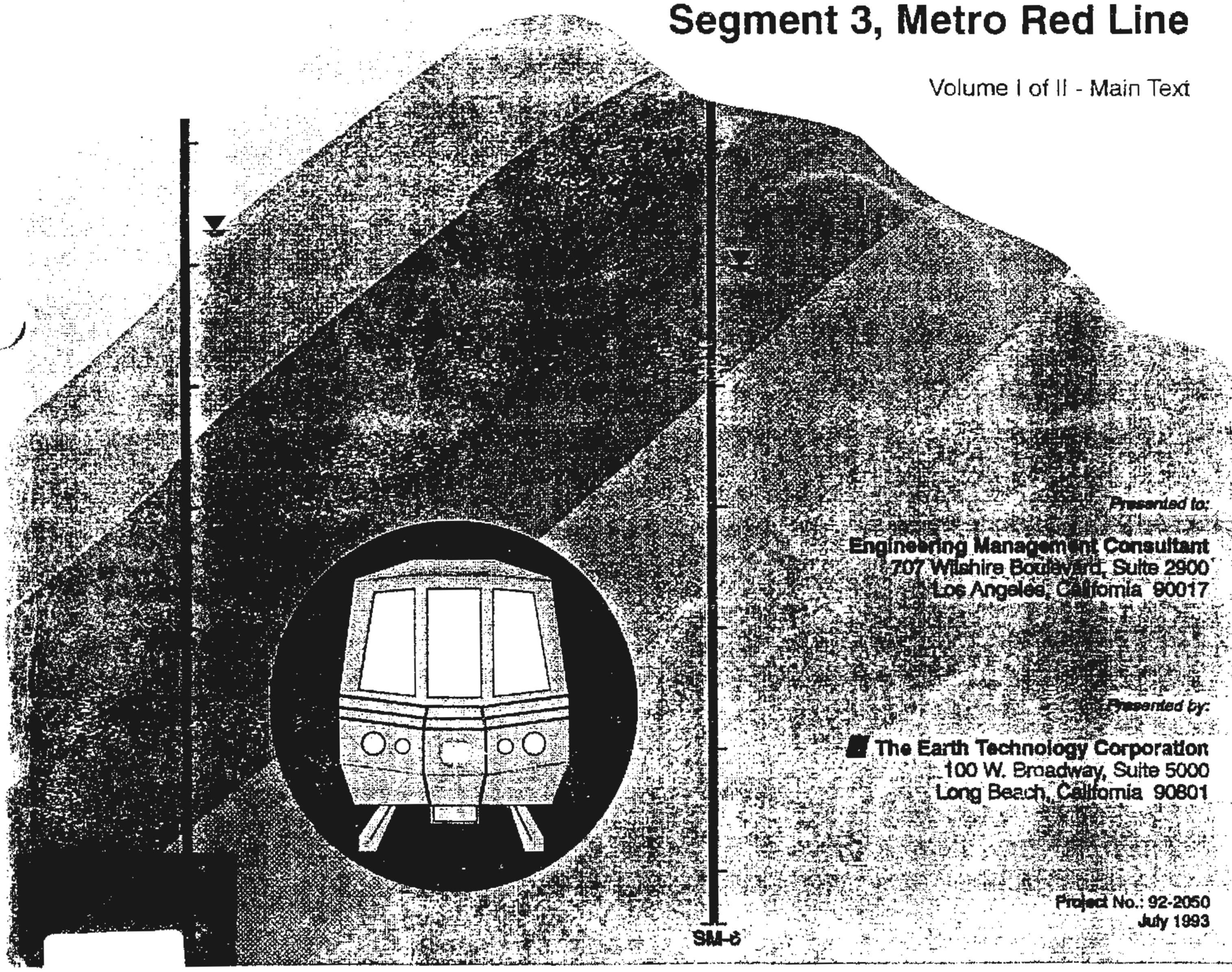
Geotechnical Investigation Report
Santa Monica Mountains
Segment 3, Metro Red Line

Volume I of II - Main Text



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Project No.: 92-2050
July 1993

GEOTECHNICAL INVESTIGATION REPORT
SANTA MONICA MOUNTAINS
SEGMENT 3, METRO RED LINE
VOLUME I - MAIN TEXT

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1.0 INTRODUCTION

1.1 GENERAL

This report presents the results of a geotechnical investigation performed for an approximately 14,000-foot long section of the proposed Segment 3 of the Metro Red Line crossing the Santa Monica Mountains.

1.2 BACKGROUND AND PROJECT DESCRIPTION

The proposed Metro Red Line Segment 3 alignment is shown in Figure 1-1. It starts at the proposed Hollywood/Vine Station, continues west along Hollywood Boulevard and then north off of La Brea Avenue, enters and passes through the Santa Monica Mountains, to the proposed Universal City Station, continues north following Lankershim Boulevard to the proposed North Hollywood Station located in the San Fernando Valley. Geotechnical investigations have been completed for the segments between Hollywood/Vine Station and the foot of the Santa Monica Mountains on the southern side (Earth Technology, 1990, 1991, and 1992) and between the foot of the Santa Monica Mountains on the north side and North Hollywood Station (Converse Consultants and others, 1981, 1983, 1984a and 1984b, and 1993). The segment investigated in this report lies between the soil/rock interface at the foot of the Santa Monica Mountains on the southern side, and the foot of the Santa Monica Mountains on the north side near the intersection of Lankershim and Cahuenga Boulevards.

The Red Line Segment facilities along the investigated segment will consist of side-by-side twin tunnels, one set (2) of air-ventilation shafts, and underground chambers. Each of the tunnels will have a finished inside diameter of 17 feet 10 inches. The shafts will have a finished diameter of approximately 12 feet and will be located in the vicinity of Borings SM-4, SM-5, or SM-6. The location of the underground chambers has to be determined, but they are expected to be in the vicinity of the ventilation shafts. The location of Borings SM-4, SM-5 and SM-6 and the stationing along the alignment are shown in Plate 2 which is included in Section 3.0.

It is anticipated that excavation of the tunnel will be performed by tunnel boring machines (TBM) with a partial shield to protect tunneling personnel and to provide temporary support of the tunnel crown until rock bolting and/or other support can be applied.

1.3 OBJECTIVE AND SCOPE

The primary objective of the geotechnical investigation was to evaluate subsurface soil, rock, and groundwater conditions for design and construction of the tunnels and shafts.

The scope of this investigation consisted of the following:

1. Review of available literature, reports, and project files including the reports and construction documents of the nearby Los Angeles City Sewer Tunnel and Metropolitan Water District (MWD) Hollywood Tunnel.

2. Surface geologic mapping along the tunnel alignment, analyses of available aerial photographs and remote sensing imagery, and preparation of 1" = 200' scale geologic maps along the alignment.

3. Overall planning for the field exploration program which consisted of:
   - o Developing field procedures and preparing a field manual
   - o Planning the field investigation program
   - o Obtaining permits and clearing utilities at investigation locations
   - o Coordinating with Los Angeles City agencies and utility companies
   - o Coordinating with representatives of Engineering Management Consultant (EMC) and related agencies.

4. Field exploration and testing program, including:

   - o Drilling, coring, logging, and photographing of rock cores from 18 borings (SM-1, SM-1A through SM-1D, and SM-2 through SM-14).
   - o Geophysical wireline logging at six boring locations.
   - o Hydraulic packer testing in ten borings.
   - o Installing groundwater monitoring wells and collecting groundwater samples.
   - o Installing and monitoring vibrating-wire piezometers.

5. Geotechnical laboratory testing of selected soil and rock samples to assess index and engineering properties.

6. Chemical laboratory testing on groundwater samples to assess their chemical characteristics.

7. Other laboratory analyses consisting of X-ray diffraction, thin section analyses, and micropalentology.

8. Preparation of this report documenting the results of this investigation.

1.4 REPORT ORGANIZATION

The report is presented in two volumes; Volume I contains main text and Volume II contains Appendices. The report organization in Volume I is as follows:

The details and results of a literature review are presented in Section 2 which includes a summary of the available tunneling data in the project area. Section 3 provides a description of the field exploration program, including geologic mapping, drilling and coring, packer testing, geophysical logging, and installing monitoring wells and vibrating-wire piezometers. Relevant regional and site geologic conditions are detailed in Section 4. The evaluation of the results of the field packer tests, geophysical wireline logging and geotechnical, chemical and other (x-ray diffraction, micropaleontology and thin section analysis) laboratory analyses are presented in Section 5. Section 6 describes geotechnical characterization of the bedrock materials. Anticipated ground behavior along the tunnel alignment and at the proposed shaft location are presented in Section 7. Section 8 provides a list of references. In each section the text is presented continuously, followed by tables, figures and plates.

Volume II contains eight appendices which present the boring logs and the details of the field and laboratory tests results and analyses.

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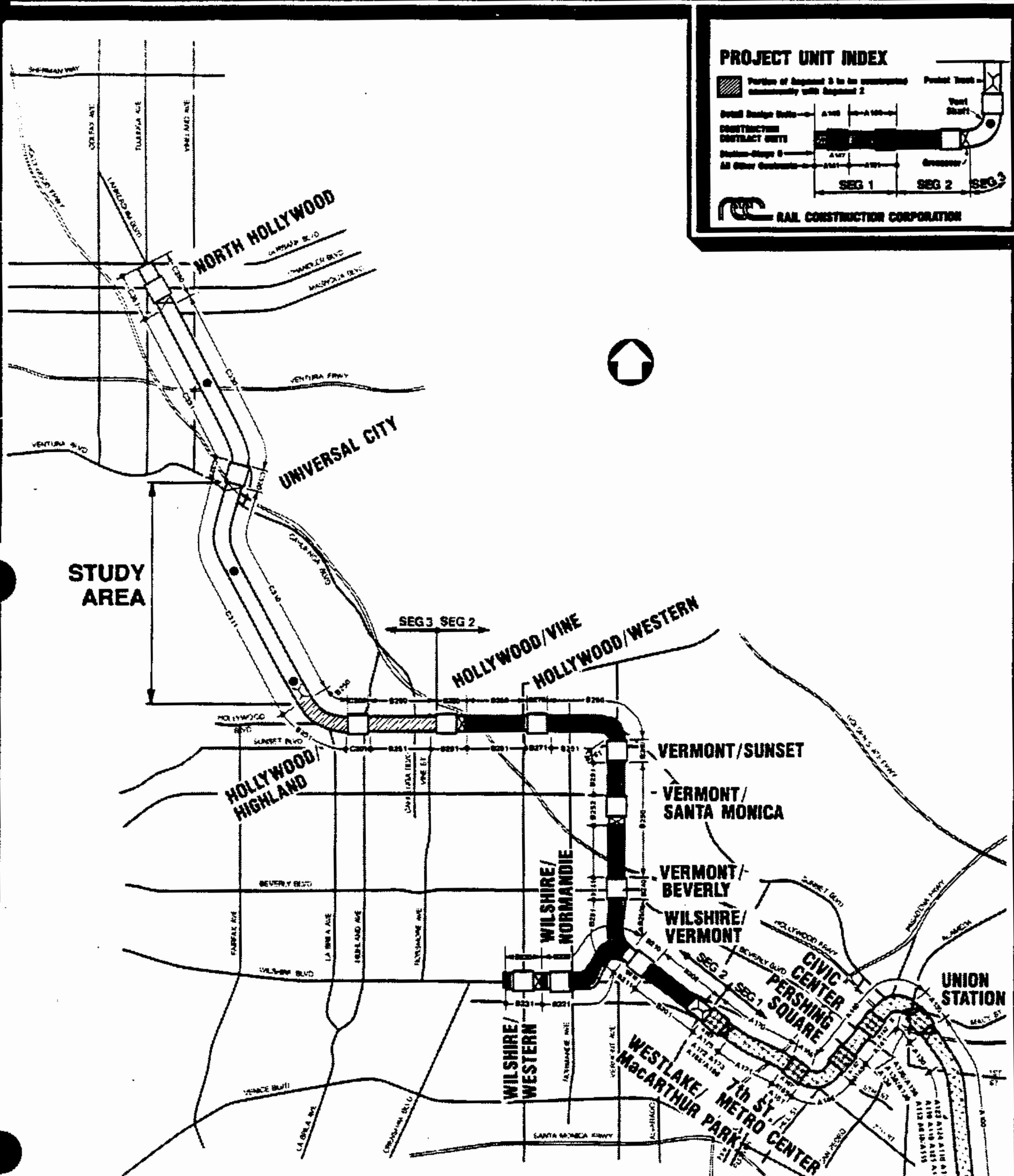
METRO RED LINE PROJECT



KEY PLAN

FIGURE 1-1

2.0 LITERATURE REVIEW

2.1 GENERAL

Available publications and documents were obtained and reviewed to provide an initial understanding of the subsurface conditions along the tunnel alignment. This initial review was important to enable us to identify deficiencies in the database that needed to be addressed, and to effectively plan the subsurface exploration program. In general, sources of data included federal, state and local government agencies; papers in professional journals; aerial photographs from various sources, and Metro Rail project files. Earth Technology contacted Caltrans District 7 Geology Department and Caltrans Bridge Maintenance Department (May 5 and May 6, 1993, respectively) to inquire about geotechnical data for the Hollywood Freeway overcrossing at Lankershim Boulevard; however, Caltrans indicated that no data were available for this structure.

2.2 SUMMARY OF LITERATURE

The geologic maps of the eastern Santa Monica Mountains published by the Association of Engineering Geologist (AEG), Southern California Section (1982) served as the geologic base for this project. Geologic information from this set of maps was compiled onto 1" = 200' topographic strip maps. The AEG maps are based on data compiled by the Bureau of Engineering, Department of Public Works, City of Los Angeles, which involved extensive field mapping as well as review of pertinent literature. The maps illustrate the surficial distribution of geologic units and structural features such as faults and folds, and the orientation of bedrock discontinuities such as bedding, foliation, and joint planes.

Additional surficial geologic mapping data and descriptions of the geologic units and structural features in the vicinity of the tunnel alignment, were obtained from reports and maps prepared by various investigators including Hoots (1930), Durrell (1954), Colburn (1973), Weber (1980), Colburn and Novak (1989), and Dibblee (1982 and 1991).

Review of the preconstruction exploration data and as-built construction records for the La Cienega and San Fernando Valley Relief Sewer Tunnel (Los Angeles Sewer Tunnel, Department of Public Works, City of Los Angeles, 1954 - 1955) and the as-built construction records for the Metropolitan Water District (MWD) Hollywood Tunnel (MWD, 1942), provided data on the subsurface geologic and groundwater conditions encountered by these tunnels and general information on the response of the subsurface materials to excavation, methods of excavation and support, construction difficulties, and rates of advance. Since these tunnels were constructed in the same geologic environment and encountered essentially the same geologic units as the planned Metro Red Line tunnel alignment, the as-built records provide a representative portrayal of underground conditions. Our analyses of these data are discussed in Section 2.3. The locations of the preconstruction exploratory borings for the sewer tunnel as well as the locations of the two existing tunnels (Los Angeles Sewer Tunnel and MWD Hollywood Tunnel) are shown in Figure 2-1.

Previous geotechnical investigations have been conducted by various consultants for the Metro Rail Project. Converse Consultants in association with Earth Sciences Associates and Geo/Resource Consultants (1981 and 1984c) conducted geotechnical investigations along the original 3-mile long tunnel alignment through the Santa Monica Mountains. That alignment was located directly west of and roughly parallel to the Hollywood Freeway (U.S. 101). The extreme northern end of the original tunnel alignment nearly coincides with the alignment studied during the current project. The purpose of their investigations was to provide geotechnical information to be used by engineers in preparing designs for the tunnel and to aid potential construction contractors. The investigations included a total of 31 exploratory borings of which 19 were core borings. Additional work included geophysical measurements, oil and gas analysis, water quality analysis, rock petrographic analysis, and a suite of geotechnical laboratory tests. The geologic units encountered during exploration activities for these investigations included, middle Topanga Formation basalt, upper Topanga

Formation sandstone and conglomerate, and upper Topanga Formation interbedded siltstone, claystone, and sandstone.

Converse Consultants (1984a, 1984b, and 1989) also conducted geotechnical investigations for the proposed Universal City Station and the tunnel segment extending to the north.

In 1989, Earth Technology drilled two borings (R-8 and R-9 shown in Plate 2 in Section 3.0) located at the northern side of the Santa Monica Mountains. These borings were drilled to provide subsurface data on the bedrock and groundwater conditions in this area. Earth Technology (1993) also performed an extensive subsurface exploration program to provide information on the Hollywood fault-zone. A total of 29 borings were drilled to delineate the location, width, and geometry of the fault zone and to provide subsurface information needed to describe the fault-controlled transition from alluvium to bedrock for tunnel construction. The subsurface data collected by Earth Technology was used by Dr. Kerry Sieh (1993) in his evaluation which included the latest age of fault activity, anticipated style of faulting, amount of displacement per earthquake event, recurrence interval, and appropriate design earthquake magnitude associated with the fault zone.

2.3 SUMMARY OF AVAILABLE TUNNELING DATA IN PROJECT AREA

2.3.1 General

For tunneling and underground chamber excavations, ground conditions have a major impact on cost of construction and method(s) of excavation. Accurate portrayal of rock strength, deformation characteristics, anticipated loads, geologic structure, and groundwater conditions helps the construction contractor anticipate conditions and plan the excavation appropriately. Such information comes from geological and geotechnical subsurface investigations as well as case-history information. Knowledge of the ground conditions by prospective contractors allows for less variation in bidding, fewer contingencies, and tighter controls on costs of construction. This portion of the report is, therefore, devoted to describing ground conditions of past tunnel excavations in the vicinity of Segment 3 of the Metro Rail Red Line. From those case histories, the underground conditions along the Red Line alignment can be portrayed with greater confidence.

Significant data are available from pre-construction exploration and as-built records for the La Cienega and San Fernando Valley Relief Sewer (Los Angeles Sewer Tunnel) and MWD Water Tunnel (MWD Hollywood Tunnel), both excavated through the Santa Monica Mountains. The Los Angeles Sewer Tunnel was excavated in 1953/1954 from two tunnel headings, one on the south side of the Santa Monica Mountains at Sierra Bonita (Wattles Park, west of the Metro Rail) and one at the north side near Universal Studios for a combined 14,414 feet of tunnel. The proposed Metro Rail alignment crosses beneath the Los Angeles Sewer Tunnel by about 70 feet near Station 674+00. Because the Los Angeles Sewer Tunnel alignment is so close to the proposed Metro Rail alignment, it traverses the same geologic terrain and should provide a good portrayal of ground conditions to be interpreted from the as-built tunneling records. In addition, the MWD Hollywood Tunnel (completed in 1941) crosses the proposed Metro Rail Alignment but approximately 300 feet above it at elevation 775. The MWD tunnel is 3,739 feet-long and traverses the basalt and part of the Topanga Formation. A geology report and as-built conditions of the MWD Hollywood Tunnel are described in reports by Buwalda, J.P. (1940) and J.F. Shea Company (1942) respectively. Pertinent data from those reports are included here.

2.3.2 Los Angeles Sewer Tunnel

2.3.2.1 General

The Los Angeles Sewer Tunnel was excavated by conventional drill and blast techniques with an approximate 7 foot tunnel for a finished 6-foot diameter sewer tunnel. The preconstruction geology and hydrogeology of the Los Angeles Sewer Tunnel are described in a report by Ruscardon Engineers (July 20, 1953) titled "The Los Angeles Sewer Tunnel through the Santa Monica Mountains". Seven test holes were cored to help describe the subsurface conditions. Locations of these borings and static water levels are shown on the sewer tunnel profile (Plate 1). Ruscardon Engineers (1953) described the rock units from south to north as granite, conglomerate, sandstone, basalt, sandstone, conglomerate, sandstone, and bedded sandstone, and sandy shale. In general, the formation contacts and bedding dip steeply northeast.

Ruscardon Engineers anticipated that the highest water inflows while driving the tunnel would come from the conglomerates and sandstones (Chico, Simi, Las Virgenes, and Lower Topanga Formations) between the granitics and basalt and from fractures in the basalt. The maximum flow of water was estimated to be 1,000 to 1,500 gallons per minute (gpm). This was partly inferred from water flows encountered in the MWD Hollywood Tunnel based on maximum reported flow rates from basalt and also on their interpretation of the geology. They also reported that extremely heavy ground should not be found in the granite, conglomerate or sandstone if no water is encountered. In the bedded sandstones and sandy shales, only occasional support was anticipated. In general, 4" H-Beams set on 5-foot centers were anticipated as sufficient support for most sections. At the far north end of the tunnel where dry alluvial sand and gravel were expected, 4" H-Beams set on 2.5 foot centers could be used if the material provided to be heavy. Actual conditions varied slightly from the Ruscardon report.

2.3.2.2 Geologic Conditions

The actual geologic conditions and supports required for driving the tunnel are presented in a series of field notes and project file notes held in the archives of the Los Angeles City Department of Public Works and assembled under the heading "Geotechnical Data, Department of Public Works, Relief Sewer, Santa Monica Mountains." These documents had been retrieved from archives and were referenced as Campbell (1955) "Geologic Notes and Log of Los Angeles City Sewer Tunnel" by Converse Consultants (1981). Those field notes and project files are summarized in Plate 1. In Plate 1, the data include geologic contacts as recorded in the tunnel, zones of high water flows at the tunnel heading in gpm, measured water flow from the south portal in gallons per day (gpd), quantity of water pumped from the North portal locations of special supports for heavy ground, and spacings between rib supports.

The tunnel was excavated from both south and north portals using conventional drill and blast techniques. Two logs of tunnel excavation were prepared at the time of construction by Department of Public Works personnel; one log from the south portal between Station 351+03 and Station 432+53.6 where the southern heading met the northern heading, and the second log from the north portal at Station 495+16.65. Each of these logs consists of two components, the Tunnel Geology (i.e., strikes and dips, and lithology) and Record of Structural Conditions (i.e. support types, rib spacing, spilling, lagging, timber quantities, and crown rock profile).

Based on the tunnel geology data, the following rock types and lengths of tunnel section were encountered from south portal to north portal:

Granite and/or granodiorite:	4,770 feet
Conglomerate (clasts up to 8"):	1,040 feet
Sandstone (and mudstone):	488 feet
Basalt (and agglomerate):	1,289 feet
Conglomerate (clasts up to 24"):	699 feet
Sandstone:	1,042 feet
Sandstone and shale:	4,348 feet
Alluvium:	339 feet
Sandstone and shale:	399 feet

Each of these geologic units has unique characteristics which affected the tunnel excavation and support differently. These conditions are described according to each lithologic unit from south to north.

The granitic rock was expected to require little support for tunnel construction, however, one area of fault gouge, shearing, and hydrothermal alternation was encountered that required "Type V" support for "very heavy" or "squeezing" ground conditions in over 200 feet of tunnel length. The contractor used 13-pound steel ribs set at 1.5- to 2-foot spacings. The location of this condition is shown in Plate 1 (Stations 391+72 to 394+00). The geologic log indicates many randomly oriented fault planes, but many of them are nearly horizontal. It appears that the tunnel encountered a large shear zone that intersected the tunnel at a very low angle causing caving of the tunnel roof until the tunnel heading passed through the zone. An area of heavy ground that was expected was near the tunnel south portal where it appears the excavation encountered the Hollywood fault at the foot of the mountain front. A gouge and breccia zone with fragments of granitic rock was encountered from Station 352+20 to 354+44. In this tunnel reach, the contractor placed Type I (heavy ground) supports at 2.5-foot spacing. Other areas of the tunnel also required Type I support for heavy ground at eight locations within the granitic rock. This is likely reflective of the general blocky nature of the rock with a nearly random pattern of discontinuities. The orientation of all shears, joints and foliation from the Geologic Record are illustrated as polar plots on the stereo nets in Plate 1. We divided the granitic rock data somewhat arbitrarily at Station 375+00 to illustrate structural differences between the northern part of the granitic rocks and the southern part nearest the Hollywood fault zone. Within the southern part of the granitic rock, there appears to be a bias of low angle (dips of 20 and 50 degrees) shears, joints, and foliation planes dipping to the north and north-northeast. Discontinuities in the northern part of the granitic rock are nearly random but indicate a nearly horizontal set of shears in combination with nearly vertical east-west, north-south and northeast-trending shears and joints. The combination of these discontinuity orientations likely created a blocky condition requiring the "heavy" ground support reported.

The conglomeratic rock and sandstone (some mudstone) between the granitic rocks and basalt provided relatively stable conditions for tunneling. Although a highly brecciated zone was reported near the basal contact of the conglomerate and granitic rocks, no special tunnel support was indicated for that reach. Geologic structure summarized on the stereo net plots

(Plate 1) indicates that bedding strikes northwest and dips 60 to 70 degrees into the tunnel heading. Most shears also maintained the same general orientations as the bedding planes. A nearly vertical set of shears also was indicated trending northeast-southwest.

The basalt appeared to provide quite favorable tunneling conditions. Although many shears exist, many appear to be healed or "cured" often with calcite or zeolite infillings up to 1/4 inch thick. No special tunnel supports were used by the contractor and the rate of tunnel excavation was approximately 185 feet per week compared to approximately 125 feet per week within the granitic rock. Orientations of shears encountered in the basalt are plotted on a stereo net (Plate 1). Those data indicate predominantly, nearly vertical shears trending east-west, northwest-southeast, and east-northeast.

The conglomerates overlying the basalt appear to interfinger with layers of basalt in a conformable depositional contact. The conglomerates and the overlying sandstones tend to be massive enough to have provided good tunneling conditions requiring no special support. On the contrary, the interbedded sandstone and shale appear to have been less stable than expected where Types I (heavy ground), IV (softened subgrade), and V (very heavy ground) supports were necessary. The extra support does not correlate well with where the significant shear zones were noted (Plate 1).

Based on the geologic descriptions for the Los Angeles Sewer Tunnel excavation, the sandstone and shale bedding ranges from thin to massive but is predominantly thin bedded shale near the northern end of the tunnel where most "heavy" ground conditions were encountered. Since the tunnel was excavated toward the south in this reach, the bedding was consistently dipping into the tunnel from its heading.

Bedding is striking approximately 60 to 70 degrees northwest and dipping from 35 to 70 degrees northeast into the tunnel. This likely caused blocks of rock to fall into the tunnel from the heading due to the general abundance of sheared bedding planes especially within the shale.

From Station 489+20.4 to Station 491+30.5 the contractor used Type V (very heavy ground) and Type VI (very heavy alluvial ground) tunnel supports. Seven alluvial dewatering wells had to be installed due to unanticipated shallow groundwater. Ruscardon Engineers (1953) had indicated dry alluvium in the preconstruction document. During the dewatering process for construction through the alluvium, an average of 95,000 gpd was pumped for the month of July 1954. About 50 feet of alluvium overburden was above the crown of the tunnel. Between Stations 491+17.9 and 491+25, the tunnel "caved to surface". This may have been a running ground condition that allowed progressive failure to the ground surface. Type VI supports had to be used with "tight" spilling to keep the excavation open. Within the adjacent weathered bedrock, Type V support was utilized.

2.3.2.3 Groundwater Conditions

Groundwater was encountered in all of the geologic formations during tunneling. Ruscardon Engineers estimated that water flow could be between 1,000 and 1,500 gallons per minute (gpm) within the conglomerate, sand, and basalt just north of the granitic rock. They also estimated that the granitic rock would not produce much water. These estimates appear to have been based on packer testing, occurrence of groundwater in test holes, and geologic structure, which had been interpreted to trap water between the granitic and basaltic rocks. The preconstruction data from test holes and the actual flows encountered during construction are shown in Plate 1. The estimated flow volumes were close to actual but the occurrence of the flows differed from that predicted by the tunnel engineers.

The conglomerates and sandstone north of the granitic rock produced very little water in the tunnel, whereas the granitic rocks produced relatively high concentrated flows with some tunnel sections yielding as much as 350 gpm. One individual flow at Station 386+57 yielded 150 gpm. Tunnel sections where high water flows were noted are shown in Plate 1 along with the total flow from the south portal as the tunnel heading was advanced. From Plate 1 it can be seen that the total water flow steadily decreased while the tunnel was being driven through the conglomerates and sandstones north of the granitic rocks.

The highest water flows were produced from basalt. Plate 1 shows that the total water flow from the tunnel dramatically increased while the tunnel was being driven through the basalt and it began decreasing immediately after leaving the basalt. The maximum weekly flow was recorded on January 28, 1955 at 1,221,120 gpd with an instantaneous peak of 1,076 gpm that rapidly diminished within a few hours at the south portal.

The north portal produced far less water than the south portal. The tunnel excavation at the north portal generally yielded less than 100,000 gpd which was pumped from a sump. The tunnel section was entirely within the sandstones and shales north of the basalt. Generally, flows were limited to seeps from the walls and ceiling of the tunnel.

In all cases the water flow from geologic formations penetrated by the Los Angeles Sewer Tunnel peaked as the tunnel was advanced through the producing rock but rapidly declined as water drained from the formation. This is illustrated in Plate 1 which shows flows peaking in zones of high flow and then declining rapidly. This tendency continued after the two tunnel headings met on February 21, 1955. Figure 2-2 illustrates the general decline in water flow until about 60 days after measurements started. The flow stabilized at just over 400,000 gpd until measurements ceased in August 1955.

Chemical test results including minerals, pH, and conductance were reported for water samples collected during construction of the Los Angeles Sewer Tunnel. Table 2-1 presents the test results with corresponding station locations of tunnel headings. Samples 1843 and 764 are water derived from the granodiorite. Sample 1061 was taken after the tunnel heading had penetrated conglomerates and sandstones of the Chico and Lower Topanga formations. Samples 1420 and 1421 were taken five days before the north and south tunnel headings met, and represent the overall water quality information of the south tunnel versus the north tunnel, respectively. Sample 765 was taken from water produced while the north tunnel was entirely within the Upper Topanga Formation.

In general the Los Angeles Sewer Tunnel water quality data reflect the same trends as those for the groundwater obtained during this investigation. The samples from the granodiorite and volcanic rocks have lower hardness, lower calcium, lower potassium and lower specific conductance than samples from the sedimentary rock units. This is consistent with the marine origin of rock Samples 1061, 1421 and 765. In general, the sedimentary rocks have higher concentrations of soluble salts and yield water with higher total dissolved solids (TDS) and other minerals.

2.3.3 MWD Hollywood Tunnel

The MWD Hollywood Tunnel was constructed between June 6, 1940 and May 22, 1941, as part of the MWD distribution for Colorado River water to Beverly Hills, Santa Monica and West Los Angeles. The South Portal was located in Nichols Canyon at elevation 770.34 (Inv.), and the North Portal was located at elevation 775.00 (Inv.) near Oakshire Drive. The tunnel excavation was conducted by the drill and blast method resulting in a 7-foot wide opening that was finished with a 6-foot diameter concrete lining. The total length between the portals was 3,739 feet.

A preconstruction geology report was prepared by John P. Buwalda (1940) titled "Geology of the Hollywood Tunnel". Buwalda indicated that the southern reach of the tunnel would encounter conglomerate (with up to 12-inch boulders). The middle reach would be excavated in basalt that is not columnar but rather massive. North of the basalt, the tunnel would penetrate sandstone with some shale and conglomerate. Very little water was anticipated.

The actual geologic materials encountered during excavation are as follows from south to north for the Hollywood Tunnel:

Conglomerate (600 ft) and sandstone (250 ft):	850 feet
Basalt:	2,100 feet

Conglomerate (650 ft) and sandstone (100 ft): 750 feet

The southern conglomerate and sandstone require little tunnel support, but some delays in drilling were caused by the "hard diorite boulders" some up to 12 inches in diameter. The sandstone and basalt stood well without supports. Only in areas where the basalt was sheared or crushed was support needed, otherwise the basalt provided the most favorable excavating conditions.

North of the basalt, the conglomerate tended to air slake where exposed in the tunnel. No major faults were reported in the tunnel. The supports used in the tunnel consisted of 7.7 pound I-beams set at 1 to 8-foot centers. For the entire tunnel length, there were 1,643 feet needing support and 2,089 feet that stood unsupported. Most of the supports were needed in the weathered zones of conglomerate and where shales were interbedded.

The amount of water encountered in the tunnel exceeded what was expected prior to construction. With only 400 feet maximum of overburden, water flows at the tunnel elevation were not expected to be a construction factor but ended up being a cause for delay in project completion. The north portal water was pumped from near the tunnel heading and never exceeded 50 gpm. The south portal water flow peaked at 600 gpm (864,000 gpd) for a few hours and decreased to a sustained flow of approximately 250 gpm (360,000 gpd). After completing tunnel excavation, the water flow from the entire tunnel diminished to 100 gpm after two months. A direct impact of rain recharge was noted after heavy rains in March 1941, when the flow increased to 250 gpm for a period of time.

Excavation rates using drilling and blast methods averaged 17.4 feet per day with three eight-hour work shifts. The most rapid excavation was 33 feet per day with three work shifts.

TABLE 2-1. REPORTED LABORATORY CHEMICAL TEST RESULTS OF GROUNDWATER SAMPLES FROM LOS ANGELES SEWER TUNNEL DISCHARGE WATER

Analyte	Sample No. 1843 Sta. 369 + 82	Sample No. 764 Sta. 394 + 59.3	Sample No. 1061 Sta. 411 + 51	Sample No. 1420 Sta. 427 + 32	Sample No. 1421 Sta. 434 + 4	Sample No. 765 Sta. 464 + 34.5
TOTAL HARDNESS as Calcium Carbonate (mg/L)	281	298	437	102	250	987
ALKALINITY as Calcium Carbonate (mg/L)	239	281	340	301	303	344
CALCIUM (mg/L)	68	37	116	19	46	116
MAGNESIUM (mg/L)	27	50	36	13	34	170
SODIUM (mg/L)	23	46	86	126	80	120
POTASSIUM (mg/L)	6	0	2.5	2	2	5
CHLORIDE (mg/L)	33	60	44	18	21	62
SULFATE (mg/L)	38	50	213	64	118	781
NITRATE (mg/L)	0	NA	NA	NA	NA	NA
SILICA (mg/L)	25	30	55	66	48	24
IRON (mg/L)	<0.01	0.06	108	<0.01	0.10	0.15
BORON (mg/L)	0.07	0.16	0.10	0.29	0.23	0.21
FLUORIDE (mg/L)	0.05	0.40	0.20	0.40	0.40	0.50
SPECIFIC CONDUCTANCE (umho/cm)	611	702	1096	715	792	1934
TEMPERATURE (°C)	23	NA	22	19	20	NA
pH (pH units)	7.35	8.11	7.88	8.30	8.0	8.01

NOTES: Units - mg/L = milligrams per liter
umho/cm = micro mhos per centimeter
NA = not analyzed

060493.TBL/92-2050-01

URCE:
U.S. Geological Survey, 7.5 Minute Topographic Map Series, Burbank Quadrangle, Photorevised 1972, and Hollywood Quadrangle, Photorevised 1981.

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Proposal No.: 92-2050
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Location of Various Exploration Activities

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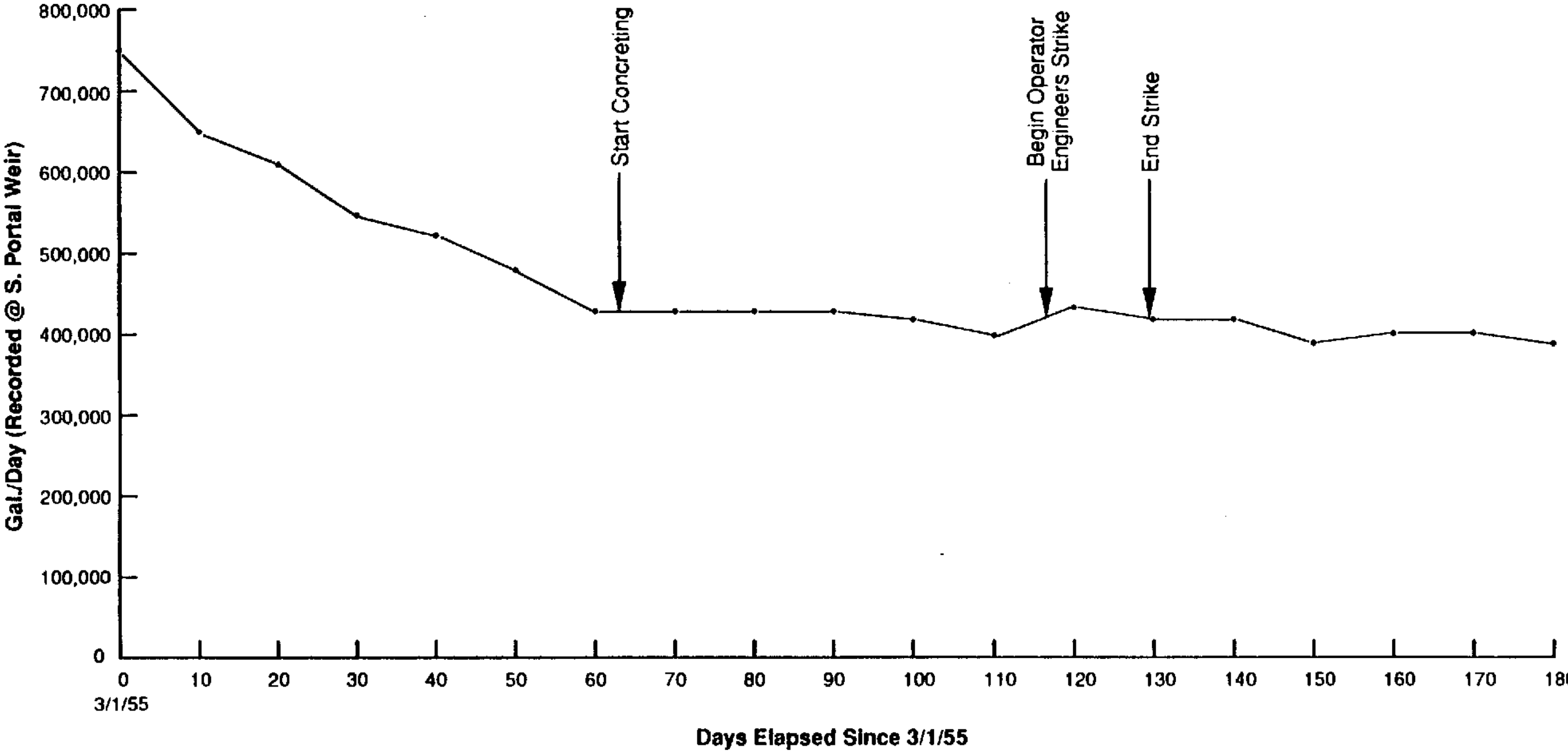
Figure 2-1



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Post Tunnel Excavation Water Flows from L.A. Sewer Tunnel

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Figure 2-2

Note: Data from Department of Public Works, City of Los Angeles (1954-1955).

3.0 FIELD EXPLORATION AND LABORATORY TESTING

3.1 GENERAL

This section provides a description of the field exploration program as well as laboratory testing performed during this investigation. The field exploration program consisted of field geologic mapping, drilling and coring of 15 borings, geophysical wireline logging, hydraulic packer testing, installation and development of monitoring wells, groundwater sampling, and installation and monitoring of vibrating-wire piezometers. The laboratory program consisted of geomechanical, chemical, and other testing.

3.2 GEOLOGIC MAPPING

3.2.1 Purpose

The purpose of the geologic mapping was to map and characterize the surficial geologic conditions exposed along the tunnel alignment. Since the existing geologic maps illustrate the regional geology at a scale too large to provide sufficient definition, detailed site-specific geologic mapping was conducted to focus on the tunneling aspects of the geologic units exposed along the tunnel alignment. Geologic mapping is essential for understanding the structural relationships between geologic units and rock discontinuities that may be present at depth. The elements of the geologic mapping consisted of compiling available geologic data from existing reports, reviewing available aerial photographs, and mapping exposed geology in the field.

3.2.2 Existing Geologic Reports

The AEG's (1982) and Dibblee's (1991) geologic maps of the Santa Monica Mountains served as the initial geologic database for the entire alignment. Geologic data from these maps were photographically enlarged and compiled onto the 200-scale topographic strip map. In addition, the compiled data included detailed geologic mapping by Colburn and Novak (1989) of the Paleocene rocks exposed in the northern part of Runyon Canyon Park. Subsurface geologic data from the Los Angeles Sewer Tunnel and MWD Hollywood Tunnel as-built records provided an understanding of the distribution, physical conditions, and construction characteristics of the geologic units in the subsurface. These data in conjunction with the compiled surficial geology, were used to interpret the subsurface geology along the tunnel alignment and to help select optimal boring locations for the field exploration program.

3.2.3 Aerial Photography Interpretation

Stereo-paired aerial photographs providing coverage of the tunnel alignment were obtained and interpreted. The aerial photographs interpreted and their sources are listed below:

Source	Date	Flight	Frame	Scale
UCSB	1928-1929	C300	K40, K41, K69-K72	1 Inch = 1,500 feet
UCSB	4-3-71	2755	21-25, 21-26, 22-20, 22-21, 23-15, 23-16, 23-17, 24-27, 24-28	1 Inch = 900 feet
PB/DMJM	7-25-88		4-3 through 4-19	1 Inch = 300 feet

Geologic data interpreted from the aerial photographs were limited due to the extensive urban development apparent on the recent photographs (1971 and 1988). The Runyon Canyon Park area is mostly undeveloped terrain; however, thick vegetation and residual soil tend to obscure the geology. The older set of photographs (1928-1929) predates the development of the Hollywood Hills with the exception of the extensive road network.

3.2.4 Field Geologic Mapping

Field geologic mapping was performed to evaluate and refine the office compiled data. The office compiled data were checked in the field for consistency with conditions observed by our field geologists. Field mapping was conducted from July 13 to July 15, 1992, and encompassed a strip approximately 1,000 feet wide centered along the tunnel alignment. Because of the extensive development along most of the alignment, the geologists relied on scattered road cut exposures to record and plot geologic data. Within Runyon Canyon Park, geologic observations were made along traverses of ridge lines, canyon bottoms and trails, as well as road cuts.

At each outcrop, the lithology and structure of the rocks were noted. Measurements were made with a Brunton compass to record the orientations (strike and dip) of rock discontinuities such as bedding partings, joints, shears, faults, and contacts between different lithologic units. Rock discontinuity descriptions included discontinuity type, surface texture, width, nature of coatings or infilling, distribution or spacing, and continuity.

The results of our field geologic mapping program are presented in Section 4.2. The distribution of the geologic units and mapped structural features are illustrated in the Geologic Plan and Profile, Plate 2.

3.3 FIELD INVESTIGATION PROGRAM

A field investigation program was performed following completion of the geologic mapping and included the following:

- Planning, permitting, and coordination
- Drilling, coring, and logging of 15 borings along the alignment
- Geophysical wireline logging
- Hydraulic packer testing
- Monitoring well installation, development, and sampling

- o Vibrating-wire piezometer installation and monitoring

3.3.1 Planning, Permitting and Coordination

The following planning, permitting, and coordination efforts were performed prior to and during the field exploration and testing program:

- o Coordinating with Rail Construction Corporation (RCC) personnel and residents affected by the field work to minimize disturbance and inconvenience to the public.
- o Coordinating with Los Angeles City Department of Recreation and Parks and obtaining permission to drill at five boring locations in Runyon Canyon Park.
- o Obtaining permits from City of Los Angeles and West Los Angeles Engineering Department for drilling in the right-of-way of public streets and roads.
- o Coordinating with utility companies to ensure clearance of underground utilities at the boring locations.
- o Obtaining storage/staging yards to store equipment, supplies, and drummed drill cuttings.
- o Providing necessary traffic control and coordination during field exploration program.

3.3.2 Drilling, Coring, and Logging

A total of 18 borings were drilled. Fifteen borings were cored using rotary wash wireline techniques and visually logged. The remaining three borings were drilled by hollow-stem auger. The locations of these borings are shown in Plate 2. All of the borings generally extended to about 40 feet below the tunnel invert elevation (except SM-4, which was extended to 21 feet below the tunnel invert). The borings were located at the centerline to 335 feet from the centerline of the right tunnel track (AR). A detailed summary of the borings showing locations, elevations, total depth, and subsurface rock types encountered is presented in Table 3-1.

Several drilling and sampling methods were utilized. Borings SM-1, SM-1A, SM-1B, SM-12 and SM-13 were initially advanced within unconsolidated sediments by a Christensen 94 mm core barrel wireline system. The system was set up as a "punch system" which positions the sampler tip ahead of the core bit to avoid washing out the sample by the circulating drilling fluid (water). Borings SM-3 and SM-11 were initially drilled through unconsolidated deposits using a hollow-stem auger, with continuous drive samples obtained using standard split-spoon samplers. Rotary wash wireline techniques were then used for rock coring in the borings. Borings SM-1C, SM-1D, and SM-14 were drilled entirely by hollow-stem auger with samples being collected by a standard California drive sampler. Borings SM-1C and SM-1D were sampled continuously and Boring SM-14 was sampled at 5-foot intervals.

The rock coring was accomplished using an HQ drill rod with impregnated, surface-set or Stratapax™ (bit with synthetic diamond cutting elements) drill bits. Bentonite drilling mud and/or easy mud (clear biodegradable polymer mud) and air were used in rock coring. Coring/sampling was completed using an HQ size double tube core barrel.

Borings were drilled using a core barrel with a 5-foot long split inner tube (i.e., core diameter of about 2.4 inches). Individual coring runs were limited to a maximum of 5 feet per run. Upon achieving the maximum run length or when the core barrel became blocked, the core barrel was lifted from the boring via the wireline system. The core was then carefully removed from the split inner barrel and placed in core boxes equipped with vertical separators. The core barrel was reassembled and returned to the boring to resume the next coring run. Most cores were HQ size (core 2.4 inches in diameter); however, N-size cores (diameter = 1;875") were obtained below the depths of 456.7 and 512 feet in Borings SM-5 and SM-7, respectively. For these two borings, HQ-rods were unable to advance and NQ-wireline coring technique and equipment could be used through the inner opening of the HQ-drill rod to complete these borings. Table 3-2 provides a summary of drilling methods, bits, and drill rigs used in this investigation.

The cores were examined and logged by an experienced geologist in accordance with the field guidelines specifically prepared for this project and under direct supervision of an experienced Certified Engineering Geologist (CEG). Items for logging included general project/boring data, drilling equipment and method, lithic description, depth and run number, drilling rate, rock quality designation, core recovery, discontinuity frequency and a suite of structural/discontinuity characteristics that were intended to facilitate the classification of the encountered rock masses. The boring logs are presented in Appendix A (Volume II).

After coring, hydraulic packer testing (Section 3.3.3), and geophysical wireline logging (Section 3.3.4), all the borings, except Borings SM-1, SM-1A, SM-1B, SM-1C, SM-1D, SM-11, and SM-14, were left open with surface casing in place for future inspection and testing purposes. To protect these borings from damage, each of these open borings was covered with a metal protection box with lock provisions and installed flush with the ground surface. Because artesian groundwater conditions were encountered in Boring SM-11, it was grouted closed after completion of field work. Borings SM-1B, SM-1C and SM-1D were grouted closed after completion, since they were located very close to Borings SM-1 and SM-1A. Borings SM-1, SM-1A, and SM-14 were converted to groundwater monitoring wells as detailed in Section 3.3.5.

The cores were sequentially arranged in the core boxes in accordance with the depths of cores and core runs. Each core box was clearly labelled with boring number, box number, core run numbers, depth intervals covered by the core runs, project name and number, date, and drilling subcontractors. This information was placed on the inside and outside of the cover lid, one end, and the front side of the core box. After a core box was full and completely labelled, it was shipped to a nearby field storage warehouse; subsequently the core boxes were shipped to Earth Technology's Huntington Beach Laboratory, California. All the above field activities were supervised and performed by experienced geologists under constant supervision and coordination of a CEG.

After their arrival in the field storage warehouse, all cores were further cleaned and photographed. A photo album containing the core photographs were presented under separate cover for record keeping and future examination purposes. The cores were further examined to edit and check the field logs. Selected cores were removed for laboratory testing.

After completion of drilling, the locations of the borings were surveyed by a licensed land surveyor. The coordinates and elevation of each boring are included on the borings logs contained in Appendix A. The results of the survey were used to plot the locations of the borings on Plate 2 and to determine the elevations of geologic contacts at the boring locations.

3.3.3 Hydraulic Packer Testing

A series of hydraulic packer tests were performed to estimate the hydraulic conductivity of the in situ rock masses along the tunnel alignment. A total of 22 tests were performed in 10 borings at selected zones near or within the tunnel envelope or at selected highly fractured zones to help estimate near upper bound hydraulic conductivity. The 22 tests included 16 single packer and six double packer tests. The details of equipment, test setup, procedures, and results and analyses of individual hydraulic packer tests are presented in Appendix B. A summary of the test results and their evaluation are presented in Section 5.1.1.

3.3.4 Geophysical Wireline Logging

Geophysical wireline logging was done in six borings (SM-2, SM-4, SM-6, SM-8, SM-10 and SM-12). The logging consisted of sonic velocity and electric logs. The geophysical wireline data measured in situ physical properties of subsurface materials. The data primarily respond to bulk rock conditions and are especially sensitive to the effects of fractures and shear zones in the rock matrix. Survey results represent in situ properties that can be compared with data obtained from visible inspection of the rock core and laboratory testing.

Two complementary wireline techniques were used:

- o Sonic Velocity Log - This technique measures sonic waves (compressional and shear) propagation in the formation to semi-quantitatively assess rock quality and tube wave propagation along the formation wall to determine fracture locations.

- o Electric Log - This technique measures several electrical properties between boring fluid and the formation to help qualitatively assess rock quality.

Appendix C presents the instrumentation and procedures used to collect and interpret the wireline data. The field logs are also included in Appendix C. The results are discussed in Section 5.1.2.

3.3.5 Groundwater Monitoring Wells

During this investigation, a total of six groundwater monitoring wells were installed. Three borings (SM-1, SM-1A, and SM-14) were converted into monitoring wells. The remaining three wells SM-3A, SM-6A, and SM-9A were installed adjacent to Borings SM-3, SM-6 and SM-9 in boreholes that were drilled with compressed air. These monitoring wells were installed in first encountered water to provide groundwater level data along the alignment and to obtain water samples for chemical analyses. The boring diameters for Monitoring Wells SM-1 and SM-1A were about 4 inches while the boring diameter for Monitoring Well SM-14 was about 8 inches. The boring diameters for Monitoring Wells SM-3A, SM-6A, and SM-9A were about 6 inches. Design, installation procedures, and well construction diagrams for these monitoring wells are included in Appendix D. A brief description is provided below.

After completion of drilling, tap water was used to flush the boring to remove cuttings or remove and thin the drilling fluid as appropriate prior to well installation. About 2 to 4 feet of No. 2/12 Monterey sand backfill was placed at the bottom of the boring prior to installing the well-casing assembly. The well casing assembly consisted of a selected length of slotted polyvinyl chloride (PVC) well screen (with slot sizes of 0.01 inch and 0.02 inch) connected to solid PVC casing (1" or 2" diameter) at the top. After insertion of the PVC casing assembly, backfill sand was placed to about 1 to 5 feet (for Monitoring Well SM-1, it was 13 feet above the slotted screen) above the slotted screen section. Bentonite pellets and/or chips were then poured to form a bentonite seal layer of approximately 3 to 12 feet thick. After the bentonite was allowed to hydrate (about 45 minutes), cement/bentonite grout was pumped by tremie to near ground surface below the top cap of the PVC casing assembly. At completion, a metal traffic box was installed flush with the ground surface at each monitoring well location except Monitoring Well SM-6A where a locking monument cover was installed. Monitoring well installation diagrams of the six wells are also presented in Appendix D. Two monitoring wells, R-8 and R-9, were installed in 1989. Schematic well diagrams for R-8 and R-9 are also included in Appendix D.

3.3.6 Groundwater Level Monitoring

Groundwater levels along the alignment were monitored using an electronic water-level indicator in the six monitoring wells installed during this investigation (i.e., SM-1, SM-1A, SM-3A, SM-6A, SM-9A, and SM-14), two previously-installed monitoring wells (R-8 and R-9) and eight of the open borings (SM-2, SM-4, SM-5, SM-7, SM-8, SM-10, SM-12 and SM-13). Groundwater level monitoring data are summarized in Table 3-3 and are graphically depicted on the geologic profile (Plate 2).

3.3.7 Groundwater Sampling

Four monitoring wells (SM-3A, SM-6A, SM-9A and R-8) were developed first, and groundwater samples were then obtained for chemical analyses. The details of well development and groundwater sampling are presented in Appendix D.

3.3.8 Vibrating-Wire Piezometers

Vibrating-wire piezometers were installed in selected borings to provide true hydrostatic pressure information in situ at critical depths for use in tunnel design. The instruments were installed and sealed at different depths in Borings SM-4, SM-5 and SM-6. Two depth intervals were chosen in each of the borings for monitoring. The lower monitoring interval was selected to encompass the tunnel zone with the piezometer tip placed approximately at the elevation of the tunnel crown. The upper interval was selected to monitor water pressures in a zone of highly fractured rock. Bedrock units being monitored included plutonic rocks (SM-4 and SM-6), Chico Formation conglomerate (SM-6), and Topanga Formation basalt (SM-9).

The vibrating-wire piezometers were installed in previously drilled 4-inch diameter coreholes in June 1993. Prior to installation, the drilled depth of the borings was confirmed by lowering a water-level sounder to the bottom of the boring. Volclay grout was pumped through a tremie pipe to seal the bottom of the boring and brought up to the base of the lower monitoring interval. After allowing the grout to set up for a minimum of 12 hours, the vibrating-wire piezometer was lowered to a predetermined depth. A sand pocket was formed around the piezometer by placing No. 1/20 Monterey sand through the tremie pipe. Volclay grout was pumped through the tremie pipe to create a seal above the sand pocket, and it was brought up to the base of the upper monitoring interval. The upper piezometer and surrounding sand pocket were installed, as before, after allowing the grout to set up for a minimum of 12 hours. The remainder of the boring above the upper sand pocket was sealed with volclay grout. Vibrating-wire piezometer installation details are illustrated in Figure 3-1.

3.3.9 Vibrating-Wire Piezometer Monitoring

Hydrostatic pressures are being periodically monitored by six vibrating-wire piezometers installed in Borings SM-4, SM-6 and SM-9. Each of these borings has two piezometers installed to monitor two separate depth intervals. Vibrating-wire piezometer monitoring data are summarized in Table 3-4.

3.4 LABORATORY TESTING

The laboratory testing consisted of geomechanical laboratory testing of soil samples and rock cores, chemical laboratory testing of groundwater samples, and other laboratory analyses of rock cores (x-ray diffraction, thin section analyses, and micropalentology).

3.4.1 Geomechanical Laboratory Testing

A geotechnical laboratory test program was developed and performed on selected soil and rock core samples. The purposes of testing were to provide data for soil and rock classification and to assess relevant physical and engineering properties of the rocks encountered along the tunnel alignment.

Emphasis of soil testing was placed on basic index properties for classification purposes. In addition to basic index properties, emphasis of rock testing was also placed on assessing strength, Young's modulus, swelling, slake durability, and hardness (drillability) characteristics for design and construction consideration.

The following sections provide a description of the scope and test procedures of the test program. A more detailed description of test procedures and results of individual tests are presented in Appendix E.

3.4.1.1 Soil Testing

A series of index property tests including 15 grain size analyses and 21 Atterberg Limits were performed on selected soil samples. Grain size analyses and Atterberg Limits were performed in accordance with the test methods and procedures specified in American Society for Testing Materials (ASTM) D422-63 and D4318-84, respectively. Grain size distribution curves are included in Appendix E.

3.4.1.2 Rock Testing

A series of rock tests were performed on selected rock core samples. All tests were performed in general accordance with applicable methods specified by ASTM, suggested by International Society of Rock Mechanics (ISRM). Samples tested under uniaxial compression were not saturated but were tested at existing moisture contents of the core in the core boxes. Point load tests were conducted on rock core after twelve hours of saturation. The test program and test standards are presented in Table 3-5. A summary of the test results and their evaluation are presented in Section 5.2.1.

3.4.2 Chemical Laboratory Testing

Chemical analytical laboratory testing of groundwater samples was performed to obtain groundwater quality data on the Santa Monica Mountains alignment. We understand that these data will be used by Parsons Dillingham (PD), Construction Management Consultant (CMC) to obtain a National Pollutant Discharge Elimination System (NPDES) permit from the California Regional Water Quality Control Board - Los Angeles Region (CRWQCB) to discharge groundwater encountered during tunnel construction.

Groundwater samples from Monitoring Wells SM-3A, SM-6A, SM-9A, and R-8 were collected after the wells were developed and purged. The well development and groundwater sample collection procedures are described in Appendix D. The groundwater samples were analyzed for volatile organic compounds, total recoverable petroleum hydrocarbons, gasoline hydrocarbons, general water quality parameters, EPA priority pollutants, and other analyses specified by the CRWQCB. The list of analyses is presented in Table 3-6. A summary of the chemical test results and their evaluation are presented in Section 5.2.2. The detailed chemical analyses test results are presented in Appendix F. We understand that the results will be evaluated by the CMC before applying for an NPDES permit.

During drilling of Boring SM-11, an artesian condition was observed. A groundwater sample was obtained and analyzed for volatile organic compounds, semivolatile organic compounds, selected metals, TDS, sulfide, specific conductance, and pH. The test results are summarized in Table F-2 of Appendix F.

3.4.3 Other Laboratory Analyses

Other laboratory analyses of the rock core samples consisted of x-ray diffraction, thin section analyses, and micropalentology. Brief descriptions of these analyses are outlined in the following paragraphs. Summaries of the results of the various laboratory analyses and their evaluation are presented in Section 5.2.3. The detailed results are presented in Appendix G.

3.4.3.1 X-Ray Diffraction

As part of the tunnel zone characterization program, 30 x-ray diffraction analyses were conducted on the various rock units occurring along the tunnel alignment to evaluate the mineralogy of selected samples. The samples submitted for analyses were taken from the tunnel envelope that extends 20 feet above the tunnel crown to approximately 20 feet below the tunnel invert. The analyses were done on nine granitic samples, three Chico Formation conglomerate samples, four Lower Topanga Formation sandstone and conglomerate samples, two Middle Topanga Formation basalt breccia samples, and ten Upper Topanga Formation sandstone and shale samples. These analyses were conducted by University of Utah Research Institute, Earth Science Laboratory (UURI) for Science Applications International Corporation. Results are tabulated in Table 5-7. In order to verify the UURI results, duplicate samples of Topanga Formation basalt breccia were submitted to Dr. Robert E. Winchell of California State University, Long Beach for verification purposes. A copy of Dr. Winchell's results is included in Appendix G.

3.4.3.2 Thin Section Analyses

Thin sections of representative rock core samples were analyzed microscopically. The microscopic analyses were conducted to provide additional data on the mineralogical composition of the various rock types present along the tunnel alignment. In addition to the rocks mineralogical makeup, the type of cementing agent, alteration and weathering products, and micro-structural or features associated with tectonic strain, were analyzed. The analyses were conducted on selected rock cores obtained from Borings SM-3, SM-4, SM-5, SM-7, SM-8, SM-9 and SM-11. A total of 22 thin sections were examined and described, and the results are summarized in Section 5.2.3. Detailed descriptions of each thin section are presented in Appendix G.

3.4.3.3 Micropaleontology

Micropaleontologic analyses were conducted on samples of claystone/clay gouge material obtained from Borings SM-1 and B-8 drilled within the Hollywood fault zone. Boring SM-1 is located on La Brea Avenue on the south side of the Santa Monica Mountains. Boring B-8 was drilled along Camino Palmero about 1,200 feet west of La Brea Avenue. The analyses were done in order to identify the age of the material and its provenance. The samples from Borings SM-1 and B-8 were sent to Micropaleo Consultants, Inc. in Encinitas, California for microfossil and pollen identification. The evaluation of the results is presented in Section 5.2.3. The results of their analyses are presented in Appendix G.

TABLE 3-1. SUMMARY OF BORINGS

Boring No.	Location	Approximate Station Along Center Line of AR Track	Approximate Offset From Center Line of AR Track[1] (feet)	Approximate Elevations[2]			Total Depth of Boring (feet)	Lithology
				Ground Surface (feet)	Tunnel Crown (feet)	Tunnel Invert (feet)		
SM-1	1850 La Brea Avenue	627+95	335RT.	485	347	327	199	0-45' Alluvium; 45'-95' Granodiorite; 95'-116' Puente Formation Claystone; 116'-199' Alluvium
SM-1A	1851 La Brea Avenue	628+60	320RT.	492	348	328	180	0-7' Alluvium; 7'-180' Granodiorite
SM-1B	1850 La Brea Avenue	628+10	340RT.	487	348	328	170	0-29' Alluvium; 29'-104' Granodiorite; 104'-125' Puente Formation Claystone; 125'-143' Granodiorite; 143'-170' Alluvium
SM-1C	1850 La Brea Avenue	627+40	330RT.	481	347	327	76	0-46' Alluvium; 46-59' Granodiorite; 59-63' Alluvium; 63-66' Granodiorite; 66-76' Alluvium
SM-1D	1850 La Brea Avenue	627+15	330RT.	476	346	326	46	0-34' Alluvium; 34-42' Granodiorite; 42-46' Alluvium
SM-2	Runyon Canyon Park	637+30	130LT.	720	350	330	431	0-4' Fill; 4'-431' Granodiorite
SM-3	Runyon Canyon Park	645+85	60LT.	686	350	330	394	0-10' Alluvium; 10'-394' Granodiorite
SM-4	Runyon Canyon Park	662+60	70LT.	960	375	355	626	0-12' Fill; 12'-626' Granodiorite
SM-5	Runyon Canyon Park	672+10	130LT.	1226	396	376	890	0-439' "Chico" Formation Conglomerate; 439'-558' "Chico" Formation Conglomerate with Sheared and Brecciated Zones; 558'-890' Granodiorite
SM-6	Runyon Canyon Park	677+50	60RT.	1180	408	388	830	0-7' Fill; 7'-720' "Chico" Formation Conglomerate with Intervals of Sandstone; 720'-727' "Chico" Formation Claystone; 727'-830' Granodiorite
SM-7	2649 La Cuesta Drive	686+40	225LT.	1100	428	408	739	0-47' Las Virginis Sandstone; 47'-275' Simi Conglomerate; 275'-739' "Chico" Formation Conglomerate with Intervals of Sandstone
SM-8	7404 Mulholland Drive	696+35	0RT.	1175	450	430	788	0-9' Fill; 9'-55' Topanga Formation Basalt Breccia; 55'-398' Topanga Formation Basalt; 398'-567' Topanga Formation Basalt Breccia; 567'-788' Topanga Formation Sandstone with Conglomerate
SM-9	Mulholland Drive/ Woodrow Wilson Drive	709+50	170LT.	1112	479	459	693	0-8' Alluvium; 8'-211' Topanga Formation Basalt Breccia; 211'-315' Topanga Formation Basalt; 315'-693' Topanga Formation Basalt Breccia
SM-10	Mulholland Drive/ Floye Drive	721+70	190LT.	1147	505	485	703	0-703' Topanga Formation Conglomerate and Sandstone

TABLE 3-1. SUMMARY OF BORINGS

Boring No.	Location	Approximate Station Along Center Line of AR Track	Approximate Offset From Center Line of AR Track[1] (feet)	Approximate Elevations[2] Ground Surface (feet)	Tunnel Crown (feet)	Tunnel Invert (feet)	Total Depth of Boring (feet)	Lithology
SM-11	3600 Multiview Drive	734+60	30LT.	778	528	508	307	0-8' Alluvium; 8-307' Topanga Formation Sandstone and Shale
SM-12	3773 Fredonia Drive	742+40	230LT.	671	525	505	207	0-10' Alluvium; 10'-207' Topanga Formation Shale and Sandstone
SM-13	Lankershim Boulevard/ Cahuenga Boulevard	756+05	10LT.	590	521	501	130	0-15' Alluvium; 15'-130' Topanga Formation Shale and Sandstone
SM-14	Lankershim Boulevard/ Hollywood Freeway	759+05	80RT.	580	520	500	56	0-51' Alluvium; 51'-56' Topanga Formation Sandstone and Shale

Notes: (1) RT = Right, LT = Left

(2) Elevations refer to Los Angeles City Engineers Datum - 1975 Adjustment

TABLE 3-2. SUMMARY OF DRILLING METHODS AND EQUIPMENT (1 of 2)

Boring	Bits	Drilling Rig
SM-1	Christensen core to 70'; Surface set diamond to T.D.[1]	Mobile B-53
SM-1A	Christensen core to 25.5'; Surface set diamond to T.D.	Mobile B-53
SM-1B	Christensen core to 50'; Surface set diamond to T.D.	Mobile B-53
SM-1C	Hollow-stem auger to T.D.	Failing F-10
SM-1D	Hollow-stem auger to T.D.	Failing F-10
SM-2	Stratapax to 200' with air; Diamond impreg[2] to T.D.	Ingersol-Rand 300 and Mobile B-80
SM-3	Stratapax to 10'; Diamond impreg. to T.D.	Mobile B-53
SM-4	Surface set diamond to 265'; Stratapax to 291'; Surface set diamond to 583'; Diamond impreg. to T.D.	Mobile B-80
SM-5	Diamond impreg. to T.D.; HQ to 456.7'; NQ to T.D.	Longyear 38
SM-6	Geoset (tungsten carbide) to 30'; Diamond impreg. to T.D.	Longyear 38
SM-7	Auger to 4'; Stratapax to 30'; Diamond impreg. to T.D.; HQ to 512', then NQ to T.D.	Mobile B-53
SM-8	Diamond impreg. to 100'; Surface set to T.D.	Longyear 38
SM-9	Stratapax to 63.5'; Diamond impreg. to 137'; Stratapax to 145'; Surface set diamond to 149'; Stratapax to 265'; Surface set diamond to 300'; Geoset (tungsten carbide) to T.D.	Mobile B-80

TABLE 3-2. SUMMARY OF DRILLING METHODS AND EQUIPMENT (2 of 2)

Boring	Bits	Drilling Rig
SM-10	Diamond impreg. to T.D.	Mobile B-80
SM-11	Hollow-stem auger to 23.5'; Diamond impreg. to T.D.	Mobile B-53
SM-12	Christensen core to 13'; Diamond impreg. to T.D.	Mobile B-53
SM-13	Christensen core to 40'; Diamond impreg. to T.D.	Mobile B-53
SM-14	Hollow-stem auger to T.D.	Acker D2

Notes: (1) T.D. = Total Depth
(2) Impreg. = Impregnated bit

TABLE 3-3. SUMMARY OF GROUNDWATER LEVEL DATA

Monitoring Well No.	Date of Installation	Depth of Well/Boring (feet)	Ground Surface Elevation (feet)	Depth to Water Level (feet)		Elevation of Groundwater Level (feet)	
				Nov 92	March 93	Nov 92	March 93
SM-1	Nov 92	199 (WELL)	485	Dry	Dry	–	–
SM-1A	Nov 92	180 (WELL)	492	16	13	476	479
SM-2	Oct 92	431 (BORING)	720	198	188	522	532
SM-3A	Nov 92	95 (WELL)	686	43	12	643	674
SM-4	Oct 92	626 (BORING)	960	97	72 (June 93)	863	888 (June 93)
SM-5	Dec 92	890 (BORING)	1226	–	72	–	1154
SM-6A	Nov 92	127 (WELL)	1180	76	50	1104	1130
SM-7	Sep 92	739 (BORING)	1100	156	137	944	963
SM-8	Sep 92	787.5 (BORING)	1175	141	87	1034	1088
SM-9A	Nov 92	152 (WELL)	1112	106	96	1006	1016
SM-10	Nov 92	703 (BORING)	1147	84	63	1063	1084
SM-11	Oct 92	307 (BORING)	778	+3	–	781	–
SM-12	Oct 92	206 (BORING)	671	26	21	645	650
SM-13	Nov 92	130 (BORING)	590	12	10	578	580
SM-14	June 93	55.5 (WELL)	580	–	7 (June 93)	–	573 (June 93)
R-8	May 89	201 (WELL)	665	18	13	647	652
R-9	May 89	139 (WELL)	605	–	10	–	595

NOTE: Water in Boring SM-11 flowed to the ground surface and stabilized overnight in the stickup of drill pipe at 3 feet

TABLE 3-4. SUMMARY OF VIBRATING-WIRE PIEZOMETER DATA

Boring No.	Ground Surface Elevation (ft)	Date of Installation	Static Groundwater Level Depth/Elevation[1] (ft)	Upper Piezometer				Lower Piezometer			
				Tip Installation Depth/Elevation (ft)	Lithology	Depth of Instrument Below Static Groundwater Level (ft/psi)[2]	Reading[3] (psi)	Tip Installation Depth/Elevation (ft)	Lithology	Depth of Instrument Below Static Groundwater Level (ft/psi)[2]	Reading[3] (psi)
SM-4	960	6-93	73/887	268/692	granodiorite	195/85	106	585/375	granodiorite	512/222	221
SM-6	1,180	6-93	63/1117	300/880	conglomerate	237/103	105	771/409	granodiorite	708/307	268
SM-9	1,112	6-93	94/1018	310/802	basalt breccia	216/94	119	633/479	basalt breccia	539/234	232

(1) Measurement immediately prior to installation
(2) 2.307 feet = 1 psi
(3) Measurement made on June 12, 1993

TABLE 3-5. SUMMARY OF ROCK TEST PROGRAM AND PROCEDURES

Test Type	No. of Tests	Test Standard[1]
Bulk Specific Gravity	51	ASTM C97-83
Bulk Density	101	ISRM (Brown, 1981)
Moisture Content		ASTM D2216-80
Uniaxial Compression with and without Stress-Strain Measurements	106	ISRM (Brown, 1981)
Slake Durability	15	ASTM D4644-87
Swell Pressure	2	ISRM (Brown, 1981)
Modified Taber Abrasion Hardness	24	Acceptable Method Used in Engineering Practice

Note: (1) Refer to Appendix E for a description of these test procedures.

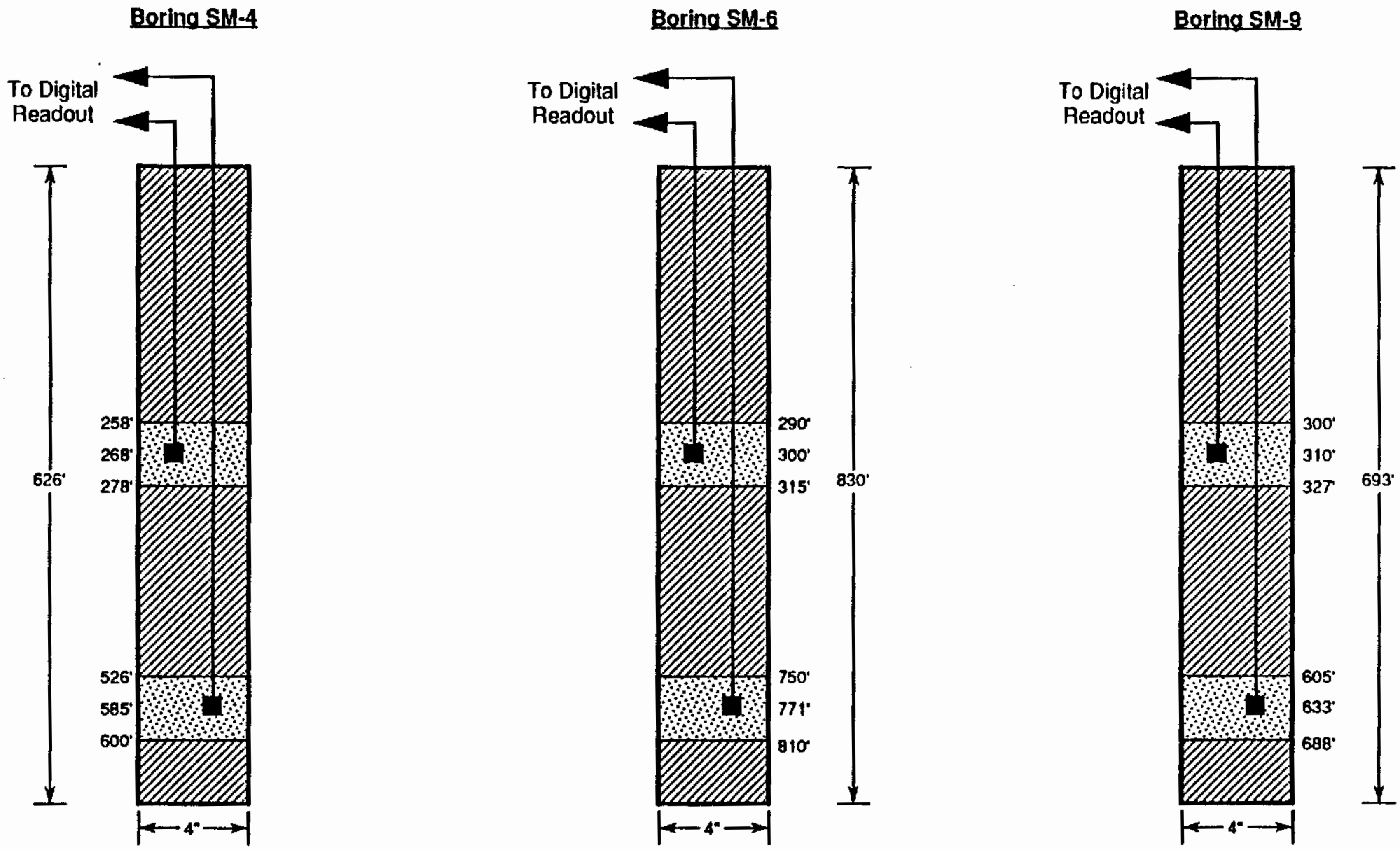
TABLE 3-6. LIST OF CHEMICAL ANALYSES FOR GROUNDWATER SAMPLES (1 of 2)

Analyte Number	Analyte	EPA Test Method	Requested Detection Limit (ppb)	Preservatives	Field Filter	Container	Storage
1	Purgeable Volatile Organic Compounds	624	5 to 20	Cool 4°C 0.008% $Na_2SO_2O_3$ [1]	No [4]	Two - 40 ml glass	7 days [2]
2	Semivolatile Organic Compounds	625	5 to 50	Cool 4°C	No	Two - 1 liter glass	7 days
3	Total Petroleum Hydrocarbons	418.1	500	H_2SO_4 to pH <2 Cool 4°C	No [5]	One - 1 liter glass	28 days
4	Oil & Grease	413.1 or 413.2	500	H_2SO_4 to pH <2 Cool 4°C	No	One - 1 liter glass	28 days
5	Total Fuel Hydrocarbons, Gasoline and Diesel	8015 LUFT	Gasoline 20 Diesel 200	Cool 4°C	No [5]	Two - 40 ml glass	14 days
6	CCR Title 22 Metals	SW-846 or ICP-MS	1/2 the MCL	HNO_3 to pH <2	Yes [3]	One - 1 liter plastic	6 months
7	Chromium VI	7196	10	Cool 4°C	Yes [3]	One - 500 ml liter plastic	24 hours
8	Aquatic Toxicity	NA	N/A	Cool 4°C	No	One - 5 gallon plastic	24 hours
9	Biological Oxygen Demand (BOD)	405.1	5,000	Cool 4°C	No [6]	One - 500 ml glass	48 hours
10	Chemical Oxygen Demand (COD)	Hach Kit	20,000	Cool 4°C	No	One - 400 ml glass	28 days
11	Nonfilterable Residues Total Suspended Solids (TSS)	160.2	1,000 to 5,000	Cool 4°C	No	One - 1 liter plastic or glass	7 days
12	Settleable Solids (SS)	160.5	1,000 to 5,000	Cool 4°C	No	One - 1 liter plastic or glass	2 days
13	Turbidity	180.1	1,000 to 5,000	Cool 4°C	No	One - 100 ml plastic	48 hours
14	Filterable Residues - Total Dissolved Solids (TDS)	160.1	10,000	Cool 4°C	No	One - 1 liter plastic or glass	7 days
15	Chloride	325.3	10,000	None	No	One - 100 ml plastic	28 days
16	Sulfide	376.2	100	$ZnCO_2CH_3$ & NaOH to pH > 9 - Cool 4°C	No	One - 500 ml plastic	7 days
17	Sulfate	375.3	10,000	Cool 4°C	No	One - 500 ml plastic	28 days

TABLE 3-6. LIST OF CHEMICAL ANALYSES FOR GROUNDWATER SAMPLES (2 of 2)

Analyte Number	Analyte	EPA Test Method	Requested Detection Limit (ppb)	Preservatives	Field Filter	Container	Storage
18	Nitrite	300	100	Cool 4°C H_2SO_4 to pH <2	No	One - 100 ml plastic	28 days
19	Nitrate	300	100	H_2SO_4 to pH <2 Cool 4°C	No	One - 100 ml plastic	28 days
20	Specific Conductance	120.1	N/A	Cool 4°C	No	One - 500 ml plastic	28 days
21	pH	150.1	N/A	None	No	One - 100 ml glass	Immediately

Notes:
(1) Should only be used in presence of residual chlorine
(2) CRWQCB recommends 7 day storage time for EPA 624
(3) Field filter with 0.45 micron filter
(4) 24 hour gravity settle of solids in the laboratory prior to analysis
(5) Filter sample in laboratory prior to analysis using centrifugation
(6) Laboratory filtration prior to analysis



#1/20 Monterey Sand

Volclay Grout

Vibrating-Wire Piezometer and Attached Cable

Not to Scale

The Earth Technology Corporation

Project No.: 92-2050

Geotechnical Investigation
Santa Monica Mountains
Segment 3, Metro Red Line

Vibrating-Wire Piezometer Installation Details

6-93

Figure 3-1

4.0 GEOLOGIC CONDITIONS

4.1 REGIONAL SETTING

4.1.1 Geologic Setting

The proposed subway tunnel will pass through the eastern portion of the Santa Monica Mountains, between the Hollywood area in the Los Angeles Basin to the south, and the Universal City area in the San Fernando Valley to the north (Figure 4-1). Except for about 800 feet of its northern end in the San Fernando Valley, the proposed alignment is entirely beneath the steep terrain of the mountains.

The Santa Monica Mountains are an east-west trending range that extends about 50 miles along the Southern California coast, from the Oxnard Plain to the narrows of the Los Angeles River at Glendale. The range is a maximum of about 13 miles wide and reaches an elevation of over 3,000 feet near its western end, but it is only about 3 miles wide near the study area and elevations rarely exceed 1,500 feet.

The Santa Monica Mountains and San Fernando Valley are within the Transverse Range physiographic province in Southern California. The southern margin of the Santa Monica Mountains is considered to be on the border of the province, with the Los Angeles Basin and San Gabriel Valley separating the Transverse Ranges from the northwest-trending Peninsular Ranges.

The general geology and structure of the mountains is that of a large complexly faulted east-west trending anticline that has a core of metamorphic and plutonic basement rocks and a partial cover of overlying sedimentary and volcanic strata. The oldest rocks in the range are slates and phyllites of the Late Jurassic Santa Monica Formation and younger Cretaceous plutonic rocks. Bedrock of Late Cretaceous and Tertiary ages are exposed along the north flank of the Santa Monica Mountains, and include units of both sedimentary and volcanic origin. The succession of rocks is not continuous with several unconformities interrupting the sequence. Erosion of the exposed bedrock formations has resulted in alluvial fans projecting from the main canyons out onto the adjacent basin floors.

North-south compression within the Transverse Ranges folded the plutonic, sedimentary and volcanic bedrock formations into an anticlinal structure that has since had its south limb truncated by faulting. Faulting has caused rocks of the northern limb of the anticline to partially override bedrock and alluvial deposits to the south along the north-dipping Hollywood fault zone. Late Pleistocene age alluvial units and possibly Holocene alluvium have been displaced along the Hollywood fault, indicating that the same structural processes active in the past are continuing today.

4.1.2 Tectonic Setting

The greater Los Angeles area occupies the juncture between two major intersecting fault systems, the east-west trending fault system, associated with the Transverse Ranges and the northwest-southwest-trending San Andreas system, which dominates the structural fabric of California. Development of the Los Angeles Basin and bordering mountain ranges is controlled by the two structural features.

The Transverse Ranges are dominated by range-bounding faults that display reverse displacement (thrust faults). Major active and potentially active faults associated with this system are the Sierra Madre-Cucamonga, Raymond, Hollywood, Santa Monica and Malibu Coast faults (Figure 4-2). The Hollywood fault, in the site area, forms the boundary between the Peninsular Ranges to the south and the Transverse Ranges to the north. The Santa Monica Mountains are a product of uplift along the Hollywood and Santa Monica faults, which occur along the south flank of the range.

The faults of the San Andreas system are characterized by right-lateral-slip faults that trend to the northwest. Major components of the system in Southern California include the San Jacinto, Whittier-Elsinore, Newport-Inglewood, and Palos Verdes fault zones. The recent 1992 Landers earthquake occurred in the Mojave Desert along the Johnson Valley, Camp Rock and Emerson faults which are also associated with the San Andreas system (Figure 4-2). Based on analysis of the 1987 Whittier Narrows earthquake, investigators find that deep beneath the alluvial basins and low hills of the region are a system of north-dipping reverse faults (blind thrusts) that underlie large portions of the central Los Angeles Basin and adjacent uplands. These faults generally do not rupture the ground surface but are commonly associated with folding expressed at the ground surface. Many of the surrounding upland hills consist of folds, often anticlines that may have buried blind thrusts beneath them. The Whittier Narrows earthquake of 1987 is believed to be associated with a blind thrust.

4.1.3 Seismicity

The project site is located in an area having relatively high seismic potential and has experienced shaking from numerous large earthquakes in historical time. Two regionally intersecting, major, active fault systems generate earthquakes. These are including the northwest-trending San Andreas system and the east-west-trending faults associated with the Transverse Ranges.

Figure 4-2 shows the known major active and potentially active faults in the greater Los Angeles area and includes the recently active faults associated with the June 1992 Landers Earthquake (magnitude 7.5) in San Bernardino County (approximately 105 miles east of the site).

An earthquake computer search (Blake, 1992) was performed to graphically show where historic earthquakes (epicenters) have occurred relative to the site. A search radius of 150 miles was made from the approximate mid-point of the tunnel alignment. Earthquakes with a magnitude 4 to 7.9 that have occurred since 1800 are shown in Figures 4-3A and 4-3B. The largest historic earthquake was a magnitude 7.9 (1857 Fort Tejon Earthquake) on the San Andreas fault located about 116 miles northwest of the project area. The closest moderate-sized earthquake (magnitude 6.4, 1971) was located 20 miles to the north of the project site on the San Fernando fault.

Moderate or major earthquakes (magnitude 5 or above) historically have not occurred along the Hollywood fault which traverses the tunnel corridor. Numerous small earthquakes have occurred in proximity to the fault zone, but may or may not be associated with movement on the feature. The Hollywood fault has ruptured in late Quaternary time and very likely in Holocene time (past 10,000 years) based on recent studies by Earth Technology (1993) and Dr. Kerry Sieh (1993). The 1987 Whittier Narrows Earthquake (magnitude 5.9) occurred on a buried north-dipping fault with no surface expression. The previously unidentified fault is part of a system of blind thrust faults that underlie the basin between Whittier Narrows and the Pacific Ocean.

Earthquakes are expected to periodically occur in the site region during the life of the project. There is a possibility of direct surface-fault rupture along the Hollywood fault at the tunnel crossing, though the probability of such an event is considered low, based on relatively long return periods of displacement (Sieh, 1993). In the event that the Hollywood fault was to rupture and produce a major earthquake near or within the site area, it is likely that very strong ground motions could occur locally, and slip of the fault across the tunnel would be possible.

4.1.4 Hydrogeology

The hydrogeology of the greater Los Angeles area consists of two general types of groundwater regimes that include bedrock uplands and broad alluvial basins. The bedrock uplands surrounding most of the basins are generally referred to as being non-water bearing. Adjacent alluvial basins are considered excellent resources for groundwater, and historically have been utilized extensively for domestic and commercial water supply. The study area is situated almost entirely in the uplands of the Santa Monica Mountains. North of the mountains lies the San Fernando Valley Basin and to the south is the Central Coastal Plain, which is divided into four interconnected groundwater basins (Figure 4-4). The valley area south of the tunnel corridor is referred to as the Hollywood Basin. The details of the groundwater regimes associated with the Santa Monica Mountains and adjacent basins are discussed in Appendix H. Groundwater conditions specific to the project are described in Section 4.2.4.

4.2 SITE GEOLOGY

4.2.1 Geologic Units

The tunnels will be driven through eight different bedrock units (formational status) ranging in age from Cretaceous to Upper Miocene. These consolidated bedrock units have been grouped into six tunnel reaches based on lithology and geologic age. Each reach has been identified by station number and is described below from south to north (oldest to youngest). Detailed formational descriptions are presented in Appendix H.

Three general rock types will be encountered and include: plutonic (granitics), volcanics (basalt), and a variety of sedimentary lithologies (conglomerates to siltstone/shale). Boundaries between each unit or reach include conformable, unconformable, and fault contacts. All contacts dip at intermediate angles to the north/northeast. Plate 2 shows, in profile, the succession of the anticipated lithologies along the tunnel alignment. The stratigraphic sequence of rock units and their relative thicknesses are portrayed in Figure 4-5. Each of these is described below according to tunnel reaches from the south to the north.

Reach 1 - Station 629+60 to 679+80, Length, 5,020 Feet; Plutonic Rocks, Cretaceous Age

Reach I contains undifferentiated plutonic rocks that consist of granodiorite, quartz diorite, and quartz monzonite. These plutonic (granitic) rock types are generally massive, weakly foliated, and medium to coarse grained. Dikes of basalt, felsite, and aplite will be encountered that range from a few inches to several tens of feet thick at irregular intervals. Infrequent inclusions of gneiss or schist a few inches to a few feet across are expected. These are typically rich in biotite mica that facilitates partings along schistosity.

The rock is differentially weathered and fractured. In general, the greater the overburden the less the rock is weathered. Nearly decomposed and intensely sheared and brecciated granitic rocks are anticipated within and for a few hundred feet north of the Hollywood fault zone. Borings SM-1, SM-1A, SM-1B and SM-2 indicate that the most weathered rock occurs nearest the fault. The degree of weathering decreases northward as cover increases. Near the middle of Reach 1, the rock slowly transitions to fresh (unweathered/unaltered).

Sheared zones are anticipated at irregular intervals along the reach and may vary from a few inches to a few tens of feet wide. Weathering, brecciation, and alteration in these zones usually intensifies and lowers rock strengths significantly.

Reach 2 - Station 679+80 to 693+00, Length 1,320 Feet; Chico Formation and Simi Conglomerate, Late Cretaceous and Paleocene Age

The Chico Formation and Simi Conglomerate consist of thick beds of gravel to cobble conglomerates and sandstone interbeds, with a few widely-spaced thin claystone/shale layers. Clasts within the conglomerate beds are rounded and usually do not exceed 8 inches and rarely to 24 inches in diameter.

The conglomerate is matrix-supported by sandstone and silty sandstone with calcite and argillaceous cement. Clasts consist of quartzite, and granitic and metavolcanic rock types. The sandstone is fine- to medium- grained and generally massive and arkosic.

At tunnel elevation, the rock is fresh without apparent alteration. The rock is slightly to moderately well cemented. Cobbles tend to break out of matrix with minimal to moderate mechanical effort. Granitic clasts may not easily disintegrate once dislodged.

A sheared zone (fault unnamed) up to about 15-feet wide, forms the contact between the underlying plutonic rock and the sediments. The zone consists of a brecciated and sheared rock mass with angular clasts of broken siltstone and other rocks related to the conglomerate. The contact is abrupt and the rock to either side of the zone is expected to be altered and sheared.

Reach 3 - Station 693+00 to Station 698+30, Length 530 Feet; Las Virgenes Sandstone and Lower Topanga Formation, Paleocene and Lower Miocene Age

The Las Virgenes and Lower Topanga formations collectively consist of thick massive beds of sandstone and conglomeratic sandstone. Three-foot thick conglomerate beds with clasts to 18-inches diameter may be encountered but are rare. Near the base of this lithologic assembledge, are possible multicolored mudstone and claystone interbeds.

The rocks are essentially fresh and just slightly hydrothermally altered (chlorite and clay minerals) at tunnel depth. The sandstone beds are moderately well-cemented with calcite, and the conglomerate beds generally are weakly cemented and slightly friable. The Las Virgenes sandstone is an arkosic unit up to 125 feet thick and is poorly cemented. Bedding is indistinct and massive.

Reach 4 - Station 698+30 to 716+10, Length 1,780 Feet; Middle Topanga Formation, Miocene Age

The Middle Topanga Formation consists of a black, very thick sequence of extrusive and possibly minor intrusive volcanic basalt breccia and basalt flows. The breccia dominates and is composed of angular basalt fragments up to several inches across in an altered (chlorite) volcanic fine-grained matrix. Occasional and widely spaced sandstone lenses and layers to 50-feet thick lie conformably within the volcanics, and dip northeast similar to the regional structural trend.

At tunnel elevation, the rock is unweathered (fresh), but the rock mass appears to have undergone hydrothermal alteration with alteration of some minerals to chlorite and smectite group minerals. Many joints, shears, and vesicles are filled with white zeolite, calcite, or chlorite minerals. The sequence lacks quartz entirely. Iron pyrite has been disseminated within the rock mass or deposited along some joints locally.

The lack of quartz and the high degree of chemical (hydrothermal) alteration, have produced a rock with properties not like most hard intact basalt. The Topanga basalts are massive, though jointed and sheared, but have low strength and can be mechanically broken with just moderate effort.

Reach 5 - Station 716+10 to 730+70, Length 1,460 Feet; Upper Topanga Formation (Massive Sandstone), Upper Miocene Age

Reach 5 contains the lower sandstone sequences of the Upper Topanga Formation. The base of the Upper Topanga Formation is predominantly conglomerate with rare clasts up to 24 inches diameter. Nearby tunnels encountered 650 to 700 feet of conglomerate overlying the basalt. The sandstone is medium-to coarse-grained, massive to thickly bedded, and locally contains widely spaced gravel conglomerate zones (lenses). The rock is very massive and bedding is indistinct. At tunnel elevations, the rock is unweathered (fresh), not altered and is moderately cemented with calcite.

As Reach 6 is approached to the north, the rock slowly transitions from coarse to finer grained materials. Bedding becomes more apparent within the transition.

Reach 6 - Station 730+30 to 761+40, Length 3,070 Feet; Upper Topanga Formation (Sandstone and Siltstone/Shale) Upper Miocene Age

Interbedded sandstone and siltstone/shale dominate the northern most reach of the tunnel section. The sandstones are fine to coarse grained, and beds are up to several feet thick. The siltstone/shale is thinly bedded to laminated with moderately well developed parting along many bedding planes.

The rock is fresh (unweathered) at tunnel depth. Cementation is variable ranging from slight to moderate. Some sandstone beds are weakly cemented and easily friable. The siltstone and shales are judged to be slightly expansive.

At the end of Reach 6, lies the east-northeast trending Benedict Canyon fault zone. The width of the shearing and gouge is unknown at the tunnel. Adjacent to the zone, the Topanga Formation is sheared and deformed as observed in Boring SM-13. Rock strengths are anticipated to be low. In the same area, the bedrock overburden is rapidly diminishing and alluvium is thickening as found in Boring SM-14. Although SM-14 is located 100 feet south of the alignment, it indicates a trend that the thickest alluvium occurs beneath the Hollywood Freeway. It is possible that young alluvial materials and groundwater will be encountered in the tunnel crown beneath the Hollywood Freeway.

4.2.2 Structural Geology

The gross geologic structure along the tunnel corridor consists of a relatively uncomplicated faulted asymmetrical anticline. The anticline trends approximately east-west. The tunnel will traverse only the north flank of the structure. Plate 2 depicts the general structural features (bedding and lithologic contacts) that have moderate northeast inclinations. The axis of the anticline lies either within the granitic terrain, probably south of Station 670+00, or has been faulted away at the tunnel and may lie beneath the alluvium south of the mountain front.

Faulting was accompanied by uplift and folding of the mountains. The Hollywood fault is the dominant feature and marks the south side of the mountain. This fault is inclined to the north at 60 to 70 degrees displays vertical displacement, and likely some left-slip movement. The fault juxtaposes Quaternary-age alluvium to the south against the Cretaceous age granitic rocks within the mountain mass. The width of the fault gouge and crushed rock may be up to 150 feet-wide (horizontal distance), and is judged to form an effective groundwater barrier, ponding water to the north. The Hollywood fault is known to have been active in late Quaternary time with the possibility of Holocene movement. The tunnels will penetrate the fault at the south end of the alignment. Additional information regarding the Hollywood fault is discussed in reports by Earth Technology (1993) and Sieh (1993).

Many minor and a few more significant faults and shear zones will be crossed by the tunnel. Though faults have been mapped on the ground surface, their projected intercepts at tunnel depth can not be determined. The minor zones may be inches to a few feet wide and consist of several intersecting or closely spaced shears with associated gouge. More significant faults, if any, may consist of sheared, brecciated and chaotic zones several tens of feet wide with an abundance of gouge.

The tunnels will cross a shear zone or unnamed fault separating the plutonic rocks and the Chico Formation (near Station 679+80). The sense or amount of displacement along this north-dipping zone are unknown. The zone is about 15 feet wide and consists of fragmented bedrock materials contained within clayey gouge.

Another major fault that the tunnel will cross is the Benedict Canyon fault inferred from literature to be located at the extreme north end of the alignment (near Station 756+10). The actual location of this fault zone is questionable. Based on published data, it is characterized as a near vertical fault with both vertical and left lateral displacement. The zone of faulting is likely to be 100 or more feet wide in the tunnel, and consists of sheared and brecciated sandstone and siltstone/shale materials. An associated sheared zone (AEG, 1982) is also inferred to intersect the tunnel just south of the Benedict Canyon fault (Plate 2). None of the field explorations encountered either of these fault structures.

Bedding along the corridor strikes generally to the northwest and dips to the northeast at moderate to steep angles. This general trend represents the north flank of the Santa Monica Mountain anticline. Bedding is indistinct (vague) in the coarse grained units of massive conglomerate and sandstone. The interbedded sandstone and siltstone/shale units display very pronounced bedding, especially in the north portion of the alignment. Locally, in Reach 6, reversal in dip and overturning of beds may occur that are related to minor folds superimposed on the north flank of the anticline. Bedding becomes near vertical adjacent to the Benedict Canyon fault.

4.2.3 Rock Mass Discontinuities

Rock mass discontinuities are any defects in the rock mass and include joints, shears, foliation, and bedding partings. The discontinuities are also differentiated according to the infilling materials (clay or non-clay). If discontinuities are healed (i.e. cemented together), the type of cementation (calcite, chlorite, zeolite, quartz) is noted on the boring logs. Very few patterns were recognized relative to the frequency or orientation of discontinuities at tunnel depth, especially for joints. Locally, areas of intense rock breakage are described as brecciated or fractured rock. Table 4-1 characterizes the various types of discontinuities and statistically shows ranges for various parameters from the boring data. Table 4-2 summarizes the rock mass discontinuity data for the tunnel envelope only. Table 4-3 provides an explanation of the terminology used in Tables 4-1 and 4-2. The descriptive terms used are defined in Appendix A.

Discontinuities for each tunnel reach are discussed below.

Reach 1 - Station 629+60 to 679+80, Length 5,020 Feet; Plutonic Rocks

Discontinuities in the plutonic rocks consist of joints, shears, and foliation. Joint spacing in the plutonic rocks varies from moderately close to very close with the highest percentage of joints spaced between 2 and 8 inches apart. Most of the joints appear in one or two sets, with a possible random set. Dip angles vary from horizontal to vertical. Surfaces are mostly planar and are slightly rough. Jointing within the plutonic rocks is expected to be variable, but there is an indication that spacing between joints is greatest north of Boring SM-3. The plutonic rocks are weakly foliated with a vaguely north-dipping orientation.

Reach 2 - Station 679+80 to 693+00, Length 1,320; Chico Formation and Simi Conglomerates

Massive sandstone and conglomerate units are poorly bedded except along rare thin clayey or silty beds. Bedding generally dips northward between 40 and 60 degrees. Joints are commonly closely spaced (2.4 to 8 inches), and surfaces are characteristically planar and rough. Joint openings are tight or clay filled. Joints occur mostly in two intersecting sets with a third superimposed random set.

Reach 3 - Station 693+00 to 698+30, Length 530; Lower Topanga Formation and Las Virgenes Sandstone

Sandstones and conglomeratic sandstone beds are generally massive, indistinctly bedded and dip northward at approximately 50 degrees. Joints are spaced close to moderately close (2.4 to 8 inches, and occasionally to 24 inches apart). Joint surfaces are planar and rough. Joint openings are tight to slightly weathered.

Reach 4 - Station 698+30 to 716+10, Length 1,780 Feet; Middle Topanga Formation

Volcanic rocks of the Middle Topanga Formation are nearly massive in structure. Flow structure is not apparent, but interbedded sandstone lenses indicate that the volcanic flows and breccias, at least in part, were deposited over flat-lying beds of the lower Topanga Formation. Subsequently, the entire formation was tilted by folding to the north roughly 40 degrees.

At tunnel depth, the volcanic rocks contain at least one systematic set of joints superimposed by one random set. Joints are spaced close to very close (0.4 to 8 inches). Surfaces are planar often polished (smooth), and clay coated or filled. Random shearing within the rock mass is common but most have been healed with chlorite, smectite, zeolites, or calcite.

Reach 5 - Station 716+10 to 730+70, Length 1,460 feet; Upper Topanga Formation (Sandstone)

Reach 5 contains massive sandstone beds with occasional conglomeratic zones. Bedding is poorly developed but generally dips toward the north at about 60 to 65 degrees. Joint spacing ranges from moderately close to wide (8 inches to 6.6 feet apart). Joint surfaces are planar and rough. Some joints are healed typically with calcite.

Reach 6 - Station 730+30 to 761+40, Length 3,070 Feet; Upper Topanga Formation (Sandstone and Siltstone/Shale)

The bedrock in Reach 6 is poorly indurated and nearly soil-like in engineering properties. Bedding is very pronounced and generally dips northeast from 50 degrees to near vertical, although variations due to folding locally exist. Spacing between joints ranges from moderately close to wide (8 inches to 6.6 feet apart). Joint surfaces are planar and slightly rough. Fracture openings are filled or coated with clay. Shearing and polished surfaces along bedding planes are common and are often clay coated.

4.2.4 Groundwater Conditions

This section provides a summary of the groundwater conditions along the tunnel alignment. A detailed discussion of the groundwater conditions is provided in Appendix H.

Groundwater levels measured in the borings vary from 7 to 198 feet below the ground surface with one boring having a groundwater level above the ground surface related to artesian conditions (Table 3-3). Field readings from November 1992 and March 1993, indicate groundwater elevations range from a minimum of 53 feet and 128 feet above the tunnel crown on the north and south flanks of the mountains to a maximum of 758 feet above the crown near the mountain crest at Boring SM-5. The differences in groundwater elevation generally form an average gradient that descends to the north at approximately 7 percent and to the south at about 15 percent. The readings in March 1993 indicate that the groundwater elevations have risen in response to the rains in Southern California during December 1992, and January and February 1993. The groundwater system in the mountains rapidly responds to recharge from rainfall. Rapid response to rainfall was also noted in the Los Angeles Sewer Tunnel as discussed in Section 3.2. This suggests that the near surface recharge is in hydraulic communication with the groundwater at tunnel depth. To evaluate the hydrostatic pressure at tunnel depth, vibrating wire piezometers were installed in Borings SM-4, SM-6 and SM-9. At those three locations, the hydrostatic pressures at the tunnel crown are approximately equivalent to the static groundwater elevations measured in the exploratory borings. The zones where hydrostatic pressures are measured are isolated from the rest of the borings by volclay grout. The readings indicate that continuity exists vertically throughout the rock mass, most likely through the frequent rock discontinuities.

Borings SM-1 and SM-1A indicate that the Hollywood fault acts as a barrier to groundwater flow from the mountains to the alluvial sediments of the Hollywood Basin. The shallow groundwater depth (Boring SM-1A) measured north of the fault zone in the hanging wall, was not present to the south of the fault zone in the footwall (Boring SM-1). The Benedict Canyon fault, which is projected across the alignment between Borings SM-13 and SM-14, and the proposed Universal City Station does not appear to affect the groundwater surface in that area based on available data.

Within the Santa Monica Mountains, the bedrock formations are expected to yield varying amounts of water to the tunnel. The volume of water that could be produced by the rocks, is dependent on the rock type and rock discontinuities. The water-bearing characteristics of the bedrock units are largely controlled by secondary permeability (discontinuities), particularly in the plutonic and volcanic rocks. Primary permeability (intergranular) as well as secondary permeability (along discontinuities), are associated with the clastic sedimentary rocks. Artesian conditions were indicated in the sedimentary rocks by Borings SM-10 and SM-11. These borings encountered bedded sedimentary rock (sandstone and shale) of the Upper Topanga Formation, suggesting that semi-confined conditions are possible for these rocks as primary permeability. Hydraulic conductivities, calculated from packer tests conducted for the various rock types encountered along the tunnel alignment, are low, varying from 4.2×10^{-4} cm/s to 4.6×10^{-8} cm/s. The results of the packer tests are discussed in Section 5.1.1.

TABLE 4-1. SUMMARY OF ROCK DISCONTINUITIES IN VARIOUS FORMATIONS BASED ON EACH ROCK TYPE (1 OF 2)

FORMATION: GRANODIORITE

Core Recovery (%)					RQD (%)					Joint Set Characteristics			Spacing			Roughness			Planarity			Discontinuity Filling			Weathering		
Count	Min.	Max.	Avg.	Std Dev	Count	Min.	Max.	Avg.	Std. Dev	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent
607	0	100	81	39	605	0	100	24	32	A	62	8.8	M			VR	1	0.2	D	12	2.5	I	52	11	F	314	65
										A1			T			R	131	27	W	58	12	II	85	18	FW	50	10
										B	6	0.66	MM	48	9.9	SR	188	39	P	387	81	III	11	2.3	SW	46	9.4
										B1	208	25	TH	182	41	S	53	11	S	18	4	IV	18	3.8	MW	43	7.8
										C	22	2.7	VT	220	47	SK	106	22	O	1	0.2	V	123	26	HW	22	3.8
										C1	317	38	L	7	1.5							VI	76	16	CW	53	11
										D	50	6										VII	44	9	RS	25	4.4
										D1	72	8.7										VIII	65	13.7			
										E	37	4.5															
										F	35	4.2															

FORMATION: CHICO & SIMI

Core Recovery (%)					RQD (%)					Joint Set Characteristics			Spacing			Roughness			Planarity			Discontinuity Filling			Weathering		
Count	Min	Max	Avg	Std Dev	Count	Min	Max.	Avg	Std Dev	Desig	Count	Percent	Desig.	Count	Percent	Desig	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent
453	0	100	90	18	451	0	100	37	31	A	99	26	M	15	4	VR	1	0.3	D	1	0.25	I	41	10	F	338	87
										A1			T	2	0.5	R	76	20	W	39	10	II	121	31	FW	10	2
										B	20	5	MM	94	24	SR	229	59	P	337	86	III	11	3	SW	11	2
										B1	129	34	TH	214	55	S	72	118	S	17	4.3	IV	1	0.25	MW	14	3
										C	8	2	VT	63	16	SK	9	2	O			V	41	10	HW	13	3
										C1	102	27	L	1	0.3							VI	138	35	CW	10	2
										D	5	1										VII	3	0.8	RS		
										D1	12	3										VIII	36	9			
										E	3	0.8															
										F	3	0.8															

FORMATION: LOWER TOPANGA & LAS VIRGENES

Core Recovery (%)					RQD (%)					Joint Set Characteristics			Spacing			Roughness			Planarity			Discontinuity Filling			Weathering		
Count	Min	Max	Avg.	Std Dev	Count	Min	Max.	Avg.	Std Dev	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent
46	84	100	96	4	46	17	100	87	20	A	29	69	M	3	6.8	VR	1	3	D			I	17	45	F	43	96
										A1			T	14	32	R	5	15	W	2	6	II	17	45	FW		
										B	1	2.4	MM	9	20	SR	11	33	P	27	82	III	2	5	SW		
										B1	8	19	TH	14	32	S	16	48	S	4	12	IV			MW		
										C			VT	2	4.5	SK			O			V			HW	1	2
										C1	4	9.5	L	2	4.5							VI	1	2.5	CW		
										D												VII	1	2.5	RS		
										D1												VIII					
										E																	
										F																	

TABLE 4-1. (CONTD.) SUMMARY OF ROCK DISCONTINUITIES IN VARIOUS FORMATIONS BASED ON EACH ROCK TYPE (2 OF 2)

FORMATION: MIDDLE TOPANGA VOLCANICS

Core Recovery (%)					RQD (%)					Joint Set Characteristics			Spacing			Roughness			Planarity			Discontinuity Filling			Weathering		
Count	Min.	Max.	Avg.	Std. Dev	Count	Min.	Max.	Avg.	Std. Dev	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent
274	0	100	95	13	274	0	100	76	26	A	53	18.8	M			VR	21	7.8	D			I	27	10	F	221	82
										A1	3	1.1	T	21	7.8	R	54	20	W	90	33	II	78	29	FW	22	8.2
										B	4	1.5	MM	55	20	SR	132	48	P	127	47	III			SW	10	3.7
										B1	72	27	TH	58	21.8	S	27	10	S	43	16	IV			MW	10	3.7
										C	2	0.74	VT	136	48	SK	34	13	O	9	3.3	V	112	43	HW	5	1.9
										C1	100	37	L	5	2							VI	2	0.78	CW		
										D												VII	43	16	RS		
										D1	27	10										VIII	3	1			
										E	1	0.4															
										F	8	3															

FORMATION: UPPER TOPANGA (SANDSTONE)

Core Recovery (%)					RQD (%)					Joint Set Characteristics			Spacing			Roughness			Planarity			Discontinuity Filling			Weathering		
Count	Min.	Max.	Avg.	Std. Dev	Count	Min.	Max.	Avg.	Std. Dev	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent
145	35	100	88	8	145	0	100	61	25	A	66	52	M	10	7	VR	4	4	D	3	3	I	53	43	F	121	83
										A1			T	23	16	R	47	40	W	22	19	II	15	12	FW	1	1
										B	32	24	MM	55	38	SR	18	15	P	93	78	III	3	2	SW	9	6
										B1	17	13	TH	36	25	S	10	8	S			IV			MW		
										C	5	4	VT	16	11	SK	38	32	O			V	4	3	HW	14	10
										C1	9	7	L									VI	32	26	CW		
										D												VII			RS		
										D1												VIII	17	14			
										E																	
										F																	

FORMATION: UPPER TOPANGA (SILTSTONE/SHALE)

Core Recovery (%)					RQD (%)					Joint Set Characteristics			Spacing			Roughness			Planarity			Discontinuity Filling			Weathering		
Count	Min.	Max.	Avg.	Std. Dev	Count	Min.	Max.	Avg.	Std. Dev	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent
130	0	100	85	7	126	0	100	76	29	A	106	86	M	3	2	VR			D			I	64	54	F	106	88
										A1			T	20	16	R	6	5	W	15	13	II	7	6	FW	2	2
										B	3	2	MM	64	52	SR	77	65	P	100	84	III	3	3	SW	4	3
										B1	13	10	TH	18	15	S	35	29	S	4	3	IV	1	1	MW	3	3
										C	1	1	VT	16	13	SK	1	1	O			V	2	2	HW	4	3
										C1	1	1	L	2	2							VI	20	17	CW	2	2
										D												VII			RS		
										D1												VIII	18	15			
										E																	
										F																	

TABLE 4-2. SUMMARY OF ROCK DISCONTINUITIES IN VARIOUS FORMATIONS BASED ON TUNNEL ENVELOPE[1] (1 OF 2)

FORMATION: GRANODIORITE

Core Recovery (%) Count	Min.	Max.	Avg.	Std. Dev	RQD (%) Count	Min.	Max.	Avg.	Std. Dev
107	0	100	80	19	106	0	100	48	38

Joint Set Characteristics Desig.	Count	Percent	Spacing Desig.	Count	Percent	Roughness Desig.	Count	Percent	Planarity Desig.	Count	Percent	Discontinuity Filling Desig.	Count	Percent	Weathering Desig.	Count	Percent
A	16	17	M			VR			D	5	5	I	8	8	F	77	75
A1			T			R	12	14	W	35	38	II	15	16	FW	5	5
B	1	1	MM	19	22	SR	47	55	P	57	58	III	2	2	SW	6	6
B1	33	34	TH	47	55	S	8	9	S			IV			MW	6	6
C			VT	17	20	SK	19	22	O	1	1	V	28	28	HW	1	1
C1	21	22	L	3	3							VI	18	18	CW		
D	4	4										VII	16	18	RS	5	5
D1	4	4										VIII	17	18			
E	4	4															
F	13	14															

FORMATION: CHICO & SIMI

Core Recovery (%) Count	Min.	Max.	Avg.	Std. Dev	RQD (%) Count	Min.	Max.	Avg.	Std. Dev
15	73	100	92	6	15	0	100	32	33

Joint Set Characteristics Desig.	Count	Percent	Spacing Desig.	Count	Percent	Roughness Desig.	Count	Percent	Planarity Desig.	Count	Percent	Discontinuity Filling Desig.	Count	Percent	Weathering Desig.	Count	Percent
A	1	7	M			VR			D			I	3	20	F	15	100
A1			T			R	15	100	W	1	7	II			FW		
B	2	12	MM	5	33	SR			P	13	86	III			SW		
B1	3	20	TH	9	60	S			S	1	7	IV			MW		
C	1	7	VT	1	7	SK			O			V			HW		
C1	7	47	L									VI	10	67	CW		
D												VII			RS		
D1	1	7										VIII	2	13			
E																	
F																	

FORMATION: LOWER TOPANGA & LAS VIRGENES

Core Recovery (%) Count	Min.	Max	Avg.	Std Dev	RQD (%) Count	Min.	Max.	Avg	Std Dev
13	84	100	99	4	13	17	100	69	22

Joint Set Characteristics Desig	Count	Percent	Spacing Desig.	Count	Percent	Roughness Desig.	Count	Percent	Planarity Desig.	Count	Percent	Discontinuity Filling Desig.	Count	Percent	Weathering Desig.	Count	Percent
A	6	55	M			VR			D			I	4	45	F	10	91
A1			T			R			W			II	3	33	FW		
B	1	9	MM	4	33	SR	4	67	P	6	100	III	1	11	SW		
B1	2	18	TH	6	50	S	2	33	S			IV			MW		
C			VT	1	8.5	SK			O			V			HW	1	9
C1	2	18	L	1	8.5							VI	1	11	CW		
D												VII			RS		
D1												VIII					
E																	
F																	

TABLE 4-2. (CONTD.) SUMMARY OF ROCK DISCONTINUITIES IN VARIOUS FORMATIONS BASED ON TUNNEL ENVELOPE[1] (2 OF 2)

FORMATION: MIDDLE TOPANGA VOLCANICS

Core Recovery (%)					RQD (%)					Joint Set Characteristics			Spacing			Roughness			Planarity			Discontinuity Filling			Weathering		
Count	Min.	Max.	Avg	Std Dev	Count	Min.	Max.	Avg.	Std. Dev	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent
14	85	100	96	5	14	58	95	84	11	A			M			VR	1	7	D			I			F	14	100
										A1	1	7	T			R	1	7	W	3	21	II			FW		
										B			MM	1	7	SR	1	7	P	10	71	III			SW		
										B1	8	57	TH	7	50	S			S	1	8	IV			MW		
										C			VT	6	43	SK	11	79	O			V	13	93	HW		
										C1	4	29	L									VI			CW		
										D												VII	1	7	RS		
										D1	1	7										VIII					
										E																	
										F																	

FORMATION: UPPER TOPANGA (SANDSTONE)

Core Recovery (%)					RQD (%)					Joint Set Characteristics			Spacing			Roughness			Planarity			Discontinuity Filling			Weathering		
Count	Min	Max.	Avg	Std Dev	Count	Min.	Max.	Avg.	Std. Dev	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent
12	97	100	100	0.83	12	97	100	100	0.83	A	11	92	M	6	50	VR			D			I	4	100	F	12	100
										A1			T	6	50	R	3	75	W	1	25	II			FW		
										B	1	8	MM			SR	1	25	P	3	75	III			SW		
										B1			TH			S			S			IV			MW		
										C			VT			SK			O			V			HW		
										C1			L									VI			CW		
										D												VII			RS		
										D1												VIII					
										E																	
										F																	

FORMATION: UPPER TOPANGA (SILTSTONE/SHALE)

Core Recovery (%)					RQD (%)					Joint Set Characteristics			Spacing			Roughness			Planarity			Discontinuity Filling			Weathering		
Count	Min	Max.	Avg	Std. Dev	Count	Min	Max.	Avg	Std. Dev	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent	Desig.	Count	Percent
40	57	100	92	12	40	0	100	76	29	A	31	78	M			VR			D			I	21	64	F	38	95
										A1			T	8	21	R			W	4	11	II	2	6	FW	1	2.5
										B	2	5	MM	20	53	SR	28	78	P	31	86	III			SW	1	2.5
										B1	6	15	TH	5	13	S	7	19	S	1	3	IV			MW		
										C			VT	5	13	SK	1	3	O			V			HW		
										C1	1	2	L									VI	8	24	CW		
										D												VII			RS		
										D1												VIII	2	6			
										E																	
										F																	

NOTE: (1) Tunnel envelope comprises of section from 20 feet above the tunnel crown to 20 feet below the tunnel invert.

TABLE 4-3. EXPLANATION OF TERMINOLOGY USED IN TABLES 4-1. AND 4-2.

(A) Joint & Set

Description	Designation
No joints	A
Few joints	A
One joint set	B
One joint set plus random	B1
Two joint sets	C
Two joint sets plus random	C1
Three joint sets	D
Three joint sets plus random	D1
Four or more joint sets, random etc.	E
Crushed rock, soil like	F

(B) Joint Roughness

Description	Field Recognition	Designation
Very Rough	Near vertical steps and ridges occur on the discontinuity.	VR
Rough	Some ridges and side-angle steps are evident; asperities are clearly visible; surface feels very abrasive.	R
Slightly Rough	Asperities on the discontinuity surfaces are distinguishable and can be felt.	SR
Smooth	Surface appears smooth and feels smooth to the touch.	S
Slickensided	Visual evidence of polishing and movement are visible.	SK

(C) Joint Spacing

Spacing	Bedding Layers	Joints (Fractures)	Designation
> 2m (> 6.6 ft)	massive	very wide	M
0.6m to 2m (2' to 6.6')	thick	wide	T
0.2m to 0.6m (8" to 2')	medium	moderately close	MM
60 to 200mm (2.4 to 8")	thin	close	TH
10 to 60mm (0.4" to 2.4")	very thin	very close	VT
10mm (0.4")	laminated	extremely close	L

(D) Planarity

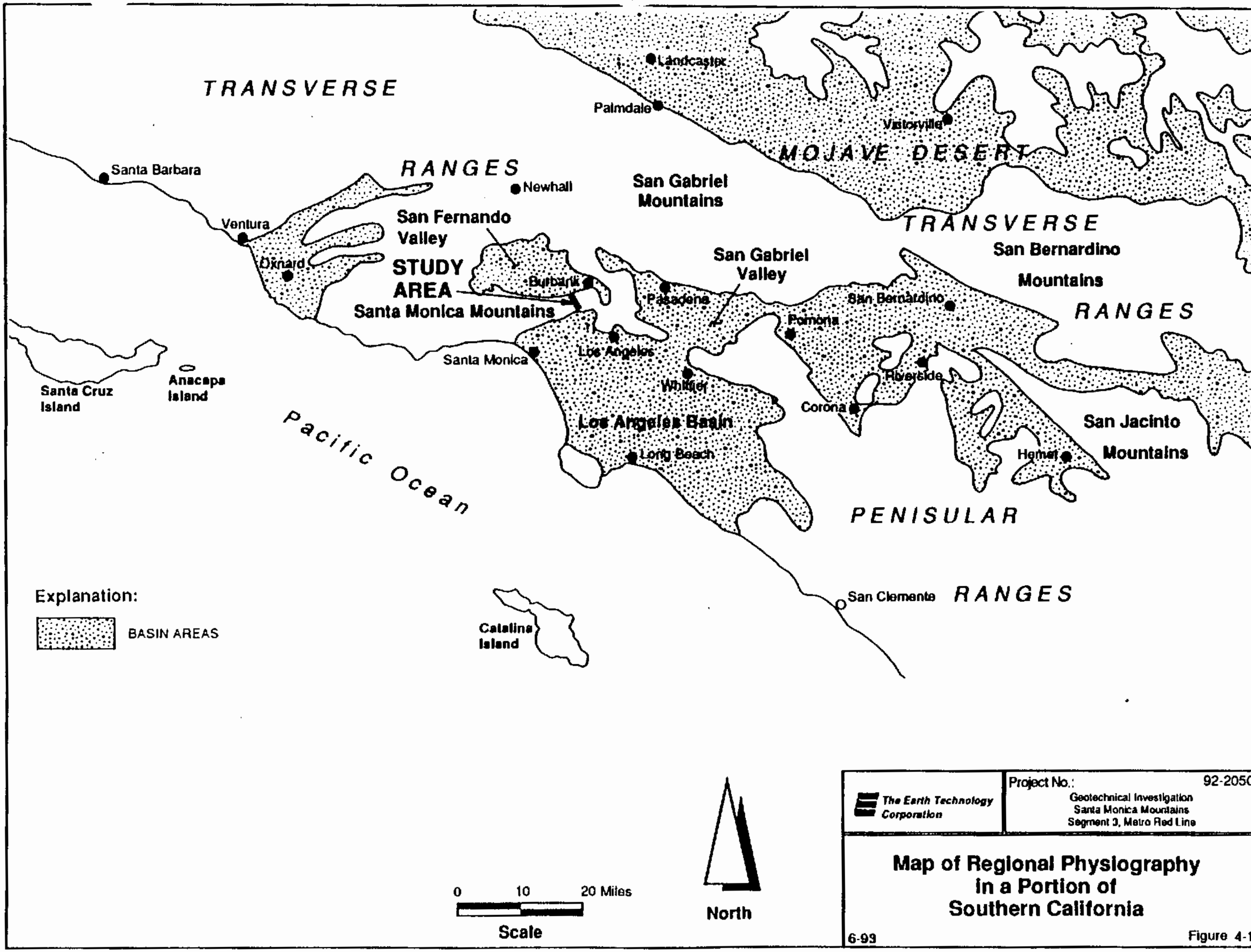
Description	Field Recognition	Designation
Discontinuous	Not continuous	D
Wavy	A moderately undulating surface, with no sharp breaks or steps.	W
Planar	A flat surface.	P
Stepped	A surface with asperities or steps. The height of the asperity should be estimated or measured.	S
Open	Separation exists between surfaces	O

(E) Filling Characteristics

Description	Approximate Separation	Designation
Tightly healed or unweathered	0	I
Slightly weathered with non clay coating	0 to 1 mm	II
Moderately weathered with some clay coating	0 to 1 mm	III
Highly weathered with clay	0 to 1 mm	IV
Non-clay filling	1 to 5 mm	V
Clay filling	1 to 5 mm	VI
No clay filling	> 5 mm	VII
Clay filling	> 5 mm	VIII

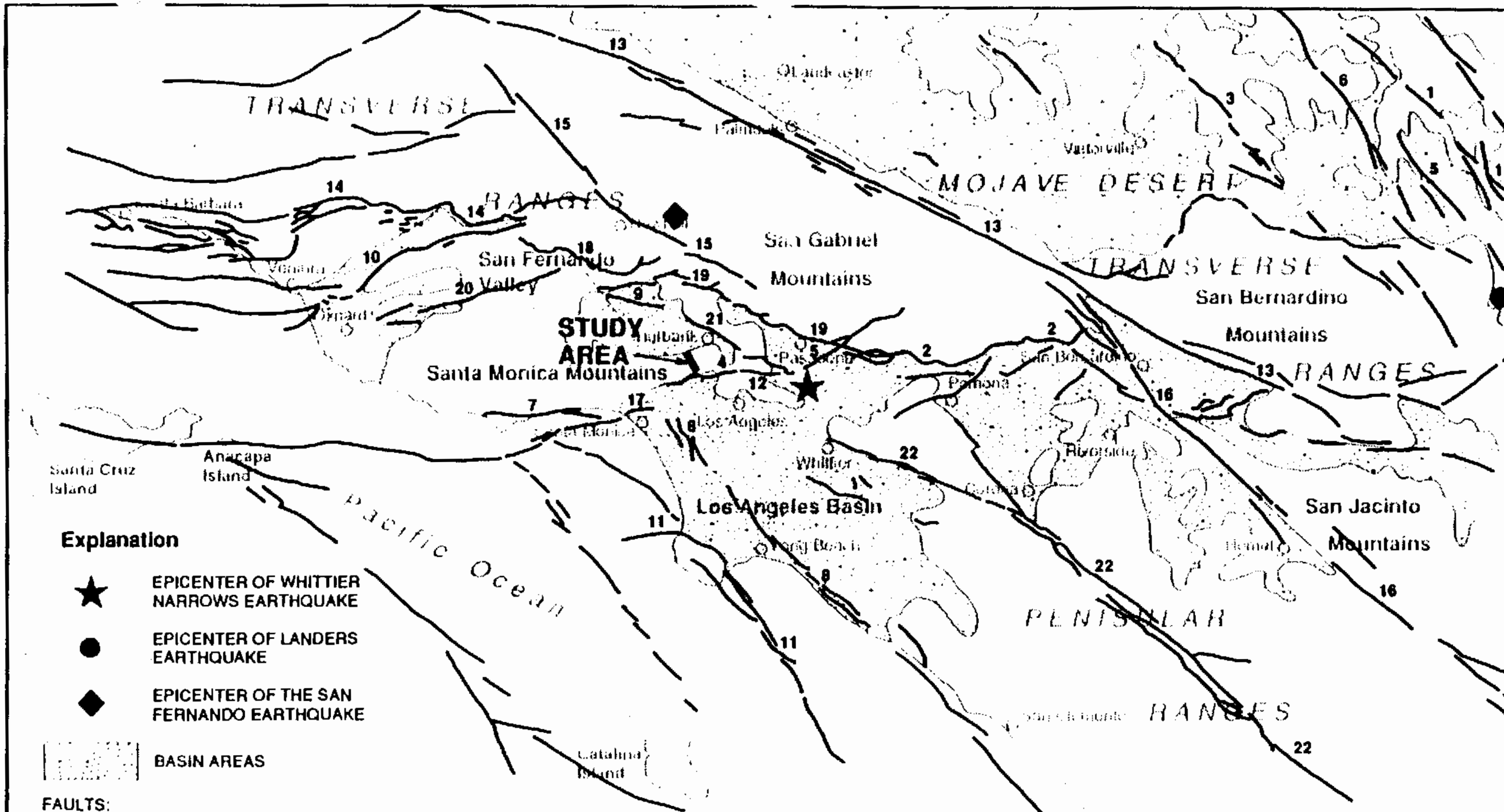
(F) Weathering

Description	Field Description	Designation
Fresh	No visible sign of weathering.	F
Faintly Weathered	Weathering limited to the surface of major discontinuities.	FW
Slightly Weathered	Penetrative weathering developed on open discontinuity surfaces but only slight weathering of rock material.	SW
Moderately Weathered	Weathering extends throughout the rock mass but the rock material is not friable.	MW
Highly Weathered	Weathering extends throughout the rock mass and the rock material is partly friable.	HW
Completely Weathered	Rock is wholly decomposed and in a friable condition but the rock texture and structure are preserved.	CW
Residual Soil	A soil material with the original texture, structure, and mineralogy of the rock completely destroyed.	RS



Map of Regional Physiography in a Portion of Southern California

Figure 4-1



Explanation

★ EPICENTER OF WHITTIER NARROWS EARTHQUAKE

● EPICENTER OF LANDERS EARTHQUAKE

◆ EPICENTER OF THE SAN FERNANDO EARTHQUAKE

BASIN AREAS

FAULTS:

1. CAMP ROCK
2. CUCAMONGA
3. HELENDALE
4. HOLLYWOOD
5. JOHNSON VALLEY
6. LENWOOD
7. MALIBU COAST
8. NEWPORT - INGLEWOOD
9. NORTHRIDGE
10. OAKRIDGE
11. PALOS VERDES
12. RAYMOND
13. SAN ANDREAS
14. SAN CAYETANO
15. SAN GABRIEL
16. SAN JACINTO
17. SANTA MONICA
18. SANTA SUSANA
19. SIERRA MADRE - SAN FERNANDO
20. SIMI
21. VERDUGO
22. WHITTIER - ELSINORE

Source:
Jennings, 1992 and Ziony and Yerkes, 1985.

0 10 20 Miles
Scale

North

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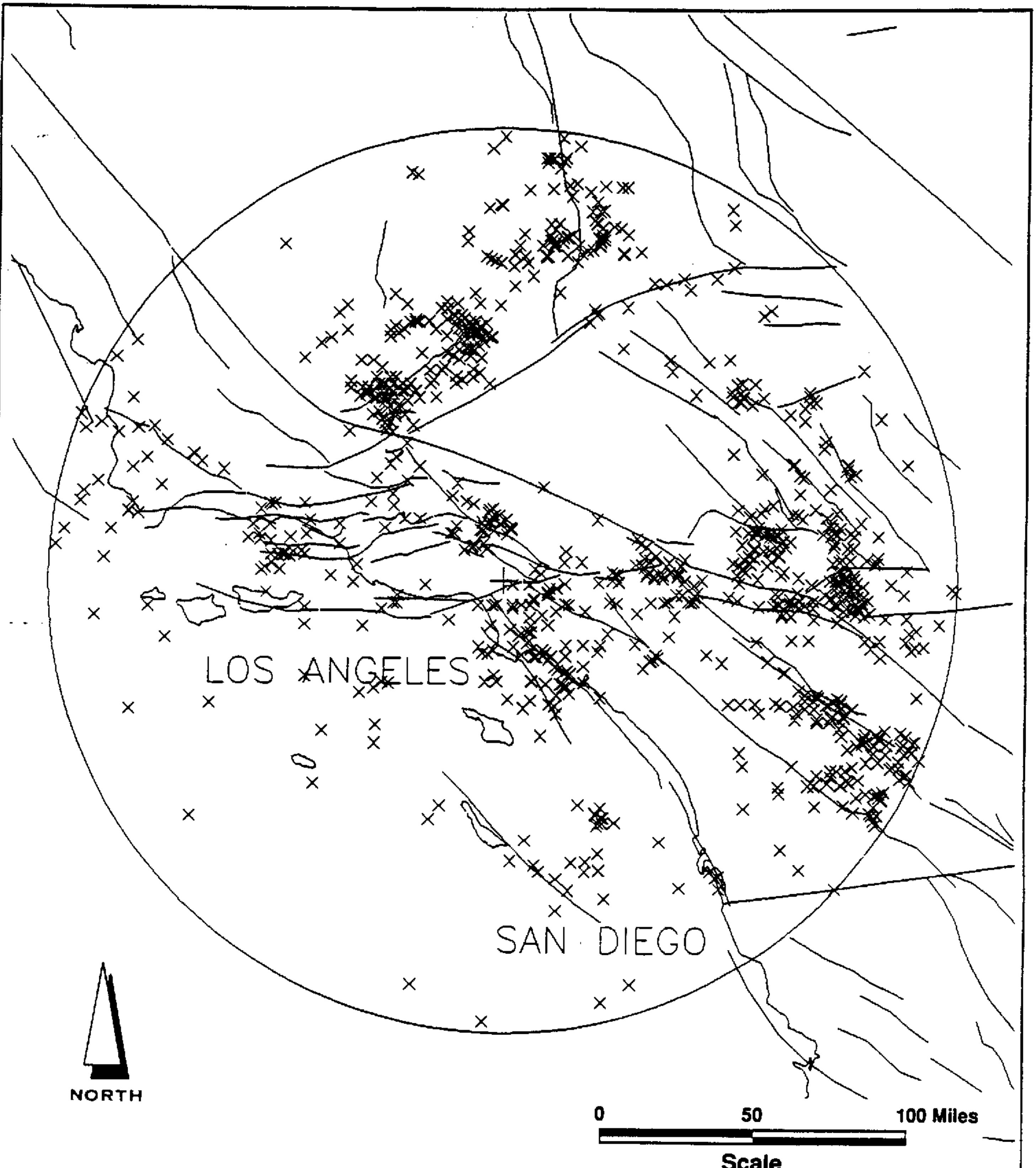
Santa Monica Mountains
Segment 3, Metro Red Line

Map of Major Faults in a Portion of Southern California

6-93

Figure 4-2



Explanation

× M = 4.0-4.9

Site Location (+): Latitude = 34.1190
Longitude = 118.3540

Source:
Epicenters from Blake, 1992.

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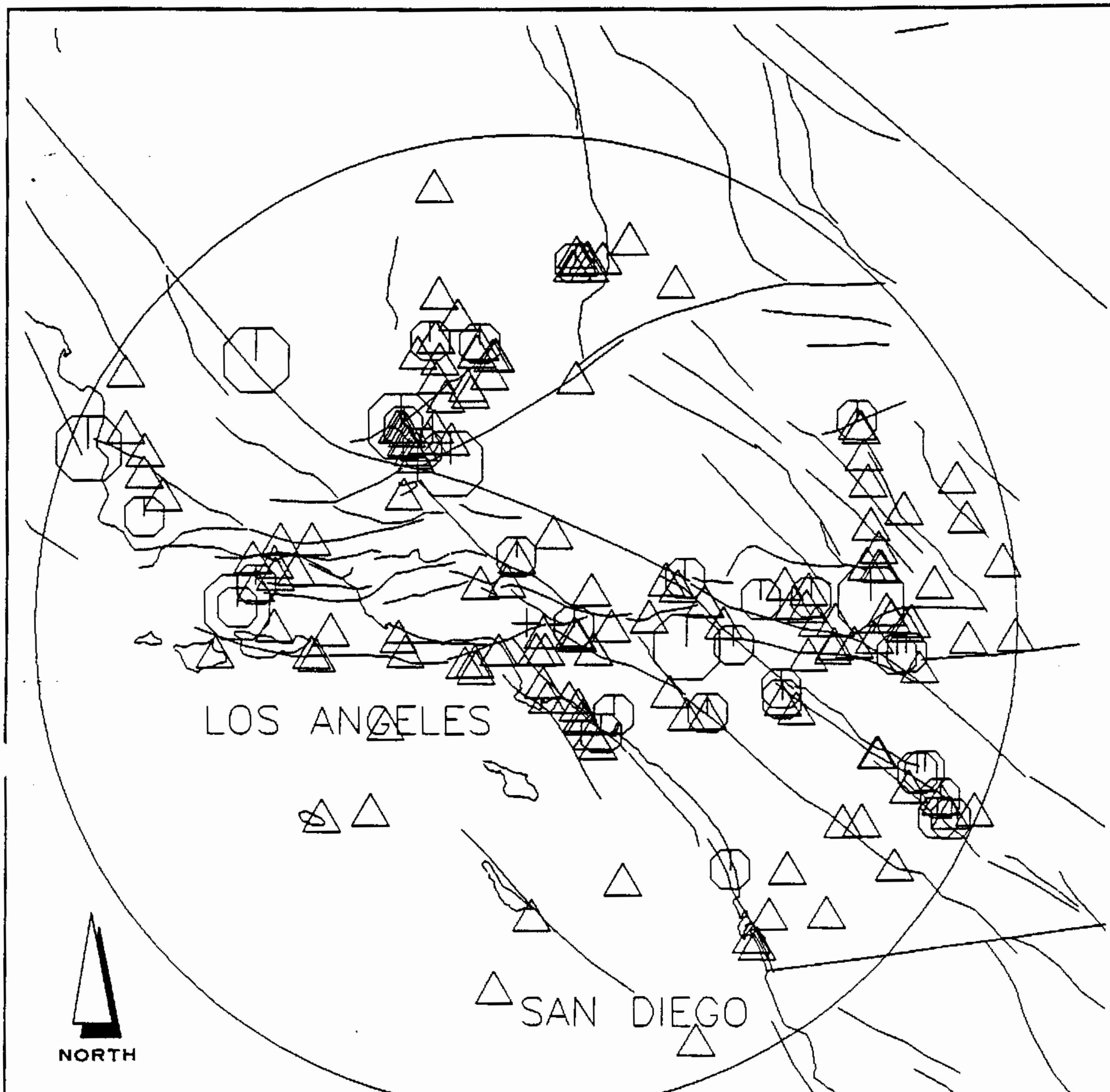
Relationship of Earthquake Epicenters (M=4) to Faults in Southern California

6-93 Figure 4-3A



Explanation

M = 7.0-7.9

M = 6.0-6.9

M = 5.0-5.9

Site Location (+): Latitude = 34.1190
Longitude = 118.3540

Source:
Epicenters from Blake, 1992.

0 50 100 Miles

Scale

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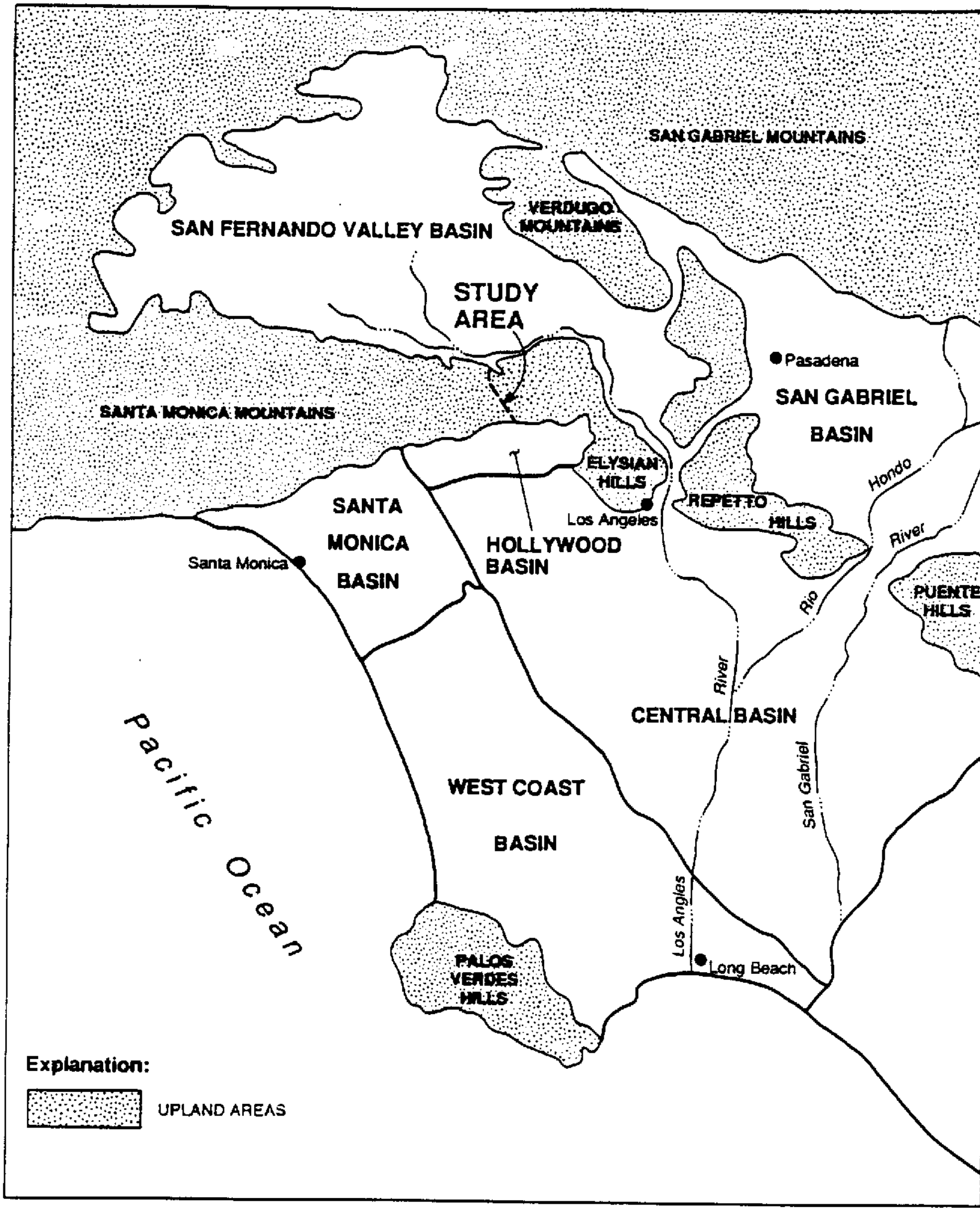
Relationship of Earthquake Epicenters (M=5-7+) to Faults in Southern California

6-93

Figure 4-38



0 10 20 Miles

Scale

North

Source:
California Division of Water Rescources, 1961.

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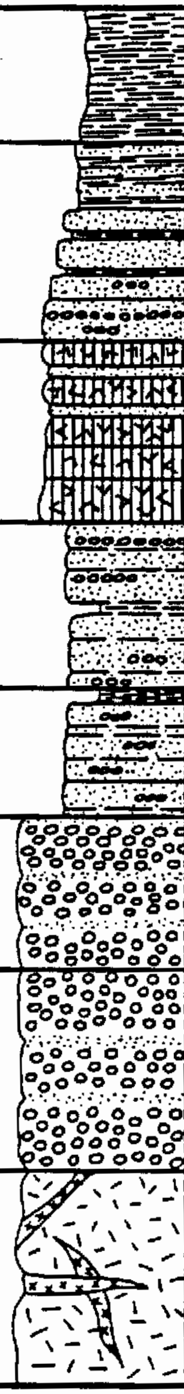
Santa Monica Mountains
Segment 3, Metro Red Line

Map of Groundwater Basins

6-93

Figure 4-4

AGE: Period	AGE: Epoch	FORMATION (Map Symbol)	APPROXIMATE STRATIGRAPHIC THICKNESS IN PROJECT AREA (Feet)	LITHOLOGY	DESCRIPTION
TERTIARY	MIOCENE	PUENTE (Tp)	30+		Highly sheared dark gray to black claystone and shale. Thin bedded to laminated. Occurs as a fault sliver within the Hollywood fault zone. Marine.
					FAULT
		TOPANGA — UPPER (Tlu)	3200+		Light gray to tan bedded sandstone and pebbly conglomerate. Grades upward into mostly gray micaceous shale or claystone with thin interbeds of sandstone. Marine.
		TOPANGA — MIDDLE (Tlv/Tts)	1200-1500		Dark gray to black fine-grained basaltic volcanic rocks. Typically massive to brecciated. Locally vesicular with vesicles filled with white zeolite, calcite and chlorite. Typically hydrothermally altered to chlorite and serpentine group minerals. Includes interbeds of resistant sandstone. Marine.
		TOPANGA — LOWER (Tll)	350-400		Light gray to tan massive conglomeratic sandstone and sandstone. Locally includes thin bedded sandstone, shale and cobble conglomerate. Clasts consist of quartzite, sandstone, slate, plutonics and volcanics. Marine.
					UNCONFORMITY
	PALEOCENE	LAS VIRGENES SANDSTONE (Tlv)	100-225		White arkosic sandstone with felsic sand pebble lenses grading into a greenish silty claystone. Thin green and red mudstone interbedded. White bentonite bed occurs near base. Nonmarine.
		SIMI CONGLOMERATE (Tsc)	200-300		Cobble and boulder conglomerate with coarse sand lenses. Lower half characterized by distinctive quartzite clasts. The upper half contains mostly volcanic clasts. Nonmarine.
					UNCONFORMITY
CRETACEOUS	LATE	"CHICO" (Kc)	700-800		Massive brown and gray cobble conglomerate with sandstone and dark gray shale interbedded. Clasts consist of metavolcanic and granitic rocks and quartzite in a sandy matrix. Locally includes reddish sandstone and claystone. Base sheared locally. Marine.
					UNCONFORMITY/FAULT
	(?)	UNNAMED PLUTONIC ROCKS (gd)	3500+		Medium to light gray granodiorite, quartz diorite and quartz monzonite that is massive to locally gneissic. Composed mostly of plagioclase feldspar, quartz, biotite and hornblende. Dikes and veins of basalt and quartz aplite occur. Mafic xenoliths locally abundant. Deeply weathered near surface. Nonmarine.

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Santa Monica Mountains
Segment 3. Metro Red Line

Bedrock Stratigraphic Column

6-93

Figure 4-5

5.0 DISCUSSION OF FIELD AND LABORATORY TESTING RESULTS

5.1 FIELD TEST RESULTS

5.1.1 Packer Tests

As explained in Section 3.3.3, a total of 22 single and double packer tests were performed in ten borings. The results of the tests, including locations, relevant rock type in the test sections, and calculated hydraulic conductivity, are presented in Table 5-1. The test results grouped by rock types to be encountered along the tunnel alignment, are further summarized in Table 5-2. An evaluation of the packer test results is as follows:

1. The test data indicate a wide range of hydraulic conductivity for each of the rock types encountered along the tunnel alignment. Based on the packer tests alone, no distinction can be drawn between rock types for potential water inflows during tunnel construction. Based on experience during excavation of the Los Angeles Sewer Tunnel (Section 2.3), the packer tests are not representative of potential inflow conditions but indicate the rock mass as a whole has a low permeability.

2. Within plutonic rocks (granodiorite), tests in five borings (SM-1A, SM-2, SM-3, SM-4 and SM-6) indicate hydraulic conductivity ranging from 1.7×10^{-4} cm/s to 4.6×10^{-8} cm/s. Hydraulic conductivities in the plutonic rocks appear to be primarily controlled by joints and shears, and show a trend of increasing values with a decrease in RQD (rock quality designation) as anticipated.

3. In all other rock types, except the plutonic rocks, there is no clear relationship between hydraulic conductivity and RQD.

4. The widest range of hydraulic conductivities occurs within the sedimentary rocks. The calculated values range from 4.2 x 10^{-4} cm/s to 5.2 x 10^{-8} cm/s and lower.

5. Hydraulic conductivities calculated for the basalt ranged from 3.2 x 10^{-5} cm/s to 8.0 x 10^{-7} cm/s for three tests. As with the granodiorite, the hydraulic conductivities appear to be controlled by discontinuities in the basalt.

6. The hydraulic conductivities of the Chico Formation (including Simi Conglomerate) and Lower Topanga Formation, are generally lower than the adjacent plutonic and basalt/basalt breccia rocks.

5.1.2 Geophysical Wireline Logging

Wireline sonic velocity logging was performed in six borings (SM-2, SM-4, SM-6, SM-8, SM-10 and SM-12). Table 5-3 provides an overall summary of interpreted ranges of compressional wave and shear wave velocities for various geologic units. The results indicate the following:

1. The plutonic rocks and the Upper Topanga Formation have the widest range of seismic velocities. This is indicative of the variability of the in situ rock mass within these two geologic units.

2. The lower section of the Upper Topanga Formation is much stronger and stiffer than the upper section of the Upper Topanga Formation. This likely reflects the more homogeneous and cemented nature of the sandstone/conglomerate of the lower section than the interbedded sandstone/shale of the upper section of the Upper Topanga Formation.

3. Sonic velocity data from Boring SM-8 yields higher than expected seismic wave velocity (compressional wave velocity >20,000 ft/sec) in the Middle

Topanga Formation. These high values are not expected based on the very low strength results from laboratory testing of basalt and basalt breccia.

5.2. LABORATORY TEST RESULTS

5.2.1 Geomechanical Laboratory Testing

The results of soil testing are summarized in Table 5-4. The results indicate that the alluvium encountered south of the Hollywood fault consists of sand, clayey sand, and silty clay. The overburden above the bedrock in the northern flank of the Santa Monica Mountains, consists of sand, silty sand, clayey sand, silt, and silty clay.

A summary of the rock test results is presented in Table 5-5. Statistics of the test results in terms of minimum, maximum, and mean values, and standard deviation, are presented in Table 5-6. The following are our observations based on a review of the aforementioned data:

1. BULK SPECIFIC GRAVITY AND BULK DENSITY - The bulk specific gravity (BSG) of the rocks range from 2.02 to 2.83. The plutonic rocks and Chico Formation have BSG higher than 2.4, whereas the BSG for much of the Topanga Formation (basalts, basalt breccias, conglomerates, and sandstones) is approximately 2.25. The bulk density of the rocks ranges from 119 pounds per cubic foot (pcf) to 178 pcf; and the plutonic rocks and Chico Formation have higher bulk densities, whereas some of the basalts, conglomerates, and sandstones of the Topanga Formation have lower densities. As per IAEG (Anon, 1979), grouping of the rocks into different classes by bulk density is as follows:

Rock Type	Range of Bulk Density (pcf)	Class	Description of Densities
Plutonic Rocks	162-178	4 and 5	High to very High
Chico Formation	140-164	3 and 4	Moderate to High
Lower Topanga Fm.	149-154	3	Moderate
Middle Topanga Fm.	128-154	2 and 3	Low to Moderate
Upper Topanga Fm.	119-163	2 to 4	Low to High

2. UNIAXIAL COMPRESSIVE STRENGTH - There is a wide scatter in the uniaxial compressive strength values of the rock cores tested. This scatter primarily reflects the high frequency of pre-existing discontinuities in the rock core specimens tested under laboratory conditions. Generally, the discontinuities are healed but caused preferential breakage of the core samples. Notes on discontinuities are included in Table 5-5. The discontinuities included clast-matrix contacts in conglomerates and basalt breccias, healed joints, shears, and bedding partings. Another factor affecting rock strength is intensive microshearing (fissuring) within the rock mass that was recognized in the thin section analysis (Section 5.2.3.2). Using only the test results from the intact rock (core without discontinuities) and Deere and Miller's (1966) rock classification system, the rocks can be classified, in general, as follows based on their intact compressive strength:

Rock Type	Description of Strengths
Plutonic Rocks	Very Low to High
Chico Formation	Very Low to High
Lower Topanga Formation	Very Low to Low
Middle Topanga Formation	Very Low to Low
Upper Topanga Formation (Ss-Cgl)	Very Low to Medium
Upper Topanga Formation (Ss-Sh)	Very Low to Low

3. POINT LOAD STRENGTH - Point load strength tests were conducted on 55 core samples in accordance with the ISRM method for determining point load strength. The point load tests were conducted to supplement the uniaxial compressive strength tests because many discontinuities exist in the core, which bias the uniaxial strengths on the low side. The point load test provides a method of testing both the small intact segments of core without discontinuities and the individual clasts found in the conglomerates, which were not tested under uniaxial methods. The results of the point load strength (normalized for diameter) were used as an indication of rock strength and for estimating equivalent uniaxial compressive strengths, for comparison purposes. The results of the tests are presented in Table 5-5.

   In general, the point load strengths and estimated uniaxial compressive strengths are comparable to the intact rock core uniaxial test results for the same rock formations. The point load tests also indicate that the matrix materials of conglomerates and sandstones are significantly weaker than the conglomerate clasts. The clasts which typically consist of quartzite or granitic rock composition are similar in strength to the plutonic rocks in the southern reach of the tunnel.

4. SLAKE DURABILITY - The slake durability tests estimate the resistance to wetting and drying of a rock sample. The slake durability indices of the rocks encountered in the tunnel envelope, vary over a wide range due to their different composition. The degree of slaking for the various rocks, based on the grading system developed by Franklin and Chandra (1972), can be classified as follows:

Rock Type	Range of Slake Durability (%)	Amount of Slaking
Plutonic Rocks	24.5 (1)	Very High
Chico Formation	95.3 - 97.4	Very Low
Lower Topanga Fm.	93.8 (1)	Very Low
Middle Topanga Fm.	59.0 - 96.7	Medium to Very Low
Upper Topanga Fm.	1.1 - 95.7	Very High to Very Low

(1) Only one test was performed.

5. SWELL PRESSURE - Only one swell pressure test was performed on a sheared claystone/siltstone, mylonite, sample from Boring SM-5. This test was done in a clayey section of the boring where the driller reported squeezing ground and difficult drilling conditions. The swell pressure index of 8.2 psi indicates that the clay has low swell potential. The clay was not encountered in the tunnel envelope, but was about 300 feet above the tunnel invert at Boring SM-5. It seems unlikely that swelling or squeezing clay caused drilling difficulty.

No swell pressure tests were performed on other rock types due to their relatively low or negligible clay content.

5.2.2 Chemical Laboratory Testing

The chemical laboratory test results of the groundwater samples collected from four monitoring wells, are summarized in Table F-2 of Appendix F. The results of tests for purgeable volatile organic compounds, semivolatile organic compounds, total recoverable petroleum hydrocarbons, and oil and grease, yielded sporadic low levels of detection. As shown in Table F-2, chloroform, bis (2-Ethylhexyl) phthalate, and oil and grease were detected at relatively low levels in a few monitoring wells. The analytes detected are typical of petroleum refinery products and are either indicators of near surface groundwater contamination or contamination of the boring due to the drilling/sampling methods. The test results do not indicate the presence of crude oil in the formations.

During drilling of Boring SM-11, an artesian condition was observed. The driller indicated it could be water used during drilling. A groundwater sample was obtained and analyzed for volatile organic compounds, semivolatile organic compounds, selected metals, TDS, sulfide, specific conductance, and pH. The test results are summarized in Table F-3 of Appendix F. The relatively high TDS and specific conductance of groundwater from SM-11 are similar to the test results of groundwater samples from R-8 (Table F-2), which are also from the Topanga Formation. These results suggest that the artesian water of SM-11 is groundwater and not drilling fluids returning from the formation.

In general, the water quality data indicate that water from the plutonic rock and the volcanic rocks have lower TDS than water from the sedimentary rocks. This likely reflects the marine origin of the sedimentary rocks, which includes higher availability of soluble minerals.

5.2.3 OTHER LABORATORY ANALYSES

5.2.3.1 X-Ray Diffraction

The x-ray diffraction method offers a means to identify specific minerals that are difficult to name in a hand specimen. For this project, certain minerals could not be positively differentiated during field core logging. X-ray diffraction was used to help identify minerals, especially a translucent green mineral that appeared in the basalt, granodiorite, and conglomerate between the two igneous rock units. The results of the x-ray diffraction analyses are presented in Table 5-7. The x-ray diffraction results indicate a high abundance of vermiculite. This result is somewhat ambiguous because it is inconsistent with the hand specimen identification and geologic environment. To check the results, duplicate samples were sent to Dr. Winchell. The analysis performed by Dr. Winchell indicates a general clay mineral (smectite) composition similar to the vermiculite. This is an alteration product derived from minerals that composed the basalt.

5.2.3.2 Thin Section Analyses

The results of the thin section analyses are presented in Table 5-8. Generally, the thin section analysis seems to have provided the most thorough understanding of the mineral content of the rocks to be encountered by the tunnel alignment. The data indicate intensive microshearing (fissuring) and chemical (perhaps hydrothermal) alteration of original minerals. Extensive alteration of minerals to clays and chlorites has occurred essentially in all rock types south of the upper Topanga Formation including the granodiorites, Cretaceous and Paleocene sediments, Lower Topanga Formation and basalts. The thin section analysis also provides estimates of mineral content including quartz content in the plutonic rocks. The quartz content of the plutonic rocks ranges from 19 to 33 percent.

5.2.3.3 Micropaleontology

Microscopic analyses of claystone from Borings SM-1 and B-8 (Earth Technology, 1993) within the Hollywood fault zone, were conducted to help identify their origin. The results indicate that a claystone sample obtained from Boring SM-1 contains marine microfossils of middle to late Miocene age with preference given to the latter. This would correspond to the Puente Formation in this area of the Los Angeles Basin. The clay sample from Boring B-8 was submitted for analyses to check if that clay also could have been derived from the Puente Formation claystone. The analyses indicated that the sample contains no definite fossils and is age indeterminate based on the micropaleontology analysis. The presence of abundant plutonic fragments contained in the clay, its sheared nature, and lack of microfossils suggest that the material is a fault gouge. The results of micropaleontology analyses are presented in Appendix G.

TABLE 5-1. SUMMARY OF PACKER HYDRAULIC CONDUCTIVITY TESTS

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations Ground Surface (feet)	Tunnel Crown (feet)	Tunnel Invert (feet)	Test No.	Type of Test	Approximate Elevations Water Table (feet)	Top of Test Interval (feet)	Bottom of Test Interval (feet)	Depth Below Ground Surface Water Table (feet)	Top of Test Interval (feet)	Bottom of Test Interval (feet)	Rock Characteristics Type	Recovery (%)	RQD[1] (%)	Average Hydraulic Conductivity (cm/sec)	Remarks
SM-1A	320RT.	492	348	328	1	Single	476	335	327	16	157	165	Granodiorite/Gouge	75	72	3.3E-06	
SM-2	130LT.	720	350	330	1	Single	512	340	330	208	380	390	Granodiorite	89	7	9.2E-06	
					2	Single		299	289	208	421	431	Granodiorite	81	5	2.0E-05	
SM-3	60LT.	686	350	330	1	Single	643	342	332	43	344	354	Granodiorite	97	38	4.3E-06	
					2	Single		302	292	43	385	394	Granodiorite	98	12	5.2E-05	
SM-4	70LT.	960	375	355	1	Single	863	344	334	97	616	626	Granodiorite	100	99	4.6E-06	
					2	Double		361	345	97	599	615	Granodiorite	86	63	9.0E-06	
					3	Double		422	406	97	538	554	Granodiorite/Crushed	96	25	1.7E-04	
SM-6	60RT.	1180	408	388	1	Double	1106	485	469	74	695	711	Conglomerate	100	47	2.9E-06	
					2	Double		406	390	74	774	790	Granodiorite	100	99	1.9E-06	
SM-8	0RT.	1175	450	430	1	Single	1008	460	447	167	715	728	Sandstone	100	99	2.3E-07	
					2	Single		444	433	167	731	743	Sandstone/Siltstone	100	83	----	No Measurable Flow
					3	Single		405	388	167	770	788	Sandstone/Siltstone	100	100	4.7E-07	
SM-9	170LT.	1112	479	459	1	Single	1008	488	479	104	624	633	Basalt Breccia	99	94	1.7E-06	
					2	Single		474	465	104	638	648	Basalt Breccia	95	81	8.0E-07	
					3	Single		434	419	104	678	693	Basalt Breccia	99	79	3.2E-05	
SM-11	30LT.	778	528	508	1	Single	781	528	518	-3	250	260	Sandstone/Siltstone	100	100	----	No Measurable Flow
					2	Single		498	483	-3	280	295	Sandstone/Siltstone	100	78	5.2E-06	
					3	Double		613	597	-3	165	181	Sandstone	98	79	4.2E-04	
					4	Double		623	607	-3	155	171	Sandstone/Siltstone	99	69	3.5E-04	
SM-12	230LT.	671	525	505	1	Single	645	524	510	26	147	161	Sandstone/Siltstone	82	48	2.0E-05	
SM-13	10LT.	590	521	501	1	Single	578	515	500	12	75	90	Sandstone/Siltstone	98	83	1.0E-06	

Note: (1) RQD = Rock Quality Designation

TABLE 5-2. RANGE OF FIELD HYDRAULIC CONDUCTIVITY

Rock Type in the Test Section	Range of RQD in the Test Section (%)	Range of Hydraulic Conductivity (cm/s)
Granite and/or Granodiorite	5-99	4.6×10^{-8} to 1.7×10^{-4}
Conglomerate[1] - Chico Formation	47	2.9×10^{-6}
Sandstone or sandstone/ siltstone - Lower Topanga	93 - 100	near impervious[2] to 4.7×10^{-7}
Basalt - Middle Topanga	79 - 94	8.0×10^{-7} to 3.2×10^{-5}
Sandstone/Shale - Upper Topanga	48 - 100	5.2×10^{-8} to 4.2×10^{-4}

Notes: (1) Only one packer test was performed in this rock type.
(2) Near impervious denotes that no measurable flow was observed during packer testing

TABLE 5-3. SUMMARY OF SONIC VELOCITY DATA

Geologic Unit	Boring Number	Compressional Wave Velocity (ft/s)	Shear Wave Velocity (ft/s)
Plutonic Rocks	SM-2, SM-4 and SM-6	10,400 to 19,000	2,800 to 6,600
Chico Formation	SM-6	11,500 to 16,100	4,000 to 5,700
Lower Topanga(1)	SM-8	18,900 to >20,000	7,700 to 10,000
Middle Topanga(1)	SM-8	>20,000	7,100 to 8,300
Lower Section of Upper Topanga	SM-10	10,300 to >20,000	4,800 to 7,800
Upper Section of Upper Topanga	SM-12	5,800 to 8,000	3,000 to 4,000

Note: (1) Data were interpreted from sonic velocity logging in Boring SM-8. The interpreted seismic velocity is inconsistent with the very low strength of the rock.

TABLE 5-4. SUMMARY OF LABORATORY TEST RESULTS FOR SOILS

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Approximate Elevations: Tunnel Crown (feet)	Approximate Elevations: Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Sample Interval: Depth To (feet)	Sample Interval: Elevation From (feet)	Sample Interval: Elevation To (feet)	USCS Classification	Grain Size Distribution: Gravel (%)	Grain Size Distribution: Sand (%)	Grain Size Distribution: Fines (%)	Atterberg Limits: LL (%)	Atterberg Limits: PI (%)	Swell Pressure (psi)
SM-1	335RT.	485	347	327	6.0	10.0	479.0	475.0	CL	0	39	61	41	22	
					95.0	100.0	390.0	385.0	CH	0	5	95	65	41	
					128.0	130.0	357.0	355.0	SC-SM	1	71	28	26	6	
					136.0		349.0		SC	0	54	46	37	20	
					155.0	160.0	330.0	325.0	CL	0	43	57	46	25	
SM-1A	320RT.	492	348	328	139.0	143.0	353.0	349.0	CL				28	13	
					155.5	156.5	336.5	335.5	SC	7	46	47	34	20	
					156.5	160.0	335.5	332.0	CL				37	24	
					162.0	165.0	330.0	327.0	CL				40	25	
					173.0	175.5	319.0	316.5	SC	5	54	41	23	8	
SM-1B	340RT.	487	348	328	144.0	145.0	343.0	342.0	SP	1	98	1	36	12	
					169.0	169.8	318.0	317.2	SP	4	95	1	33	12	
SM-4	70LT.	960	375	355	0.0	7.0	960.0	953.0	CL	0	25	75	39	24	
					10.0	11.0	950.0	949.0	SM	0	85	15			
SM-5	130LT.	1226	396	376	451.0	451.5	775.0	774.5	SP	8	91	1	37	17	4.9
SM-11	30LT.	778	528	508	8.5	10.0	769.5	768.0	SC	0	70	30	39	19	
SM-12	230LT.	671	525	505	3.8	4.4	667.2	666.6	CL	0	46	54	37	20	
					6.9	7.4	664.1	663.6	CL	0	45	55	35	19	
SM-13	10LT.	590	521	501	4.1	4.6	585.9	585.4	CL				40	25	
					7.3	7.8	582.7	582.2	ML				27	4	
					9.0	9.5	581.0	580.5	CL				38	20	
					14.1	14.6	575.9	575.4	CL				40	24	
					15.0	20.0	575.0	570.0	SC	0	54	46	30	8	

TABLE 5-5. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS

Boring No	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Approximate Elevations: Tunnel Crown (feet)	Approximate Elevations: Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Sample Interval: Depth To (feet)	Sample Interval: Elevation From (feet)	Sample Interval: Elevation To (feet)	Rock Type (Formation)	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Mode (1) (Discontinuity)	Uniaxial Compression: Failure Stress (psi)	Uniaxial Compression: Young's Modulus (psi)	Uniaxial Compression: Poisson's Ratio	Point Load: Strength Index (2) (psi)	Point Load: Estimated Uniaxial Compressive Strength (5) (psi)	Slake Durability (%)	Swell Pressure (psi)
SM-1A	320RT.	492	348	328	124.0	124.6	368.0	367.5	Granodiorite/Gouge	2.66										
					162.0	165.0	330.0	327.0	Granodiorite/Gouge	2.70									24.5	
SM-2	130LT.	720	350	330	242.3	242.8	477.7	477.2	Granodiorite				Axial Splitting	13900	7.0E+06	0.19				
					251.7	252.7	468.3	467.3	Granodiorite	2.75	171	0.2	Shear Plane	10700	6.7E+06	0.21				
					367.0	367.5	353.0	352.5	Granodiorite	2.68	166	0.8	Conical Failure (Joints)	1730	1.1E+06	0.02				
					368.5	368.8	351.5	351.2	Granodiorite		162	0.5								
					382.0	382.3	338.0	337.7	Granodiorite	2.73	170	0.3								
					394.0	394.3	326.0	325.7	Granodiorite		171	0.2								
					408.1	408.7	311.9	311.3	Granodiorite				Axial Splitting	15900	6.7E+06	0.25				
SM-3	60LT.	686	350	330	154.5	155.6	531.5	530.4	Granodiorite		176	0.4	Axial Splitting (Joint)	13100						
					223.7	224.8	462.3	461.2	Granodiorite	2.83	175	0.2	Axial Splitting	11200	5.7E+06	0.40				
					265.1	266.3	420.9	419.7	Granodiorite		170	0.2	Axial Splitting	14300						
					295.0	295.5	391.0	390.5	Granodiorite				Shear Plane	3060						
													(Joint, calcite healed)							
					303.7	305.3	382.3	380.7	Granodiorite		172	0.2	Axial Splitting	10600						
					324.4	324.9	361.6	361.1	Granodiorite	2.79	175	0.1	Shear Plane(Joints)	12200						
					335.3	335.9	350.7	350.1	Granodiorite	2.70	173	0.1	Shear Plane(Joint)	10000	4.4E+06	0.10				
					338.0	339.0	348.0	347.0	Granodiorite		171	0.1	Axial Splitting	21200	6.4E+06	0.13				
					341.0	341.4	345.0	344.6	Granodiorite		172	0.1	Axial Splitting	17200						
					344.7	345.5	341.3	340.5	Granodiorite	2.73	170	0.3	Conical Failure	14600	1.2E+07	0.13				
					358.5	359.2	327.5	326.8	Granodiorite	2.71	169	0.7	Axial Splitting	8600						
													(Joints, calcite healed)							
SM-4	70LT.	960	375	355	77.6	78.3	882.4	881.7	Granodiorite		167	1.3	Shear Plane	3890						
													(Joint, calcite healed)							

TABLE 5-5. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Approximate Elevations: Tunnel Crown (feet)	Approximate Elevations: Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Sample Interval: Depth To (feet)	Sample Interval: Elevation From (feet)	Sample Interval: Elevation To (feet)	Rock Type (Formation)	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Mode (1) (Discontinuity)	Uniaxial Compression: Failure Stress (psi)	Uniaxial Compression: Young's Modulus (psi)	Uniaxial Compression: Poisson's Ratio	Point Load: Strength Index (2) (psi)	Point Load: Estimated Uniaxial Compressive Strength (5) (psi)	Slake Durability (%)	Swell Pressure (psi)
					109.0	109.5	651.0	650.5	Granodiorite				Shear Plane	15600						
					396.0	396.7	564.0	563.3	Granodiorite				Axial Splitting	16400						
					467.8	469.0	492.2	491.0	Granod./Aphanitic dike(?)	2.68	166	0.4	Axial Splitting	6670	5.4E+06	0.27				
					573.3	575.0	386.7	385.0	Granodiorite								1440	31680		
					578.0	579.1	382.0	380.9	Granodiorite	2.72	169	>0.1	Axial Splitting	22600	9.5E+06	0.15				
					580.4	581.7	379.6	378.3	Granodiorite	2.65	169	0.1	Conical	22900	1.0E+07	0.15				
					583.4	585.0	376.6	375.0	Granodiorite	2.72	169	0.1	Axial Splitting	20700						
					588.6	589.6	371.4	370.4	Granodiorite		168	0.1	Conical	17400						
					590.0	590.9	370.0	369.1	Granodiorite		167	0.2	Shear Plane	20500						
					596.6	597.6	363.4	362.4	Granodiorite	2.72	169	0.2	Conical	14000	8.4E+06	0.26				
					608.5	609.6	351.5	350.4	Granodiorite	2.69	167	0.2	Axial Splitting	15400	9.1E+06	0.23				
					623.0	624.5	337.0	335.5	Granodiorite								1070	23540		
SM-5	130LT.	1226	396	376	148.0	149.5	1078.0	1076.5	Sandstone (Chico)								365	8030		
					167.8	168.4	1058.2	1057.6	Conglo. Sandstone (Chico)				Axial Splitting (Clast Boundary)	3320						
					180.3	180.6	1045.7	1045.2	Sandstone (Chico)								368	8096		
					294.8	295.6	931.2	930.4	Conglo. Sandstone (Chico)	2.55	161	0.4	Conical (Clast Boundaries)	5050						
					305.3	306.0	920.7	920.0	Granitic Clast (Chico)								648(3)	14256		
					315.2	315.9	910.8	910.1	Sandstone (Chico)								309	6798		
					330.2	332.0	895.8	894.0	Sandstone (Chico)								235	5170		
					364.5	366.0	861.5	860.0	Conglomerate (Chico)								160	3520		
					396.1	396.6	829.9	829.4	Sandstone Clast (Chico)								120(3)	2640		
					400.0	401.7	826.0	824.3	Sandstone (Chico)		159	0.3	Shear Plane	8700						
					539.9	541.0	686.1	685.0	Conglomerate (Chico)								4	88		

TABLE 5-5. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Tunnel Crown (feet)	Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Depth To (feet)	Elevation From (feet)	Elevation To (feet)	Rock Type (Formation)	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Mode (1) (Discontinuity)	Failure Stress (psi)	Young's Modulus (psi)	Poisson's Ratio	Point Load: Strength Index (2) (psi)	Estimated Uniaxial Compressive Strength (5) (psi)	Slake Durability (%)	Swell Pressure (psi)
					551.5	552.0	674.5	674.0	Conglo. Clay Gouge (Chico)				Shear Plane	500						
													(Clay Shear)							
					553.2	553.9	672.8	672.1	Conglo. Clay Gouge (Chico)											6.2
					564.4	565.0	661.6	661.0	Granod./Chlorite alteration				Shear Plane	1640	4.9E+05	0.45				
													(Joints)							
					697.9	698.7	528.1	527.3	Granodiorite/Jointed								148	3256		
					722.8	723.4	503.2	502.6	Granodiorite				Conical	1620						
													(Joints, chlorite lined)							
					726.3	727.2	499.7	498.8	Granodiorite/Weathered								57	1254		
					760.2	770.0	465.8	456.0	Granodiorite								573	12606		
					826.9	827.4	399.1	398.6	Granodiorite				Conical	5030	2.8E+06	0.10				
													(Joint)							
					836.3	837.0	389.7	389.0	Granodiorite		163	1.1								
					838.7	839.6	387.3	386.4	Granodiorite	2.63	166	1.2	Shear Plane	10100	4.7E+06	0.25				
					841.9	842.5	384.1	383.5	Granodiorite											
					853.5	854.4	372.5	371.6	Granodiorite	2.67	169	1.4	No Discernible Plane	10300						
					860.4	861.0	365.6	365.0	Granodiorite				Shear Plane	3320						
													(Joints, chlorite lined)							
					861.4	861.9	364.6	364.1	Granodiorite		162	1.0								
					869.3	870.1	356.7	355.9	Granodiorite/Jointed								387	8514		
					886.5	887.3	339.5	338.7	Granodiorite								1142	25124		
SM-6	60RT.	1180	408	388	51.5	52.6	1128.5	1127.4	Conglomerate (Chico)	2.65	150	0.7	Conical	970	1.4E+05	0.44				
													(Clast Boundaries)							
					121.3	121.7	1058.7	1058.3	Conglomerate (Chico)				Conical	6050						
					158.3	159.0	1021.7	1021.0	Sandstone Clast (Chico)								19(3)	418		
					233.1	234.1	946.9	945.9	Granitic Clast (Chico)								492(3)	10824		

TABLE 5-5. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Approximate Elevations: Tunnel Crown (feet)	Approximate Elevations: Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Sample Interval: Depth To (feet)	Sample Interval: Elevation From (feet)	Sample Interval: Elevation To (feet)	Rock Type (Formation)	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Mode (1) (Discontinuity)	Uniaxial Compression: Failure Stress (psi)	Uniaxial Compression: Young's Modulus (psi)	Uniaxial Compression: Poisson's Ratio	Point Load: Strength Index (2) (psi)	Point Load: Estimated Uniaxial Compressive Strength(5) (psi)	Slake Durability (%)	Swell Pressure (psi)
					282.6	283.8	897.4	896.2	Conglomerate (Chico)										97.4	
					375.9	376.9	804.1	803.1	Conglomerate (Chico)	2.49	156	0.3	Conical	3002	1.6E+06	0.37				
													(Clast Boundaries)							
					439.1	440.9	740.9	739.1	Conglo. Sandstone (Chico)								336(4)	7392		
									Quartzite Clast (Chico)								500(3)	11000		
					492.5	493.0	687.5	687.0	Sandstone (Chico)				Axial Splitting	6060						
					571.2	572.0	608.8	608.0	Sandstone (Chico)								405(4)	8910		
									Quartzite Clast (Chico)								731(3)	16082		
					591.4	592.1	588.6	587.9	Conglo. Sandstone (Chico)								583	12826		
					687.0	687.6	493.0	492.4	Conglomerate (Chico)				Shear Plane	7170						
													(Clast Boundary)							
					738.0	739.0	442.0	441.0	Granodiorite/Weathered								107	2354		
					754.2	755.0	425.8	425.0	Granodiorite/Weathered								197	4334		
					773.5	774.1	406.5	405.9	Granodiorite	2.64	164	2.8	Shear Plane (Joint ?)	3330	1.1E+06	0.04				
					777.6	778.6	402.2	401.4	Granodiorite	2.57	162	1.0	Axial Splitting	2930	4.0E+05	0.35				
					782.5	783.8	397.5	396.2	Granodiorite		162	0.6	Conical	4400	4.6E+06	0.36				
					789.3	790.0	390.7	390.0	Granodiorite	2.63	164	0.9	Conical	3210						
					800.6	801.0	379.4	379.0	Granodiorite											
					807.9	808.9	372.1	371.1	Granodiorite/Weathered								61	1342		
SM-7	225LT.	1100	428	408	73.0	74.3	1027.0	1025.7	Sandstone (Simi)		155	0.50	Conical (Joint)	1270						
					111.5	112.7	988.5	987.3	Sandstone (Simi)		159	0.60	Shear Plane	4560						
					161.7	162.1	918.3	917.9	Quartzite Clast (Chico)								606(3)	13332		
					186.0	186.8	914.0	913.2	Sandstone (Chico)								6	132		
					192.4	193.3	907.6	906.7	Sandstone (Chico)		152	1.00	Shear Plane	5870						
					289.0	290.0	811.0	810.0	Sandstone (Chico)	2.50	152	0.3	Shear Plane	4980	1.4E+06	0.35				
					303.3	304.0	796.7	796.0	Sandstone (Chico)								96	2112		

TABLE 5-5. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Approximate Elevations: Tunnel Crown (feet)	Approximate Elevations: Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Sample Interval: Depth To (feet)	Sample Interval: Elevation From (feet)	Sample Interval: Elevation To (feet)	Rock Type (Formation)	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Mode (1) (Discontinuity)	Uniaxial Compression: Failure Stress (psi)	Uniaxial Compression: Young's Modulus (psi)	Uniaxial Compression: Poisson's Ratio	Point Load: Strength Index (2) (psi)	Point Load: Estimated Uniaxial Compressive Strength (5) (psi)	Slake Durability (%)	Swell Pressure (psi)
					432.7	433.6	667.3	666.4	Sandstone (Chico)		164	0.2	Conical	18106						
					565.7	566.6	534.3	533.4	Conglomerate (Chico)		160	0.8	Conical (Clast Boundaries)	5190						
					590.3	591.4	509.7	508.6	Conglomerate (Chico)								34	748		
					662.0	662.4	438.0	437.6	Conglomerate (Chico)											
					672.6	673.3	427.4	426.7	Conglomerate (Chico)	2.55	157	0.6	No Discernible Plane (Clast Boundaries)	1800	9.7E+05	0.50				
					681.5	682.0	418.5	418.0	Sandstone (Chico)											
					685.3	685.8	414.7	414.2	Conglomerate (Chico)		140	0.5	Shear Pl.(Shear, calcite h	1190	4.0E+05	0.38				
					699.5	700.6	400.5	399.4	Conglomerate (Chico)	2.50	157	0.6	Shear Plane (Sheared Surface)	3890						
					701.5	702.0	398.5	398.0	Conglomerate (Chico)											
					703.0	703.7	397.0	396.3	Conglomerate (Chico)		152	0.6	Shear Plane (Shears)	2430	1.6E+06	0.10				
					704.0	704.6	396.0	395.4	Conglomerate (Chico)								25	50		
					704.7	705.7	395.3	394.3	Conglomerate (Chico)										95.3	
					706.0	706.8	394.0	393.2	Conglomerate (Chico)	2.43	152	0.6	Shear Plane (Clay Coated Shears)	280						
					706.8	707.8	393.2	392.2	Conglomerate (Chico)		154	0.4	Axial Splitting (Shears)	3340	1.8E+06	0.31				
					730.3	731.2	369.7	368.8	Conglomerate (Chico)								639	14058		
SM-8	0RT.	1175	450	430	77.6	79.4	1097.4	1095.6	Basalt (M Topanga)		151	5.1	Conical (Joint)	4310					96.7	
					210.6	211.7	964.4	963.3	Basalt (M Topanga)								32	704		
					217.7	218.3	957.3	956.7	Basalt (M Topanga)				Axial Splitting	4200						
					271.0	272.4	904.0	902.6	Basalt (M Topanga)								20	440		

TABLE 5-5. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Tunnel Crown (feet)	Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Depth To (feet)	Elevation From (feet)	Elevation To (feet)	Rock Type (Formation)	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Mode (1) (Discontinuity)	Failure Stress (psi)	Young's Modulus (psi)	Poisson's Ratio	Point Load: Strength Index (2) (psi)	Estimated Uniaxial Compressive Strength (5) (psi)	Slake Durability (%)	Swell Pressure (psi)
					323.8	324.6	851.2	850.2	Basalt (M Topanga)	2.38	150	3.7								
					325.5	326.3	849.5	848.7	Basalt (M Topanga)								248	5456		
					397.5	398.8	777.5	776.2	Basalt (M Topanga)								32	704		
					453.5	454.5	721.5	720.5	Basalt (M Topanga)		126	10.0	Shear Plane	2400						
					491.0	492.5	684.0	682.5	Basalt (M Topanga)								173	3806		
					538.3	540.1	636.7	634.9	Basalt Breccia (M Top.)	2.57	137	7.7							59.0	
					654.4	655.6	520.6	519.4	Sandstone (L Topanga)								36	792		
					712.4	713.4	462.6	461.6	Sandstone (L Topanga)											
					721.4	722.2	453.6	452.8	Sandstone (L Topanga)	2.42	149	0.8	Conical	4620	1.2E+06	0.39				
					731.3	732.0	443.7	443.0	Conglomeratic Sandstone (L Topanga)	2.45	154	0.8	Axial Splitting	3230	2.5E+06	0.26				
					737.1	737.5	437.9	437.5	Sandstone (L Topanga)											
					741.5	742.6	433.5	432.4	Sandstone (L Topanga)	2.41	152	1.8	Axial Splitting	1500	4.3E+05	0.43				
					745.0	745.3	430.0	429.7	Conglo. Sandstone (L Top.)											
					752.5	753.6	422.5	421.4	Sandstone (L Topanga)		152	1.0	Shear Plane*/Axial Splitti	3320						
					762.7	763.5	412.3	411.5	Sandstone (L Topanga)	2.39	154	2.5	Shear Plane (Joints)	970	3.4E+05	0.11			93.8	
					786.5	787.5	388.5	387.5	Sandstone (L Topanga)								261	6182		
SM-9	170LT.	1112	479	459	33.5	34.3	1078.5	1077.7	Basalt Breccia (M Topanga)								27	594		
					62.5	63.5	1049.5	1048.5	Basalt Breccia (M Topanga)		134	5.8	Shear Plane	3850						
					117.0	117.8	995.0	994.2	Basalt (M Topanga)		154	4.7								
					151.9	152.7	960.1	959.3	Basalt Breccia (M Topanga)								39	858		
					196.9	197.9	915.1	914.1	Basalt Breccia (M Topanga)		142	5.6	Shear Plane (Shears, zeolite healed)	930						
					286.5	288.2	825.5	823.8	Basalt Breccia (M Topanga)								38	836		
					315.1	317.0	796.9	795.0	Basalt Breccia (M Topanga)		136	4.7	Axial Splitting (Shears, clacite-chlorite healed)	1050					60.6	

TABLE 5-5. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS

Boring No	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Tunnel Crown (feet)	Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Depth To (feet)	Elevation From (feet)	Elevation To (feet)	Rock Type (Formation)	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Mode (1) (Discontinuity)	Failure Stress (psi)	Young's Modulus (psi)	Poisson's Ratio	Point Load: Strength Index (2) (psi)	Estimated Uniaxial Compressive Strength(5) (psi)	Slake Durability (%)	Swell Pressure (psi)
					437.7	439.0	674.3	673.0	Basalt Breccia (M Topanga)		148	3.5								
					567.7	568.3	544.3	543.7	Basalt Breccia (M Topanga)								259	5698		
					575.5	577.0	536.5	535.0	Basalt Breccia (M Topanga)		134	6.8	Conical (Shear, chlorite healed)	1870						
					623.0	624.6	489.0	487.4	Basalt Breccia (M Topanga)	2.25	148	9.6	Axial Splitting (Shear, clacite-chlorite healed)	950						
					626.0	626.6	486.0	485.4	Basalt Breccia (M Topanga)										83.8	
					627.5	628.0	484.5	484.0	Basalt Breccia (M Topanga)											
					635.7	636.3	476.3	475.7	Basalt Breccia (M Topanga)		144	7.0	Conical (Clast Boundaries)	40						
					644.2	645.2	467.8	466.8	Basalt Breccia (M Topanga)										75.0	
					645.8	646.9	466.2	465.1	Basalt Breccia (M Topanga)	2.27	147	5.8	Conical (Shear, chlorite-zeolite healed)	430	3.8E+05	0.45				
					663.8	664.9	448.2	447.1	Basalt Breccia (M Topanga)		142	7.2	Conical (Clast Boundaries)	1510						
					672.4	673.0	439.6	439.0	Basalt Breccia (M Topanga)	2.31	135	7.6	Shear Plane	1040	5.2E+05	0.22				
SM-10	190LT.	1147	505	465	46.0	48.0	1101.0	1099.0	Sandstone (U Topanga)		138	2.6								
					89.0	90.0	1058.0	1057.0	Conglo. Sandstone (U Top.)		131	4.0								
					173.9	175.0	973.1	972.0	Cong. Sandstone (U Top.)								433	9526		
					186.7	187.5	960.3	959.5	Sandstone (U Topanga)				Axial Splitting	3750						
					290.0	291.3	857.0	855.7	Sandstone (U Topanga)		139	2.5								
					349.0	350.0	798.0	797.0	Sandstone (U Top.)								140	3060		
					366.2	367.2	780.8	779.8	Sandstone (U Top.)								217	4774		
					435.0	437.0	712.0	710.0	Conglo. Sandstone (U Top.)	2.22	143	2.2	Shear Plane	2670	7.8E+05	0.35				
					542.6	543.7	604.4	603.3	Conglo. Sandstone (U Top.)		142	2.0								

TABLE 5-5. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Approximate Elevations: Tunnel Crown (feet)	Approximate Elevations: Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Sample Interval: Depth To (feet)	Sample Interval: Elevation From (feet)	Sample Interval: Elevation To (feet)	Rock Type (Formation)	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Mode (1) (Discontinuity)	Uniaxial Compression: Failure Stress (psi)	Uniaxial Compression: Young's Modulus (psi)	Uniaxial Compression: Poisson's Ratio	Point Load: Strength Index (2) (psi)	Point Load: Estimated Uniaxial Compressive Strength(5) (psi)	Slake Durability (%)	Swell Pressure (psi)
					600.0	601.5	547.0	545.5	Granitic Clast (U Top.)								522(3)	11484		
									Cong. Sandstone (U Top.)								90(4)	1980		
					611.5	613.9	535.5	533.1	Sandstone (U Topanga)		143	1.0	Axial Splitting	5170						
					630.0	631.1	517.0	515.9	Sandstone (U Topanga)	2.22	138	1.1	Conical	2830						
					635.0	635.4	512.0	511.6	Sandstone (U Topanga)										77.4	
					640.0	641.0	507.0	506.0	Conglo. Sandstone (U Top.)		144	3.4	Shear Plane	5320	2.5E+06	0.32				
					641.5	641.9	505.5	505.1	Conglo. Sandstone (U Top.)											
					643.9	645.0	503.1	502.0	Conglo. Sandstone (U Top.)		143	2.1	Axial Splitting	4810						
					645.0	646.0	502.0	501.0	Sandstone (U Topanga)	2.24	139	0.7	Shear Plane	3540	1.9E+06	0.39				
					655.0	656.1	492.0	490.9	Sandstone (U Topanga)		142	1.7	Axial Splitting	3640						
					659.1	659.5	487.9	487.5	Sandstone (U Topanga)											
					668.8	670.0	478.2	477.0	Sandstone (U Topanga)	2.60	163	0.3	Conical	13500	5.4E+06	0.35				
					670.0	670.7	477.0	476.3	Granitic Clast (U Top.)								366(3)	8052		
					676.6	677.6	470.4	469.4	Granitic Clast (U Top.)								803(3)	17666		
					678.4	680.0	468.6	467.0	Sandstone (U Top.)								181	3982		
SM-11	30LT.	778	528	508	63.7	64.6	714.3	713.2	Sandstone/Siltstone (U Top.)		126	5.2								
					111.2	112.5	666.8	665.5	Sandstone (U Topanga)	2.64	124	7.8	Shear Plane	1110						
					115.0	116.7	663.0	661.3	Sandstone (U Topanga)								61	1342		
					160.2	162.3	617.8	615.7	Cong. Sandstone (U Top.)		141	1.0							95.7	
					190.0	192.0	588.0	586.0	Sandstone (U Topanga)								153	3366		
					212.9	214.6	565.1	563.4	Shale/Sandstone (U Top.)								22	484		
					217.5	218.7	560.5	559.3	Sandstone (U Topanga)		149	2.4	Shear Plane	1020						
													(Bedding)							
					236.9	237.9	541.1	540.1	Sandstone (U Topanga)	2.02	130	7.8	Axial Splitting	2260	5.2E+05	0.28				
					239.0	239.7	539.0	538.3	Sandstone (U Topanga)											
					242.5	244.5	535.5	533.5	Sandstone (U Topanga)		131	5.7	Shear Plane	4480	1.1E+06	0.33				

TABLE 5-5. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS

Boring No	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Approximate Elevations: Tunnel Crown (feet)	Approximate Elevations: Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Sample Interval: Depth To (feet)	Sample Interval: Elevation From (feet)	Sample Interval: Elevation To (feet)	Rock Type (Formation)	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Mode (1) (Discontinuity)	Uniaxial Compression: Failure Stress (psi)	Uniaxial Compression: Young's Modulus (psi)	Uniaxial Compression: Poisson's Ratio	Point Load: Strength Index (2) (psi)	Point Load: Estimated Uniaxial Compressive Strength (5) (psi)	Slake Durability (%)	Swell Pressure (psi)
					245.0	246.0	533.0	532.0	Sandstone (U Topanga)		127	4.6	Conical	3170						
					253.8	254.8	524.2	523.2	Cong. Sandstone (U Top.)	2.34	145	2.1	Shear Plane	4790	1.5E+06	0.24				
					260.0	261.1	518.0	516.9	Sandstone (U Topanga)		138	2.1	Axial Splitting	3070						
					275.0	276.0	503.0	502.0	Sandstone/Siltstone (U Top.)	2.77	135	7.9	Conical	140	1.4E+05				50.1	
													(Bedding Plane)							
					300.5	301.0	477.5	477.0	Sandstone/Siltstone (U Top.)								57	1254		
SM-12	230LT.	671	525	505	36.8	37.3	634.2	633.7	Sandstone/Siltstone				Shear Plane	60						
									(U Topanga)				(Bedding)							
					89.6	90.1	581.4	580.9	Sandstone (U Topanga)				Shear Plane	270						
					95.0	96.0	576.0	575.0	Siltstone (U Topanga)								76	1672		
					103.4	104.1	567.6	566.9	Sandstone/Siltstone				Shear Plane	50	9.3E+03	0.27				
									(U Topanga)				(Bedding)							
					142.6	143.6	528.4	527.4	Sandstone/Siltstone		124	12.5	Conical	230						
									(U Topanga)				(across bedding)							
					151.7	152.9	519.3	518.1	Sandstone (U Topanga)	2.26	141	6.9	Axial Splitting	1760	5.5E+05	0.44				
					162.1	162.9	508.9	508.1	Sandstone/Siltstone	2.70	127	10.1	Shear Plane	140	3.2E+04	0.37				
									(U Topanga)				(Bedding)							
					165.2	166.0	505.8	505.0	Sandstone/Siltstone(U Top.)		128	5.0	Shear Plane (Bedding)	100					11.3	
					167.0	168.0	504.0	503.0	Sandstone/Siltstone(U Top.)		126	8.8	Shear Plane	100						
													(Bedding)							
					174.8	175.8	496.2	495.2	Sandstone/Siltstone(U Top.)	2.72	131	5.6	Shear Plane	20						
													(Bedding)							
					191.5	192.0	479.5	479.0	Sandstone (U Topanga)								38	792		

TABLE 5-5. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Approximate Elevations: Tunnel Crown (feet)	Approximate Elevations: Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Sample Interval: Depth To (feet)	Sample Interval: Elevation From (feet)	Sample Interval: Elevation To (feet)	Rock Type (Formation)	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Mode (1) (Discontinuity)	Uniaxial Compression: Failure Stress (psi)	Uniaxial Compression: Young's Modulus (psi)	Uniaxial Compression: Poisson's Ratio	Point Load: Strength Index (2) (psi)	Point Load: Estimated Uniaxial Compressive Strength(5) (psi)	Slake Durability (%)	Swell Pressure (psi)
SM-13	10LT.	590	521	501	46.9	48.0	543.1	542.0	Sandstone/Siltstone (U Top.)										1.1	
					60.3	62.2	529.7	527.8	Sandstone/Siltstone (U Top.)	2.64	123	7.6	Shear Plane (Bedding)	280	5.6E+04	0.43				
					65.1	66.4	524.9	523.6	Sandstone/Siltstone (U Top.)			13.5	Shear Plane (Bedding)	230						
					71.1	72.9	518.9	517.1	Sandstone/Siltstone (U Top.)	2.61	119	6.0	Shear Plane (Bedding)	40						
					79.0	79.9	511.0	510.1	Sandstone/Siltstone (U Top.)		122	12.6	Shear Plane (Bedding)	120						
					92.5	93.7	497.5	496.3	Sandstone/Siltstone (U Top.)		124	11.0	Shear Plane (Bedding)	60						
					96.7	98.7	493.3	491.3	Sandstone/Siltstone (U Top.)	2.70	124	3.5	Shear Plane (Bedding)	170					1.3	

Notes: (1) Three failure modes were observed. These included:

(i) Axial Splitting mode where failure planes were near vertical and splitted the samples into two pieces.

(ii) Shear plane mode where well-defined inclined failure (shear) planes (i.e. at an angle to vertical) were observed.

(iii) Conical failure mode where cone-shaped failure planes were observed.

(2) The point load strength has been corrected for size effects as per ISRM Standards.

(3) Point load strength index for the sample clast.

(4) Point load strength index for the sample matrix.

(5) Estimated uniaxial compressive strength calculated by multiplying Point Load Strength Index by a factor of 22.

TABLE 5-6. SUMMARY OF LABORATORY TEST RESULTS FOR ROCKS IN VARIOUS FORMATIONS

	Bulk Specific Gravity	Bulk Density (pcf)	Moisture Content (%)	Uniaxial Compression: Failure Stress (Ksi)	Uniaxial Compression: Young's Modulus (psi)	Uniaxial Compression: Poisson's Ratio	Point Load: Strength Index (psi)	Point Load: Estimated Uniaxial Compressive Strength (Ksi)	Slake Durability (%)	Swell Pressure (psi)
FORMATION: GRANODIORITE										
COUNT / INTACT	21	32	32	36 / 23	19 / 14	19 / 14	10 / 4	10 / 4	1	
MINIMUM	2.57	162	0.1	1.62	4.0E+05	0.02	57			
MAXIMUM	2.83	178	2.6	22.90	1.2E+07	0.45	1440			
AVERAGE / INTACT	2.70	168	0.5	10.87 / 14.18	5.6E+06 / 6.9E+06	0.21 / 0.24	516 / 981	11.4 / 21.8	24.50	
FORMATION: CHICO (including Simi)										
COUNT / INTACT	7	16	16	21 / 8	7 / 3	7 / 3	14 / 14	14 / 14	2	1
MINIMUM	2.43	140	0.2	0.28	1.4E+05	0.10	4		95.3	
MAXIMUM	2.65	164	1.0	18.11	1.8E+06	0.50	731		97.4	
AVERAGE / INTACT	2.52	155	0.5	4.46 / 7.17	1.1E+06 / 1.8E+06	0.35 / 0.24	254.6 / 254.6	5.6 / 5.6	96.4	8.2
QUARTZITE AND GRANITIC CLASTS							5.95	13.09		
FORMATION: LOWER TOPANGA										
COUNT / INTACT	4	5	5	5 / 4	4 / 2	4 / 2	2 / 2	2 / 2	1	
MINIMUM	2.39	149	0.8	0.97	3.4E+05	0.11	36			
MAXIMUM	2.45	154	2.5	4.62	2.5E+06	0.43	281			
AVERAGE / INTACT	2.42	152	1.4	2.73 / 3.17	1.1E+06 / 0.84E+06	0.30 / 0.41	159 / 159	3.49 / 3.49	93.8	
FORMATION: MIDDLE TOPANGA										
COUNT / INTACT	5	15	15	12 / 4	2 / 1	2 / 1	9 / 9	9 / 9	5	
MINIMUM	2.25	128	3.5	0.04	3.8E+05	0.22	20		59.0	
MAXIMUM	2.57	154	10.0	4.31	5.2E+05	0.45	259		96.7	
AVERAGE / INTACT	2.36	142	6.3	1.88 / 2.87	4.5E+05 / 5.2E+05	0.34 / 0.22	96 / 96	2.11 / 2.11	75.0	
FORMATION: UPPER TOPANGA - SANDSTONES / CONGLOMERATES										
COUNT / INTACT	4	12	12	9 / 9	4 / 4	4 / 4	6 / 6	6 / 6	1	
MINIMUM	2.22	131	0.25	2.67	7.8E+05	0.32	90			
MAXIMUM	2.80	163	4.00	13.50	5.4E+06	0.39	803			
AVERAGE / INTACT	2.32	142	1.96	5.03 / 5.03	2.6E+06 / 2.6E+06	0.35 / 0.35	242.8 / 242.8	5.34 / 5.34	77.4	
QUARTZITE AND GRANITIC CLASTS							5.64	12.4		
FORMATION: UPPER TOPANGA - SANDSTONES / SHALES										
COUNT / INTACT	10	21	22	23 / 9	8 / 4	7 / 4	6 / 6	6 / 6	5	
MINIMUM	2.02	119	1.0	0.02	9.3E+03	0.24	22		1.1	
MAXIMUM	2.77	149	13.5	4.79	1.5E+06	0.40	153		95.7	
AVERAGE / INTACT	2.54	130	6.8	1.03 / 2.35	0.5E+06 / 0.9E+06	0.34 / 0.32	68 / 68	1.49 / 1.49	31.9	

TABLE 5-7. SEMI-QUANTITATIVE X-RAY DIFFRACTION ANALYSIS (1 OF 2)

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations			Sample Interval				Rock Type	Percentage by Weight														
		Ground Surface (feet)	Tunnel Crown (feet)	Tunnel Invert (feet)	Depth		Elevation			Quartz	Plagioclase	K-Feldspar	Calcite	Ferroan Dolomite	Pyrite	Hematite	Amphibole	Illite + Mica	Chlorite	Vermiculite	Smectite	Amorphous	Analcime	Laumontite
					From (feet)	To (feet)	From (feet)	To (feet)																
SM-1A	320RT.	492	348	328	124.0	124.5	368.0	367.5	Granodiorite/Gouge	19	35		23	3				10	7	3				
					162.0	165.0	330.0	327.0	Granodiorite/Gouge	25	23	4	10	4	Tr			9	14	4	7			
SM-2	130LT.	720	350	330	367.0	367.5	353.0	352.5	Granodiorite	24	30			2			Tr	19	12	11				2
					382.0	382.3	338.0	337.7	Granodiorite	24	32			2			2	13	6	21				
SM-3	60LT.	686	350	330	335.3	335.9	350.7	350.1	Granodiorite	26	32		1				12	16	7	6				
					344.7	345.5	341.3	340.5	Granodiorite	24	31		1				10	1	16	17				
SM-4	70LT.	960	375	355	578.0	579.1	382.0	380.9	Granodiorite	30	33				3		3	25	4		2			
					596.6	597.6	363.4	362.4	Granodiorite	27	40				2		4	9	17		1			
					608.5	609.6	351.5	350.4	Granodiorite	31	39				1		10	4	15		Tr			
SM-5	130LT.	1226	396	376	451.1	451.9	774.9	774.1	Conglomeratic Sandstone	27	16	9			5			18	8		17			
					553.2	553.9	672.8	672.1	Conglomeratic Clay Gouge	29	18	7			Tr			2	4		11	29		
					826.9	827.4	399.1	398.6	Granodiorite	18	15						Tr	2	11		30			24
					838.7	839.6	387.3	386.4	Granodiorite	25	23	2	11	3	Tr			6	16	5	8			
					860.4	861.0	365.6	365.0	Granodiorite	10	45	8					12	2	19					4
SM-6	60RT.	1180	408	388	773.5	774.1	406.5	405.9	Granodiorite	20	26		1	2				2	21			20		6
					777.8	778.6	402.2	401.4	Granodiorite	18	31		1	1				2	21	2				24
SM-7	225LT.	1100	428	408	672.6	673.3	427.4	426.7	Conglomerate	41	22	15	1		1			7	13					
					699.5	700.6	400.5	399.4	Conglomeratic Sandstone	45	23	19	2		1			4	6					
					706.0	706.8	394.0	393.2	Conglomerate	45	16	13			4			9	13					
SM-8	0RT.	1175	450	430	721.4	722.2	453.6	452.8	Sandstone	41	26	20	20	1				3	2		7			
					731.3	732.0	443.7	443.0	Conglomeratic Sandstone	35	24		26	2				4	Tr		8			
					741.5	742.6	433.5	432.4	Sandstone	36	12		20					5	4		23			
					762.7	763.5	412.3	411.5	Sandstone	27	23		11					9	10		20			

TABLE 5-7. SEMI-QUANTITATIVE X-RAY DIFFRACTION ANALYSIS (2 OF 2)

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Approximate Elevations: Tunnel Crown (feet)	Approximate Elevations: Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Sample Interval: Depth To (feet)	Sample Interval: Elevation From (feet)	Sample Interval: Elevation To (feet)	Rock Type	Percentage by Weight: Quartz	Plagioclase	K-Feldspar	Calcite	Ferroan Dolomite	Pyrite	Hematite	Amphibole	Illite + Mica	Chlorite	Vermiculite	Smectite	Amorphous	Analcime	Laumontite
SM-9	170LT.	1112	479	459	635.7	636.3	476.3	475.7	Basalt Breccia	Tr			1							84			15	
					663.8	664.9	448.2	447.1	Basalt Breccia	Tr			2							87			11	
SM-10	190LT.	1147	505	485	630.0	631.1	517.0	515.9	Conglomeratic Sandstone	21	35	28	2		1	1		2		7		3		
					643.9	645.0	503.1	502.0	Conglomeratic Sandstone	26	31	26	1		1			2		8		5		
					668.8	670.0	478.2	477.0	Sandstone	33	39	16	2					9		1				
SM-11	30LT.	778	528	508	242.5	244.5	535.5	533.5	Sandstone	22	26	21	8	3	4			2						
					253.8	254.8	524.2	523.2	Conglomeratic Sandstone	24	28	28	2	2	3	Tr		2	6			3		
					275.0	276.0	503.0	502.0	Sandstone	32	21	12	3	2	6			8						
SM-12	230LT.	671	525	505	151.7	152.9	519.3	518.1	Sandstone/Siltstone	37	17	19	4	6	2			5	2		8			
					165.2	166.0	505.8	505.0	Sandstone/Siltstone	31	21	15	13	2	3			4	2		9			
					167.0	168.0	504.0	503.0	Sandstone/Siltstone	27	22	11	1	1	5			11	5		17			
					174.6	175.6	496.2	495.2	Sandstone	22	23	11	2	2	10			11	4		15			
SM-13	10LT.	590	521	501	60.3	62.2	529.7	527.8	Sandstone/Siltstone	35	20	14			3		1	7	1		19			
					71.1	72.9	518.9	517.1	Sandstone/Siltstone	31	18	17	Tr		5			8	1		20			
					96.7	98.7	493.3	491.3	Sandstone/Siltstone	31	21	11	Tr		6			10	1		20			

TABLE 5-8. THIN SECTION ANALYSIS

Boring No.	Approximate Offset From Center Line of AR Track (feet)	Approximate Elevations: Ground Surface (feet)	Approximate Elevations: Tunnel Crown (feet)	Approximate Elevations: Tunnel Invert (feet)	Sample Interval: Depth From (feet)	Sample Interval: Depth To (feet)	Sample Interval: Elevation From (feet)	Sample Interval: Elevation To (feet)	Rock Type
SM-2	130LT.	720	350	330	407.2	407.6	312.6	312.4	Granite
SM-3	60LT.	686	350	330	264.2	264.4	421.8	421.6	Quartz Monzonite
					348.0	348.3	340.0	339.7	Quartz Monzonite
SM-4	70LT.	960	375	355	363.8	364.0	598.2	598.0	Quartz Monzonite
					363.8	364.0	598.2	598.0	Basalt
					418.1	418.6	541.9	541.4	Granodiorite
					491.0	491.4	469.0	468.6	Basalt
SM-5	130LT.	1226	396	376	555.7	556.0	670.3	670.0	Sandstone
					555.7	556.0	670.3	670.0	Tuff
					605.8	606.3	620.2	619.7	Mylonite-Plutonic
SM-6	60RT.	1180	408	388	727.5	727.8	452.5	452.2	Quartz Monzonite
SM-7	225LT.	1100	428	408	303.0	303.7	797.0	796.3	Sandstone
					353.9	354.2	746.1	745.8	Sandstone
					702.5	702.9	397.5	397.1	Conglomerate
SM-8	0RT.	1175	450	430	345.0	345.4	830.0	829.6	Basalt
					442.2	442.5	732.8	732.5	Basalt
					474.8	475.1	700.2	699.9	Basalt
					568.8	569.0	606.2	606.0	Sandstone
					720.1	720.4	454.9	454.6	Sandstone
					729.3	729.6	445.7	445.4	Sandstone
					788.2	788.5	386.8	386.5	Sandstone
SM-9	170LT.	1112	479	459	409.8	410.1	702.2	701.9	Basalt
					852.0	852.3	460.0	459.7	Basalt
SM-11	30LT.	776	528	508	301.5	302.0	478.5	478.0	Sandstone/Siltstone

Composition (%)

Boring No.	Depth From (feet)	Quartz & Others: Quartz	Chalcedony	Glass	Tridymite	Feldspar: Orthoclase	Plagioclase	Amphibole: Hornblende	Kaersutite	Pyroxene	Chlorite Group: Chlorite	Pennine	Chlinochlore	Prochlorite (Ripidolite)	Antigorite (Serpentine Group)	Mica: Biotite	Muscovite	Clays: Sericite	Vermiculite	Montmorillonite	Zeolite: Zeolite	Natrolite	Analcite	Olivine: Olivine	Fayalite	Epidote & Clinozoisite	Accessory: Pyrite	Hematite	Magnetite	Spinel	Garnet	Zircon	Calcite	Other	Rock Fragments: Quartz Grains	Quartz Rich Rock Fragments	Other Rock Fragments	Feldspar Grains	Porosity
SM-2	407.2	20				14	5		20			6					2	26			2							4		1	1	<1							
SM-3	264.2	21				33	16	18								8		<1										<1		<1		1		1					
	348.0	25				28	27	13			5					<1												1		<1		<1		1					
SM-4	363.8	31				13	7		7			13						29										<1		<1									
	363.8						15			3	17				65																<1								
	418.1	33				20	25	6		2		3				6		5										<1		<1		<1							
	491.0						13							48	37									1				1											
SM-5	555.7										47																		3				1		25		13	11	
	555.7						27				68																		<1				5						
	605.8	32					2				22															43	1	<1					<1						
SM-6	727.5	18				21	13		2			15		3				21										6				<1							
SM-7	303.0															5				27							<1								45			22	1
	353.9															2		16									<1								31	13	20	13	5
	702.5															1.9		14																	18	3	38	17	6
SM-8	345.0						7						2	34	46				4				6					1											
	442.2						16				37				43								2				2							<1					
	474.8		2	16	56		16																		7		<1							1					
	568.8																										1						28	<1	28	13	12	18	<1
	720.1															1	2			20							3								47			25	1
	729.3										4					1	<1										<1								30	2	36	26	1
	788.2															7	<1			6							1								43		1	25	17
SM-9	409.8						2					<1		41	45				10				1				1												
	852.0						1					2		34	31				5			2	24				<1												
SM-11	301.5										11						<1											5					4		55		7	18	

Note: Percentages have been rounded off to the nearest whole number. See Appendix G for actual percentages of components and descriptions.

6.0 GEOTECHNICAL CHARACTERIZATION AND ANTICIPATED TUNNELING CONDITIONS

6.1 GENERAL DESCRIPTION AND METHODS

This section provides a geotechnical characterization of various rocks anticipated to be encountered along the proposed alignment based on data from the current laboratory and field investigations. The laboratory investigations were conducted on rock core samples selected from the borings completed for this project. The field data interpretations are based on the boring logs and in situ field testing within the borings. The geotechnical parameters from the field and laboratory testing are presented in Section 5.0. Those geotechnical parameters are the basis for characterizing the in situ rock masses through which the tunnels will be excavated for anticipating the ground behavior affecting tunneling conditions. This section first discusses the geotechnical parameters considered significant to tunneling, and then applies those parameters to selected tunneling-related rock mass classification systems. The last part of this section reviews the anticipated tunneling conditions for each of the rock types grouped in reaches of the tunnel.

A number of rock classification systems have been developed and published for use in engineering of excavations in rock masses using the basic geotechnical parameters presented in this report. Four of those classification systems are reviewed in this section as examples of how the rocks in the Santa Monica Mountains along the proposed Metro Rail alignment can be classified according to the different systems. The geotechnical parameters considered relevant for design and construction of the planned tunnel and shaft facilities include but are not necessarily limited to the following:

- o Strength, deformation, and index parameters intact rock cores including uniaxial compressive strength, point load tests, Young's modulus and Poisson's ratio, slake durability, swell pressure, abrasive hardness characteristics, and deformation modulus of the rock mass.

- o Rock mass parameters derived from field observations include core recovery, RQD*, and discontinuity characteristics including types, joint sets, joint spacing, roughness and discontinuity filling, dip, and degree of weathering as presented on the boring logs.

- o Other field-derived parameters that affect rock mass quality include seismic velocities and hydraulic conductivity characteristics.

The evaluation of the geotechnical parameters in this report is limited to the data from the tunnel envelope, which is defined as the zone between approximately 20 feet above the tunnel crown and 20 feet below the tunnel invert. The geotechnical parameters and their applications to the rock mass classification systems have been derived for the geologic units/rock types that were encountered in the borings. These include the following as they occur along the alignment from south to north.

- o Plutonic rocks (granodiorite and quartz diorite)
- o Chico Formation (conglomerate and sandstone)
- o Lower Topanga Formation (sandstone and conglomerate)
- o Middle Topanga Formation (basalt and basalt breccia)
- o Upper Topanga Formation (including a lower section of massive sandstone and an upper section of interbedded sandstone and shale).

Due to the locations of exploratory borings and geologic structure of the dipping bedding, suitable samples for testing the Simi Conglomerate and Las Virgenes sandstone were not obtained or not encountered in the borings. Although these two formational types were not

*RQD is defined as the ratio (in percent) of the total length of all core pieces exceeding 4 inches to the total length of rock drilled in each core run.

tested in the laboratory, their properties are believed to be similar in nature to the adjacent materials due to the similarity in lithology and close stratigraphic association. It is anticipated that the Simi Conglomerate is most like the Chico Formation, and the Las Virgenes sandstone is most like the Lower Topanga Formation. In a broad sense, these can be grouped together with regard to geotechnical parameters.

6.2 LABORATORY GEOTECHNICAL PARAMETERS OF INTACT ROCK CORES

The results of index, strength, and stiffness parameters of the intact rock cores as determined from the geotechnical testing program, are presented in Table 5-5 and Appendix E. These parameters include uniaxial compressive strength, point load strength, Young's modulus and Poisson's ratio, bulk density, moisture content, bulk specific gravity, slake durability, swell pressure, and deformation modulus.

The ranges of the laboratory test values, maximum and minimum, for rocks in different geologic units of all tested rock and of the tunnel envelope are provided in Tables 5-6A and 5-6B. For uniaxial compressive strength and point load tests, the average strengths for the total data set and for intact rock cores (i.e., excluding cores with apparent discontinuities) only, are both presented. The intact rock core data include those results from tests that did not fail on pre-existing discontinuities. The strengths of the intact core best represents the strength of the rock mass for each formation. Plots of the uniaxial compressive strength versus Young's modulus for all intact core test data and intact core data just from the tunnel envelope, are shown in Figures 6-1 and 6-2, respectively. The following observations can be made based on review of the data presented in Tables 5-6A and 5-6B and Figures 6-1 and 6-2:

- o Strength and modulus values as determined from the laboratory test program show significant data scatter. This scatter may primarily reflect the in situ variation of the rock mass as shown in Figures 6-1 and 6-2.

- o Tests on samples from the interbedded sandstone and shale in the upper section of the Upper Topanga Formation indicate second cycle slake durability indices ranging from 1.1 to 13.1 percent. Thus, these rocks will be extremely susceptible to slaking. The test results also show that for the rocks in the basalt and basalt breccia in the Middle Topanga Formation, second cycle slake durability indices range from about 59 to 97 percent. Thus, those rock types are medium to low susceptibility to slaking, and may require prompt protection/support as tunnel excavation proceeds through the basalts. The Lower Topanga Formation and Chico Formation have second cycle slake durability indices more than 94 percent and are less susceptible to slaking. Although no tests were performed on samples of plutonic rocks, these rocks, except the materials in gouge zones, are also less susceptible to slaking. Gouge materials from the plutonic rocks visibly swelled and slaked when placed in water.

- o Relatively lower uniaxial strength values were observed in some tests on samples from the plutonic rocks, Chico Formation, Lower Topanga Formation, basalt breccia of the Middle Topanga Formation, and the interbedded sandstone and shale of the Upper Topanga Formation. The lower strength values of those rock types are generally attributable to unique conditions or pre-existing discontinuities within the tested cores, and do not necessarily represent the typical intact core strength of the formational material. This is evident from examination of the tested cores and consideration of the presence of discontinuities that resulted in a preferred failure. For example, the Chico Formation and Lower Topanga Formation are held together by varying degrees of cementation of the sandstone or sandstone matrix of conglomerates. The failure mode of many of these samples was conical along the interface between clasts and the matrix; very low strengths (<2,000 psi) were along pre-existing, clay-lined shears (SM-7, elevation 414 and elevation 394 feet). The low uniaxial compressive strength of the basalt breccia results from its composition of basalt fragments floating in a matrix of chlorite and/or smectite-like minerals (clay). The basalt is typically highly sheared in a random fashion with healed surfaces being coated by the low strength chlorite or smectite. Within the Upper Topanga Formation, distinct bedding planes within the core samples usually controlled the failure mode. Clay-coated bedding partings within the siltstone or between the siltstone and sandstone typically failed during the uniaxial compression testing for samples from Borings SM-12 and SM-13.

o The frequency of pre-existing rock core discontinuities has influenced the laboratory test results of rock strength, biasing the strengths on the lower bound. To better represent the intact rock strength of each formation, the tests influenced by discontinuities have been removed from the data set to estimate the typical intact rock strengths from both uniaxial compression test data and point load test data as follows:

FORMATION	TYPICAL UNIAXIAL COMPRESSIVE STRENGTH	TYPICAL EQUIVALENT UNIAXIAL COMPRESSIVE STRENGTH BASED ON POINT LOAD STRENGTH
Plutonic Rocks	14,200 psi	21,600 psi
Chico Formation	7,200 psi	5,600 psi
Lower Topanga	3,200 psi	3,500 psi
Middle Topanga	2,900 psi	2,100 psi
Upper Topanga Sandstone/Conglomerate	5,000 psi	5,300 psi
Upper Topanga Sandstone/Shale	2,500 psi	1,500 psi

6.3 FIELD GEOTECHNICAL PARAMETERS OF THE ROCK MASS

6.3.1 General

In addition to the geotechnical parameters of intact rock cores discussed above, a number of field characteristics related to the presence of rock discontinuities and water are considered significant for tunnel design and construction. These include, but are not limited to, the following.

- o Core recovery
- o Rock discontinuity characteristics in terms of RQD and discontinuity frequency
- o Characteristics of discontinuities such as spacing, roughness, planarity, discontinuity filling, joint set, dip angle, and weathering.
- o Deformation modulus
- o Seismic velocity
- o Hydraulic conductivity

These parameters are described in the following subsections.

6.3.2 Core Recovery and RQD

The core recovery, RQD, discontinuity frequency, and descriptions of the rocks encountered in the borings are presented in the boring logs included in Appendix A.

A statistical summary of these data for both the entire depth of all borings and for the tunnel envelope only, are presented in Tables 4-1 and 4-2, respectively. Explanations for the various symbols used in these summary tables are provided in Table 4-3. The core recovery and RQD data are presented graphically in Plate 3 in order to visually evaluate the trends among the borings. An examination of these tables and Plate 3 indicates the following:

1. Core recovery in the Lower, Middle and Upper Topanga Formation is better than that in the Chico Formation and plutonic rocks. Overall, core recovery in plutonic rocks appears to be the lowest of all the rock types. Core recovery in the tunnel envelope is generally better than the overlying rock. This represents improving rock quality with depth typically.

2. On the basis of data from all borings, RQD values for the plutonic rocks and Chico Formation are relatively low compared to other geologic units. This is due to the extensive degree of jointing, fissuring, and past tectonics that these rocks have been subjected to, causing fragmentation and weakness of the rock mass and core.

3. The RQD values within the tunnel envelope with the exception of Boring SM-7 are higher than the overlying rock. RQD values in Boring SM-7 are generally low even though recovery is high, apparently due to the poor cementation of the sandstones and conglomerates relative to the adjacent Borings SM-6 and SM-8.

4. The discontinuity (joints and bedding partings) characteristics of all rocks as presented in the boring logs, vary significantly and are indicative of the heterogeneous nature of the in situ rock masses. This variability of joint characteristics also indicates that tunneling conditions, in terms of tunnel support needs and groundwater inflows, etc., will vary from location to location.

5. The degree of weathering (principally degrees of oxidation at depth) within the tunnel envelope, is likely to be greatest near the north and south ends of the tunnel. In the vicinity of the north end, interbedded sandstone/shale in the upper section of the Upper Topanga Formation is most extensively weathered near the ground surface. Such materials may be encountered in

the tunnel envelope where there will be the least overburden north of Boring SM-13. The plutonic rocks are also extensively weathered near the south edge of the Santa Monica Mountains at Boring SM-1. The plutonic rocks have been weathered to a residual soil at the Hollywood fault with decreasing weathering northward, toward the core of the mountains. Within the tunnel envelope, the degree of weathering varies from slight weathering of discontinuity surfaces to moderate weathering (throughout the rock mass but the rock material is not friable). More detailed definitions of the various extent of weathering are presented in Table 4-3 and Appendix A.

6.3.3 Hydraulic Conductivity

The results of hydraulic packer tests have been presented and summarized in Tables 5-1 and 5-2, respectively. It should be noted that the limited number of packer tests may not represent the highest permeability zones to be encountered during tunnel construction. This is suggested by the results of the water flows reported during excavation of the MWD Hollywood Tunnel and Los Angeles Sewer Tunnel described in Section 2.3. Based on the packer test results, the following observations can be made about hydraulic conductivity versus the various rock types.

1. A wide range in hydraulic conductivity exists among the tested rock types. For example, hydraulic conductivity varies by four orders of magnitude in the Upper Topanga Formation. This is likely due to the primary permeability of the sedimentary rock being controlled by grain size, fines content (silt and clay), and degrees of cementation. In contrast, the hydraulic conductivity data of the plutonic rocks show a general trend of increasing hydraulic conductivity with decreasing RQD. This is likely due to the hydraulic conductivity of the plutonic rock being controlled by discontinuities, where increased discontinuity frequency causes lower RQD.

2. The two relatively high hydraulic conductivity values in the Upper Topanga Formation (3.5×10^{-4} cm/s and 4.2×10^{-4} cm/s) appear to be associated with the friable, thinly bedded sandstone and laminated shale, and is due to primary permeability (intergranular). The two data points are almost equivalent to the results expected in the uncemented fine-grained silty sand.

3. The Middle Topanga Formation (especially in the basalt breccia portion) may be relatively more permeable than the Chico Formation and Lower Topanga Formation based on Table 5-1 data.

6.3.4 Seismic Velocities

Wireline sonic velocity logging was performed in six borings (SM-2, SM-4, SM-6, SM-8, SM-10 and SM-12). Details and results of this logging are presented in Appendix D. Table 5-3 provides an overall summary of ranges of compressional wave and shear wave velocities calculated from seismic data for various geologic units. Based on the results, the following observations are made:

1. Among all geologic units, the plutonic rocks and the Upper Topanga Formation have the widest scatters for seismic velocities. This is indicative of the variability of the in situ rock masses within these two geologic units.

2. As shown in Table 5-3, the lower section (conglomerates and sandstones) of Upper Topanga Formation, as represented by the sonic velocity data from Boring SM-10, is much stronger and stiffer than the upper section (siltstones and sandstones) of the Upper Topanga Formation, as represented by the data from Boring SM-12. This likely reflects the more homogeneous and cemented nature of the sandstone/conglomerates of the lower section than the

interbedded sandstone/shale of the upper section of the Upper Topanga Formation.

3. As shown in Table 5-3, interpretation of sonic velocity data from Boring SM-8, yields exceptionally high seismic wave velocity (compressional wave velocity >20,000 ft/s) in the Middle Topanga Formation; which are unexpected given the very low laboratory strength values of basalt and basalt breccia (Table 5-5 and Figures 6-1 and 6-2). A suitable explanation for the data anomaly is unknown and would require further seismic survey (sonic logging, uphole or cross-hole geophysical surveys etc.) for any refinement.

4. Similarly, the interpreted seismic velocity values for the Lower Topanga Formation are also extremely high relative to what is expected from shear strength data. These data are also obtained from sonic logging in Boring SM-8.

6.4 INTACT ROCK AND ROCK MASS CLASSIFICATION

There are numerous rock mass classification systems that exist, which consider parameters and factors important in the design and construction of underground facilities. The following four available systems were selected for this investigation as examples to classify the rock mass to be encountered along the tunnel alignment:

- Intact rock classification (Deere and Miller, 1966)
- RQD (Deere, 1963)
- Geomechanics Rock Mass Rating (RMR) system (Bieniawski, 1979)
- Q-system (Barton, 1991)

These systems are not necessarily comparable to one another because they represent different perspectives of how to classify the intact rock mass. For example, the intact rock classification system is based on the strength of intact rock cores and the numerical ratio of this rock strength to Young's modulus (strain related to stress) of the intact rock cores, whereas the RQD is a method of quantifying existing rock mass discontinuities based on core recovery. The RMR system helps to provide guidelines about the stand up time of an excavation without supports, whereas the Q-system gives a means to decide what type of long-term rock support may be required for a rock mass with specific characteristics or geotechnical parameters. Each of these classification systems is described with respect to the rock types anticipated in the Metro Rail tunnel alignment in the following paragraphs.

6.4.1 Intact Rock Classification

As introduced by Deere and Miller (1966) and as shown in Figures 6-1 and 6-2, this rock classification system is based on the strength of intact rock cores and the ratio of compressive strength (σ_c) to Young's modulus. According to this classification system, the rocks in various geologic units encountered along the tunnel alignment can be classified as follows:

1. Plutonic rocks range from low strength (4 kilograms per square inch (ksi) $< \sigma_c < 8$ ksi), to high strength (16 ksi $< \sigma_c < 32$ ksi) with medium to high modulus ratios.

2. Rocks in the Chico Formation (including the Simi Conglomerate) have a wide variation of strength with uniaxial compressive strength ranging from 3,000 psi (very low strength) to as high as 18,000 psi (high strength).

3. The Lower Topanga Formation predominantly ranges from very low strength ($\sigma_c <$ 4ksi) to low strength (4ksi $< \sigma_c <$ 8ksi) with medium to high modulus ratios.

4. The test results show that the massive basalt in the Middle Topanga Formation has a uniaxial compression strength on the order of 2.4 to 4.3 ksi (i.e., very low strength rock to lower bound of low strength rock), while basalt breccia is weaker with uniaxial compressive strength ranging from about 0.95 to about 3.8 ksi (i.e. very low strength rocks.)

5. Among all rocks encountered along the tunnel alignment, rocks in the Upper Topanga Formation exhibit the largest variation in strength with σ_c ranging from about 100 psi to more than 13,000 psi (i.e., from sheared rock to medium strength rocks). In general, the massive sandstone in the lower section of the Upper Topanga is stronger with σ_c ranging from about 2,670 to about 13,500 psi. The interbedded sandstone/shale rocks in the upper section of Upper Topanga Formation are significantly weaker with σ_c ranging from about 100 psi to about 1,760 psi (i.e. very low strength rocks). It should be noted that most all of the lowest strength values were derived by failures along previously sheared bedding planes.

6.4.2 Rock Quality Designation

The boring logs shown in Appendix A, include RQD for a quantitative classification of the in situ rock masses. The RQD is a percent of intact rock core longer than 4 inches within each core run. Thus it gives a general quantitative representation of frequency of discontinuities within the rock mass, without consideration of orientations or patterns of the discontinuities and other features (i.e., rock strength, groundwater conditions, in situ stress conditions, etc.) that affect tunneling behavior. Rock mass quality as defined by Deere et al (1963), in terms of RQD, is classified as follows:

RQD (%)	Rock Quality
0-25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90 to 100	Excellent

Statistics of RQD for various geologic units encountered along the tunnel alignment, based both on all RQD data and on the tunnel envelope RQD data, have been tabulated in Tables 4-1 and 4-2, respectively. The RQD of each core run is shown in Plate 2.

Among all geologic units, rock quality of the plutonic rocks in terms of RQD appears to be the poorest. This is illustrated in Plate 2, which is a compilation of the RQD data from the borings. However, RQD values of the plutonic rocks, especially along the tunnel envelope, appear to increase toward the north direction, apparently reflecting the effects of increasing overburden and the greater distance from the Hollywood fault (Plate 2). Within the Chico Formation, the worst RQD is in Boring SM-7, where the rock was found to be sometimes poorly cemented, very low strength rock. As shown in Plate 2 and Tables 4-1 and 4-2, the rock quality in terms of RQD values varies widely for all geologic units encountered along the tunnel alignment. This variation is a result of localized intense fracturing effects near sheared zones or chemical alteration, and in sedimentary rock, weak cementation of grains. Generalized predominant rock quality is as follows for the Metro Rail tunnel:

Geologic Unit (Rock Type)	Generalized Predominant Rock Quality (as defined by Deere et al, 1966)	
	All Data within Penetration Depths	Within Tunnel Envelope
Plutonic Rocks	Very poor to good	Very poor to good (SM-2 and SM-3) fair to good (SM-4 to SM-6)
Chico Formation (conglomerate and sandstone)	Very poor to fair	Very poor to poor (SM-7)
Lower Topanga (sandstone, sandstone/siltstone)	Good to excellent	Good to excellent (SM-8)
Middle Topanga (basalt, basalt breccia)	Fair to excellent	Good to excellent (SM-9)
Upper Topanga (sandstone, interbedded sandstone/shale)	Fair to excellent	Fair to excellent (SM-10 to SM-13)

The following observations are made from the RQD data:

1. The predominantly very poor to good rock quality of plutonic rocks (SM-2 and SM-3) and very poor to fair quality of the Chico Formation, indicate that tunneling in these rock units may frequently need some support to alleviate potential stability concerns. However, within the northern half of the alignment within plutonic rocks (SM-4 through SM-6) in the tunnel envelope, the RQD ranges from fair to good rock which are indicators of improving estimated standup time. Similar conditions are likely in the planned area of the pocket track construction.

2. Based on the RQD criteria alone, the Upper Topanga Formation ranks better than expected with respect to historical and anticipated tunneling conditions. For the most part, Upper Topanga is weak rock with a high frequency of weak bedding planes. Although core recovery is high and RQD is relatively high, the rock itself is of the lowest strength of those to be encountered in the tunnel.

6.4.3 Geomechanics Rock Mass Rating (RMR)

The RMR system was first introduced in 1973, and has undergone several changes (Bieniawski, 1973, 1974, 1975, 1976, and 1979). The system was devised to provide a means of estimating standup time for excavations in rock considering, orientations of discontinuities, as well as geotechnical test data. Descriptions of ratings and classifications of this system and their associated implications with respect to strength parameters and tunnel standup time, are shown in Table 6-1 and Figure 6-3. The RMR system uses the following factors for ratings:

- o Uniaxial compressive strength or point-load strength of intact rock
- o RQD

- o Spacing of joints
- o Conditions of joints
- o Groundwater in terms of inflow or joint pore pressure, or general groundwater conditions
- o Strike and dip of bedding/discontinuities with respect to tunnel, or foundation or cut slope.

The factors influencing RMR values were estimated based on available data and simple hydraulic analysis in order to estimate inflow rates. Only data within the tunnel envelope from Borings SM-2 through SM-13 were used. The results of estimated RMR values with respect to boring locations and geologic units, are shown in Table 6-2. It should be noted that actual in situ variation of the RMR values in the tunnel envelope should be more than those shown in Table 6-2, which was solely based on information from borings and available laboratory test data.

Since strike of bedding is generally northwest and the dip is to the north, a tunnel driven from the north as currently planned will encounter bedding, dipping out of the tunnel face into the tunnel. This is particularly true for the upper section of the Upper Topanga Formation. In the other bedded sedimentary rocks (sandstones and conglomerates), the bedding is more massive and not as significant a factor. Within the plutonic rocks and the basalt/basalt breccia, the discontinuities are more random based on borings data and have no effect on the RMR ratings.

The classification system shown in Table 6-1 does not account for the slake/durability of the rocks when exposed to air and water during construction. The slake potential can be taken into account by applying a slake adjustment multiplier in accordance with the method developed by Newman and Bieniawski (1985). Based on the results of laboratory tests (Appendix E), the slake adjustment multiplier for various geologic units was estimated and is shown in Table 6-2.

Based on the estimated RMR values shown in Table 6-2, the following rock mass classes, as defined by Bieniawski (refer to Table 6-1), can be used to describe the rock masses in the various geologic units of the proposed Metro Rail alignment:

Geologic Unit	Estimated Range of Rock Mass Classes	Estimated Average Rock Mass Class
Plutonic Rocks	Classes III to IV (fair to poor rocks)	Class III (fair rocks) - Average RMR ≈ 52
Chico Formation	Classes I to IV (very good to poor rocks)	Lower bound of Class III (fair rocks) RMR ≈ 42
Lower Topanga	Classes II to III (good to fair rocks)	Lower Bound of Class II (good rocks) - Average RMR ≈ 61
Middle Topanga	Classes III to IV (fair to poor rocks)	Lower Bound of Class III (fair rocks) - Average RMR ≈ 43
Lower Section of Upper Topanga	Class II (good rocks)	Class II (good rocks) - Average RMR ≈ 69
Upper Section of Upper Topanga	Classes II to IV (good to poor rocks)	Lower Bound of Class III (fair rocks) - Average RMR ≈ 42

Figures 6-3 provides a general guideline for estimating the standup time for various geologic units based on RMR rating and unsupported span. It should be noted that this guideline was originally developed for tunnels constructed by drilling and blasting methods. and is considered to be somewhat conservative for the planned excavation by TBM. Based on Figure 6-3 (correction between RMR and standup time as developed by Bieniawski, 1979), the following observations can be made:

1. Lower bound RMR values for most geologic units in the tunnel envelope, except the Lower Topanga and the lower section of Upper Topanga Formations, are in the poor rock mass class (Class IV), that would likely

require immediate support after excavations of 20-foot diameter Metro Rail tunnels.

2. Estimated average rock mass classes for all geologic units vary from near lower bound of fair rocks (Class III) to lower bound of good rocks (Class II). Based on Figure 6-3, the predominant standup time is in terms of hours to months.

3. As a comparison, the Los Angeles Sewer Tunnel diameter (7 feet) is shown on Figure 6-3. In general, the standup time is several hours or more even for the very minimum estimated RMR values of some rock. This contrasts with the Metro Rail Tunnel which has a nominal diameter of about 20 feet.

6.4.4 Q-system Classification

The Q-system classification was proposed by Barton et al (1974), based on their evaluation of a large number of underground excavation case studies. They proposed the use of a Q index value for determining the tunneling quality of a rock mass. The value of Q is defined as follows:

$$Q = \frac{RQD \ x \ Jr \ x \ Jw}{Jn \ x \ Ja \ x \ SRF}$$

where: RQD = rock quality designation in percent
Jn = the joint set number
Jr = the joint roughness number
Ja = the joint alteration number
Jw = the water reduction factor
SRF = stress reduction factor.

The descriptions and ratings for the aforementioned six parameters used to describe rock mass quality Q value are explained in Table 6-3.

The Q-system was used to estimate the tunneling quality and long-term support needs of the rock masses in various geologic units within the tunnel envelope. The upper section of the Upper Topanga Formation has thin bedded shale with low second cycle slake durability, and is susceptible to slake deterioration. It should be noted that the effect of slake deterioration can not be taken into account in the Q-system.

As shown in Table 6-3, the determination of the SRF for Q index value requires a detailed knowledge of the state of stresses. In situ stress conditions in the Santa Monica Mountains are unknown. Neither were in situ determinations performed in this investigation, nor are they known to have been performed by others. For this study, we have assumed that the major principal stress is approximately equal to the effective vertical overburden stress at any specific location, which can be computed from densities of the subsurface materials and groundwater levels.

Barton et al (1974) have defined the following rock mass qualities in accordance to Q-values:

Rock Mass Quality	Q-value
Exceptionally Poor	$Q \leq 0.01$
Extremely Poor	$0.01 < Q \leq 0.1$
Very Poor	$0.1\ Q \leq 1$
Poor	$1 < Q \leq 4$
Fair	$4 < Q \leq 10$
Good	$10 < Q \leq 40$
Very Good	$40 < Q \leq 100$
Extremely Good	$100 < Q \leq 400$
Exceptionally Good	$400 < Q \leq 1{,}000$

As shown in Figure 6-4, Barton et al (1986) and Barton (1991) have also defined a quantity of the excavation, termed the "equivalent dimension", to relate Q-values to the behavior and support requirements of an underground excavation. The "equivalent dimension" is obtained by dividing span, tunnel diameter or wall height of the excavation by an "excavation support ratio" (ESR). As recommended by Barton (1976), the numerical value of ESR for major road/railway tunnels is 1. Thus, for the 20-foot (6.08 meters) diameter Metro Rail Tunnels, the "equivalent dimension" is 20 feet (6.08 meters), which is represented by a horizontal line shown in Figure 6-4.

Based on Figure 6-4, which shows the equivalent dimension for the planned Segment 3 tunnels, the minimum required rock support is identified as follows:

Rock Mass Quality	Minimum Support Required
o Exceptionally poor ($Q \leq 0.01$)	Cast concrete lining
o Extremely poor ($0.001 < Q \leq 0.1$)	Cast concrete lining or bolts and fibercrete
o Very poor ($0.1 < Q \leq 1$)	Same as above
o Poor ($1 < Q \leq 4$)	Bolts and shotcrete to systematic bolting
o Fair ($4 < Q \leq 10$)	Systematic bolting to spot bolting
o Good ($10 < Q \leq 40$)	Spot bolting to no support needed
o Very good ($40 < Q \leq 100$) Extremely good ($100 < Q \leq 400$) Exceptionally good ($400 < Q \leq 1,000$)	No support needed

Based on the aforementioned assumption of in situ stress conditions, available laboratory data, RQD and joint (discontinuities) characteristics, and groundwater levels above the tunnel envelope at individual boring locations, Q values for various geologic units were estimated. The estimated Q values are shown in Table 6-4, in terms of estimated rock mass quality in accordance to Q values and corresponding statistics of occurrence (number and percentage of total).

Based on these results, the following observations can be made on the rock mass qualities within the tunnel envelope:

1. Plutonic rocks are predominantly exceptionally poor to fair rocks.

2. Chico Formation in Boring SM-7 appears to have the poorest rock mass quality amongst all geologic units evaluated within the tunnel envelope. In addition to being significantly fractured and sheared, the poor quality rating is also due to rock stress problems (i.e., low strength to major principal stress ratio). Within the tunnel envelope (SM-7), the rock mass qualities of Chico Formation are estimated to be mostly exceptionally poor to very poor. Based on other Chico Formation core data from Borings SM-5 and SM-6, the quality of Chico Formation elsewhere could be better than that predicted at the tunnel envelope in Boring SM-7. The poor rock quality at Boring SM-7 may correspond to localized conditions, and better quality may be encountered elsewhere.

3. Rock masses in the lower section of the Upper Topanga Formation, appear to be the most favorable to tunneling; their rock mass qualities predominantly range from good to extremely good. Rock masses in the Lower Topanga Formation (predominantly very poor to good) and the upper section of the Upper Topanga Formation, appear to be the second most favorable. However, it should be noted that the upper section of the Upper Topanga Formation is subject to slake deterioration, which cannot be accounted for by the Q values.

4. Rock mass qualities in the Middle Topanga Formation (basalt and basalt breccia) are estimated to be predominantly extremely poor to poor. Their low ratings are primarily due to joint conditions and rock-stress related problems (i.e., low strength to major principal stress ratio). The low strength of the Middle Topanga is postulated to be due to the high chlorite content and chlorite coatings of discontinuities as described in Section 6.2.

5. Based on the results of estimated Q values in the tunnel envelope, rock support will likely be needed almost everywhere along the tunnel alignment,

except in a major portion of the lower section of the Upper Topanga Formation.

6. For comparison purposes, the equivalent dimension of the Los Angeles Sewer Tunnel is also plotted on Figure 6-4. The smaller tunnel diameter results in less support requirements according to the Q-system. In fact, poor to excellent quality rock, according to the Q-system of evaluation, requires no support. From Figure 6-4, it appears that the rock support requirements will be influenced by tunnel diameter in the Metro Rail alignment.

6.4.5 General Comments

A review of the four classification systems in this section are presented as an example for a general understanding of the rock mass characteristics that the Metro Rail tunnels and shaft will encounter. The systems are not intended for comparisons relative to one another, but present different ways of interpreting complex ranges of geotechnical parameters in the context of tunneling conditions. The intact rock classification of Deere and Miller (1966) gives an understanding of the rock strengths versus the in situ stresses that could affect tunnel stability. The RQD data (Deere, 1963) provide a general means of interpreting how frequently discontinuities occur in a rock mass. The later developed systems, RMR and Q-systems, incorporate much more information and lead to guidelines for estimating standup time and support requirements, respectively.

TABLE 6-1. GEOMECHANICS CLASSIFICATION OF JOINTED ROCK MASSES (AFTER BIENIAWSKI 1979)

A. Classification Parameters and their Ratings

	Parameter		Ranges of Values				
1	Strength of intact rock material	Point-load strength index	>10 MPa	4—10 MPa	2—4 MPa	1—2 MPa	For this low range — uniaxial compressive test is preferred
		Uniaxial compressive strength	>250 MPa	100—250 MPa	50—100 MPa	25—50 MPa	5—25 MPa / 1—5 MPa / <1 MPa
	Rating		15	12	7	4	2 / 1 / 0
2	Drill core quality *RQD*		90 %—100 %	75 %—90 %	50 %—75 %	25 %—50 %	<25 %
	Rating		20	17	13	8	3
3	Spacing of discontinuities		>2 m	0.6—2 m	200—600 mm	60—200 mm	<60 mm
	Rating		20	15	10	8	5
4	Condition of discontinuities		Very rough surface Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation <1 mm Slightly weathered walls	Slightly rough surfaces Separation <1 mm Highly weathered walls	Slickensided surfaces OR Gouge <5 mm thick OR Separation 1—5 mm Continuous	Soft gouge >5 mm thick OR Separation >5 mm Continuous
	Rating		30	25	20	10	0
5	Ground water	Inflow per 10 m tunnel length	None	<10 litres / min	10—25 litres / min	25—125 litres / min	>125 litres/min
			OR	OR	OR	OR	OR
		Ratio (joint water pressure / major principal stress)	0	0.0—0.1	0.1—0.2	0.2—0.5	>0.5
			OR	OR	OR	OR	OR
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing
	Rating		15	10	7	4	0

B. Rating Adjustment for Joint Orientations

Strike and dip orientations of joints		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Ratings	Tunnels	0	−2	−5	−10	−12
	Foundations	0	−2	−7	−15	−25
	Slopes	0	−5	−25	−50	−60

C. Rock Mass Classes Determined from Total Ratings

Rating	100←81	80←61	60←41	40←21	<20
Class No.	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. Meaning of Rock Mass Classes

Class No.	I	II	III	IV	V
Average stand-up time	10 years for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hours for 2.5 m span	30 minutes for 1 m span
Cohesion of the rock mass	>400 kPa	300—400 kPa	200—300 kPa	100—200 kPa	<100 kPa
Friction angle of the rock mass	>45°	35°—45°	25°—35°	15°—25°	<15°

E. Effect of Discontinuity Strike and Dip Orientations in Tunnelling

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Dip 0°—20° irrespective of strike
Drive with dip		Drive against dip				
Dip 45°—90°	Dip 20°—45°	Dip 45°—90°	Dip 20°—45°	Dip 45°—90°	Dip 20°—45°	
Very favourable	Favourable	Fair	Unfavourable	Very unfavourable	Fair	Unfavourable

TABLE 6-2. ESTIMATED RMR VALUES IN THE TUNNEL ENVELOPE

Boring Location/ Geologic Unit	Total Counts	Estimated RMR Values			Slake Adjustment Multiplier Used in Rating
		Minimum Value	Maximum Value	Average	
SM-2/Plutonic Rocks	17	39	54	42	1.0
SM-3/Plutonic Rocks	15	46	69	58	1.0
SM-4/Plutonic Rocks	19	37	79	58	1.0
SM-5/Plutonic Rocks	11	35	62	45	1.0
SM-6/Plutonic Rocks	9	35	67	49	1.0
SM-7/Chico Formation	10	26	82	42	1.15
SM-8/Lower Topanga	14	48	72	61	1.0
SM-9/Middle Topanga	15	34	53	43	0.95
SM-10/Lower Section of Upper Topanga	9	65	76	69	0.9
SM-11/Upper Section of Upper Topanga	12	29	53	43	0.8
SM-12/Upper Section of Upper Topanga	10	38	46	40	0.8
SM-13/Upper Section of Upper Topanga	9	41	48	44	0.8
TOTAL FOR: SM-2 to SM-6/Plutonic Rocks	71	35	79	52	1.0
TOTAL FOR: SM-11 to SM-13/Upper Section of Upper Topanga	31	29	53	42	0.8

TABLE 6-3. DESCRIPTIONS AND RATINGS FOR PARAMETERS USED IN Q-SYSTEM (1 OF 2) (FROM BARTON ET AL. 1974)

1.	ROCK QUALITY DESIGNATION	(*RQD*)	
A.	Very poor	0–25	*Notes*
B.	Poor	25–50	(i) Where *RQD* is reported or measured as ≤10 (including 0) a nominal value of 10 is used to evaluate *Q* in Eq. (3.2)
C.	Fair	50–75	
D.	Good	75–90	
E.	Excellent	90–100	(ii) *RQD* intervals of 5, i.e. 100, 95, 90, etc. are sufficiently accurate
2.	JOINT SET NUMBER	(J_n)	
A.	Massive, no or few joints	0.5–1.0	*Notes*
B.	One joint set	2	(i) For intersections use ($3.0 \times J_n$)
C.	One joint set plus random	3	(ii) For portals use ($2.0 \times J_n$)
D.	Two joint sets	4	
E.	Two joint sets plus random	6	
F.	Three joint sets	9	
G.	Three joint sets plus random	12	
H.	Four or more joint sets, random, heavily jointed, 'sugar cube', etc.	15	
J.	Crushed rock, earthlike	20	
3.	JOUNT ROUGHNESS NUMBER	(J_r)	
	(a) *Rock wall contact* and (b) *Rock wall contact before 10 cms shear*		
A.	Discontinuous joints	4	*Notes*
B.	Rough or irregular, undulating	3	(i) Add 1.0 if the mean spacing of the relevant joint set is greater than 3 m
C.	Smooth, undulating	2	
D.	Slickensided, undulating	1.5	(ii) $J_r = 0.5$ can be used for planar slickensided joints having lineations, provided the lineations are favourably orientated
E.	Rough or irregular, planar	1.5	
F.	Smooth, planar	1.0	
G.	Slickensided planar	0.5	
	(c) *No rock wall contact when sheared*		
H.	Zone containing clay minerals thick enough to prevent rock wall contact	1.0 (nominal)	
J.	Sandy, gravelly or crushed zone thick enough to prevent rock wall contact	1.0 (nominal)	

4.	JOINT ALTERATION NUMBER	(J_a)	φr (approx.)	
	(a) *Rock wall contact*			
A.	Tightly healed, hard, non-softening, impermeable filling i.e. quartz or epidote	0.75	(–)	*Note*
B.	Unaltered joint walls, surface staining only	1.0	(25–35°)	(i) Values of (φ)r are intended as an approximate guide to the mineralogical properties of the alteration products, if present
C.	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock etc.	2.0	(25–30°)	
D.	Slity-, or sandy-clay coatings, small clay-fraction (non-softening)	3.0	(20–25°)	
E.	Softening or low friction clay mineral coatings, i.e. kaolinite, mica. Also chlorite, talc, gypsum and graphite etc., and small quantities of swelling clays. (Discontinuous coatings, 1–2 mm or less in thickness)	4.0	(8–16°)	
	(b) *Rock wall contact before 10 cm shear*			
F.	Sandy particles, clay-free disintegrated rock etc.	4.0	(25–30°)	
G.	Strongly over-consolidated, non-softening clay mineral fillings (Continuous, <5 mm in thickness)	6.0	(16–24°)	
H.	Medium or low over-consolidation, softening, clay mineral fillings. (Continuous, <5 mm in thickness)	8.0	(12–16°)	
J.	Swelling clay fillings, i.e. montmorillonite (Continuous, <5 mm in thickness). Value of *Ja* depends on percent of swelling clay-size particles, and access to water etc.	8.0–12.0	(6–12°)	
	(c) *No rock wall contact when sheared*			

TABLE 6-3. DESCRIPTIONS AND RATINGS FOR PARAMETERS USED IN Q-SYSTEM (2 OF 2) (FROM BARTON ET AL. 1974)

K. L. M.	Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition)	6.0. 8.0 8.0–12.0	(6–24°)
N.	Zones or bands of silty or sandy clay, small clay fraction (non-softening)	5.0.	
O. P. R.	Thick, continuous zones or bands of clay (see G, H, J for description of clay condition)	10.0, 13.0, or 13.0–20.0	(6–24°)

5. JOINT WATER REDUCTION FACTOR	(J_w)	Approx. water pressure (kg/cm^2)
A. Dry excavations or minor inflow, i.e. <5 *l/min* locally	1.0	<1
B. Medium inflow or pressure occasional outwash of joint fillings	0.66	1.0–2.5
C. Large inflow or high pressure in competent rock with unfilled joints	0.5	2.5–10.0
D. Large inflow or high pressure, considerable outwash of joint fillings	0.33	2.5–10.0
E. Exceptionally high inflow or water pressure at blasting, decaying with time	0.2–0.1	>10.0
F. Exceptionally high inflow or water pressure continuing without noticeable decay	0.1–0.05	>10.0

Notes

(i) Factors C to F are crude estimates. Increase J_w if drainage measures are installed

(ii) Special problems caused by ice formation are not considered

6. STRESS REDUCTION FACTOR			(*SRF*)
(a) *Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated*			
A. Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)			10.0
B. Single weakness zones containing clay, or chemically disintegrated rock (depth of excavation ≤50 m)			5.0
C. Single weakness zones containing clay, or chemically disintegrated rock (depth of excavation ≥50 m)			2.5
D. Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)			7.5
E. Single shear zones in competent rock (clay free; (depth of excavation ≤50 m)			5.0
F. Single shear zones in competent rock (clay free) (depth of excavation >50 m)			2.5
G. Loose open joints, heavily jointed or 'sugar cube' etc. (any depth)			5.0
(b) *Competent rock, rock stress problems*	σ_c/σ_1	σ_t/σ_1	
H. Low stress, near surface	>200	>13	2.5
J. Medium stress	200–10	13–0.66	1.0
K. High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)	10–5	0.66–0.33	0.5–2.0
L. Mild rock burst (massive rock)	5–2.5	0.33–0.16	5–10
M. Heavy rock burst (massive rock)	<2.5	<0.16	10–20
(c) *Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure*			(*SRF*)
N. Mild squeezing rock pressure			5–10
O. Heavy squeezing rock pressure			10–20
(d) *Squeezing rock, chemical swelling activity depending on presence of water*			
P. Mild swelling rock pressure			5–10
R. Heavy swelling rock pressure			10–20

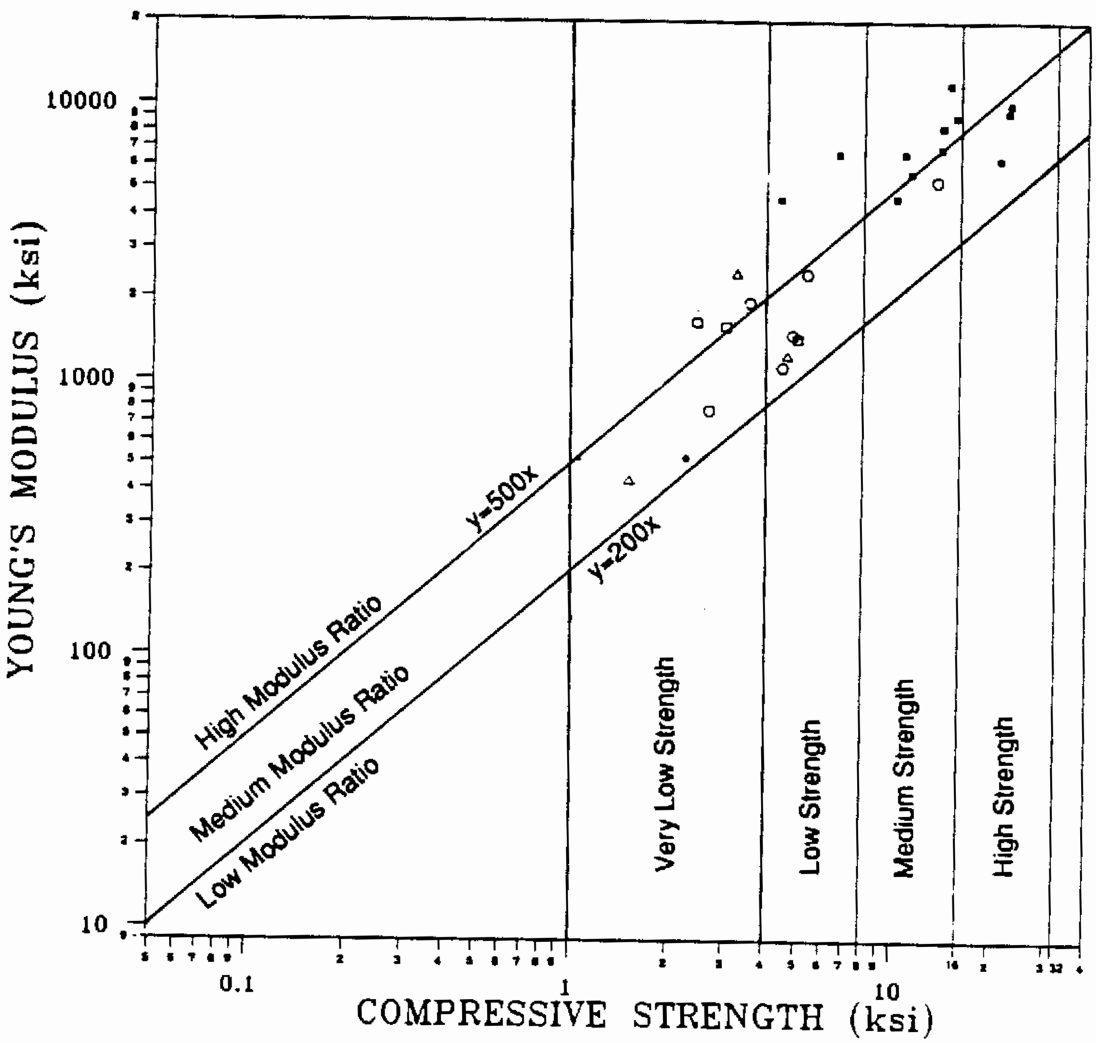
Notes

(i) Reduce these values of *SRF* by 25–50% if the relevant shear zones only influence but do not intersect the excavation

(ii) For strongly anisotropic stress field (if measured) when $5 \leq \sigma_1/\sigma_3 \leq 10$, reduce σ_c and σ_t to $0.8\sigma_c$ and $0.8\sigma_t$; when $\sigma_1/\sigma_3 > 10$, reduce σ_c and σ_t to 0.6σ, where: σ_c = unconfined compression strength. σ_t = tensile strength (point load), σ_1 and σ_3 = major and minor principal stresses

TABLE 6-4. ESTIMATED ROCK MASS QUALITIES WITHIN TUNNEL ENVELOPE BASED ON Q-SYSTEM

Boring Location/ Geologic Unit	Total Count	Estimated Rock Mass Quality - Number of Occurrences (percent of total)								
		Exceptionally Poor $Q \le 0.01$	Extremely Poor $0.01 < Q \le 0.1$	Very Poor $0.1 < Q \le 1$	Poor $1 < Q \le 4$	Fair $4 < Q \le 10$	Good $10 < Q \le 40$	Very Good $40 < Q \le 100$	Extremely Good $100 < Q \le 400$	Exceptionally Good $400 < Q \le 1{,}000$
SM-2/Plutonic Rocks	17	10 (58%)	1 (6%)	3 (18%)	2 (12%)	-	1 (6%)	-	-	-
SM-3/Plutonic Rocks	15	6 (40%)	-	2 (13%)	4 (27%)	3 (20%)	-	-	-	-
SM-4/Plutonic Rocks	17	2 (12%)	-	1 (6%)	4 (23.5%)	5 (29%)	4 (23.5%)	-	-	1 (6%)
SM-5/Plutonic Rocks	11	-	-	5 (45.5)	5 (45.5%)	1 (9%)	-	-	-	-
SM-6/Plutonic Rocks	9	-	-	-	7 (78%)	2 (22%)	-	-	-	-
SM-2 to SM-6/Plutonic Rocks	69	18 (26%)	1 (1.5%)	11 (16%)	22 (32%)	11 (16%)	5 (7%)	-	-	1 (1.5%)
SM-7/Chico Formation	10	5 (50%)	3 (30%)	1 (10%)		1 (10%)	-	-	-	-
SM-8/Lower Topanga	14	-	-	3 (21%)	4 (29%)	2 (14%)	5 (36%)	-	-	-
SM-9/Middle Topanga	15	-	2 (13%)	11 (74%)	2 (13%)	-	-	-	-	-
SM-10/Lower Section of Upper Topanga	4	-	-	-	-	-	1 (25%)	2 (50%)	1 (25%)	
SM-11/Upper Section of Upper Topanga	12	-	-	4 (33%)	5 (42%)	-	3 (25%)	-	-	-
SM-12/Upper Section of Upper Topanga	10	-	-	-	2 (20%)	1 (10%)	7 (70%)			
SM-13/Upper Section of Upper Topanga	9				3 (33%)		6 (67%)			
SM-11 to SM-13/Upper Section of Upper Topanga	31			4 (13%)	10 (32%)	1 (3%)	16 (52%)			
All/All Geologic Units	143	23 (16.1%)	6 (4.2%)	30 (21.0%)	38 (26.6%)	15 (10.5%)	27 (8.8%)	2 (1.4%)	1 (0.7%)	1 (0.7%)



••••• GRANODIORITE
□□□□□ CHICO (CONGLOMERATE)
■■■■■ CHICO (SANDSTONE)
△△△△△ LOWER TOPANGA
••••• MIDDLE TOPANGA (BASALT & BRECCIA)
○○○○○ UPPER TOPANGA (SANDSTONE)
••••• UPPER TOPANGA (SANDSTONE & SHALE)

After Deere and Miller (1966)

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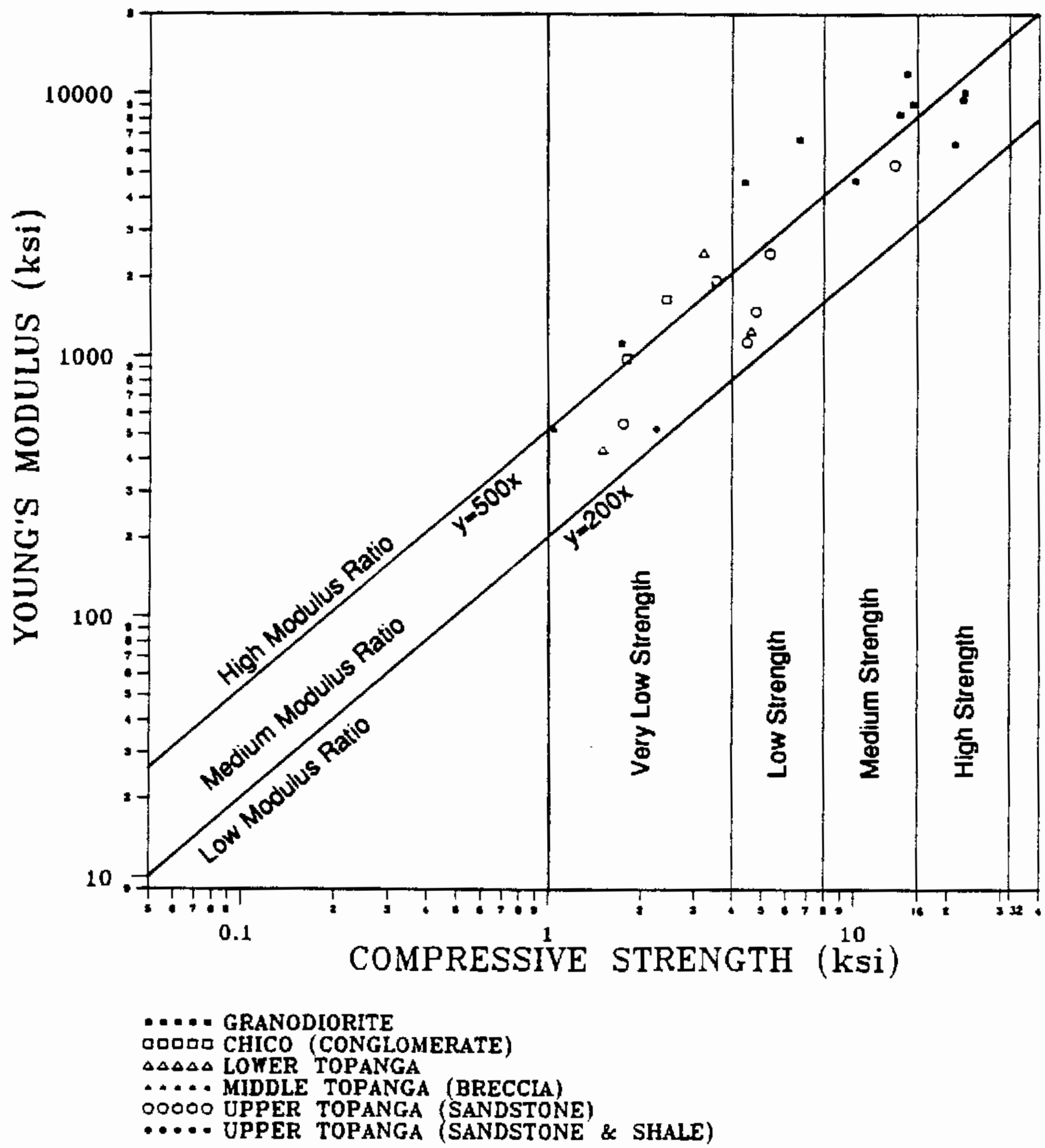
Geotechnical Investigation
Santa Monica Mountains
Segment 3, Metro Red Line

Uniaxial Compressive Strength versus Young's Modulus Using All Test Data

6-93

Figure 6-1



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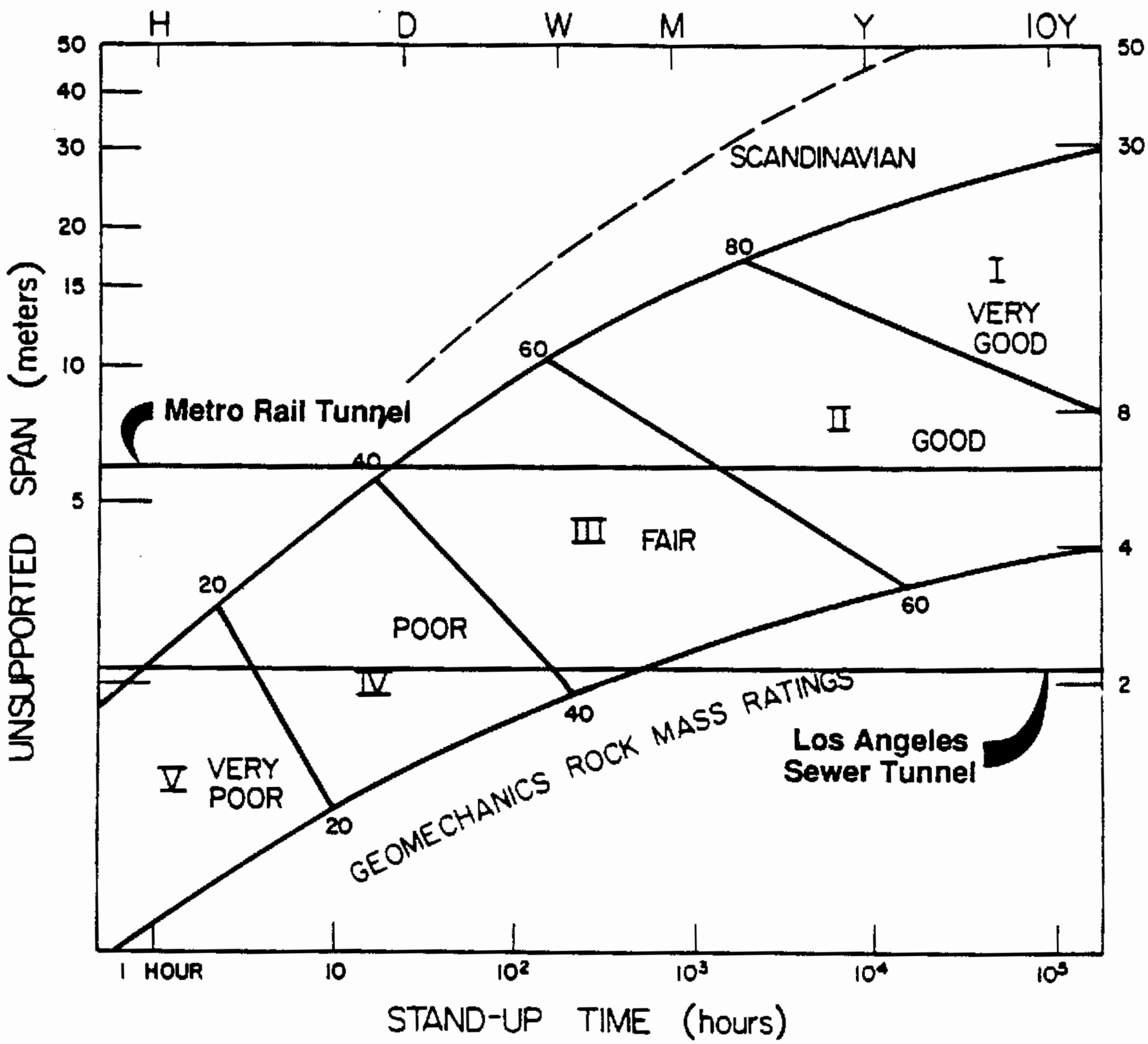
Uniaxial Compressive Strength versus Young's Modulus in Tunnel Envelope

6-93

Figure 6-2

After Deere and Miller (1966)



Source: Bieniawski (1979)

Notes:
H = Hour
D = Day
W = Week
M = Month
Y = Year

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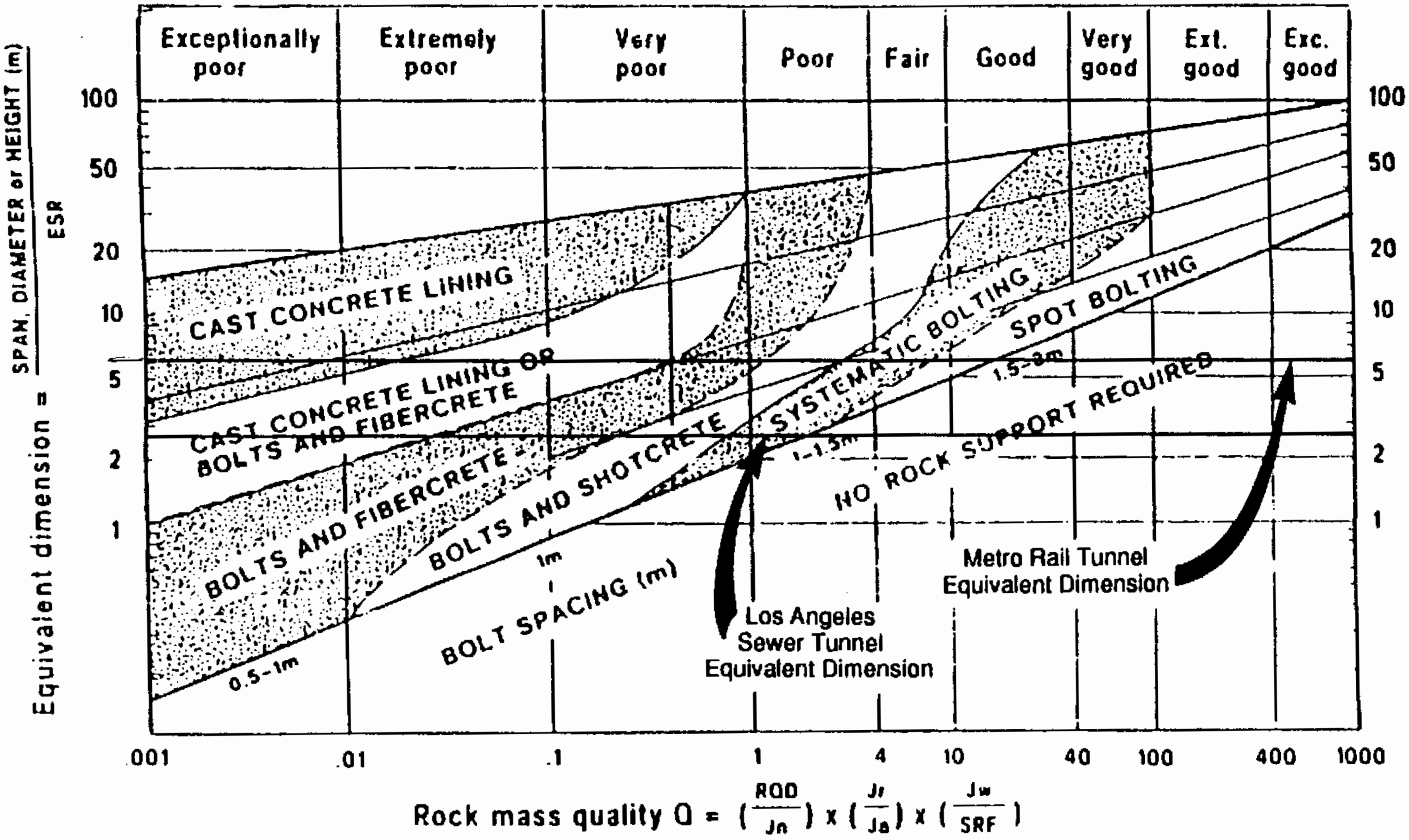
Relationship Between RMR-Value and Stand-Up Time

6-93 Figure 6-3



Notes:
RQD = Rock Quality Designation
Jn = Joint Set Number
Jr = Joint Roughness Number
Ja = Joint Alteration Number
Jw = Water Reduction Factor
SRF = Stress Reduction Factor
ESR = Excavation Support Ratio
(1.0 for Metro Rail Tunnel)

Source: Barton 1991

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Santa Monica Mountains
Segment 3, Metro Red Line

Relationship between Rock Mass Quality (Q) and Equivalent Dimension

6-93

Figure 6-4

7.0 SUBSURFACE CONDITIONS SUMMARY AND CONSTRUCTION CONSIDERATIONS

7.1 OVERVIEW

This section provides a summary of relevant geologic and geotechnical conditions, as well as a number of construction considerations that may significantly affect the construction of the proposed Metro Red Line, Segment 3 tunnels and ventilation shafts. As described in Section 1.0, the portion of the Segment 3 alignment addressed in this report extends from the foot of the Santa Monica Mountains on the southern side, immediately north of the Hollywood fault zone through the mountains, to the foot of the Santa Monica Mountains on the north side, near the intersection of Lankershim and Cahuenga Boulevards.

In addition to the data obtained from this investigation and the results of geologic and geotechnical characterizations of various geologic units to be encountered in the planned tunnel alignment (Sections 4.0, 5.0, and 6.0), the anticipated subsurface conditions and construction considerations presented in this section were also based on the following:

1. Previous experience and performance of the Los Angeles Sewer Tunnel and the MWD Hollywood Tunnel (detailed in Section 2.3) in the Santa Monica Mountains and in the vicinity of the planned tunnel alignment.

2. Engineering assumptions and judgment.

7.2 SUMMARY OF GEOLOGIC AND GEOTECHNICAL CONDITIONS

Tunneling through the Santa Monica Mountains will encounter a number of geologic units with a wide variety of ground conditions. Consideration of the behavior and characteristics of these geologic units is critical for the understanding of ground behavior and potential construction constraints. In general, the subsurface conditions along the planned tunnel alignment can be divided into six reaches based on similar geologic units, rock types, and anticipated ground behavior. These reaches are as follows:

REACH	APPROXIMATE STATION NO.	GEOLOGIC UNITS (ROCK TYPES) WITHIN TUNNEL ENVELOPE
1	629+60 to 679+80	Plutonic Rock (predominantly granodiorite)
2	679+80 to 693+00	Chico Formation (conglomerate and sandstone) and Simi Conglomerate (conglomerate)
3	693+00 to 698+30	Las Virgenes Sandstone and Lower Topanga Formation (sandstone and conglomeratic sandstone)
4	698+30 to 716+10	Middle Topanga Formation (basalt and basalt breccia)
5	716+10 to 730+30	Lower section of Upper Topanga Formation (sandstone, partly conglomerate)
6	730+30 to 761+40	Upper section of Upper Topanga Formation (interbedded sandstone and siltstone/shale)

Geologic conditions and geotechnical engineering characteristics of the geologic units and rock types within the above reaches, have been presented in Sections 4.0 to 6.0. For tunneling consideration, the following aspects affecting tunneling conditions and anticipated tunneling conditions, are summarized in Tables 7-1 through 7-6 for individual reaches:

1. General information including station numbers, length, overburden depths, surface elevation, and tunnel crown elevations.

2. Geologic conditions and features including general lithology and description, discontinuities, characterization, weathering, cementation, quartz content, and other features such as faulting.

3. Geotechnical conditions including strength and modulus characteristics of intact rock cores, various index properties, RQD, seismic wave velocity and deformation modulus of in situ rock masses, groundwater conditions

(groundwater level, hydraulic conductivity, estimated groundwater inflows, and type of flow region), and estimated rock mass classification.

The following considerations are noted:

1. The dipping nature of various geologic units (due to tectonic-uplift, and tilting of geologic units), and the geologic conditions above or below the tunnel envelope in a specific boring location, could project into the tunnel envelope elsewhere along the alignment (Plate 1). Thus, data from all depths at individual borings are applicable for tunneling considerations.

2. Data below the ground surface were obtained at widely spaced (up to 1,600 feet) boring locations during this investigation. Thus, actual in situ variations of rock conditions to be encountered during tunnel excavation along the planned alignment may be greater than those shown by boring data.

3. Tunneling conditions for the Metro Red Line Tunnel through the Santa Monica Mountains will be largely similar to those encountered in the Los Angeles Sewer Tunnel and MWD Hollywood Tunnel, because of similarity in subsurface conditions and depth of tunneling. Thus, the experience and performance in terms of ground conditions, groundwater inflows, and encountered construction constraints of these existing tunnels will be generally applicable. However, the existing experience will require modifications to account for the following factors for use in delineating the tunneling conditions for the planned Metro Rail tunnels through the Santa Monica Mountains:

   o Nominal tunnel opening diameter of both sewer and water tunnels is about 7 feet while the nominal tunnel opening for Metro Rail tunnel is 20 feet. It should be noted that under the same subsurface conditions, larger tunnels will incur larger groundwater inflow, exhibit less standup time, and more severe tunnel stability problems (i.e., need heftier support to be applied sooner).

   o Both sewer and water tunnels were advanced by the conventional drill and blast methods. Compared with the use of a TBM, conventional drill and blast methods generally create more disturbance to the tunnel openings and headings which tends to accentuate stability problems.

   o Overburden depths of the sewer and water tunnels are generally about 100 feet and 300 feet above the depths of the planned Metro Rail Tunnel through the Santa Monica Mountains. For very low strength to low strength rocks (such as those in the Chico Formation, Middle

Topanga Formations and upper section of the Upper Topanga Formation, as well as in some portions of the Lower Topanga Formation), greater depths correspond to lower strength to stress ratio, which may present more severe concerns with respect to tunnel stability and long-term creep.

Based on the results of this investigation and the anticipated conditions summarized in Tables 7-1 through 7-6, the following observations are made:

1. Excavation and construction of the planned Metro Rail Red Line Segment 3 Tunnels through the Santa Monica Mountains are technically feasible, although various physical constraints will affect tunnel excavation. However, it should be noted that all physical constraints can be alleviated through conventional tunnel technology and construction methods.

2. Tunneling through the Santa Monica Mountains will encounter a wide range of ground conditions as summarized in Tables 7-1 through 7-6. The variations in ground conditions may be gradational or abruptly changed. For example, tunneling in Chico Formation may suddenly encounter boulder-sized clasts that may require special handling. Thus, excavation or support systems to be designed and used by the Contractor must be capable of adapting to all the ground conditions expected.

3. Groundwater inflow data from the Los Angeles Sewer Tunnel provide more representative data to estimate potential inflows for the planned Metro Rail Tunnel through the Santa Monica Mountains, than those predicted by hydraulic conductivity data and hydraulic analyses. Considering the potential effects of tunnel opening size, groundwater head, and excavation methods, it was estimated that the groundwater inflows for the Metro Rail Tunnel, may be about 30 to 100 percent higher than incurred in the Los Angeles Sewer Tunnel (Plate 1).

The shaft locations have not been finalized, but are being conducted in the vicinity of either Borings SM-4, SM-5 or SM-6. At any one of those locations, the bottom of the shaft terminates in plutonic rocks. If located near SM-4, the shaft depth would be entirely within the plutonic rocks. For shaft locations near both SM-5 and SM-6, the upper 558 to 727 feet of the shaft would be in the Chico Formation. As shown in Plate 3, the differences in rock quality within the Chico Formation is evident in Borings SM-5 and SM-6, where the RQD is highly variable and averages on the order of 50 percent. Support of the shaft excavation during construction would be necessary.

7.3 CONSTRUCTION CONSIDERATIONS

7.3.1 Construction Material

As shown in Section 5.2.2, the results of the chemical tests on groundwater samples indicate that sulfate contents in samples from groundwater Monitoring Wells SM-6A, SM-9A and R-9, are respectively about 470, 330 and 750 parts per million (ppm). While the sulfate content in a sample from groundwater Monitoring Well SM-3 is about 78 ppm. A sulfate content between 150 ppm and 1,000 ppm is considered moderately deleterious to concrete, and will require Type II cement. Monitoring Well SM-6A is located near the north end of Reach 1, while Wells SM-9A and R-8 are located in Reaches 4 and 6, respectively. Thus Type II cement is likely to be required for the construction of the Metro Rail Tunnel through the Santa Monica Mountains.

7.3.2 Gas

The results of x-ray diffraction analyses show that the subsurface rocks contain pyrite ranging from trace to about 10 percent pyrite, which is a potential source of producing hydrogen sulfide. Thus, continuous monitoring of hydrogen sulfide during construction will be necessary. This is of particular concern in the Upper Topanga Formation where pyrite is associated with fossilized wood and thin coal seams.

The geologic formations in the Santa Monica Mountains are not known to produce appreciable oil, and are not expected to contain crude oil or petroleum gases. During the subsurface exploration program, all borings were monitored for organic vapors but none were detected. Based on the geologic data and field test data, petroleum and related methane gas are not anticipated during tunnel excavation. Some methane may be present in association with the thin coal seams encountered within the Upper Topanga Formation. Therefore, continuous monitoring is recommended during construction.

7.3.3 Conglomerates

Large boulders occur within the Chico, Simi and Topanga formations conglomerates. In many cases, the poor RQD of the core is directly attributable to the poor cementation of the matrix surrounding the cobble to boulder-sized clasts. The most durable of these clasts are composed of granite and quartzite with very high strength (in excess of 12,000 psi) compared to the matrix. This is apparent in the mode of failure for some specimens that occurred at the matrix-clast interface during uniaxial compression testing of the core. The weak bond between matrix and clasts could result in plucking of cobbles or boulders from the tunnel face by TBM cutters if they are not cut in place. This may result in accumulating cobble- to boulder- (up to 24 inches) size clasts at the tunnel heading, causing impairment of cutter action and possible cutter/cutter head damage. During construction of the MWD Hollywood Tunnel and Los Angeles Sewer Tunnel, drilling for the blast holes was impaired by the durable granitic clasts in the conglomerate, which resulted in delaying advance rates.

7.3.4 Shear Zones

In the Los Angeles Sewer Tunnel, a condition was encountered that is, in our opinion, not represented in the boring data obtained for the Metro Rail Tunnel. This conditions relates to a change order within the plutonic rocks. A zone of gouge, shearing, and hydrothermal alteration was encountered that caused heavy ground conditions for approximately 200 feet. The shearing was reported at relatively shallow dip (10 to 15 degrees), which could cause soft invert conditions and significantly affect the standup time and general stability of the tunnel crown. If a similar shear zone exists along the alignment of the Metro Rail Tunnel envelope, its relative position within the plutonic rocks could place it within the planned pocket track area. Such a zone could significantly affect construction of the wider span underground opening.

TABLE NO. 7-1, REACH NO. 1, STATION 629+60 TO STATION 679 + 80, LENGTH - 5,020 FEET
FORMATION: PLUTONIC ROCKS, ROCK TYPE GRANODIORITE, QUARTZ DIORITE
DEPTH RANGE OF TUNNEL CROWN ABOUT 160 TO 930 FEET BELOW GROUND SURFACE

GEOLOGIC CONDITIONS	ROCK PARAMETERS
General Lithology - Medium- to coarse-grained granitic rocks, blocky structure, infrequent inclusions (gneiss/schist), mildly foliated. Possible basalt dikes from few inches to several tens of feet thick and rare aplite or felsite dikes.	o Bulk density range = 160 to 175 pcf, average = 168 pcf o Uniaxial compressive strength range = 2.9 to 32 ksi, average intact rock = 15.2 ksi o No slake deterioration expected except in the gouge materials which are highly susceptible to slaking o Young's modulus of intact core range = 500 to 12,000 ksi, average ≈ 6×10^6 ksi.
Discontinuities - Joint spacing variable. From 0.4 to 24 inches, dominantly 2.4 to 8 inches. Dip angles 20 to 50 degrees (common). Near Hollywood fault, inclination toward north and northeast. Mixed horizontal and vertical with random joint sets common at northern portion of reach. Joints generally tight hairline planar features.	o Core recovery range = 0 to 100 percent, average = 90 percent o RQD range = 0 to 100 percent, average = 38 percent o Compressional wave velocity range = 10,000 to 19,000 ft/s o Shear wave velocity range = 2,800 to 6,600 ft/s o Deformation modulus of rock mass range = 0.6×10^6 to 2.5×10^6 psi o Estimated RMR rating of rock mass = Class III to IV (fair to poor rock) o Estimated Q value of rock mass - exceptionally poor ($Q \leq 0.01$) to good ($10 < Q < 40$).
Cementation - (igneous intrusive rocks) NA	
Weathering - Completely weathered/decomposed near Hollywood fault zone (estimated 200-foot section) transitioning to moderately weathered in central reach to fresh in northern two-thirds of reach. Rock will be hydrothermally altered and brecciated in shear zones.	
Percent Quartz - 19 to 33 percent of rock mass.	o Drilling rate was low and required use of diamond drill bit.
Groundwater Table - about 120 to 740 feet above tunnel crown and about 9 feet below ground surface. Groundwater barrier at Hollywood fault.	o Hydraulic conductivity range = 4.8×10^{-8} to 2×10^{-5} cm/s o Locally, higher inflows occur at shear/fracture zones (up to 500 gpm) o In Los Angeles Sewer Tunnel, areas of higher inflow rapidly decreased after initial high flow o Hydrostatic pressure at tunnel crown ranges from approximately 221 to 268 psi.
Other Geologic Conditions o One or more major shear zones up to 200 feet wide (previously reported in Los Angeles Sewer Tunnel). o Hollywood fault zone to be crossed at extreme south end of reach. Rock anticipated to be very weathered (locally decomposed) brecciated and sheared. Hollywood fault forms groundwater barrier with at least 186 feet of groundwater elevation difference across the fault. o Minor sheared zones from 1 to 10 feet wide are common.	

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TABLE NO. 7-2, REACH NO. 2, STATION 679 + 80 TO STATION 693 + 00, LENGTH - 1,320 FEET
FORMATION: CHICO/SIMI CONGLOMERATE, ROCK TYPE CONGLOMERATE/SANDSTONE

GEOLOGIC CONDITIONS	ROCK PARAMETERS
General Lithology - Conglomerate and interbedded sandstone lenses with minor (rare) thin claystone/siltstone beds. Large rounded gravel/cobbles to 8 inches and occasionally to 24 inches, matrix supported. Poorly to indistinctly bedded (massive). Simi Conglomerate contains up to 60 percent quartzite cobbles and boulders.	o Bulk density range = 140 to 160 pcf, average = 150 pcf o Uniaxial compressive strength range = 0.09 to 18.1 ksi (for matrix) average intact = 6.2 ksi; strength of clasts = 13.1 ksi o Very low susceptibility to slaking (2nd cycle slake durability index > 95 percent) o Young's modulus of intact core range = 400 to 1,800 ksi, average = 1,200 ksi.
Discontinuities - Close joint spacing (2.4 to 8 inches) common, widely spaced random sheared zones with clay seams. Joint sets generally random and contain several intersecting sets. Bedding dips 10 to 70 degrees northeast (40 to 60 degrees dominant). Conglomerate clasts are shattered and may fragment into smaller particles. Intact clasts should be anticipated.	o Core recovery range = 73 to 100 percent, average = 92 percent o RQD range = 0 to 100 percent, average = 32 percent o Seismic compressional wave velocity range = 11,500 to 16,100 ft/s o Shear wave velocity range = 4,000 to 5,700 ft/s o Deformation modulus of rock mass range = 0.9×10^6 to 1.2×10^6 psi o Estimated RMR rating of rock mass range = Class IV to Class I (poor to very good), average = lower bound of Class II (fair rock) o Estimated Q value of rock mass = exceptionally poor ($Q \leq 0.01$) to fair ($4 < Q < 10$).
Cementation - Slight to moderate (variable) should stand well at face. Cobbles and boulders usually poorly cemented to matrix and will dislodge easily.	
Weathering - Fresh, no alternation.	
Percent Quartz - Variable from 3 to 45 percent inclusive of sand grains and quartz rich rock fragments.	o MWD Hollywood and Los Angeles Sewer tunnels experienced difficulty drilling shot holes for blasting due to durable clasts.
Groundwater Table - about 700 feet above tunnel crown and about 75 feet below ground surface.	o Hydraulic conductivity - 2.9×10^{-6} cm/s (one test) o Groundwater inflows decreased in Chico/Simi Formations during Los Angeles Sewer Tunnel excavation.
Other Geologic Conditions - Interface between the granitic and conglomerate bedrock may represent a fault zone up to 15 feet-wide comprised of highly sheared and brecciated rock fragments derived from the conglomerate.	

TABLE NO. 7-3, REACH NO. 3, STATION 693 + 00 TO STATION 698 + 30, LENGTH - 530 FEET
FORMATION: LOWER TOPANGA FORMATION AND LAS VIRGENES SANDSTONE, ROCK TYPE SANDSTONE/CONGLOMERATE

GEOLOGIC CONDITIONS	ROCK PARAMETERS
General Lithology - Dominantly thick beds of sandstone and conglomeratic sandstone, and (rare) conglomerate lenses to 3 feet thick with rounded clast to 18 inches and matrix supported. Estimated 80 percent sandstone, 10 percent gravelly sandstone, 5 percent conglomerate and 5 percent siltstone. This reach includes Las Virgenes, massive arkosic 125 feet thick, friable sandstone.	o Bulk density range = 149 to 154 pcf, average = 152 pcf o Uniaxial compressive strength range = 0.8 to 4.6 ksi, average intact = 3.3 ksi o Low susceptibility to slaking o Young's modulus of intact core range = 340 to 2,500 ksi.
Discontinuities - Joints closely to widely spaced (2.4 inches to 6.6 inches) inclined from 30 to 60 degrees, generally healed with calcium carbonate. Bedding dips 30 to 60 degrees to the northeast.	o Core recovery range = 84 to 100 percent, Average = 99 percent o RQD range = 17 to 100 percent, Average = 89 percent o Compressional wave velocity range = 10,300 to 70,000 ft/s o Shear wave velocity range = 4,800 to 7,800 ft/s o Estimated deformation modulus of rock mass = 0.9 to 2.5 x 10^6 psi o Estimated RMR rating of rock mass = Class II to III (good to fair) average = Lower bound of good rock (Class III) o Estimated Q values of rock mass = very poor ($0.1 < Q \leq 1$) to good ($10 < Q \leq 4.0$).
Cementation - Sandstones are moderately well cemented (not friable). Conglomerate beds are very weakly cemented. Cementation is via calcite or clay and up to 30 percent by volume. The Las Virgenes sandstone is friable (weakly cemented).	
Weathering - Generally fresh with approximately 4 percent chlorite bearing (hydrothermal alternation).	
Percent Quartz - 28 to 47 percent (mostly sand sized grains).	
Groundwater Table - about 560 feet above tunnel crown and abut 165 feet below ground surface.	o Hydraulic conductivity ranges from nearly impermeable to 4.7 x 10^{-7} cm/s o Groundwater inflows decreased rapidly in Lower Topanga Formation during Los Angeles Sewer Tunnel excavation.
Other Geologic Conditions - Geologic contacts are judged to be conformable at each end of reach.	

TABLE NO. 7-4, REACH NO. 4, STATION 6[illegible] 0 TO STATION 716 + 10, LENGTH - 1,780 FEET
FORMATION: MIDDLE TOPANGA FORMATION, ROCK TYPE BASALT/BASALT BRECCIA

GEOLOGIC CONDITIONS	ROCK PARAMETERS
General Lithology - Extruded basalt, dominantly breccia with massive intervals of basalt flows. Breccias are coherent, matrix supported; clasts are angular to several inches across. Matrix consists of chlorite, zeolite, and smectite minerals. Infrequent depositional lenses and layers of sandstone up to 50 feet thick, fine to medium grained.	o Bulk Density = 135 to 148 pcf, Average = 143 pcf o Uniaxial compressive strength range = 0.6 to 5.7 ksi, average intact rock = 2.3 ksi o Moderately susceptible to slaking o Young's modulus of intact rock range = 380 to 520 ksi.
Discontinuities - Joints and shears often lined with chlorite/smectite are very closely to moderately closely spaced (0.4 to 24 inches), and predominantly interlocking and wavy. Generally two sets at moderate to steep inclination with one random set superimposed. Inclinations range from 24 to 60 degrees (44 degrees average). Trends E-W, NW, ENE, shears commonly are near vertical. Most joints and shears are healed with infilling of calcite, zeolite, chlorite, minerals, or smectite.	o Core recovery range = 85 to 100 percent, Average = 96 percent o RQD range = 56 to 95 percent, Average = 84 percent o Compressional wave velocity range = 1,500 to 16,000 ft/s o Shear wave velocity = 4,000 to 7,500 ft/s o Estimate RMR rating of rock mass = Class III to IV (poor to fair), Average = Lower bound of fair o Estimated Q value of rock mass: extremely poor ($0.01 < Q \leq 0.1$) to poor ($1 < Q \leq 4$).
Cementation - Igneous rock (basalt) Not Applicable. Breccia are not granular, matrix is softer than fragments, generally coherent. Sandstone lenses may be well cemented.	o Cementation on joints and shears is typically weak minerals, chlorite, zeolite, and smectite.
Weathering - Fresh (unweathered) but much of original basalt is hydrothermally altered to serpentine and chlorite group minerals.	
Percent Quartz - No quartz present but rock contains an abundance of serpentine and chlorite group minerals on fracture surfaces.	
Groundwater Table - About 650 feet above tunnel crown and about 100 feet below ground surface	o Hydraulic conductivities range from 3.2×10^{-5} cm/s to 8.0×10^{-7} cm/s o Locally high groundwater inflows that decreased rapidly in Middle Topanga Formation during Los Angeles Sewer Tunnel excavation o Sulfate content is approximately 150 ppm o Hydrostatic pressure at tunnel crown is approximately 232 psi.
Other Geologic Condition - Low percentage of iron pyrite disseminated in rock mass or locally concentrated on some joint surfaces. Geologic contacts are judged to be conformable on each end of reach.	

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TABLE NO. 7-5, REACH NO. 5, STATION 71[illegible] 10 TO STATION 730 + 70, LENGTH - 1,460 FEET
FORMATION: UPPER TOPANGA FORMATION, ROCK TYPE SANDSTONE/CONGLOMERATE

GEOLOGIC CONDITIONS	ROCK PARAMETERS
General Lithology - Dominantly a massive to thick bedded medium to coarse grained sandstone with widely spaced thin to thick gravelly sandstone zones. Sequence contain 80 percent sandstone, 15 percent conglomeratic sandstone, and 5 percent conglomerate. Clasts up to 24 inches (rare to 48 inches), subangular to subrounded, matrix supported. Minor thin (1 to 2 inches thick) siltstone rare.	o Bulk density range = 131 to 163 pcf, average = 142 pcf o Uniaxial compressive strength range = 2.0 to 13.5 ksi, average intact rock = 5.1 ksi, strength of clasts = 12.4 ksi o Moderately susceptible to slaking o Young's modulus of intact core = 780 to 5400 ksi.
Discontinuities - Joints closely to widely spaced (2.4 inches to 6.6 inches) and primarily moderately closely spaced (8 to 24 inches). No regular pattern of orientation or dip angle (random). Infrequent sheared clay seams.	o Core recovery range = 35 to 100 percent, average 98 percent o RQD range = 0 to 100 percent, average 81 percent o Compressional wave velocity = 10,300 to 20,000 ft/sec o Shear wave velocity = 4,800 to 7,800 ft/sec o Deformation modulus = 0.9 to 2.6 x 10^6 psi o Estimated RMR rating of rock mass = Class II (Good Rock) average = good rock o Estimated Q rating of rock mass = good (10, Q $\leq$ 400).
Cementation - Moderately cemented with primarily calcite.	o Clast strength is generally much greater than matrix.
Weathering - Fresh (unweathered), no alteration	
Percent Quartz - Quartz content of sand grains varies from 15 to 30 percent with intervals up to 55 percent quartz.	o Modified Taber Hardness Index = 4 to 15.1 Ha.
Groundwater Table - About 550 feet above tunnel crown and about 50 feet below ground surface.	o Groundwater inflows were low in upper Topanga Formation.
Other Geologic Conditions - Geologic contacts are judged to be conformable at each end of reach.	

TABLE NO. 7-6, REACH NO. 6, STATION 73u + 30 TO STATION 761 + 40, LENGTH - 3,070 FEET
FORMATION: UPPER TOPANGA FORMATION, ROCK TYPE SANDSTONE - SILTSTONE/SHALE

GEOLOGIC CONDITIONS	ROCK PARAMETERS
General Lithology - Interbedded sandstone and siltstone/shale. Laminated to thickly bedded (very distinct). Dominantly fine to coarse sandstone in the south portion and increase in siltstone/shale content towards the north portion. Bedrock is folded locally, but bedding predominantly dips northeast.	o Bulk density range = 119 to 149 pcf, average = 129 o Uniaxial compressive strengths range = 0.2 to 4.8 ksi, average intact rock = 2.0 ksi o Highly susceptible to slaking (second cycle slake) durability index = 1.1 to 95 percent, generally < 50 percent) o Young's modulus of intact core range = 9.3 to 1,500 ksi.
Discontinuities - Joint spacing moderately close (8 inches to 24 inches), usually one set with apparent random orientation. Bedding dips generally 50 to 90 degrees, reversals and possible overturning anticipated. Bedding parts easily on some siltstone/shale surfaces, often sheared, polished clay-lined seams present.	o Core recovery range = 0 to 100 percent, average 95 percent o RQD range = 0 to 100 percent, average 76 percent o Compressional wave velocity = 5,000 to 8,000 ft/s o Shear wave velocity = 3,000 to 4,000 ft/s o Deformation modulus of rock mass = 0.6 to 0.9 x 10^6 psi o Estimated RMR rating of rock mass Class II to IV (good to poor rocks) average = lower bound of fair rock.
Cementation - Variable, ranging from slightly to moderately well cemented. Some sandstone layers are uncemented and very friable.	
Weathering - Mostly fresh (unweathered). Locally highly weathered to residual soil.	
Percent Quartz - Quartz content of sand grains varies from 15 to 30 percent with intervals up to 55 percent quartz.	o Modified taber hardness index = 0.4 to 0.7 Ha.
Groundwater Table - About 50 to 200 feet above tunnel crown and 0 to 30 feet below ground surface	o Hydraulic conductivities range from nearly impermeable to 4.2 x 10^{-4} cm/s.
Other Geologic Conditions - The Benedict Canyon fault zone will be crossed at the north end of the reach. Two zones of shearing/brecciation are anticipated beneath the Hollywood Freeway area. No more than 9 feet of bedrock overlies tunnel crown beneath Hollywood Freeway. Stream alluvium may be encountered in crown of tunnel beneath freeway. Geologic contact at the south end of the reach is judged to be conformable.	

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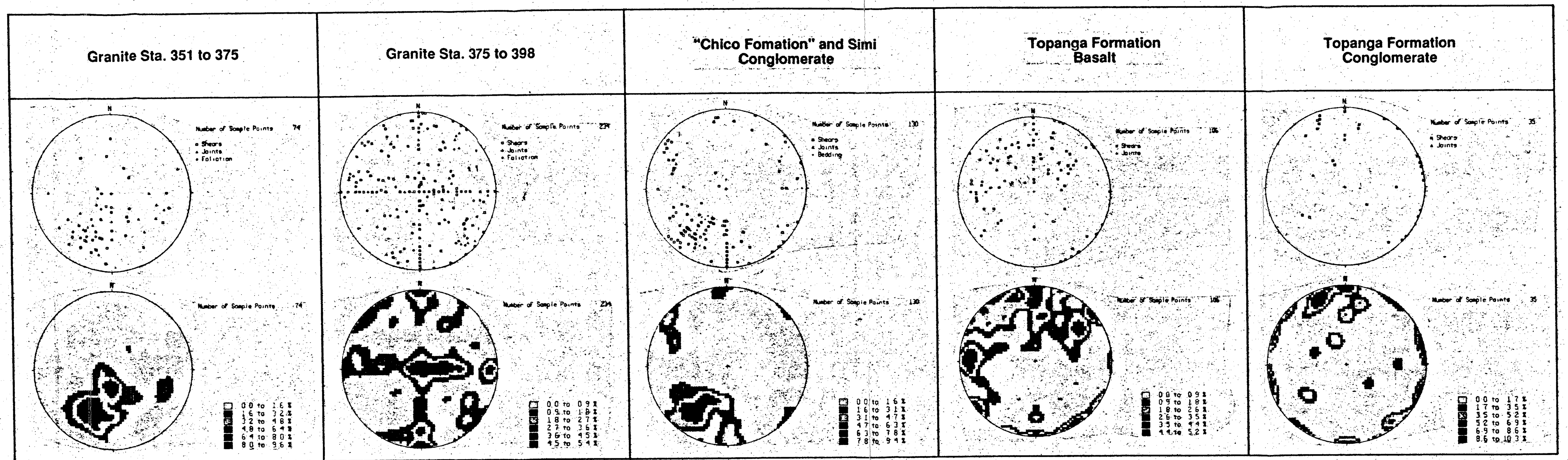
Explanation
Geologic Units
af Artificial Fill
Qal Alluvium
Qls Landslide Debris
Ttu (ss+sh) Upper Topanga Formation, interbedded sandstone and shale
Ttu (ss+Cgl) Upper Topanga Formation, sandstone with conglomerate interbedded
Tts Middle Topanga Formation, sandstone
Ttv Middle Topanga Formation, basalt and basalt breccia
Ttl Lower Topanga Formation, sandstone with conglomerate interbedded
Tlv Las Virgenes Sandstone, sandstone with shale in upper part
Tsc Simi Conglomerate, conglomerate with sandstone interbedded, bottom half consists predominantly of quartzite clasts
Kc Chico Formation- Conglomerate with sandstone interbedded
gd Plutonic Rocks- granodiorite, quartz diorite and quartz monzonite
Quaternary
Tertiary
Miocene
Paleocene
Cretaceous
Geologic Symbols
Geologic Contact, dashed where approximately located, queried where uncertain
Fault, dashed where approximately located, queried where uncertain, dotted where buried; arrow indicates dip direction and amount; D, downthrown side, U, upthrown side; parallel arrows indicate relative direction of movement
Anticline, dashed where approximately located
Syncline, dashed where approximately located
Bedding, strike and dip
Approximate Bedding, strike and dip
Vertical Bedding, strike
Foliation, strike and dip
Joint, strike and dip
Vertical Joint, strike
Shear, strike
Apparent inclination of typical bedding with respect to geologic profile from measurements made during geologic mapping
Apparent inclination of typical foliation with respect to geologic profile from measurements made during geologic mapping
Shear Zone
Basaltic Dike
Other Symbols
SM- Boring by The Earth Technology Corporation, this investigation
R- Boring by The Earth Technology Corporation, completed in 1989
CEG-33- Boring by Converse and others, (1981,1984c)
Mid Line Vent Shaft Location
Boring, illustrating the maximum inclination of bedding in sedimentary rock or foliation in plutonic rock measured in the core samples; orientation is estimated based on geologic trends in the vicinity
Location of Groundwater observed and date measured
T.D.-206' T.D. - Total Depth of Boring
Potentiometric Groundwater Surface
Runyon Canyon Park Boundary
Existing Tunnel Alignment
GEOLOGIC PLAN
SCALE
North
Notes:
1. Geologic profile constructed along centerline of AR track.
2. Geologic structures (contacts and faults) have been projected to the locations where they are anticipated to be encountered in the tunnel. The projections are based on geologic mapping at the surface combined with subsurface data obtained from widely spaced borings and L.A. City Sewer Tunnel as-built geologic logs, and should be considered as approximate only.
3. Exploratory borings that are not located on the alignment are projected to the geologic profile along the strike of the regional structural fabric as shown below.
Regional Structural Fabric
Plane of Profile
SM-7
4. Boring SM-5 has been projected onto the profile parallel to the regional structure so that it appears to intersect the Los Angeles Sewer Tunnel. Boring SM-5 is actually located approximately 200 feet east of the sewer tunnel alignment as shown on the plan view.
Project No.
Geotechnical Investigation
Santa Monica Mountain
Segment 3, Metro Red Line
Geologic Plan and Profile
6-93
Plate 2
GEOLOGIC PROFILE
℄ AR TRACK
(View West)
EXPLANATION
Lithologic Symbols (Used in Borings)
N 23 W
N 12 E
STATION
SOUTHEAST
NORTHWEST
ELEVATION (FEET)
Tunnel
Hollywood Fault Zone
SCALE: 1"=200' (HORIZONTAL & VERTICAL)
Plate 2

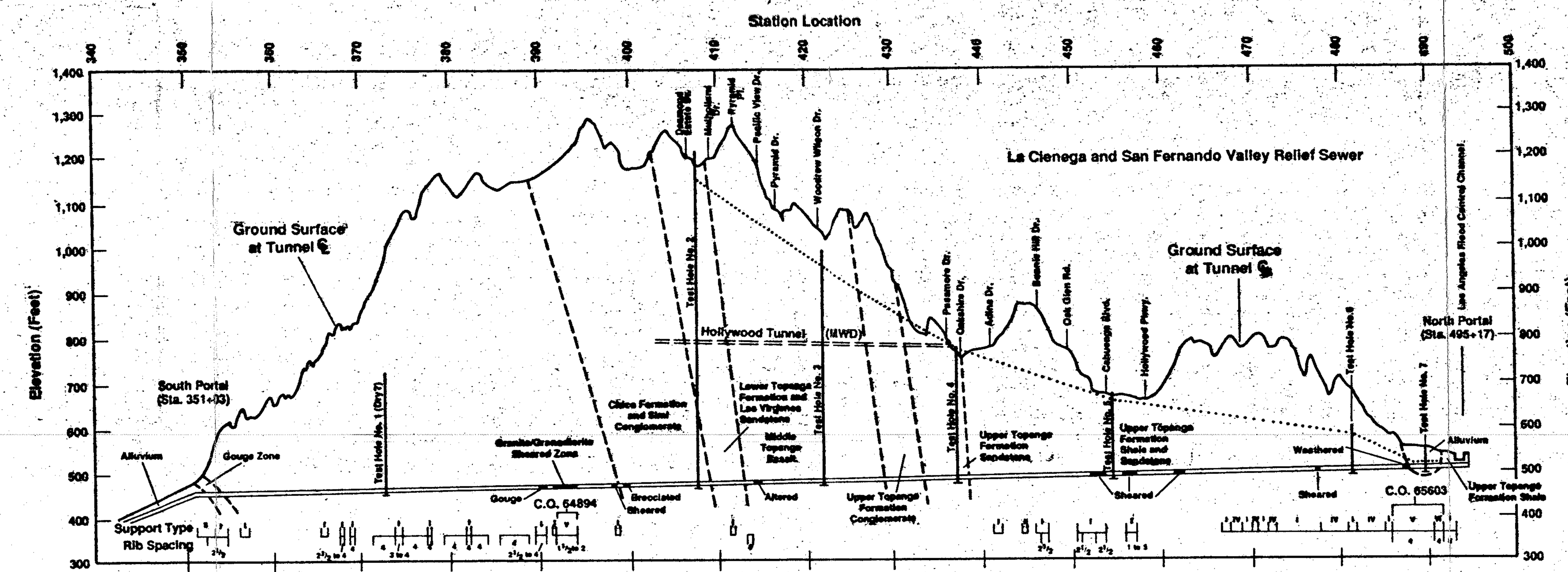
92-2050
METRO RAIL



Lower Hemisphere Stereonet Projection of Rock Discontinues

Relative Density of Rock Discontinues as a Spherical Gaussian Fuction

GEOLOGIC PROFILE AND TUNNEL SUPPORT TYPES USED



EXPLANATION

Type of Tunnel Support (I-VI) Spacing of Ribs in Feet

Piezometric Surface Estimated from Exploratory Test Hole Data

Note: Spacing of Ribs is 5ft. Center to Center or as Indicated.

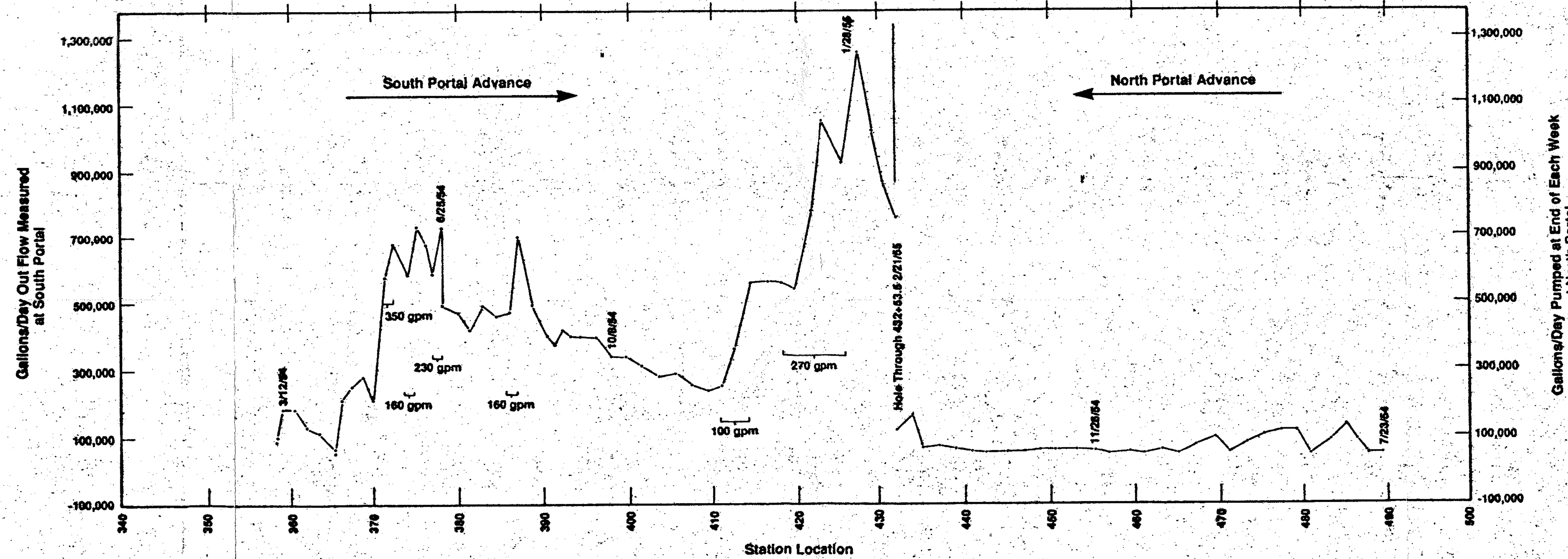
"Heavy" Ground Types and Tunnel Support Types

Type I	Used in Ground Which is Moderately " Heavy"
Type II	Used in Ground Which is Moderately "Heavy" and in Which Standard Tile Subdrain is Used
Type III	Used in Lieu of A-4 (Liner Plate) in Alluvial Ground
Type IV	Used Where Subgrade has Softened but Remainder of Ground Around Periphery is Firm
Type V	Used in Very "Heavy" or "Squeezing" Ground
Type VI	Used in Very "Heavy" Alluvial Ground

Change Orders for "Heavy" Ground

South Portal Tunnel
C.O. 64894 "Revised Tunnel Section Installed in Heavy Ground"; "Angular Fragments and Fault Clay." Type V Supports, 4", 13 lb Steel Ribs instead of 7.7 lb Ribs.

North Portal Tunnel
C.O. 65603 "Constructed Heavier Tunnel Section in Poor Ground." Alluvium Caved to the Surface at Sta. 491+17 to 491+25. Types V and VI Supports.



GROUNDWATER QUANTITIES HANDLED DURING EXCAVATION

EXPLANATION

Data Point of Gallons Per Day (gpd) Plotted Versus Where Tunnel Heading was at Time of Flow Measurement

Location Where Increase in Water Flow was Indicated at Tunnel Heading; Gallons Per Minute (gpm)

Note: Dewatering of Alluvium by Seven Wells on Universal Lot Produced 95,000 gpd at North Portal in July of 1954.

FROM: DEPARTMENT OF PUBLIC WORKS, CITY OF LOS ANGELES, 1954-1955.

The Earth Technology Corporation

Project No.: 92-2050

Geotechnical Investigation
Santa Monica Mountains
Segment 3, Metro Red Line

Summary of As-Built Tunneling Conditions Los Angeles Sewer Tunnel Santa Monica Mountains

6-93

Plate 1