GEOLOGY OF THE WHITES POINT OUTFALL SEWER TUNNEL

Thesis by

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INTRODUCTION

Two years ago, W. P. Woodring and M. N. Bramlette of the United States Geological Survey completed a geologic map of the Palos Verdes Hills. A report on the area by Mr. Woodring is now in course of preparation. Shortly after completion of the field work, excavation began on the Whites Point Outfall Sewer Tunnel, which penetrates the entire eastern portion of the hills. Since natural exposures are rare in this part of the area, Mr. Woodring took the opportunity to supplement the surface data by subsurface information afforded by the tunnel. The writer was given a temporary appointment with the Survey, and with the aid of knowledge brought together by the above workers, made a detailed study of the geology of the tunnel.

In a work of this kind much of the interest centers upon the question as to how far a structure section constructed from surface data may be relied upon at depth. Examination of figures 1 and 4 discloses that the surface work was accurate to an almost surprising degree.

The Whites Point Tunnel was constructed by Los Angeles Sanitary District No. 2 for the purpose of sewage disposal, which was formerly taken care of by a plant in Harbor City. The route shown in figure 1 was chosen by the District on recommendation of Dr. Buwalda and others, who considered the "hard" rocks of the Palos Verdes Hills a better foundation in event of earthquakes than the almost unconsolidated sands underlying the extension of the Los

Angeles city boundary into Wilmington.

The tunnel extends from the intersection of Vermont Avenue and Lomita Boulevard in Harbor City to Whites Point, a distance of nearly six miles. An open cut for the conduit joins the north portal with the intake. On the southern end a concrete pipe terminates 5,000 feet from shore, and at a depth of approximately 150 feet. Throughout the entire length the floor of the tunnel is 12 feet below sea level. The bore is a horseshoe in section and approximately 10 feet in diameter, but this was later increased to 11 feet in certain parts of the section between stations 102 and 180. The total estimated cost is in the neighborhood of $2,500,000, the funds being furnished by Los Angeles Sanitary District No. 2, and the Public Works Administration (P. W. A. Project 7133). Excavation began in September, 1935 and was completed on October 14, 1936. During this time the writer kept in close contact with progress of tunneling operations. Except where imperfect consolidation of the rock necessitated very close timbering, the data were obtained from an almost continuous exposure. Since the general trend of the tunnel is approximately normal to the regional strike, this information can be used for constructing a structure section through the eastern portion of the Palos Verdes Hills.

ACKNOWLEDGMENTS

Mr. W. P. Woodring was in charge of the tunnel work, and remained in contact with the undertaking through correspondence.

Mr. M. N. Bramlette visited the tunnel in February, 1936, and did much to help unravel the Miocene stratigraphy. Mr. A. M. Rawn, Assistant Engineer of Los Angeles Sanitary District No. 2, furnished profiles of the tunnel route, and gave permission to carry out the work. Dr. Ian Campbell of the California Institute of Technology visited the tunnel on various occasions, and has also read the manuscript. Problems of structure were discussed with Professors J. P. Buwalda of the California Institute of Technology and W. H. Bucher of the University of Cincinnati. Dr. Hampton Smith of the Texas Company offered many valuable suggestions during early stages of the work. Officials of the Los Angeles Sanitary District No. 2; the Public Works Administration; the United Concrete Pipe Corporation; the Meritt, Chapman, and Scott Company, contractors; and the contracting firm of Schoffner, Gordon, and Hinman were at all times courteous and helpful.

OUTLINE OF THE GEOLOGY OF THE PALOS VERDES HILLS

For proper orientation it is necessary to review the salient features of the geology of the Palos Verdes Hills. This area has been a classic one in the literature of palaeontology and geology since the work of Arnold.[1] At this time interest was confined largely to the Pleistocene section, which is well exposed on the

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1/ Arnold, Ralph, The palaeontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, California, reprinted from Mems. Calif. Acad. Sci., vol. 3, pp. 1-420, 1903.

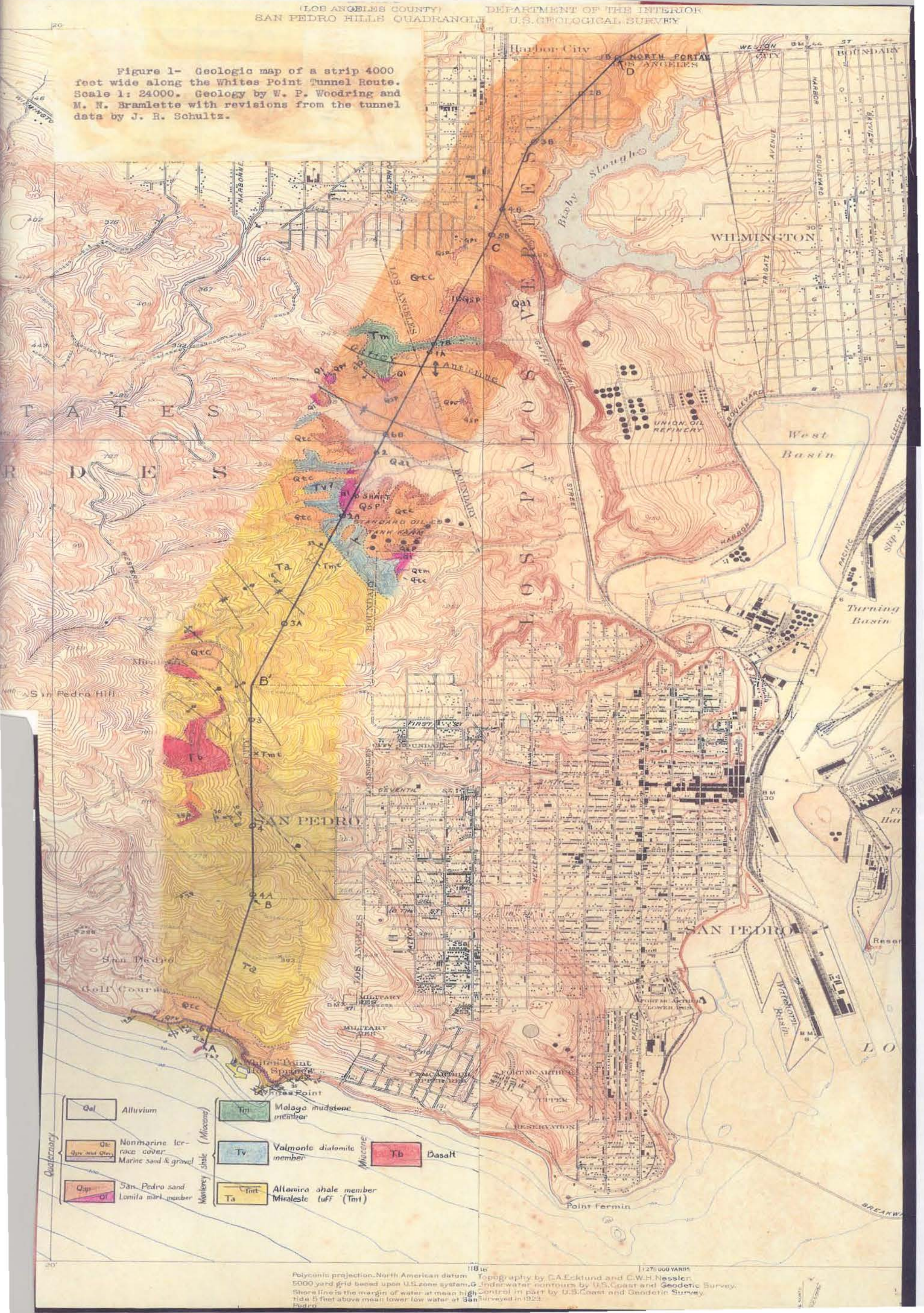

Figure 1- Geologic map of a strip 4000 feet wide along the Whites Point Tunnel Route. Scale 1: 24000. Geology by W. P. Woodring and M. N. Bramlette with revisions from the tunnel data by J. R. Schultz.

marine terraces in and west of the city of San Pedro.

Largely due to exploration for oil in the Miocene rocks of the Los Angeles Basin, later studies have tended to focus attention upon the thick section of Miocene shales, which has long been known to make up the main body of the Palos Verdes Hills. Three years ago, Hampton Smith[1] completed a thesis dealing with the siliceous shales of the area. This report includes a geologic map and detailed columnar sections of the Miocene rocks. Other recent publications dealing with the area are cited below.[2]

The tunnel work adds little to the major conclusions reached in these papers. Much of the following summary of the stratigraphy has been taken from notes furnished by Mr. Woodring. Distribution of formations along the tunnel route is shown by figure 1 of this report, but for their broader aerial extent the paper by Woodring, Bramlette and Kleinpell[2b] should be consulted.

1/ Smith, Hampton, Origin of some of the siliceous Miocene rocks of California, Ph. D. thesis submitted to the Balch Graduate School of the Geological Sciences, California Institute of Technology, 105 pages, 1934.

2/ Woodring, W. P., San Pedro Hills, Guidebook 15, XVI International Geol. Congress, pp. 34-40, 1933.

2a/ Woodring, W. P., Fossils from the marine Pleistocene terraces of the San Pedro Hills, California, Amer. Jour. Sci., ser. 5, vol. 29, pp. 292-305, 1935.

2b/ Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., Miocene stratigraphy and palaeontology of the Palos Verdes Hills, California, Bull. Amer. Assoc. Pet. Geol., vol. 20, pp. 125-149, 1936.

Pleistocene

Nonmarine terrace cover (Qtc) and marine deposits at base (Qpv and Qtm)

The nonmarine terrace cover generally consists of dirty, reddish-brown sand, and is most extensive on the lowest terrace, although in places it is preserved on higher ones. The fine, white sand of the lowest terrace constitutes the Palos Verdes marine sand (Qpv), while marine deposits under the nonmarine cover on higher terraces are designated marine terrace deposits (Qtm). These are somewhat older than the Palos Verdes, but all are of middle to late Pleistocene age.

San Pedro sand (Qsp) with Lomita marl member (Ql) and Timms Point silt member (Qtp)

These beds are of early Pleistocene age and are unconformable with both older and younger beds. The Lomita marl member, which lies at the base, is a fossiliferous marl and limestone, and shows almost perfect gradations with the San Pedro sand. The Timms Point silt member is a fossiliferous silt and sandy silt facies, which is not known to occur along the tunnel route. Exposures are found on Second Street in San Pedro, where the silt overlies the Lomita marl and underlies the San Pedro sand. The San Pedro consists of silty sand and clean sand, and in places is fossiliferous.

Pliocene

Repetto siltstone (Tr)

This formation is a glauconitic, foraminiferal siltstone, which is well exposed in the sea-cliff at Malaga Cove, where it overlies conformably the Malaga mudstone. The Repetto does not crop out near the tunnel route, although it was expected to be present under overlapping Pleistocene beds. Since such is not the case, the angular relation of the Pliocene and Pleistocene strata along the tunnel route is not known, but it must be unconformable in the broader sense of the term.

Miocene

Monterey shale

The entire Miocene section is referred to the Monterey shale. It is conformable throughout, and is divided into three members. These are in descending order of age; the Malaga mudstone, the Valmonte diatomite, and the Altamira shale.

Malaga mudstone member (Tm)

The uppermost member of the Monterey is a mudstone or fine-grained siltstone. Globular radiolaria are visible in almost any hand sample; diatoms are relatively rare. Foraminifera have been found by Hampton Smith at only one locality. Limestone concretions generally are present. At Malaga Cove, and elsewhere, laminated diatomite alternates with massive mudstone. The finer grain size, and rarity of glauconite and foraminifera serve to distinguish the Malaga mudstone from the Repetto siltstone. At Malaga Cove phosphatized limestone pebbles and schist fragments lie at the base. This contact was not accessible in the tunnel.

Valmonte diatomite member (Tv)

This member underlies the Malaga mudstone and overlies the Altamira shale. Diatomite and diatomaceous silt or clay in alternating units are the principal rocks in the Valmonte diatomite. Limestone lenses are found in the lower part. Chert is generally in the form of black chert, but in places there are cherty shales in the lower part. Beds of loose, unaltered volcanic glass occur throughout the member. In places foraminifera are abundant. The base of the Valmonte along the tunnel route is quite unsatisfactory, and was mapped on the basis of a normal thickness of phosphatic shale. The need for more precise data regarding this member was one of the reasons for initiating the tunnel work.

Altamira shale member (Ta)

This member constitutes the greater part of the Monterey. It embraces three parts made up principally in descending order of phosphatic shale, cherty shale, and silty shale.

The upper part of the Altamira consists of phosphatic and bituminous shale. This facies is best developed in the western part of the hills, for along the tunnel route diatomite and minor amounts of phosphatic and cherty shale are the predominating rocks in this division. The phosphatic material is in the form of light-brown, thin layers and nodules. Limestone lenses, cherty shale, and bentonitic tuff are the principal minor constituents. Cherty shale is more abundant in the western part of the hills than in the eastern part. Along the tunnel route sandstone, in which glaucophane is abundant, occurs in this division. This detrital material increases in thickness and grain size southward. Foraminifera are abundant in silty beds.

The middle part of the Altamira shale embraces most of the hard, cherty shale. Silty shale, bentonitic tuff, and limestone lenses form interbeds. In the eastern part of the hills diatomite is abundant in the upper part of this division. On the northern slope of the hills the upper part of this division overlaps onto the schist basement, and sandstone and conglomerate beds, which range in thickness from a few to 100 feet, lie at the base of the overlapping strata. Elsewhere in this region where the schist is not exposed there are coarse detrital beds. The Miraleste tuff (Tmt), which is readily recognized by the abundance of pumice lapilli, lies 150 feet below the top of the middle division. In the eastern part of the hills the Miraleste tuff is about in the middle of a fifty-foot diatomite bed. Valvulineria californica californica, V. c. obesa, and V. ornata are found in beds immediately underlying and overlying the tuff, and in the tuff itself. A species of Siphogenerina also occurs near this horizon. In the western part of the hills ellipsoidal opal concretions occur at a horizon above the Miraleste tuff.[1]

The lower part of the Altamira shale, which the tunnel did not penetrate, is exposed only in small areas. It consists of silty shales with minor amounts of tuffaceous shale, bentonitic tuff, cherty shale, and sandstone. The base is not exposed. At the top is a fifty-five-foot bentonitic tuff, called the Portuguese tuff.

Jurassic?

Franciscan? formation (J? f)

The metamorphic basement rocks which crop out on the north slope of the main canyon in the northwest quadrant formed by the intersection of latitude 33 46' longitude 118 20' are doubtfully referred to the Franciscan formation. Similar rocks were encountered in the tunnel. Nothing has been added to Woodford's account[2] of their petrology.

Miocene basalt and diabase (Tb)

Basalt and diabase occur in the form of sills and irregular masses more or less concordant with the bedding. Here and

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1/ Taliaferro, N. L., Contraction phenomena in chert, Bull. Geol. Soc. Amer., vol. 45, pp. 194-207, 1934.

2/ Woodford, A. O., The Catalina metamorphic facies of the Franciscan series, Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol. 15, pp. 49-68, 1924.

there apophyses penetrate overlying and underlying rocks. At some localities adjoining sediments are baked, but for the most part there is little alteration. At places, as in the reefs at Whites Point Hot Springs, the basalt appears to be extrusive. These rocks are not known to penetrate anything higher than the middle division of the Altamira shale.

Structure

The early Quaternary and older sediments have been folded along a northwest-southeast axis. In the vicinity of Malaga Cove, however, a northeast-southwest trend is apparent. On the northeastern slope of the hills late Pleistocene and perhaps Recent beds are warped into a broad fold known as the Gaffey anticline. The large normal fault on the northern margin of the hills which extends as far east as Waltheria, and is often mapped as outlining the entire northern margin of the hills, was not seen in the tunnel. However, the fault may be pre-San Pedro in age, and thus concealed under the Quaternary beds of this area.

The Gaffey anticline is the most conspicuous structural feature on the northern border of the hills. Movement has taken place repeatedly along this axis since Miocene time. South of the anticline the principal structural features along the tunnel route are the synclinal trough filled with Pleistocene and Recent sediments, and a large anticline with a schist core still farther to the south.

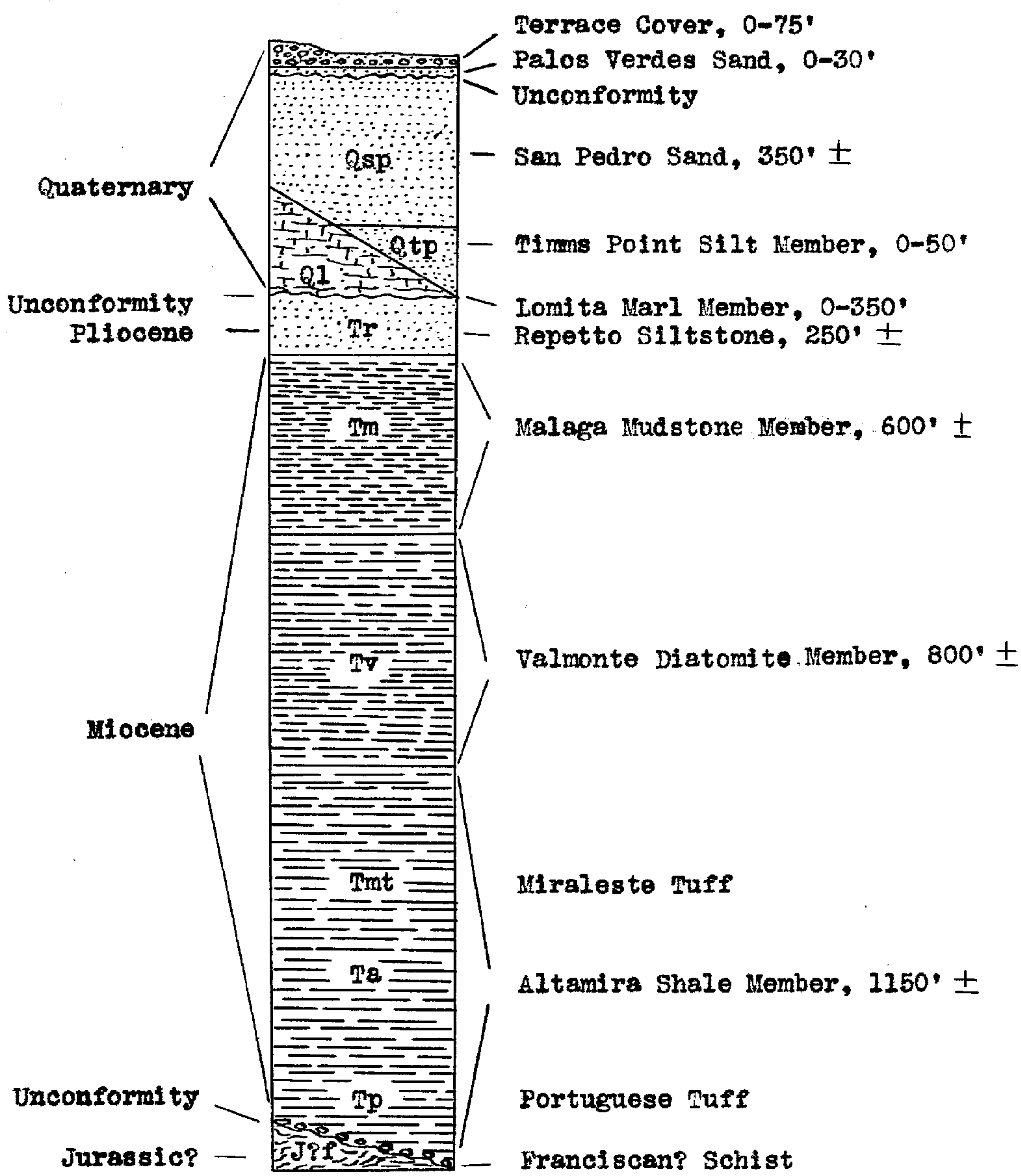


Figure 2- Generalized columnar section of the rocks exposed in the Palos Verdes Hills.

GEOLOGY OF THE TUNNEL ROUTE

Stratigraphy

The formations penetrated by the tunnel are in descending order of age: (1) the nonmarine terrace cover, (2) the Palos Verdes marine sand, (3) the San Pedro marine sand, (4) the Lomita marl member of the San Pedro, (5) the Malaga mudstone, (6) the Altamira shale with associated igneous rocks, and (7) the basement rocks doubtfully referred to the Franciscan schist.

Terrace Cover: The nonmarine terrace cover is exposed in the conduit (stations 372- 362+41), and near the northern end of the tunnel between stations 340 75-339+75 and stations 334+25-333+ 75. At the southern end of the tunnel a thin terrace cover occurs in the area between the shore line and the south portal (stations 51-50). At the first three localities the terrace materials consist of coarse, yellow and brown sand with carbonaceous and argillaceous intercalations. The maximum thickness is approximately 75 feet- a somewhat greater thickness than is usual in most parts of the hills. Near the south portal the terrace cover is made up of large, rounded boulders of silicified limestone, and small, angular shale fragments. The thickness does not exceed 6 feet.

Near the north portal the terrace cover overlies the Palos Verdes sand; while near the south portal the terrace cover occurs on a bench below the Palos Verdes sand and an older terrace cover (see figure 4). It thus appears that the terrace materials near the southern end of the tunnel are definitely younger than similar deposits near the north portal, and may be post-Pleistocene in age.

Palos Verdes Sand: The fine, white sand encountered near the base of the conduit, and which extends south to station 334+25, is referred to this formation. The basal contact in the tunnel is quite unsatisfactory, and has been placed at the southernmost occurrence of fine, white sand. Since such sand is known in some areas in the Palos Verdes Hills in the upper part of the underlying San Pedro, this determination may not be correct. The thickness is likewise difficult to determine, but probably does not exceed 30 feet. A few poorly preserved marine invertebrates, and a tooth of a sea lion were collected from this formation.

San Pedro Sand: This formation was encountered in the synclinal basin south of the Gaffey anticline (stations 249+16-229), and on the northern flank of the anticline in the area between stations 334+25 and 271+72. In the northern area, the San Pedro has a thickness of 250-280 feet, and consists of coarse, yellow sand, which becomes finer and glauconitic in the lower 200 feet. On the southern flank of the anticline the San Pedro shows a markedly different sequence of rock types on opposite sides of the synclinal basin, and neither corresponds with the section on the northern flank of the anticline. In the northern part of the basin the San Pedro consists of coarse, brown and yellow sand at the top and base, with finer and glauconitic sand in the middle part of the section. In the southern part of the basin, however, the base of the San Pedro is marked by a 50 foot conglomerate followed by a thick clay bed, which in turn is overlaid by coarse, yellow sand. The total thickness of San Pedro sand in the basin is in the neighborhood of 350 feet. The changes in facies point to very different conditions of sedimentation on the northern and southern flanks of the Gaffey anticline, and on opposite sides of the synclinal basin as well. Although marine invertebrates abound in the San Pedro, the shells are water soaked, and break so easily that collections could not be made.

On the northern flank of the Gaffey anticline the Lomita marl member is absent, and the San Pedro rests directly upon the Malaga mudstone. The contact is irregular in detail, and there is an angular discordance of 15 degrees in strike and 19 degrees in dip between the Miocene and Pleistocene strata.

Lomita Marl: This formation was encountered on the flanks of the syncline just south of the Gaffey anticline. On the northern flank the Lomita occupies the area between stations 249+28 and 249, while on the southern flank this formation occurs in the area between stations 229 and 217+60. The contact with the overlying San Pedro sand is gradational. In the northern area the rock is a fine, green silt and marl; while in the southern area the Lomita consists of fine, white sand and marl with no distinct stratification, which grades into a more sandy phase at the top. The maximum thickness is approximately 350 feet. The great disparity in thickness of the marl on the northern and southern borders of the basin seemingly indicates different conditions of sedimentation on opposite sides of the trough during early Pleistocene time. Foraminifera and larger marine invertebrates are very abundant in this formation, and a collection was forwarded to Mr. Woodring.

On the southern flank of the Gaffey anticline the Malaga- Lomita contact is irregular in detail, and there is an angular discordance of 20 degrees in strike and 32 degrees in dip between the Miocene and Pleistocene beds. In the cross section (figure 4) this contact has been drawn as a fault relation largely because of evidence supplied by a recently constructed highway excavation a few hundred feet west

Figure 3- Detail of the Miocene-Pleistocene contact on the southern flank of the Gaffey anticline as exposed in an excavation for the new extension of Western Avenue into San Pedro. Malaga mudstone at lower right overlaid at the left by San Pedro sand. The lower 15 feet of the San Pedro are quite calcareous. The overlying nonmarine terrace cover has been cut by a small southward-dipping thrust fault, the trace of which follows the Malaga-San Pedro contact.

of the tunnel line. In this cut (see figures 1 and 3) Malaga mudstone strikes 50 degrees west of north and dips gently southwest. Lying upon the mudstone is a coarse, yellow sand with limey strata in the lower 15 feet. The dip of the limestone intercalations is in the same direction as the underlying Malaga, but at an angle of 40 degrees. Mr. Woodring identified samples of the calcareous strata as a part of the San Pedro rather than the Lomita member. Lying upon the beveled upper surfaces of the Malaga and San Pedro is a thin layer of rounded limestone cobbles, above which is approximately 4 feet of rudely stratified dark brown sand and gravel which represents the nonmarine terrace cover. That the San Pedro-Malaga contact marks the trace of a thrust fault is evidenced by a 4 foot displacement of the terrace cover. The fault strikes 45 degrees west of north and dips south at an angle of 50 degrees. Since the fault seems to follow the contact of the Malaga and early Pleistocene beds, it seems probable that in the tunnel the contact is likewise a fault relation, although the physical character of the Lomita is such as to leave little trace of differential movements. It seems probable that this small thrust is the result of quite recent movements on the Gaffey anticline.

On the southern flank of the basin the Lomita is in contact with a diatomite, which may either represent the lower part of the Valmonte or a diatomaceous phase of the upper part of the Altamira shale. For reasons that will be given later, it is tentatively concluded that the diatomite belongs in the Altamira shale member. The contact shows a marked angular discordance between the Miocene and Pleistocene beds, and is marked by a basal conglomerate which is made up of large, rounded limestone boulders, and small, angular shale fragments. The upper 3 feet of the diatomite is broken by vertical and horizontal fractures, which are possibly the result of pre-Lomita weathering. The fractures are filled with dark-colored, viscous petroleum.

Malaga Mudstone: A vertical thickness of approximately 300 feet of this formation was encountered in the core of the Gaffey anticline between stations 271+72 and 249+28. The contact with the overlying early Pleistocene beds is unconformable. The rock is a fine-grained, nearly black radiolarian mudstone with diatomaceous streaks, and minor amounts of limestone and chert. Oil seeps are rare.

Altamira Shale: Except for the areas between stations 179+20 and 175+50 and stations 140+70 to 140, the remainder of the tunnel south of station 217+60 is thought to be in the middle division of the Altamira shale. The contact with the overlying early Pleistocene beds is unconformable. Between stations 217+60 and 202 the rock is predominately diatomite. The Miraleste tuff occurs approximately 100 feet from the base. It is possible that on the surface a narrow strip is to be referred to the Valmonte diatomite member, but since the tuff was not encountered in the tunnel at this level the entire section would appear to belong to the Altamira shale. It is possible, however, that the tuff has been squeezed out of the flanks of the close folds which occur in this area, so no definite judgement can be made. The total thickness of the diatomite is approximately 250 feet. Drill hole No. 3 encountered diatomaceous streaks in the upper 100 feet (approximately at the horizon of the Miraleste tuff), and it may be that in the eastern part of the Palos Verdes Hills the middle division of the Altamira is diatomaceous in the upper part.

On the northern flanks of the large anticline the axis of which is located near station 178, the sequence extending from the black and grey cherts at the base of the diatomite to the contact with the schist is : (1) approximately 300 feet of black chert and silicified shale, (2) 250 feet or so of mudstone with glaucophane sandstone streaks, limestone lenses, and a few phosphate nodules, and (3) approximately 50 feet of coarse, schist breccia. The total thickness of the Altamira on the northern flank of the anticline is approximately 850 feet. Drill hole No. 3 penetrated black chert 180 feet above sea level and approximately 350 feet below the Miraleste tuff. It would thus appear that the black chert in the upper part of zone 1 is a persistant horizon marker in the area between the shear zone and fault at station 122+50 and the northernmost occurrence of such cherts in the tunnel (station 201).

The sequence on the southern limb of the anticline between stations 175+50 and 122+50 is in descending order: (1) approximately 200 feet of mudstone with minor amounts of silicified shale, limestone, and phosphate nodules, (2) 25 feet of massive green sandstone, and (3) approximately 50 feet of coarse, schist breccia. The thickness to the horizon of the Miraleste tuff is approximately 775 feet. Since several northward-dipping normal faults occur in the vicinity of station 156, it is difficult to estimate either the thickness or the sequence on the southern flank of the anticline. However, it would appear that toward the south the thickness increases somewhat, while glaucophane sandstone becomes slightly more abundant in that direction. The occurrence of a bed of green sandstone above the schist breccia on the southern border of the schist high, as contrasted with the absence of similar rocks above the breccia on the northern border, indicates different conditions of sedimentation on opposite sides of the anticlinal core.

South of the fault at station 122+50 the sequence cannot be determined accurately. The rocks consist of thick alternating units of mudstone and silicified shale with limestone lenses and abundant phosphate nodules. Fairly thick beds of coarse, schist debris occur in the lower part of the section. Reference of these rocks to the middle division of the Altamira shale rests largely upon the occurrence of a species of Valvulineria near the south portal and the absence of the Portuguese tuff in the tunnel. The thickness of this part of the section is in the neighborhood of 850 feet.

Fish scales and bones occur at many places in the Altamira, and are especially abundant in the area between stations 140 and 90. In this area whale bones are also not uncommon, but those recovered are too fragmentary for generic determination. No megascopic fossils were seen in the shale. Foraminifera doubtlessly are present, but due to poor lighting conditions were very difficult to find.

Petroleum seeps occur in many places in the Altamira shale, and are especially abundant in the diatomaceous part between stations 217+60 and 202.

Igneous Rocks in the Middle Division of the Altamira Shale: These rocks are rather coarse-grained, and although now much altered, it is probable that they were originally basaltic in composition. The only occurrence in the tunnel is between stations 140+70 and 140. The contact is not well exposed, but there seems to be no very marked thermal metamorphism associated with the intrusion. This mass has been drawn as an irregularly-shaped sill on the supposition that the basic igneous rock encountered a short distance above the tunnel line by drill hole No. 3 is a part of the same intrusion. The large sill some distance above the tunnel line between stations 122 and 110 is inferred from the occurrence of a considerable thickness of basic rock in drill hole No. 4. It is probable that this body is an extension of the eastward-dipping sill which crops out 1200 feet west of the tunnel line (see figure 1). There is no assurance that the sill actually extends as far north as the fault, and there is still less that it is displaced by the fault. However, the surface geology indicates that the fault is younger than at least some of the intrusions, and it seemed desirable to illustrate the fact in this manner. Petroleum seeps occur throughout both of the sills.

The rounded basalt boulders set in a matrix of coarse, yellow sandstone and silicified limestone, which occur on the southernmost reefs to the west of Whites Point (stations 47-46), may represent a submarine lava flow.

Franciscan? Schist: A deeply weathered metamorphic rock consisting of large plates of glaucophane and other schist minerals occurs in the tunnel between stations 179+20 and 175+50, and is tentatively referred to this formation. The occurrence of an unsorted breccia of angular schist fragments in association with numerous slickensides in the vicinity of station 178+52 furnishes some evidence of a fault in the basement rocks of this area. It is inferred that the fault is of pre-Miocene age.

Drill Cores

The locations of these cores are shown on figure 1, but only those which are of major geologic importance are indicated on the structure section. In no instance was the percentage of recovery near 100. Consequently, absence from a drill core of a thin bed such as the Miraleste tuff does not necessarily indicate its absence from the section. The figures to the left indicate in feet the elevation above sea level.

Drill Hole No. 1

110-95	Sand
95-87	Sandy clay
70	Clay
28	Sandy clay
-5	Yellow sand

Drill Hole No. 1a

237-218	Loose terrace material
218-25	Dark-colored mudstone
25	Silty bed in mudstone
25 to -12	Black mudstone

Drill Hole No. 1b

20-11	Clay
-11 to -13	Coarse sand

This is apparently all a part of the terrace cover.

Drill Hole No. 2

121-115	Alluvium
115-80	Clay and coarse sand
80-50	Fine sand
50 to -12	Coarse sand and gravel

Drill Hole No. 2a

212-198	Soil
198-162	Diatomite
162-160	Silty diatomite
160 to -14	Diatomite

Drill Hole No. 2b

57-44	Mainly clay
12 to -14	Fine sand

The division between the nonmarine terrace cover and Palos Verdes sand is not well marked, but is probably between 30 and 20 feet above sea level.

Drill Hole No. 3

480-435	Shale with diatomaceous streaks
435-385	Silicified shale and diatomite
385-193	Shale, somewhat silicified
193-180	Black, porous rock- may be igneous
180-178	Black chert
178-125	No record
125-108	Weathered basic igneous rock

Drill Hole No. 3 (Continued)

105-103	Silicified limestone
103-33	Sandy limestone, at 33 a weathered basic igneous rock

Drill Hole No. 3a

468-392	Mainly unsilicified shale
392-343	Predominately silicified shale
336-315	Mainly unsilicified shale
315-291	Silicified shale
291-248	Mainly unsilicified shale
248-234	Sandstone and shale
234-225	Sand and shale
225-224	Silicified shale
224-18	Mainly unsilicified shale
18 to -12	Sandstone and shale

Drill Hole No. 3b

47-35	Yellow sandy clay
35-33	Fine silt
33-12	Clay
12-8	Fine, yellow sand
8-4	Sand and clay
4 to -15	Coarse sand

Drill Hole No. 4

500-485	Surficial debris
485-475	Shale
475-450	Silty limestone

Drill Hole No. 4 (Continued)

450-434	Silicified shale
434-421	Sandy limestone and shale
421-395	Shale
395-373	Sandstone
373-356	Shale
356-354	Sandstone
354-348	Silicified shale
348-345	Sandstone
345-150	Basic intrusive, upper 6 feet show weathering, contains petroleum in places
150-100	Shale, sandy at 130
100-90	Limestone, baked shale at 90
90-64	Shale, green sand at 64
64-16	Green sand and shale
16 to -12	Soft shale

Drill Hole No. 4a

588-454	Predominately unsilicified shale
454-380	Sandy and silicified shale
380-327	Mainly unsilicified shale
327-226	Mainly silicified shale
226-109	Mainly unsilicified shale, petroleum abundant
109-14	Mainly silicified shale
14 to -12	Mainly unsilicified shale with sand streaks

Drill Hole No. 4b

30-19	Sand
19-4	Sand and clay
4 to -6	Coarse sand
-6 to -11	Fine sand
-11 to -17	Glauconitic sand

Drill Hole No. 5b

60-40	Clay
40-36	Sandy clay
36-28	Coarse sand
28-16	Fine, grey sand
16 to -12	Yellow sand, green near base

Drill Hole No. 6

17-12	Weathered shale and clay
12-8	Loose cobbles
8 to -20	Broken shale

Drill Hole No. 6b

114-106	Alluvium
106-96	Clay
86-75	Yellow sand with traces of clay
75-72	Sand and blue clay
72-48	Sand, grey near the base
48-36	Yellow and grey sand
36-19	Sand and clay
19-16	Coarse sand, pebbles, and gravel
16-5	Coarse and fine sand
5-0	Clay and fine sand

Drill Hole No. 7b

123-112	Sand
112-104	Clay
104-25	Mudstone with petroleum seeps at 75

STRUCTURE

The principal structural features along the tunnel route are the Gaffey anticline and the broad arch with the schist core some distance to the south. The surface folds in the vicinity of the latter seem to be flexures subsidiary to the main fold. The northward-dipping normal fault, which extends from Cabrillo Beach to a point west of Miraleste, crosses the tunnel near station 122+50. South of this fault the dip is predominately toward the southwest and at a rather low angle, but between station 64 and the south portal a closely folded anticline and syncline occur. These do not appear to be overturned, and cannot be related definitely to the intricate structures at Whites Point, which include a mushroom-shaped anticline the lower limbs of which are recumbent. It may be that when traced to the east, the folds in this area become overturned. This is suggested by the attitude of the limestone reefs which are exposed in the intervening area during low tide. The dip of these reefs changes from a northeastward direction at the tunnel line to the vertical at a point mid-way between station 47 and Whites Point. The plunge of the structures is generally toward the east, but westward plunges are not unknown.[1] Other than the brecciated zone in cherty shale near station 196, the tunnel offers little evidence of a northward-trending branch of the main fault indicated by surface evidence 2750 feet south of the shaft. Consequently, this disturbed area which is shown as a fault on the preliminary map of the Palos Verdes Hills[2] seems best regarded as a shear zone of no very significant displacement.

Under the unconformable early Pleistocene cover, the Malaga mudstone in the core of the Gaffey anticline, and the diatomite on the southern flanks of the synclinal basin to the south, show very intense folding. This relationship seems adequately explained by the occurrence of intermittant compression along the Gaffey anticline in post-Miocene time. Folding of the late Pleistocene terrace cover, in addition to the occurrence of a small, post-terrace cover thrust fault on the southern flanks of the anticline (see figure 3, page 15), suggest that the movements may have continued into the present. Bixby Slough has been formed by uparching of the anticline across a stream which formerly drained down Gaffey Street[3]; while occurrence near the north portal of nonmarine terrace deposits 12 feet below sea level is another indication of perhaps recent crustal movements in this part of the Palos Verdes Hills.

1/ It will be noted that on the plan the width of the tunnel is exaggerated 20 times. The spacial relations of the folds are therefore distorted, but the direction of plunge is not affected.

2/ Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit., pp. 128-129, 1936.

3/ Woodring, W. P., op. cit., pp. 37-38, 1932.

Three fault systems are recognized: (1) a system of normal faults which dip steeply either to the north or to the south, and vary in strike from nearly east-west to 20 degrees west of north, (2) a system of normal faults which dip very steeply nearly due east, and (3) a system of small thrust faults which dip either to the north or to the south at relatively high angles, and which vary in strike from nearly east-west to 45 degrees west of north. Individual fractures of group 1 are the most abundant, but the only one of demonstrable large displacement occurs near station 122+50. This fracture may have displaced the middle division of the Altamira shale as much as 300 feet. System 2 may be younger than the first group, but this cannot be proved from tunnel observations. Small bedding thrusts occur in the core of the Gaffey anticline, and at the contact of the Miocene and Pleistocene beds on its southern flank. Another small thrust is found near the southern end of the tunnel in the vicinity of station 90. These faults may be the youngest of all, but the tunnel offers no definite proof. However, their occurrence on the flanks of the Gaffey anticline, which has many characteristics of an active fold rather suggests this to be the case. As is indicated on a later page, the relation of the normal and thrust faults has considerable engineering importance.

Four joint systems are discernible: (1) a closely spaced, almost vertical set which strikes nearly east-west and is crossed by horizontal fractures. This system is found only in the Franciscan? schist. (2) A system of the same trend as the above, but found only in the basaltic sill between stations 140+70 and 140.

(3) A system in the Altamira shale which varies in strike from nearly east-west to 20 degrees west of north. The individual fractures may dip either north or south, and usually are inclined at relatively high angles. (4) A system which dips almost due east at very high angles. Two systems of shear zones[1] occur: one nearly parallel to joint system 3, the other is very similar in attitude to joint system 4.

The first system of joints may be related genetically to joint system 3, but it seems more probable that the fractures in the schist were formed in pre-Miocene time. This conclusion is substantiated by the fact that the joints in the pre-Miocene rocks are more closely spaced than in the Miocene shale, and do not continue into the latter. However, it may be that the relatively incompetent shale squeezed around the harder Franciscan rocks, which could not accommodate the pressure otherwise than by fracturing.

Joint system 2 seems to have been formed by cooling of the basalt, for in this instance as well, the joints do not continue into the enclosing shale.

The northward-dipping fractures of system 3 are more abundant than those which dip in the opposite direction. Since a preponderance of the faults also dip to the north, there seems to be some

1/ As used in this report, a joint is a fracture with little or no movement parallel to the fracture plane; while a shear zone is a zone of fractures along which movement appears to have been less than the width of the tunnel. Where movement is known to have been greater than the width of the tunnel, the term fault is used. Technically the shear zones also are faults, but it seemed desirable to make some distinction between the two types of fractures seen in the tunnel.

reason for considering joint system 3 and the northward-dipping normal faults as approximately of the same age. This conclusion is further substantiated by the more frequent occurrence of joints in the vicinity of normal faults than elsewhere.

The relation of joint system 4 to other joint systems is unknown. It may be that systems 3 and 4 are contemporaneous, but this does not appear to be probable.

The structural sequence indicated by the tunnel is: (1) pre-Miocene jointing and faulting of the schist. (2) Following deposition of the Miocene sediments these rocks were intruded by basalt sills. Cooling of the sills gave rise to jointing in the basalt. (3) Post-Miocene but pre-Pleistocene folding followed by erosion. (4) After deposition of the Pleistocene beds normal faulting occurred along a northwest-southeast axis. The date is not known definitely from the tunnel data, and may follow rather than precede (5) late Pleistocene uplift with folding and thrust faulting along the Gaffey anticline. These movements may have continued into the present.

A small and apparently recent normal fault, which strikes a little east of north, occurs at the top of the sea-cliff approximately 1400 feet west of the south portal, and it may be that the nearly north-south trending joints and normal faults seen in the tunnel are contemporaneous with it. The surface geology indicates that the axes of the northwest-trending folds tend to converge in the area between the schist in the vicinity of station 177 and the normal fault at station 122+50. Since coarse, schist-derived clastics are abundant in the shales near the fault, it may be that this fracture outlines the northern border of a schist "high", and it is perhaps not unduly speculative to assume that in the area in question, the basement rocks rocks were deformed by a shearing couple with the forces acting along a nearly north-south direction. The northwest-trending folds would thus outline an axis of compression, while the north to northeast-trending normal faults and shear zones would correspond to the axis of tension. Other arrangments of forces are possible, perhaps, and the situation is too complex to permit a definite conclusion as to the mode of application of forces. This is unfortunate, for the mechanics of structure seem to have a definite bearing upon engineering problems presented by the squeezing ground between stations 98 and 178+52.

OCCURRENCE OF PETROLEUM IN THE TUNNEL

Petroleum seeps are common in the Altamira shale, and are not unknown in the Malaga mudstone. In places the oil is in solid form, but more frequently it is a black, highly viscous asphaltum. Since the tunnel is in the zone of circulating oxygen-bearing water, the heavy character of the oil is to be expected.

The most noteworthy occurrences are at the contact of the Lomita marl with the diatomite in the middle division of the Altamira shale (see page 16), and in the diatomite itself. In the non-diatomaceous parts of the Altamira, petroleum occurs mainly in unsilicified beds. Here it is found as segregations in the shale, in sand streaks, in fractured limestone lenses, and at contacts between shale and relatively impervious clay intercalations. Few open fissures carry oil, and the faults in particular show no trace of hydrocarbons.

Since petroleum is most abundant in the diatomite, it seems reasonable to regard diatomaceous sediments as the original source, for the modes of occurrence do not suggest extensive migration. The usual absence of oil from fracture zones may indicate that relatively little migration has taken place, although it may be that the fissures are at least in part later than the period of oil migration. This suggests a method of dating some of the fractures, for the occurrence of oil in lower Pleistocene beds indicates definitely that migration occured as late as the early Quaternary. Absence of oil from the main fault and shear zones thus may indicate a late Pleistocene to Recent age for these fractures.

Drilling equipment has been set up a few hundred feet north and east of the shaft, but at the time this report was written, drilling had not commenced. Should the Repetto sandstone be present under the overlapping early Pleistocene beds of this area, it may contain oil.

The presence of petroleum in igneous rocks in the middle division of the Altamira shale is a somewhat unusual occurrence. As indicated on a preceding page, these rocks are well supplied with fractures along which the oil may have migrated.

GEOLOGICAL-ENGINEERING FACTORS

These are classifiable under the following headings: (1) rate of mining progress as determined by character and condition of the rock, (2) water and gas, (3) temperature, and (4) which for want of a better term, is designated squeezing ground.

Rate of Progress: Since fairly close timbering was necessary in all parts of the tunnel, the rate of progress depended almost entirely upon type of rock, its condition, and the amount of water present. To a certain extent the last two factors depend upon the first, but for practical purposes it is convenient to discuss them separately.

Due to complications resulting from breakdowns, change in width of bore, labor turnover, etc., it is difficult to arrive at a reliable estimate of rate of progress per day. However, it appears that the Palos Verdes and San Pedro sands in the section north of the Gaffey anticline were the were the most favorable to rapid progress. In this part of the tunnel the least progress per day was approximately 15 linear feet, and on one occasion a record of 86 feet in 24 hours was established. Reason for so great a variation in rate of progress is found in degree of induration of the sand. Where the sand was coherent enough to stand in the face without breast boarding progress was rapid; while many of the loosely consolidated areas caused considerable trouble. As Mr. Rawn has suggested, a study of the factors conditioning coherency of sands might be a promising subject of geological-engineering research. Although the time available for the work did not permit detailed examination of this problem, it would appear that sorting, size and shape of grain, and amount and composition of the cementing materials are perhaps the principal factors involved. South of the Gaffey anticline, the San Pedro sand was usually saturated with water, but where this was not the case progress compared favorably with the same formation on the northern flank of the anticline.

The Lomita marl was of uniform texture, generally free from faults and joints, and stood well in the headings. Consequently, this formation was favorable to rapid progress, and an average of somewhat better than 40 feet per day was maintained in this formation.

When drilled with rotary drills, the Malaga mudstone was a very unfavorable rock, for the water from the drills turned the bottom of the tunnel into a sticky mud. When augurs were used, however, the rate of progress approached 40 feet per day- a somewhat better average than in other parts of the Miocene section. The plastic nature of this rock obviated water trouble in the vicinity of faults and shear zones.

For much the same reason as the last, the diatomaceous upper part of the Altamira shale was a favorable rock, but a distinction must be made between the siliceous and non-siliceous portions below the diatomite. The siliceous beds stood better in the headings, but since they were more brittle than the non-siliceous portions, they were affected more adversely by joints, faults, and shear zones. In unsilicified beds such fractures had little effect on mining operations, for the rock was plastic enough to fill up any irregularities along the fissures. In the silicified zones faults and shear zones gave trouble, due to the presence of large water pockets in the brecciated rock adjoining the breaks. As a whole, the Altamira shale was less favorable to rapid progress than the Malaga mudstone and the Pleistocene sands and marls.

The schist was a decidedly unfavorable rock. Drilling was slow, and due to presence of closely spaced joints a very jagged bore resulted. Consequently, blocking and timbering was difficult. Many rounds had to be blasted repeatedly before the heading could be cleared, and this is likewise to be attributed to the influence of intersecting joints.

Water and Gas: As stated on a preceding page, the Malaga mudstone in the Gaffey anticline carried relatively little water. The sand to the north of the anticline was dry, despite the presence of standing water in Bixby Slough. Dryness of the sand in this section is to be attributed principally to the impervious character of the terrace cover, although the dry climate and gentle northward dip may contribute to the observed depression of the water table to over 12 feet below sea level. The remainder of the tunnel may be described as wet. This is true especially for the synclinal trough south of the Gaffey anticline. Here the terrace cover is largely lacking, and the eastward-plunging syncline filled with porous sand and floored with relatively impervious marl formed an almost ideal catchment basin. Many hundreds of thousands of gallons of water had to be pumped from this area before tunneling could proceed at all, and even then serious water trouble was encountered in earlier stages. South of the shaft the Miocene section was usually saturated with water, but where open fractures in silicified shale did not exist there was no serious trouble. In the cherty part of the Altamira shale on the northern limb of the anticline (stations 198-200), the attitude of the rock and the presence of a brecciated zone produced almost ideal artesian conditions. Large quantities of water under considerable pressure were encountered in this part of the tunnel.

In view of the abundance of petroleum in the shale and diatomite, it is remarkable that no very considerable quantities of gas were encountered. It may be that the oil seeps are too old to have much gas in association, but it seems more likely that the gas has escaped along fracture zones. The only gas met with was hydrogen sulphide. This may have been derived from organic matter in the shale.

Temperature: Throughout most of the tunnel those parts in diatomite and shale were several degrees warmer than the sections in the Palos Verdes and San Pedro sands. In the shale a maximum temperature of 92 degrees Fahrenheit was measured. While it is true that the overburden on the Miocene sections is somewhat greater than on the sand, the disparity does not appear to be great enough to cause so appreciable a temperature difference. Since pyrite is abundant in the shale and mudstone and is lacking in the Pleistocene sand and marl, it may be that oxidation of pyrite furnished the additional heat.

Squeezing Ground: This term is used to designate those areas where the arched design of the tunnel could not sustain the overburden. Such conditions were encountered in four separate areas: (1) the brecciated zone between stations 73+27 and 68, (2) the area immediately adjacent to the fault in the Franciscan? schist at station 178+52, (3) the Malaga mudstone in the Gaffey anticline, and (4) the area between the southern border of the schist (station 175+50) and station 98.

In the first instance squeezing commenced almost immediately after blasting, and seems to have acted only on the west wall of the tunnel. The total movement was not more than a few inches, and after a few days practically ceased. It seems probable that the unbalanced pressures here encountered were due to sliding of broken rock along eastward-dipping bedding and fracture planes.

A zone some 50 feet wide was affected in the second instance. Here movement was most marked in the brecciated rock adjoining the fault near station 178+52. The floor of the tunnel was forced up a foot or so; while the roof was bent down to a somewhat less extent. Since this zone is localized by a a fault and coincides with the area of brecciated rock surrounding this fracture, it seems probable that the broken character of the rock is sufficient to account for the effects observed. The overburden on this part of the tunnel is considerable, and it is hardly to be expected that the broken rock could sustain the pressure.

The last two areas of squeezing ground are so similar that it is convenient to discuss them together. In the Gaffey anticline squeezing was somewhat more marked in the section south of the axis. Apparently movement occurred immediately after blasting, for the lagging was soon broken, and shortly after the ribs began to bend. After a few days the floor buckled, and often formed more or less symmetrical ripples normal to the center line of the tunnel. Squeezing was somewhat less marked in the walls and roof.

While the entire area between the southern border of the schist at station 175 and the shale at station 98 was affected to some extent by earth movements, that part between stations 145 and 116 was affected most. However, only 3 inch ribs were used in this area, and no direct comparison with the section farther north where 6 inch beams were used can be made. Throughout this area the effects observed are quite similar to those described for the Gaffey anticline, only movement from the walls and roof seemed to be somewhat more marked.

Although fractures are perhaps more abundant in squeezing zones than elsewhere, it is not possible to relate definitely the rock movements to fracture and bedding planes. In only one or two instances were ribs which were set across shear zones bent by movement along the fracture planes. In general the movement appears to be a slow, steady, inward creep, and seems to be more dependant upon plasticity of the rock than upon presence of fractures and bedding planes. In at least one instance formerly horizontal stratification was bowed downward by sagging of the roof. Arching of the floor, moreover, is most readily explained as due to pressure from the sides. If the rock were perfectly rigid, no horizontal components could develop. In one instance horizontally-bedded shales moved in from the east wall. If bedding planes were effective in transmitting stress, it is to be expected that adjacent layers would have sheared past each other. On the contrary, however, the mass moved as a unit.

Another somewhat anomalous feature is that after broken ribs were replaced, less movement than in the first instance was noted. Indeed, even before retimbering the movements appear to have slowed down considerably. No very satisfactory explanation seems possible, but it may be that movements were caused by elastically stored energy, and that the first adjustments were sufficient to release the greater part of this.

The maximum amount of movement is in the neighborhood of 3 feet, but such relatively great adjustments were limited usually to a relatively small area. Surveys of the tunnel line show pronounced lateral offsets in many places, and since they are especially abundant in squeezing zones, it at first seemed probable that actual lateral offsets of the center line had occurred. However, from the data at hand it is impossible to prove this contention, for errors in surveying and bending of the ribs which contain the spads may account for the offsets. Furthermore, the magnitude of the deflections, which in some instances exceeds 8 inches, seems to be too great to be due entirely to earth movements. It is possible, however, that some small fraction of the offsets is to be attributed to lateral movements of the center line.

Since 6 inch, 20 pound H-beams placed on 4 foot centers are usually strong enough to sustain the load, it would appear that the pressures involved do not exceed 1600 pounds per square foot. This is only a small fraction of the total overburden, and since the method used in arriving at this estimate of the pressure on the tunnel walls is not very rigorous, at one time it was planned to place electrical resistometers in the Gaffey anticline between the lining and the wall rock. While this would result in a direct measurement of pressures, for various practical reasons the project was abandoned.

There seem to be only three possible explanations for these rock movements: (1) chemical change causing increase of volume, (2) plastic flow due to weight of the overburden, and (3) active crustal movements in the areas in question. A combination of all three is possible, and of the last two even probable.

The first can be practically eliminated for the following reasons: (1) shale is a relatively stable rock since it is already in approximate chemical equilibrium. Furthermore, the tunnel is everywhere in the zone of circulating oxygen-bearing water, and any chemical changes which could be induced in the rock when in contact with the atmosphere should have taken place long ago. (2) While it is conceivable that hydration of such substances as anhydrite and bentonite may account for the apparent increase in volume, the chemist of the Los Angeles Sanitary District examined several specimens of rock from the squeezing zones, and concluded that such constituents are too rare to account for the effects observed. Furthermore, it is difficult to see how volume changes could account for buckling of the floor. The principal effect which air may have had upon the rock is to loosen slabs from the roof, which would then fall upon the ribs and exert some force.

Since the floor of the tunnel is flat, and thus not well designed for sustaining pressure, the second explanation may account for all of the rock movements observed. However, it is difficult to see why no squeezing occurred in those areas where the overburden is the greatest. It is likewise difficult to see why apparently the same part of the Altamira section did not flow on the northern limb of the anticline. It is possible, of course, to assume that some imperceptible difference in composition of the rock on opposite limbs of the anticline is responsible for the difference in behavior. Since the Altamira is known to overlap upon the schist basement with consequent changes in facies, this argument carries some force. In view of the shortcomings of both the first and second explanations, however, the last alternative deserves serious consideration.

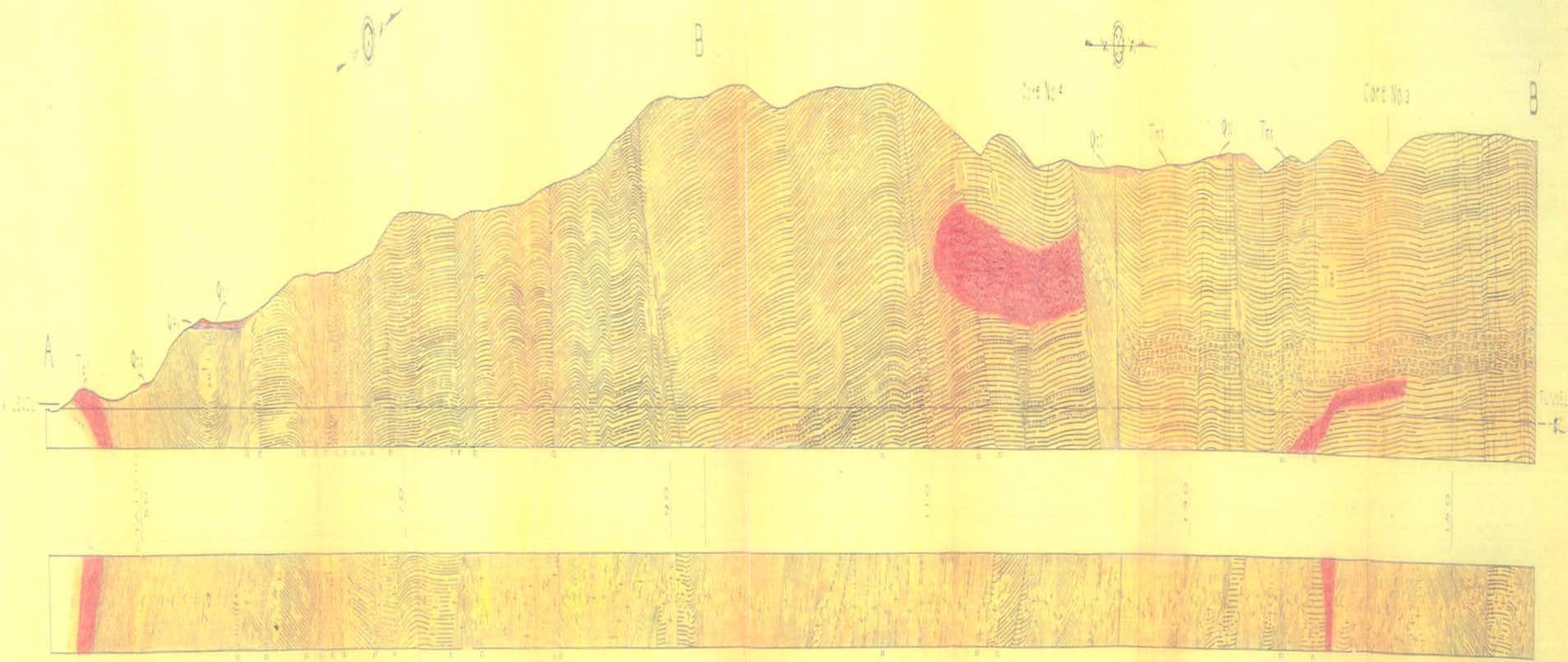
Mr. Woodring in a letter to the writer pointed out that the northwestward-trending folds in this part of the Palos Verdes Hills tend to converge in the area where squeezing is most marked in the tunnel, and suggested that active crustal movements may be responsible for the squeezing ground. This explanation is particularly well suited for the case of the Gaffey anticline, for as has been indicated on a preceding page, this structure has many characteristics of an active fold. When applied to the area between stations 98 and 175+50, however, this hypothesis encounters a difficulty: namely, why are the movements so localized? It will be recalled that in the vicinity of station 98 thick bands of coarse schist clastics were encountered, and it was suggested that a buried hill of basement rocks may be not far below the tunnel line at this point. North of station 175+50 the tunnel actually enters the schist, and it seems reasonable to assume that localization of earth movements in the area between the known and inferred schist "highs" is not entirely fortuitous. Since in any crustal movements in the Palos Verdes Hills the main thrust must be carried by the relatively rigid schist, it seems reasonable to assume that the two buried hills may act as the jaws of a vice. This would explain localization of the movements in the overlying shale.

A small northward-dipping thrust fault occurs at station 90+38, or less than 800 feet from the southern margin of the squeezing zone in question. Could it be demonstrated that this fault is younger than the normal fault near station 122+50, the above conclusion would rest upon a firmer basis, for the thrust is in approximately the position that might be expected if the Miocene shales are being compressed between two buried hills. A normal fault is incompatible with compression, and until the age relation of the normal and thrust fault is known, it seems best to avoid a definite decision as to the tenability of the above hypothesis.

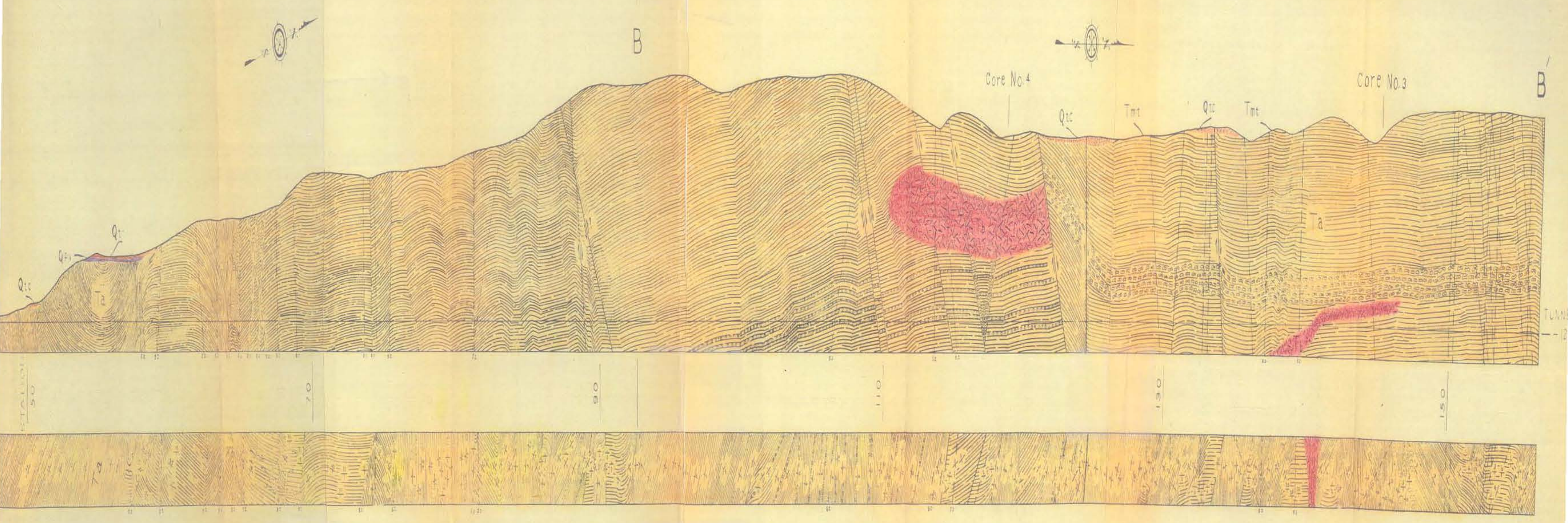
On a preceding page it was suggested that a shearing couple with forces acting parallel to the tunnel line, and in such a manner that the east wall of the tunnel is moved south relative to the west, may account for the major structural features seens in this part of the Palos Verdes Hills. While this view is theoretically possible, any movement which tends to bring the buried hills closer together would account for the squeezing seen in the tunnel. A shearing couple would produce entirely differently directed stresses upon the tunnel than would a simple compressional movement. Consequently, from an engineering standpoint the type of deformational forces which may be acting in this part of the Palos Verdes Hills is a matter of some importance. Unfortunately, the geologic evidence is incomplete and the situation is so complex that it seems best to leave this as an open question. However, the evidence of active crustal movements in the Gaffey anticline seems to be particularly strong, and in view of the similarity between the squeezing effects seen in the anticline and the area between stations 175+50 and 98, in the writer's opinion it is probable that both areas are experiencing active earth movements.

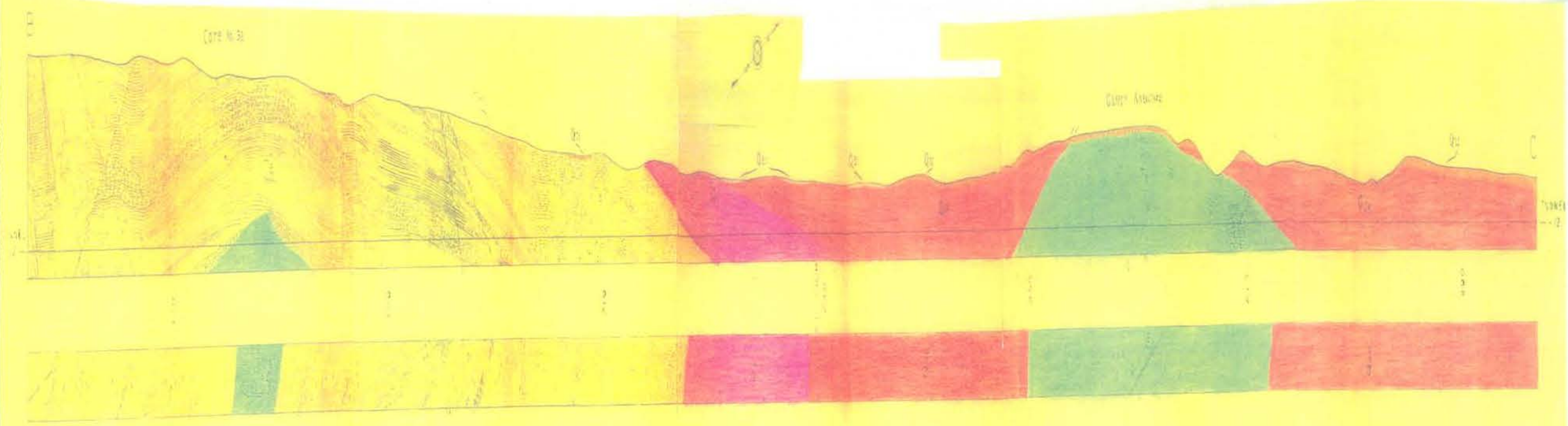
**Note: The following figures have been manipulated to fit electronic file.
For better image quality, please refer to hard copy at CIT library.

Figure 4- To Accompany a Repo rt on the Whites Point Tunnel by J. R. Schultz. Part 1, A-B'.



4- To Accompany a Repo rt on the Whites
by J. R. Schultz. Part 1, A-B'.





WHITES POINT TUNNEL

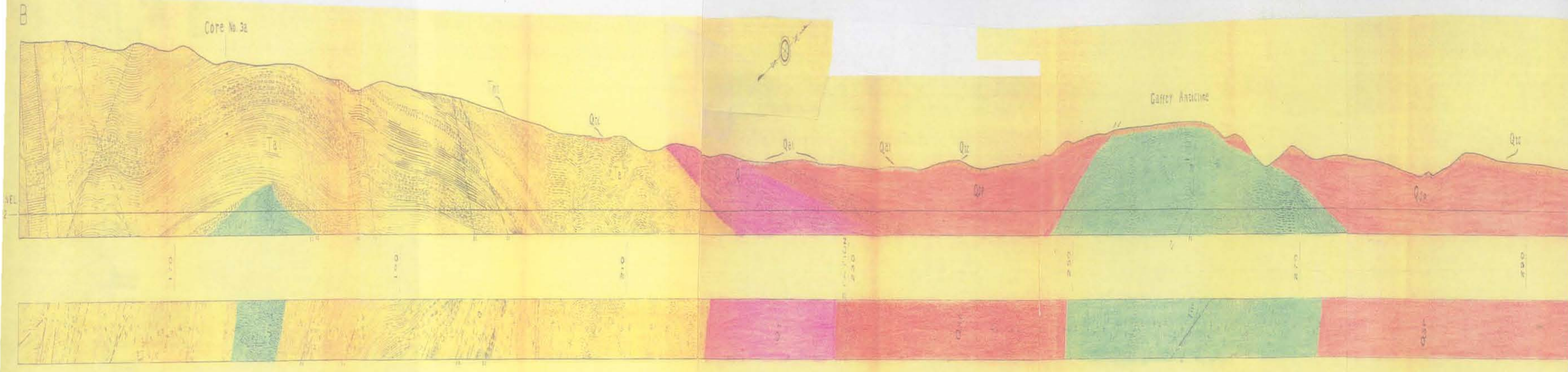
GEOLOGIC

PLAN AND STRUCTURE SECTION

HORIZONTAL AND VERTICAL SCALE

200 [illegible] = [illegible]

Figure 4- To Accompany a Report on the Whites Point Tunnel by J. R. Schultz. Part 2, B'-C.



WHITES POINT TUNNEL

GEOLOGIC

PLAN AND STRUCTURE SECTION

HORIZONTAL AND VERTICAL SCALE

200 FEET = 1 INCH

Figure 4- To Accompany a Report on the Whites Point Tunnel by J. R. Schultz. Part 2, B'-C.

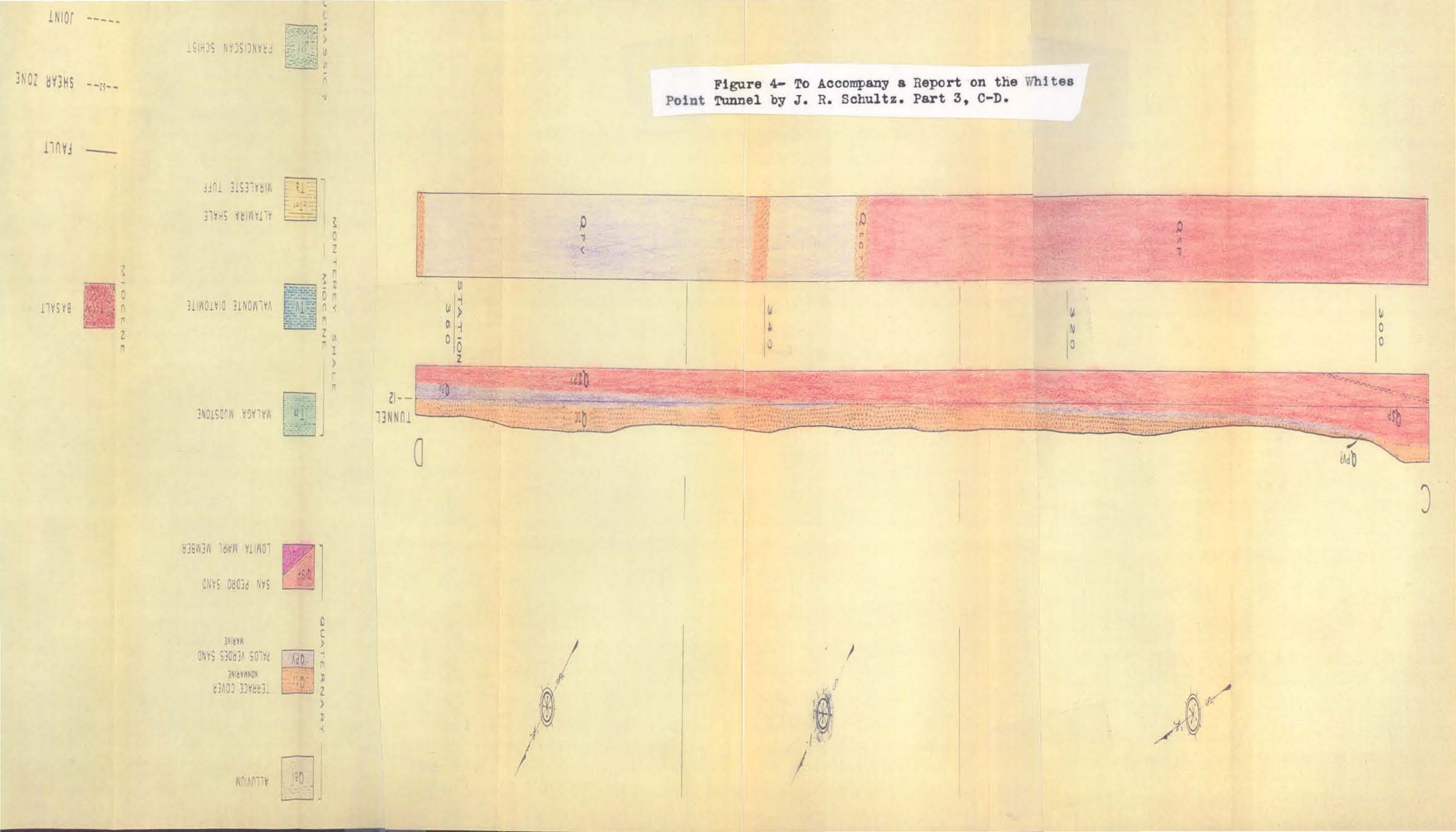


Figure 4- To Accompany a Report on the Whites Point Tunnel by J. R. Schultz. Part 3, C-D.