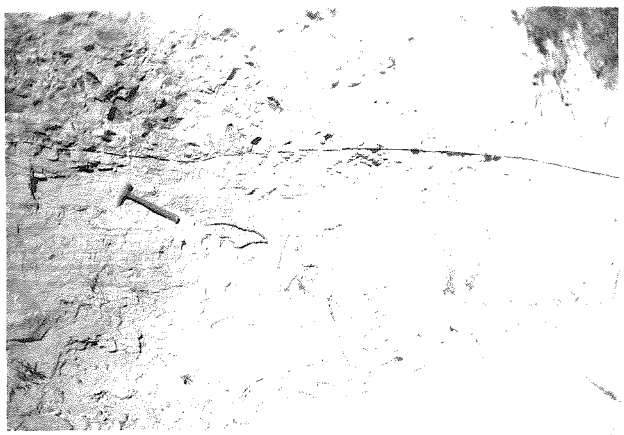


Fig. 8
Abrupt siltstone-conglomerate contact
On private road 2300' directly west of
point I in section GHI

angular. There are some shale cobbles present. The upper contact is sandstone in the west and siltstone in the east. The thick, fairly uniformly dipping rock above cannot be lithologically classed as either Puente or Repetto. Sandstone grades into bedded siltstone laterally and vertically in irregular fashion. Some massive siltstone is present and a large area gives no outcrops. No distinct difference from the sandy Puente across the fault is observed. The author's main reason for the Repetto correlation is the presence of silt cobbles in the conglomerate beds. Such silt inclusions have not been found in the Puente conglomerate. The general color is suggestive of the Repetto. In the absense of more conclusive evidence the writer must accept the more extensive experience of Mr. English, who classed it as Repetto.

The total thickness of the Repetto in the north is about 4600 feet and that in the south about 5400 as scaled from the map using approximate dips. Its upper limit in both parts of the area is the valley alluvium. The lower limit in the north portion is a questionable location along an abrupt shale- conglomerate contact at the base of the second nearly eastwest striking conglomerate bed to the northwest of Turnbull Canyon. The remaining contacts are a criss-cross of faults between it and the Puente. The base of the south portion is not exposed. The writer has without certainty located it along the lower end of Turnbull Canyon. The remaining contacts lie along the Whittier and the EW fault as shown on the map.

Origin

The mode of deposition for the opposite rock types of conglomerate and siltstone offers a difficult problem. The forams and megafossils insure a marine origin, and the abundance of conglomerate beds suggest stages of high relief. Sorting and rounding is not well enough developed to justify a beach deposit, and the thick sections of massively stratified siltstones likewise oppose this hypothesis. The abrupt change on the lower side of the conglomerate beds with a better transition above could indicate a sudden uplift with subsequent deposition of conglomerate at first with the siltstone following after some time of deposition. The lack of bedding in the siltstone indicates the long continuation of very uniform land conditions. The conclusion is that the Repetto material was carried in by rivers and deposited at some distance from shore, perhaps in an inland sea such as the Gulf of California. Sudden uplifts of land may have caused some erosion on the deposited silt. One such disconformity is apparent below the middle conglomerate series where fault A is covered by it. The presence of siltstone cobbles in the overlying conglomerate beds perhaps indicates that some erosion took place on the lower siltstones. Rotational uplift of the land rather than horizontally uplifted blocks may account for the limited erosion on the siltstones with no evidence of angular unconformity.

Age determinations

Foram material is abundant in the Repetto and sparsely represented in the Puente. Samples were collected and correlations were made by the Texas Company. The determinations with their locations on the areal map are given below. Mr. Laiming of the company's Paleontology Department has gone to especial trouble to give the specific names of some of the important forams and is responsible for making as complete a a report as this possible.

Of thirty-one samples collected only fourteen had enough well-preserved species to enable age determinations to be made. Localities 35, 36, 37, 38, 51, 52, 53, 56, 57, 58, 81, and 86 were of Repetto age. The best sample was No. 81 which had a good variety and several distinctive Repetto species. Samples No. 81, 58, and 36 were near the middle of the Repetto in age. The distinctive Repetto species found are given below. Other species having longer age ranges are not included here.

Bolivina cochei Cushman and Adams (Sample 36)

Bolivina aff. rostrata Brady (Sample 36)

Bolivina subadvena var. sulferensis Cushman and Adams (Sample 36)

Bulimina inflata Seguenza (Sample 81)

Bulimina subacumenata Stewart

Cibicides mckanni Galloway and Wissler
(Small size only is distinctive of Repetto)

Nodogenerina antilea (Sample 37)

Nonion pompillioides Fichteu and Moll (Sample 81)

Plectofrondicularia californica Cushman and Stewart (Sample 81)

Uvigerina (Repetto species)

Sample 74 was Puente in age. Its distinctive species are given below.

Valvulineria aff. araucana (d'Orbigny)

Distinctive species of Bolivina

Bolivina californicus Cushman (one specimen only)

Bolivina tumida Cushman

Radiolaria (common)

The remaining specimen, No. 69, is probably upper Miocene. Its only typical species was Bolivina obliqua Barbat and Johnson which is common in upper Miocene and not found in the Repetto. A species of Uvigerina present in the fauna is common both in the Miocene and Repetto. Radiolaria were found in the Puente shales.

Mr. Laiming cautioned the author against too much certainty in the above stated information as many of the species cannot be positively identified.

An attempt was made to use sharks' teeth, fish scales, and fish skeletons in determining the age. Some larger scales from locality 4 have been identified by Miss David of Vertebrate Paleontology Department at the Institute as a species of Ganolytes which has been found so far only in the Miocene. A smaller scale of the Sparidea family was placed by Miss David as probably Miocene. No attempt was made to use in correlations the few poorly preserved megafossils of the Repetto. Careful work on them by an expert might give some information.

GEOLOGIC STRUCTURE

Folds

Evidence of major and minor folding may be seen throughout the entire area. Even in the most uniformly dipping series of massive sandstone and conglomerate in the south Repetto section the strikes and dips vary greatly with several reverse dips present. The other extreme is the central Puente shale section where consistent attitudes are almost absent. The evidence of complex contortion and minor folding may be seen on the good exposures of the Puente Fm along the Turnbull Canyon road. On the basis of dips and strikes several small folds could be drawn in, only one of which is shown on the map. Fig. 9 shows a drag fold in a chert layer just south of the indicated anticline. The fact that such a tiny fold should have distinct drag folds as shown will give some idea of the small significance of isolated outcrops. The writer has adopted a short wavy line to indicate some of the plainly visible contortions where an attitude would be meaningless. On the basis of a few localized dips, a great many doubtful folds could be shown in the area. The writer has drawn in only the ones having a large number of dips or other good evidence to substantiate their existence.

Section CD shows the only fold having an anticline and a syncline. Here the dips obtained are good, but are not definite evidence of the folds. The upper limit of the conglomerate can be traced throughout most of its length except for a hundred feet where it crosses the canyon branching to the south of Sycamore Canyon (Black Canyon). Unfortunately, the alluvium in Black Canyon covers the other two contacts crossing it, but their positions are localized on each side. A

Fig. 9
Drag fold in Puente Fm on flank of a small anticline.
On Turnbull Canyon road 3000' west of Workman Hill.

good view of the entire structure in which the folds may be visualized can be had from the high ridge about 900' east of station 2. The only other possible explanation of the dips and structure would be that of a fault at about the position of the syncline which would exert an extraordinary drag force. However, the same conditions of crushing would be present near the axis of a fold. At the location mentioned east of station 2 one can see evidence of slipping and contortion of the shale along the shale-conglomerate contact. It is probably a product of the compression that caused the fold. At station 2 can also be seen the abrupt depositional contact which is assumed to mark the Puente-Repetto boundary.

Section GHI shows the next three most important folds, all of them individual anticlines. The one south of the Whittier fault probably has little bearing on the production of oil throughout the area. It is located almost entirely by the strikes and dips taken in the Repetto siltstone. The uncertain reliability of these dips is evident from their variation and the contorted localities. Drag folds and possible fault action may be seen at many of the indicated spots. Near the east end of the axis where the short fault (Fig. 10) is shown, a good exposure of a tiny anticline axis occurs on the

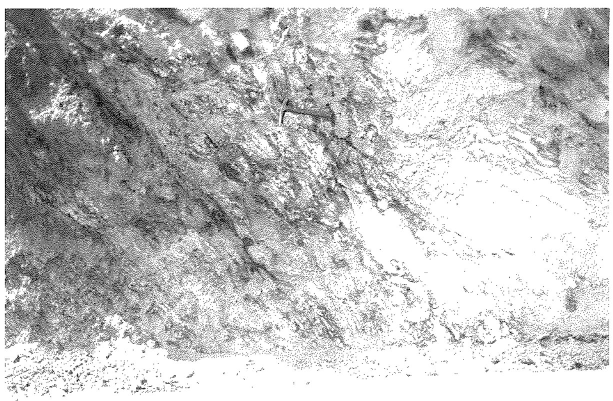


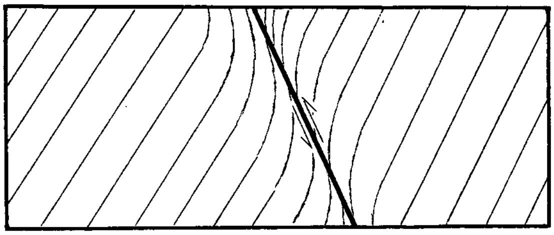
Fig. 10
Fault outcrop dipping 45° North.
On mountainous road 700' south of Whittier fault
and 1000' east of section GHI

road (Fig. 11). The beds dip away from it on both sides, locating the axis at that point. A one foot sandstone layer forms a good outline of the anticline in the picture. The shale at each side of the anticline at a distance of about a hundred yards is, however, not very certainly correlated. That to the south is of a sandy nature while that to the north is more compact, and fine grained.

Fig. 11
Anticlinal axis of southern fold of section GHI.
Where anticline crosses maintenance road 1000'
east of section GHI

The short fault shown on the map within 100' of the anticline undoubtedly accounts for the condition. This fault probably indicated a slipping movement occurring nearly in the axis of the fold. The steep sides of the anticline show that the compression forces may have caused reverse faulting after the fold was closed. Such faulting in the axis of a close fold is to be expected. Although the fold hypothesis for the structure at this locality seems the most probable to the writer, two other interpretations may be mentioned. Since the sides of the fold are very steep even in the immediate vicinity of the axis, the possibility of overturning is noticed. If the

Whittier fault is a reverse fault in this locality as suggested by Dr. Buwalda, a drag effect could explain the condition as shown below.



Possible drag effect along Whittier fault

The photographed small anticline and the nearby fault may be secondary adjustment features in the process. It is interesting to note that the dips indicated at the north side of the diagram are excellently shown where the Whittier fault crosses the Turnbull Canyon road. The third possible interpretation of the area will be mentioned later in connection with the Whittier fault.

Just to the east of this above discussed fold are irregular dips indicating a possible small anticline and syncline, but the outcrops are so scarce that nothing certain can be located. The locality may indicate an extension of the fold structure at the east in that direction rather than curving as shown on the map.

The anticline within the Puente shale north of the Whittier fault has been located entirely by the observed dips on the map. Its direction of pitch, if any, the dip of the axial plane, and its possible continuation to depth is unknown.

The third fold in section CDE lies within the fault block about 2000' east of Workman Hill. The axis lies along a contorted sandy shale bed with similar conglomerate beds dipping away on each side. Only two reliable dips were available on the southwest side because of heavy brush. The certainty of the presence of this anticline is thus somewhat lessened.

The presence of the anticline extending north from the head of Turnbull Canyon is indicated by a large number of attitudes. The uncertainty as to its existence lies in the large number of faults of unknown magnitude and length which are found right near it. Fig. 12 shows an exposure of the fault to the west of it. The two faults to the east and the

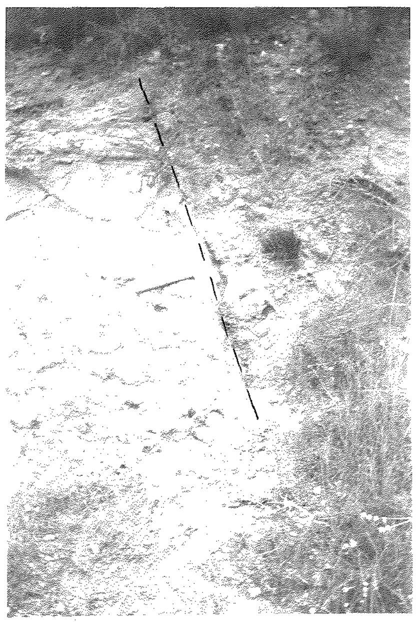


Fig. 12
Fault exposure.
On ridge 2500' east of fault B
and 800' north of Turnbull Canyon fault

one on the north dip towards it. Any of these faults may have a large enough displacement to cause the observed opposite dips.

The short syncline to the west of the last mentioned anticline is one of the most certain structures of the area. The shale across which the axis is shown on the map is only a 10' layer above the conglomerate. This layer may be plainly seen from the Turnbull Canyon road and clearly shows the syncline (Fig. 13). The numerous available dips add to its certainty. This shallow syncline has no structural significance other than its tendency to increase the possibility of the previously described anticline to be a true anticlinal structure. The presence of a syncline with an almost parallel axis to another structure believed to be an anticline shows that the proper forces for folding are at least present.

Fig. 13
Shallow syncline.
2000' NW of Workman Hill

The remaining fold of the area is located along the northwest alluvium boundary in some of the highest siltstone of the Repetto. It is a flat anticline whose sides dip similarly to the last mentioned syncline. The evidence for it is only in the few diverging attitudes. It would have been omitted as lacking in evidence had not the writer noticed in the field that its axis pointed to three producing oil wells in the alluvium along the Union Pacific Railroad line. The hypothesis may be given that this anticline extends under the alluvium and changes pitch enough to form a favorable structure.

A few noticeable variations in dip that cannot be ignored will be considered. At the extreme west of the area south of the mouth of Sycamore Canyon are a number of south dipping exposures scattered among those dipping north. Having been cautioned in English's bulletin against assuming an anticline, and not being able to find a suitable anticlinal axis has led the writer to regard them as overturned beds. Fig. 14 shows the vertical siltstone beds occurring as marked at the mouth

Fig. 14
Vertical siltstone beds.
Mouth of Sycamore Canyon

of Sycamore Canyon. The other steep dips nearby lessen the possibility of an anticline and indicate the possibility of a fan fold. The beds show no curving as in the folds a little over a mile to the east, and few shallow dips are present. The overturned condition probably resulted from the contortion of beds which were already dipping steeply.

The south dipping sandstone along the upper Puente conglomerate bed at the east end of the area is probably also overturned. The steep-dipping thick conglomerate at the east end was thick enough to resist the contortion occurring in the Puente. But the western end, as it became thinner, also became weak enough to be twisted and overturned, perhaps by the drag of the E" fault C just north of it.

Very noticeable also is the different strike and dip observed across Turnbull Canyon. There is distinctly an opposite trend in the dip although consistency in dip and strike on the southeast side is somewhat lacking. There would be considerable difficulty in placing an appropriate axis for an anticline. This anticlinal possibility must be kept in mind although the evidence for a fault is more convincing.

Faults

There are a large number of major and minor faults traceable in the area and undoubtedly many which are not evident. The writer has extended them only as far as evidence is found and has not tried to connect distant faults which have a similar strike. Many of the faults shown may actually be much longer because of this limitation.

The longest and most important fault in the area is the Whittier fault striking about 60 degrees west of north. It is a major fault of Southern California and often forms a wide zone of deformation along its trace. At its western end on the map as far as Trunbull Canyon it may be traced by the contact of massive sandstone on one side with the fine shale of Puente on the other. Several good exposures may be seen near the middle of its trace where the road crosses it and then cuts back again. Fig. 15 shows two zones of gouge five feet apart. The first is one foot wide and the other is three

Fig. 15
Two zones of fault gouge along Whittier fault trace.
On maintenance road 400' west of section GHI

feet wide. Other visible fault contacts associated with this zone are seen higher on the road where a conglomerate horse only five feet wide may be seen bounded on each side by a fault contact with siltstone (Fig. 16). A good exposure may be seen near the east end of the anticline on a small road

Fig. 16
Conglomerate fault horse associated with Whittier fault. Lies 100' south of Whittier fault on section GHI

leading to an oil well. The conglomerate bed north of the fault at its east portion curves into the fault (Fig. 17) and is lost. The fault's location from there east is determined by the fact that the conglomerate beds on each side of it are not truncated.

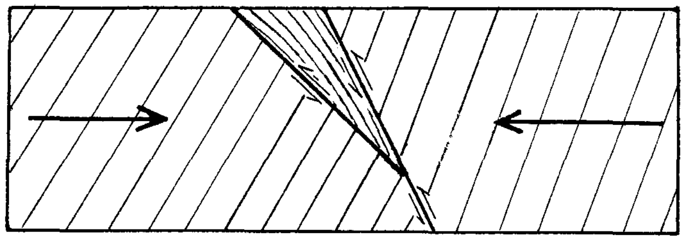
Fig. 17
Vertical conglomerate bed which curves into Whittier fault. Along Whittier fault 2200' east of section GHI

At the Turnbull Canyon road the Whittier fault is accurately located by contorted and overturned beds on the north side. On the south side saturated silt beds dip in conformity with the overlying Repetto beds. To the west of Turnbull Canyon, however, no direct evidence of it may be found. That the Puente shale is highly contorted is evidence that some type of deforming force has acted. Farther west than the shale a series of sandstones, conglomerates, and shales are apparently unbroken although possibly bent and contorted. The Whittier fault must thus be diverted into the alluvium to the south before it reaches these beds. One possibility is that it curves southward after crossing Turnbull Canyon and reaches the alluvium through the Puente shale as shown. Supporting this theory is the fact that the conglomerate and sandstone beds appear to be compressed and pushed to the northwest by a buttressing action as would exist along the curve of a strike-slip fault. However, the field evidence that the Whittier fault has a predominantly strike-slip movement is small. Only its straight course east of Turnbull Canyon suggests it. English on page 57 of his bulletin mentions the fact that it has an opposite throw along its course. Vertical movement alone, dropping the Repetto beds, could not account for the opposite dips in the Repetto of the north and south sections. The lithologic nature and the established successions of beds in the two sections are entirely different. A large anticline striking almost east-west would have to beestablished in the Puente shale.

The localized evidence of the overturning of chert beds at the Turnbull Canyon locality of the fault suggests that the fault plane dips at least 80 degrees to the north. Crushing and folding evidence of compression add to the probability of a reverse movement. The writer concludes then that the south Repetto section was moved to the northwest along the fault and downward in an oblique-slip reverse movement. The horizontal component is necessary to bring nearly together the Repetto section having such a different structure, lithology, and succession. Such a suggested movement fits well with the curved position of the trace, resulting in compressing and bending of the shale, sandstone, and conglomerate beds previously mentioned.

The other hypothesis as to the disappearance of the Whittier fault at Turnbull Canyon is that the indicated fault up the canyon displaced it out into the alluvium. An appropriate amount and direction of displacement for this shifting may be seen on the Turnbull fault up the canyon where it apparently offsets fault A-A'. The continuation of the Turnbull fault westward along the canyon could mark the contact between the Repetto sandstone and Puente shale. However, the previously mentioned outcrop of oil shale just south of the Whittier fault is about four hundred feet to the southeast of the proposed fault contact. It shows that the position of the contact probably just happens to be near the canyon and is not the result of faulting.

An improbable alternative for locating the shown anticline in the south Repetto portion along the Whittier fault is worth mentioning. The area roughly between the anticline axis and the fault as shown in section GHI may be an underthrusted wedge lifted along the fault trace by compression and tangential forces.



Such underthrusting along the San Andreas fault has been pointed out by Dr. Buwalda of the Institute. The only evidence for it here is the fault outcrop (Fig. 10) occurring about a hundred feet south of the anticlinal axis and dipping toward the Whittier fault at a 45 degree angle. That such a structure could exist in these incompetent shales and siltstones is unlikely and is not suggested for serious consideration.

Another possible difference from the mapped location may be suggested at the east end of the fault. The fault may split and trend to each side of the thick conglomerate bed at that locality. As previously stated, the connection of this bed to the west is not certain. Its dips are almost at right angles to the usual Repetto dips at the west. It is even possible that it may be a horse of Puente conglomerate, as its structure and composition are too unsorted and granitic to agree closely with the typical Repetto type. More tracing of the beds and the fault outside the area would be required before a definite conclusion could be reached.

The gouge along the exposures of the fault seem to show a vertical dip. The tendency of valleys and saddles to outline the trace of the fault (Fig. 1) is undoubtedly due to the easier erosion along the contorted and gouged material rather than to recent movement. The total displacement of the fault is unknown but must be at least a mile horizontally with considerable uplift of the Puente shale to the north.

The doubtful Turnbull Canyon fault is one of the next most important breaks in the area. It lies along the bottom of the canyon, crosses the ridge at the top, and descends in the EW canyon of the other side. It is nowhere exposed, produces no slickensides, and shows no obvious structural terminations as most of the other faults of the area do. It yields no local evidence at the head of Turnbull Canyon which is the only locality where valley alluvium does not cover it. Its presence is justified by the contortion of the Puente shale, the termination of several cross faults, the limiting of structural features, and the abrupt disappearance of shale beds into it.

Along Turnbull Canyon the attitudes in the Puente to the west of the fault are quite uniform, striking nearly EW and dipping north. On the east of the canyon the attitudes are irregular and show definite folding and crushing. An EW trend of the strikes may be detected but the dip is south. That an anticline is present is improbable because the dividing line runs NE-SW across the edges of the strikes. The only other alternative is a fault at this location.

Farther up the canyon where it curves eastward and on to the east, several faults appear to be displaced or terminated by the Turnbull fault. The first two faults, A and A', encountered on opposite sides of the canyon have similar strikes and apparently large displacements. That these two faults are displaced parts of the same one is probable. The important fault E, apparently ending at the Turnbull trace, cuts across the main highway just beyond the head of Turnbull Canyon. It cannot be located to the north of the trace. The presence of a pair of parallel short faults striking similarly to the terminated fault E on the south may be seen to the north of the Turnbull trace. They are offset almost a thousand feet west--about the same amount of displacement considered on the last mentioned faults. The dips, however, are opposite and somewhat lessen the possibility of their representing a single fault. Several other short dotted faults are shown, none of which can be traced across the Turnbull fault.

The termination of a shallow syncline and an anticline is apparent. The dips locating the axes of these structures are not present south of the fault. A fairly uniform dip to the north is there present.

The remaining evidence for the presence of the Turnbull fault is the termination of several shale beds. The shale is present to the south of the fault canyon but cannot be found to the north on the well exposed canyon wall. The actual contacts and their immediate vicinity are covered with alluvium, so that their exact locations are doubtful. This evidence, as is the case with each of the other types mentioned, is not sufficient in itself to justify the fault. But the accumulated "circumstantial" evidence makes its presence probable. The movement on the fault appears to have a strike-slip of about a thousand feet and probably some vertical movement, the east side moving NE and east. The same buttressing action, as evidenced in the west end of the Whittier fault is possible where the Turnbull fault curves. The anticline and syncline to the NE of the curve lie in the position where compression would be greatest. Though the folds are broad and not likely to be caused by local compression, their location agrees with the strike-slip hypothesis.

The other very doubtful fault of the area, labeled H, strikes EW along the SE corner of the long Puente shale region. It forms a rough triangle of Repetto northeast of the Whittier fault. The main evidence is the curving and overturning of the narrow conglomerate bed at its west end. Fig. 17 shows the narrowed bed in a vertical dip at the spot thus marked on the map. It would be difficult to explain how the Whittier fault could cause this result. The EW fault might cause it by a horizontal movement. Where the fault H crosses the saddle near its middle, an indistinct division of sandstone on the north and siltstone on the south may be seen. The difference in rock types all along the two sides of the fault is, however, not readily apparent. The trace also makes a structural division, a regular dip on the south being replaced by contorted and folded beds on the north. Either the downthrow side is on the south, or the movement is nearly strike-slip.

There are eight or ten other faults in the area which have excellent evidence, though only in isolated spots in some cases. The long NW-SE fault A-A', shown displaced by Turnbull Canyon, has excellent evidence. Fig. 18, taken along the trace, shows it crossing the ridge south of Sycamore Canyon. Its north termination is in Sycamore Canyon since it does not displace the adjacent series of conglomerate beds visible in the distance of the same picture. It cuts across the ends of the upper Puente series, putting the typical Repetto siltstone adjacent to Puente shale, sandstone, and conglomerate. What appears to be a continuation of the upper Puente conglomerate across the fault is only a coincidence.

Fig. 18
Fault A making a vertical conglomerate-siltstone contact. Undisturbed conglomerate series seen in distance.
On ridge south of Sycamore Canyon.
1000' NW of section EF

The attitudes, thickness, and composition of the two conglomerates are very different. The Puente conglomerate is a coarse, unsorted, sub-angular, lenses, decomposed granite a hundred and thirty feet thick, dipping about 45° in a N70°E direction. The Repetto conglomerate is the typical rounded, limonite-stained, well-sorted type only about 50' thick and striking nearly NS. Fig. 19 shows the beds on both sides with their different attitudes.

The supposed portion of this fault, labeled A, on the south of the Turnbull fault marks a distinct division between Puente shale and Repetto conglomerate. On the ridge near Workman Hill the conglomerate beds striking into the shale are clearly visible. The extension of fault A' to the south after

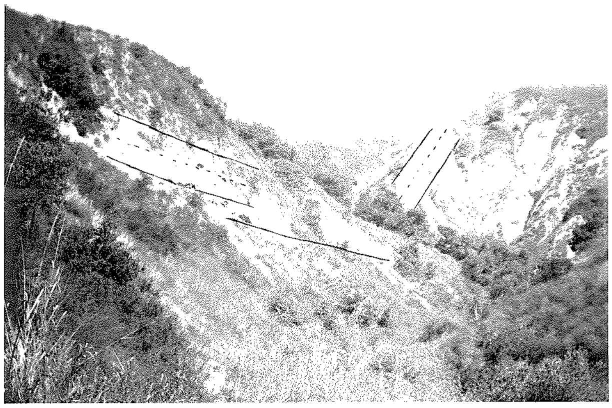


Fig. 19
Showing different attitudes of Repetto conglomerate beds (on right) and Puente conglomerate beds (on left) Along fault A 1500' NW of Turnbull fault

cutting the EW fault C is in doubt and is based only on the possible termination of the Puente anticline and the apparent truncation of fault C. Any evidence of the location of the fault A' through the Puente shale cannot be found in the seldom outcropping terrain. The fault zone is not exposed along Turnbull road, but an intense contortion of the shale 500' down the road near which the fault lies may be seen. In the absence of slickensides and drag folding in either part of fault A-A', the nature of the movement can only be based on structural evidence. The southwest side evidently rose, exposing the Miocene beds through erosion. Either a throw of at least 150' or an undeterminable amount of strike-slip would be required to cause the high angle contact of conglomerate and siltstone visible in Fig. 18. An estimated dip of 85° to the NE was taken.

The NS fault, labeled B, which meets the last mentioned fault at Turnbull Canyon also has obvious evidence. It marks a conglomerate-siltstone contact on top of two ridges and terminated two thin layers of conglomerate. The conglomerate layers are present on one side of a gully and absent on the other, being cut across their ends. The conglomerate at the top of both major ridges stands out as a resistant kno with the siltstone at the east forming a saddle, The distant high hill of Fig. 13 is the southern knob. The fault dips 70° to the east and is probably a normal fault. Small folds in the siltstone forming a drag syncline show that the east side slipped down along the dip. The presence of any strike-slip is not evidenced, but a minimum throw or dip-slip of 100' can be seen on the northern of the two ridges that it crosses. (See Figs. 20 and 21). The north end of the fault is lost in the massive Repetto siltstone.

On the tiny ridge between the two large ridges the features of a landslide may be seen (Figs. 20 and 21). The three-foot bank of resistant conglomerate which marked the conglomerate-siltstone fault contact has slid down the slope to a new position about 200' to the west. The fault trace is also twisted to a NE trend. The two pictures show the nature of the movement and the amount. The picture was taken from a point on the true trace of the fault. The resistant ridge is visible to the left of Fig. 21 and at the center of Fig. 20.

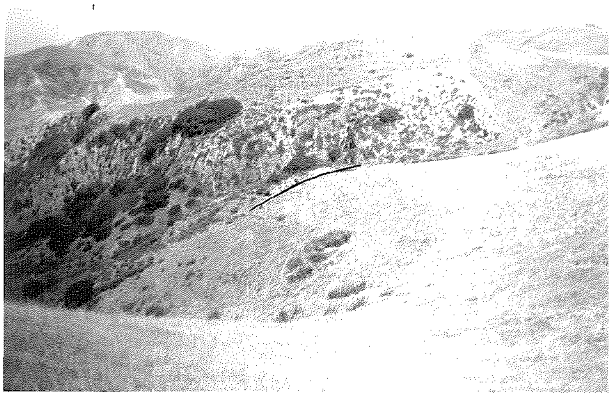


Fig. 20

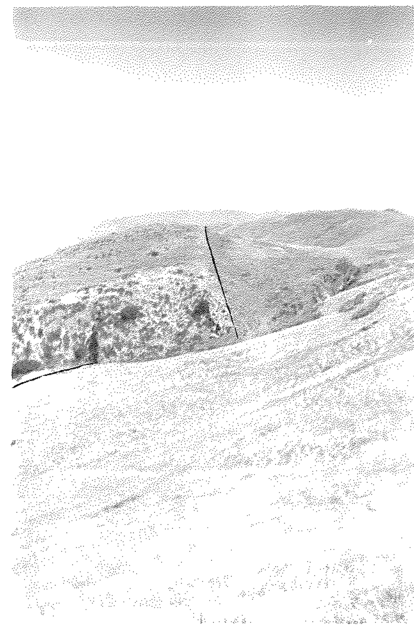
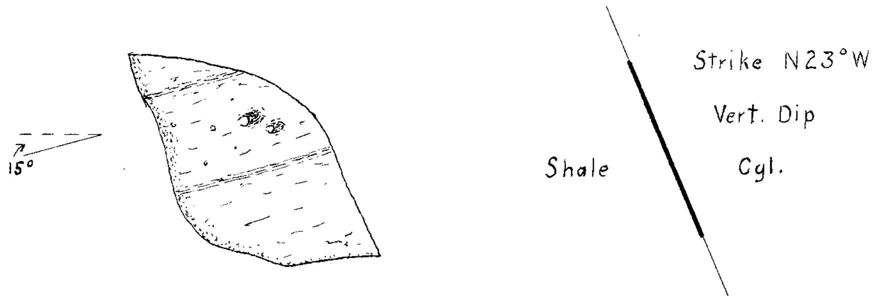


Fig. 21

Abutment of conglomerate and siltstone beds along fault B.
Photograph taken on fault trace.
Landslide in foreground.
At intersection of fault B and section EF

A slightly W of N striking fault, marked F, lies 2000' to the east of fault B along section EF. It cuts through conglomerate entirely except on two ridges where it forms siltstone-conglomerate contacts. On the small ridge near its north end it probably separates conglomerate above from siltstone below. The resistant conglomerate formed a 40' cliff, but it could be entirely an erosional feature. On the higher ridge near the middle of the fault, the top of a siltstone bed to the west is truncated by conglomerate in the east (Fig.6). On the ridge at its southern end fault F is located by slickensides visible in the conglomerate. The two ends of the fault cannot be traced. The north end disappears in a canyon and the southern end is lost within the conglomerate. Excellent evidence concerning the movement of this fault was found on a slickenside surface where it crosses the middle long ridge. An oval, vertical section of slickensides on conglomerate gouge showed not only grooves but two small pebbles which were dragged along the surface, leaving a cavity behind them. The following drawing shows the evidence:



The actual specimen may be seen in the geological museum at Caltech.

These features are good evidence that a strike-slip movement is possible within the area. In this case the west side moved north and slightly downward at a 15° angle. The visible displacement of the siltstone is fifteen feet which is only the minimum. As the strike of the beds is parallel to the fault strike, the minimum strike-slip can easily be figured from the fifteen foot throw at 56 feet. The slip is at least 58 feet.

The next fault to the east, named G, is a long, curving break separating two distinct conglomerate types at its southern end and truncating conglomerate beds by siltstone masses in the north. At the northernmost ridge where it crosses through a saddle the conglomerate bed is visibly truncated, although the fault plane is not exposed. Its location north of this point is unknown except that the conglomerate beds there are apparently continuous. It may curve out into the alluvium or less probably dies out or lies under a disconformity. The pair of beds shown cut by it a little to the south are not with certainty located. Only a few pebbles in thick mantle and alluvium suggested their continuance along the dotted portion.

The next conglomerate bed to the south (1500' SW of foram locality 58) offers the best evidence for fault G. The bed is abruptly ended as it lies along the side and top of a ridge. The saddle in the ridge marks the position of a highly contorted and broken zone. The conglomerate is bent and broken for 400 feet to the west. Small blocks of siltstone and conglomerate are mixed together and numerous large slickensides surfaces may be seen. The slickensides have various strikes, mostly with a NS trend. The scratches show a horizontal movement. One large piece of polished surface strikes N52°E, but its position may be secondary. The saddle resulted from the easy erosion of the truncated zone.

The continuance of the fault southward is shown by the difference in conglomerate types and the isolation of a section of siltstone within conglomerate. The lack of exposures on the north side of any of the ridges makes much of the siltstone-conglomerate contact questionable. The presence of the isolated siltstone chord, however, accurately locates the fault. The southward extension is only approximately located by poor outcrops of varied conglomerate. The saddle on the southern ridge somewhat influences the location as mapped. The south end of the fault is lost in the complex structure of the vicinity.

An EW fault may occur in this locality (as shown by English) and cut across this and fault F to the west, but the author could find no evidence for it. The movement along fault G is approximately horizontal but the relative direction of each side can only be inferred. Its most probable direction would be to conform with that determined on the parallel fault F to the west. That the faults are parallel and have approximately horizontal movement would tend to indicate that the acting forces were the same. In which case, the east side of this fault would have gone south and possibly a bit upward.

The remaining two major faults are located south of the east portion of the Turnbull fault. Fault E, crossing the highway in a NS direction, has an excellent visible contact on the road (Fig. 22). The fault separates conglomerate at

Fig. 22
Slickensided surface of fault E
On highway 1500' NE of Workman Hill Point

the west from siltstone on the east, cutting almost at right angles across the strikes. Only the smoothed surface on the conglomerate is visible and offers no scratching evidence for the type of movement. Further south it forms the contact of conglomerate at the east with shale on the west. It is probably cut off by the EW fault C at its south and the Turnbull fault at its north. The nature of the movement is unknown but the amount is probably in the hundreds of feet. The dip is 81° to the east.

The EW fault C, cutting fault E at the south, but itself ending along fault A' to the west, is based upon the truncation of beds only. It clearly extends across the ridge south of Workman Hill, marking a shale-conglomerate contact for several hundred feet. The next conglomerate mass to the west is likewise displaced for a short distance. The normal siltstone-conglomerate contact appeared to stop before reaching fault A', making the approximate location of fault C possible. The thinning conglomerate bed of the east fault block is apparently cut by the fault. It cannot be traced south of the fault line. The only statement concerning the movement of the fault is that the lower Puente beds to the south probably rose considerably in order to expose themselves.

Besides the ten more important faults just described, there are thirteen other distinct ones which have positive evidence for their existence. Other than the short one in the far east of the area near the Whittier fault and the one crossing Turnbull road into Workman Hill, they all occur in the highly faulted zone north of the east end of Turnbull fault. Generally a single road cut exposure will locate them and offer a strike and dip. Beyond that they cannot be traced and disappear. The many avocado orchards, private homes, and heavy brush prevent the tracing of beds and add to the confusion of the complicated structures already visible. Many of the contacts away from the roads are located with insufficient evidence and must not be accepted as fact.

A great deal of time could be spent in this small area in an attempt to unravel the complexities. The general structure seems to be that a series of thin, low-dipping beds have been intricately faulted and contorted by a set of approximately NW breaks. Fig. 12 shows the one occurring between the anticline and syncline near the head of Turnbull Canyon. The one lying between the north ends of faults B and F shows at least twenty-five feet of displacement between a siltstone and conglomerate bed, but it cannot be traced to the north and south even though exposures are fairly good. The one crossing Turnbull Road 1000' NW of Workman Hill forms the siltstone and conglomerate contact for a short ways and likewise is lost on Workman Hill where exposures are good. The short fault offsetting the two conglomerate beds at the east end of the Whittier fault shows gouge and breccia, dipping 56° NE and gives a clear picture of the amount of movement. A strike-slip of a hundred and fifty feet, a dip-slip of about a hundred and twenty feet, or a smaller oblique-slip movement would be necessary to match the offset beds. The NE side would move relatively NW and up with respect to the other side. This fault is unique to the area as it is the only one that permits correlation of beds on its two sides. No even probable correlation can be made elsewhere. The conclusion is that movement on most of the area's faults is much greater than the observed minimum. The pronounced lateral variation in the Repetto undoubtedly adds to the difficulty of matching definite beds.

Unconformities

There are no visible angular unconformities in the area. At many localities, however, may probable disconformities be seen. Fig. 7 is characteristic of them. They mark many of the contacts of conglomerate over siltstone in the Repetto formation. Figs. 8 and 25 are other examples. The siltstone or shale is abruptly ended and the uniform conglomerate is deposited above. That a hiatus occurs is not definite. The occurrence of shale blocks or slabs as in Fig 7 near the base of the conglomerate is the best indication that erosion could have taken place between deposition stages. The upper contacts of the conglomerate generally have narrow zones of transition sandstone and do not change abruptly. The abrupt contacts occur at the base of the six Repetto conglomerate beds in section AB.

The lower contact of the middle conglomerate series along Sycamore Canyon has a pronounced break. A considerable erosion period must have occurred there in order to have leveled off the topographical results of activity on fault A before deposition of the series. Several localities along the road cuts of the faulted zone north of the east end of Turnbull fault have these apparent disconformities, and are well exposed. Many of the Repetto beds in the southern position show the same features. The author could not in most cases decide whether any erosion period at all took place and cannot venture to locate them definitely as ~~such~~ disconformities. These contacts reflect the manner of deposition previously considered.

GEOLOGIC HISTORY

As the time interval represented in the area is only part of two ages, probably the lower two-thirds to one-half of the Repetto and the upper one-third of the Puente; the history will accordingly be limited. The structural development and geomorphology will be combined with the history.

The upper Puente shale complex was first deposited in a slowly sinking basin, probably a fairly deep inland sea comparable to the Gulf of Mexico. The climate was probably warm with considerable seasonal rainfall. Fish, diatoms, and other small sea animals thrived. Mild periodic rains may have supplied the source rivers with material of varied coarseness to cause some of the extremely fine bedding. Current action probably accounted for some of the sorting and especially for the sandstone lenses. Long periods of almost no deposition would permit layers of silicious skeletons and fish remains to accumulage and to consolidate into chert beds. The land forms approached the stage of a peneplain towards the end of the period, supplying less rock material and permitting a higher percentage of organic remains to be mixed with the sediments. The shallower deposits near land which supported larger littoral organisms such as molluscs, echinoderms, etc., are not represented in this area.

After the long period of quiet crustal conditions though varied seasonal precipitation, the land began to rise slowly. Coarser sediments were carried into the basin, alternating with still coarser ones as the land rose. The uplift increased in rate until coarse conglomerate and boulders were dumped over the deposits in the filling basin. The pre-uplift peneplaination had stripped the land of sediments and exposed the granitic and gneissic mountain cores to weathering. This decomposed basement rock was now the material of deposition, forming the coarse, sub-angular, unsorted, lensed conglomerate of decomposed granite that forms the upper Puente conglomerate.

This rapid though not necessarily great uplift then stopped and either subsided somewhat or continued with normal erosion. Finer sediments were laid down in the again sinking seaway until laminated shales resulted. The abundant life previously developed by the long quiet period had been considerably killed off. A few new species better adapted to the change were developed and some of the highly specialized ones were exterminated. The deposition cycle, however, was gradual enough that only a few species were lost and the life was still predominantly that of the Puente Age. The total quantity of life was greatly reduced and offerred little organic material for accumulation in the new shale. Consequently chert beds are absent, and in the uppermost Puente shale fossil remains do not compose their previous large percent of the total mass.

The next uplift at the beginning of the Repetto was a rapid one at the very start. The fast boulder-carrying streams caused sea currents to cut locally into the soft shale contemporaneous with deposition, forming at places a disconformity. Although the source material was probably the same, though possibly more distant, the basement complexes had not been subject to such a long period of weathering. Existing talus slopes and local material from the previous uplift would be fairly abundant. The new conglomerate then was of a less decomposed nature. The greater rounding and sorting in the Repetto means either that the source of material was farther away or that current action was more efficacious. The varied rock types represented tend to support the theory of a distant source. The remaining especially adapted animal species (for quiet water and fine sediment deposition) could not stand the sudden change and were largely exterminated. Species variations that happened to suit the conditions formed a new fauna and Repetto species were added to the hardy, unspecialized, long range types. A very few of the Puente forms survived a while to complete a transition between the two life periods.

The new period was characterized either by a high relief of the land or by unstable dynamic conditions. Weather cycles may have loaded the streams with products of corrasion. Sudden uplifts may account for the abrupt appearance of conglomerate beds. Before the middle conglomerate series was deposited, faulting cut the Repetto deposits. Probably the faults were themselves part of an unstable stage of crustal adjustment. The faults were levelled off by an uplifted erosion period and further sedimentation fed the basin. The siltstones were deposited in deep water as a result of large rivers with low grade or by very rapid deposition in which there was no time for sorting. A minimum of current action is also essential for the formation of massive siltstone. The large areas of unstratified shale were probably formed by a combination of these requisites. Molluscs and forams thrived during the period. Their remains are abundant above the middle conglomerate series. Local uplifts deposited conglomerate beds that would not persist far from their source. The source of the lower Repetto conglomerates appears to be from the west. The beds are thicker there and die out eastward. The upper beds where represented seem to have originated in the east although the evidence is meagre. Before deposition of the upper series, the strike-slip faulting in the central east portion may have occurred. It is more probable, however, that the movement was at least post-Repetto.

The structure of the area offers little basis upon which to postulate an orderly set of deforming forces. Obviously more than one period of deformation occurred and at least five are indicated on the map. The earliest movements occurred in early Repetto-post-Puente time. Three faults representing three age relationships are confined within this limit because all cut Repetto beds but are older than the middle conglomerate series. This conclusion is based on the assumptions that (1) the middle Repetto conglomerate series covers the central NS fault A (2) that this fault is offset to the east by the Turnbull Canyon fault, and (3) that its south portion A' is later than the other two short faults C and E in the vicinity. The further conclusion can then be drawn that any Pliocene beds cut by these faults must be lower Repetto and that the two fault blocks around and to the east of Workman Hill are of this age. Such inductive reasoning is then reenforced by the reflection that these beds do greatly resemble the lowermost Repetto section. The blocks contain two thick conglomerate beds and the associated silts which lithologically agree with the thick lowermost conglomerates of the typical section. The absence of forams is good negative evidence since they do not occur in the lower Repetto of this area.

The folding in the lower Repetto and some contortion of the Puente probably occurred at this time. It seems unlikely that the middle conglomerate series of the Repetto could have withstood some deformation if it were present when the acute folding a few hundred feet below it took place. The topographic expression of the folds must have been eroded away before the subsequent deposition.

The time relations of the tangled mass of faults in the middle east portion cannot be readily ascertained and are not important nor accurate enough to merit consideration. The longer strike-slip faults are certainly younger than lower Repetto but by how much is problematical. Their ends are lost in a lack of evidence.

The most recent faulting is that of the Whittier fault. Its age limits in this area are pre-Quaternary allumium and post-Repetto. Farther to the east English has shown it cutting Pleistocene terraces. One may safely say then that it is fairly recent and has had movement after the Pasadenan Revolution. No topographic expression can be found to indicate recent activity. It is undoubtedly associated with the diastrophism which so minutely contorted the Puente shale and which caused the steep tipping of the Repetto. I believe the fault to be part of the Pasadenan Revolution which is probably responsible for the uplift of the entire Puente Hills. The nearly mature topography is evidence of a considerable erosion period. Many of the hill tops are at an elevation of about 1100, but common variations of 200' above and below it limit the possibility of visualizing an old land surface. The present high position of the hills was probably a result of folding and compression faulting rather than uplift as a unit. In general, conglomerate beds are more resistant to erosion, but no distinctive land forms result from them in this area.

ECONOMIC CONSIDERATIONS

Since there are two producing oil fields within the area and several others in the vicinity, the oil production possibilities of the Whittier Hills should be considered. English discusses at some length the original source of oil.[3] He concludes that the Puente is the probably source, but the lower Repetto must not be entirely eliminated.

The numerous interbedded conglomerate, shale, and sandstone beds provide the means of capping and storing oil. Therefore discoveries of structures which may form traps are worthy of consideration.

The most interesting anticline from the standpoint of location is the one just south of the Whittier fault cut by section GHI. Although the fold occurs in a producing oil field, its probably close association with the Whittier fault makes it of little importance to the general structure of the area. The unknown nature of the fold's ends as well as the doubt that the whole structure really is an anticline makes any conclusions as to its significance in the producing fields nearly worthless. The producing fields to the east and west probably have different conditions for trapping the oil. To the west it seems probably that the Whittier fault cuts off a homocline, and in an unusual manner forms a limit to the migration of oil. An oil seepage found at the 32 degree dip south of the intersection of the Whittier and Turnbull faults strengthens this theory. The writer must add that the apparent seepage could be merely escaped oil from a producing well on

3. _Ibid_, pp. 69-73

top of the ridge. To comment on the underground structure of established fields any more than is justified by surface geology is not within the scope of this report. English gives a good explanation of the Whittier Field on pages 77 and 78 of Bulletin 768.

The questionable anticline cutting section GHI north of the Whittier fault is a very poor prospect for oil. The only chance of finding oil along this position is that the oil-impregnated middle sandstone member of the Puente (described by English) is similarly folded, suitably capped, and at a practical depth directly below the assumed fold.

The remaining anticline in section GHI lies in the fault block 2000' east of Workman Hill. Since the presence of the structure itself is based upon meagre evidence, its chances of producing oil are indeed small. Fault E dips under it, and the faults to its north and south would cause leakage from whatever trap could be formed.

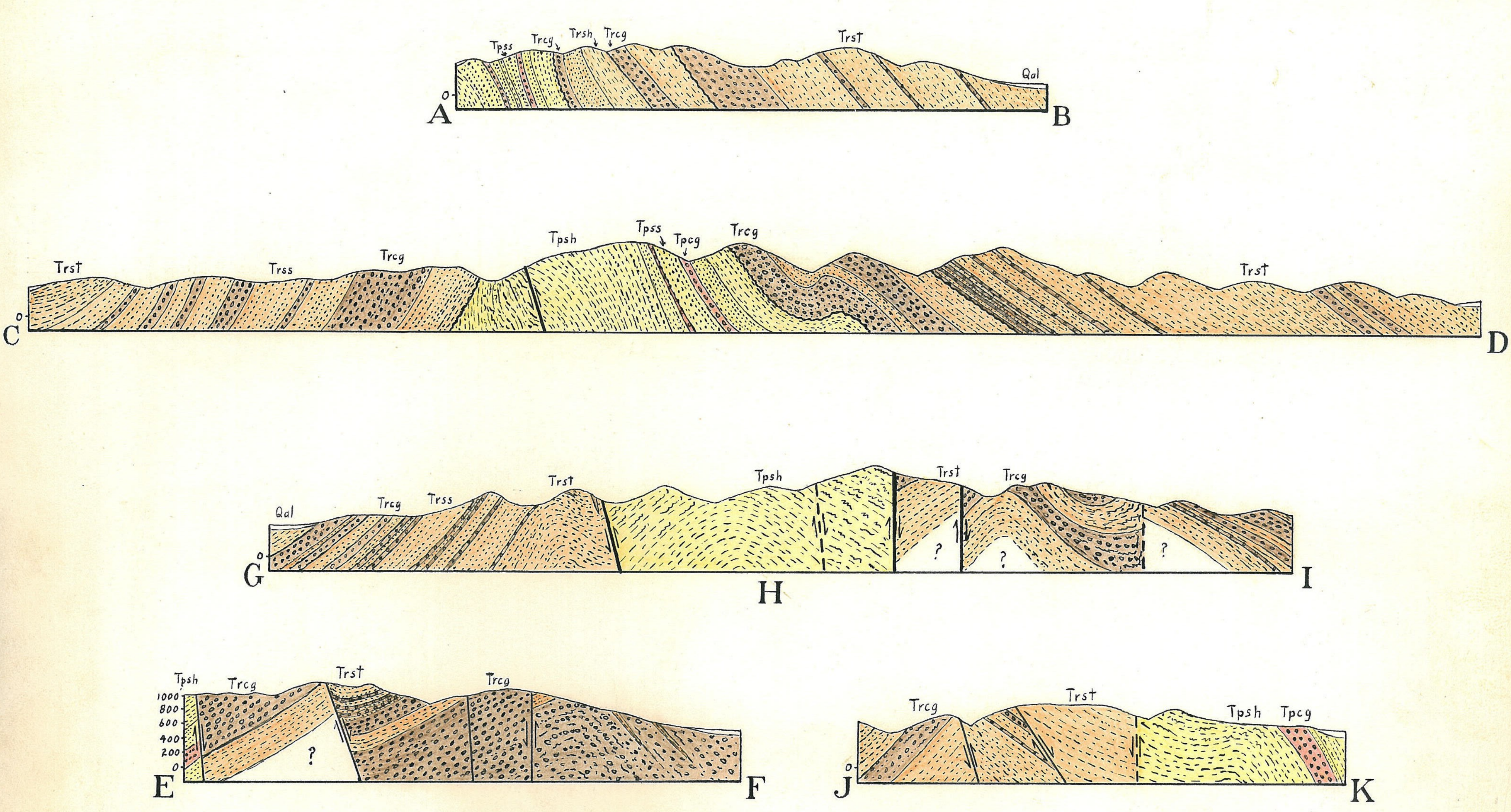
The doubtful anticline surrounded by faults at the head of Turnbull Canyon holds very little possibility of oil. The nearby faults would either cut off the structure at depth or allow any migrating oil to escape along their contacts. One wildcat well to the east of the southern end was unsuccessful.

An anticline and syncline have been mapped in the middle of section CD. The possibility of trapping oil in this structure is poor. The anticline has a fairly steep pitch to the west and flattens to the east, lacking a structural trap. Assuming that the Puente shale to be the oil source, the upper Puente sandstone to be a reservoir, and the upper shale to be a cap, the depth to the contact would be in the nature of 1000 feet if the axial plane were vertical. If the plane dipped similarly to the dip of the beds on each side as shown in the section, the depth would be much greater. Others have probably interpreted the folds as I have and have drilled wells to the north, east, and south as shown on the map in the hope that a favorable change in pitch occurred at depth. The wells were not productive and little hope may be held for the success of other or deeper wells.

A shallow westward plunging anticline near the Mill District School along the NW boundary of the area is worth a few words of discussion. Its questionable occurence, as indicated by its dashed axis, reflects the small number of dips upon which it is based. The interesting feature is that three producing wells are present about 2000' out in the valley alluvium directly in line with the axis. It might be advisable for the owners of the property to utilize what information they have on the wells as a basis for deciding if geophysical prospecting farther out in the valley is justifiable.

COLUMNAR SECTION

Epoch	Formation	Thickness in feet	Section	Symbol	Character
Pliocene	Repetto	1300+		Trst	Nearly massive buff siltstone
		350±		Trcg Trst Trcg	Well rounded compact brown conglomerate
		1200±		Trst	
		30±		Trcg	
		100±		Trst	
		30±		Trcg	
		750±		Trst	
		420±		Trcg + Trst	
					Unconformity
		500±		Trst	
		200±		Trcg	
		150±		Trst	
		180±		Trcg	
					Disconformity
Miocene	Puente	200±		Tpsh	
		250±		Tpss	
		150±		Tpcg	Angular decomposed granite conglomerate
		250±		Tpss	Fine yellow sandstone
		1580+		Tpsh	Fine bedded white to yellow siliceous organic shale



GEOLOGIC SECTIONS

0 1000' 5000'

Horizontal and vertical scale